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Subcontractor Report

LWST Phase I Project Conceptual Design Study: Evaluation of Design and Construction Approaches for Economical Hybrid Steel/Concrete Wind Turbine Towers

June 28, 2002 – July 31, 2004

M.W. LaNier, PE
Berger/ABAM Engineers Inc.
Federal Way, Washington

NREL

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
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M.W. LaNier, PE
Berger/ABAM Engineers Inc.
Federal Way, Washington

NREL Technical Monitor: A. Laxson

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Executive Summary

ES.1 Low Wind Speed Technology

The U.S. Department of Energy Wind Energy Research Program has begun a new effort to develop wind technology that will allow wind systems to compete in regions of low wind speed. The sites targeted by this effort have annual average wind speeds of 5.8 m/s (13 mph), measured at 10 m (33 ft) in height. Such sites are abundant in the United States and would increase the land area available for wind energy production twentyfold. The new program is targeting a levelized cost of energy of $0.03/kWh at these sites by 2012. A three-element approach has been initiated. These efforts are for concept design, component development, and system development. The work addressed in this report builds on previous activities under the WindPACT program and the Next Generation Turbine program.

As part of this effort, BERGER/ABAM Engineers Inc. was awarded Contract Number YAM-2-31235-1 to prepare this report on the design and construction approaches for 100-m (328-ft) hub height hybrid steel/concrete and concrete wind turbine towers. The purpose of this work is to address the economic feasibility of these towers when used as an element of the Low Wind Speed Turbine (LWST) project at low speed wind sites described above.

The goal of the LWST project is to partner with U.S. industry to develop technology that makes wind energy a competitive electricity supply option in the extensive Class 4 and 5 wind sites in the United States.

ES.2 Approach

The wind turbine/tower sizes used as a basis for comparison of concepts considered in this report are:

- 1.5-MW turbine on a 100-m tower
- 3.6-MW turbine on a 100-m tower
- 5.0-MW turbine on a 100-m tower.

The design concepts considered included hybrid steel/concrete towers with a 47- to 49-m (154- to 160-ft) tall concrete base tower sections and 51- to 53-m (167- to 174-ft) steel top tower sections and all-concrete towers 100 m (328 ft) tall. The focus on 100-m (328-ft) tower heights for all turbine sizes was recommended by representatives of GE Wind Company. Design loads used for tower design are derived from those used as input to the WindPACT Turbine Rotor Design Study [26]. Design loads and the appropriate combination of loads for design were developed in collaboration with representatives of Global Energy Concepts. The appropriate design use of these load combinations for tower design was the responsibility of BERGER/ABAM Engineers.

Several construction approaches were considered, and concept level prices were developed for the different concepts. A segmental precast concrete approach was developed in some detail for the 1.5-MW tower, and this concept was scaled for the 3.6- and 5.0-MW turbines. Additionally, cast-in-place concrete construction was evaluated by considering slip- and jump-forming construction methods.

A method for reducing the height of the heavy lifts for installing the turbine and rotors atop the tower was developed in some detail.

ES.3 Conclusions and Recommendations

The results of this study indicate that for the 1.5-MW, 100-m tower size the hybrid steel/concrete, the all cast-in-place concrete, and the tubular steel towers have reasonably comparable costs (all within 33% of each other). The cast-in-place concrete tower construction approach is estimated to be the lowest cost solution. This concept employs a modification of conventional industrial chimney construction and is judged the best design for further refinement.

The cost savings associated with nacelle semi self-erection at 50 m versus 100 m are not significant enough to provide a strong cost advantage to the hybrid steel/concrete concept presented here.

The overall cost and feasibility of fatigue-critical site welding required for the large-diameter lower sections of the tubular steel towers developed here represent the greatest uncertainty for the tubular steel tower concept.

At the time this report was being finalized (April 2004), structural steel prices were increasing at unprecedented rates as a result of international market conditions and unforeseen circumstances in the domestic market. The effects of variation in steel material cost on the various tower concepts are discussed in Section 11.

The cast-in-place concrete concept is estimated to be favored for all the turbine towers studied. This recommendation is based on the assumption that the estimated costs for the cast-in-place tower construction, including the construction cost effects of post tensioning, prove out in initial prototype construction.

For the 3.6-MW, 100-m tower size, the cast-in-place concrete concept is 68% the estimated cost of the tubular steel concept. This concept appears to have very good potential for optimized economy in this size range and is thus recommended for further development.

For the 5.0-MW, 100-m tower size, the cast-in-place concrete concept is 63% of the estimated cost of the tubular steel tower concept. This concept appears to have very good potential for optimized economy in this size range and is thus recommended for further development.

1.0 Introduction

1.1 Low Wind Speed Technology

The U.S. Department of Energy (DOE) Wind Energy Research Program has begun a new effort to partner with U.S. industry to develop wind technology that will allow wind systems to compete in regions of low wind speed. The Class 4 and 5 sites targeted by this effort have annual average wind speeds of 5.8 m/s (13 mph), measured at a 10-m (33-ft) height. Such sites are abundant in the United States and would increase the land area available for wind energy production twentyfold. The new program is targeting a levelized cost of energy of $0.03/kWh at these sites by 2012. A three-element approach has been initiated. These efforts are for concept design, component development, and system development. This work builds on previous activities under the WindPACT program and the Next Generation Turbine program. If successful, DOE estimates that his new technology could result in 35 to 45 gigawatts of additional wind capacity being installed by 2020.

BERGER/ABAM Engineers Inc. prepared this report on the design and construction approaches for 100-m (328-ft) hub height hybrid steel/concrete and all-concrete wind turbine towers to address the economic feasibility of their use as an element of the Low Wind Speed Turbine (LWST) project at low-speed wind sites described above.

1.2 Research Significance

Previous WindPACT studies indicated that the tower element and the associated costs of transportation and erection using conventional tubular steel configurations form an increasing percentage of the overall capital cost of wind turbine installations as the size of the turbine and the height of the tower increase. For a 0.75-MW turbine with a 60-m (197-ft) tubular steel tower, the tower and related balance of station costs were estimated to be 8.5% of the total cost of installation. As the size increases to a 3-MW turbine with a tower height of 119 m (390 ft), the tower and related balance of station costs were estimated to be 14% of the total cost of installation [23]. This study seeks to determine whether the use of hybrid steel/concrete or all-concrete wind turbine towers will reduce this trend of increasing tower cost.

1.3 Low Wind Speed Conceptual Design Study

Currently, most wind turbines in the United States are supported on tubular steel towers fabricated without internal stiffeners and are typically of a diameter that can be delivered to the construction site in truck bed lengths as a full circular section that does not require assembly in the field to complete the circular section. This delivery/construction situation is limited to towers with base diameters of about 4.4 m (14.4 ft). Beyond this dimension, special transportation provisions are required or the sections must be segmented for shipment and then field-assembled to complete circular tower sections. Thus, as tower sizes increase, the economics of the current solution change. The cost effects of this are outlined in some detail in [16].

Additionally, as the tower heights and turbine sizes increase, the plate thickness used for the tower base sections for tubular steel towers will approach 40 mm (1.50 in.). This near doubling of plate thickness over that used in the current tubular tower solution has implications for steel plate forming cost (whether stiffened plates should be used), welding costs, joining costs where bolted joints are used, quality control costs, and so forth. Thus, the current WindPACT metric for cost of fabricated tower steel of $1.65/kg used in [18] may not be conservative. As sections become thicker, steel fabrication issues become more complex and costly.

The hypothesis examined in this report is that for multi-turbine site installations (50 turbines baseline), prestressed concrete towers or a tower design that uses a hybrid of steel and prestressed concrete is more economical than all-tubular-steel towers for the following tower/turbine sizes:

- 1.5-MW turbine, 100-m hub height
- 3.6-MW turbine, 100-m hub height
- 5.0-MW turbine, 100-m hub height.

These turbine/tower configurations were selected based on industry input and confirmed by NREL representatives. The rationale for this hypothesis is that as plate thicknesses and structural sections get larger to resist larger loads, prestressed concrete usually becomes more economical than steel construction. This assumes that the structure can be constructed using prestressed concrete elements that are locally precast in a size that can be shipped and handled with conventional handling equipment or are constructed from cast-in-place concrete using construction technology similar to that developed for the construction of large industrial chimneys.

Concrete construction costs depend heavily on the construction methods that are used to achieve the construction objective. For this reason, we have developed a precast concrete approach in some detail for the hybrid steel/concrete 1.5-MW, 100-m (328-ft) hub height tower. This allows an overall assessment of the construction issues involved and allows the most comprehensive possible estimate of the construction cost. Estimates for the 3.6-MW and 5.0-MW hybrid steel/concrete turbine towers are developed as extensions of the work done for the 1.5-MW tower. These hybrid towers incorporate a self-erection approach to limit the requirement for and cost of large cranes at the construction site.

We have also developed construction approaches and cost estimates for all prestressed concrete towers for the same sized turbines and hub heights. We have estimated the cost of these towers to include the erection of the nacelle and rotors without self-erection, using cranes of the appropriate size. Commentary regarding appropriate self-erecting techniques for the all-concrete towers is provided. The all-concrete and steel/concrete hybrid tower costs are compared against the costs of full-height steel towers as outlined in [18] and as developed in this report.

1.4 Loads and Design Methodology

This design study was originally developed using proprietary design loads provided by GE Wind Company. The use of proprietary loads required that the input loads not be included in this public distribution document. At the final review stage, NREL representatives determined that the interests of the industry would be best served if the input loads were provided as part of the report. The decision was made to revise the report using public domain input loads from previous WindPACT studies and to include much of this background load information in the report to allow interested parties better insight into the overall tower design process used. Representatives of Global Energy Concepts provided background loads used for the WindPACT Turbine Rotor Design Study [26] and worked with BERGER/ABAM to ensure the appropriate use of this load data.

The tower top loads used to design the 1.5-MW and 3.6-MW towers were developed from input used for previous WindPACT studies. The tower top loads used for the design of the 5.0-MW tower were scaled from the 3.6-MW loads. The seismic loads used for design and the wind loads on the tower structure were developed by BERGER/ABAM with [6,9]. The tower fatigue loads used were developed from WindPACT study input with collaborative input from representatives of Global Energy Concepts regarding the appropriate use of these data.

A complete tower design example is given in Appendix B for the 5.0-MW, 100-m (328-ft) tower using loads that were developed from WindPACT studies.

The design criteria and basis of design for the prestressed concrete tower elements were developed by BERGER/ABAM and were based on [6–8].

The design methodology for the hybrid and all prestressed concrete towers was developed by BERGER/ABAM and is based on [6–9]. The design procedure for the different tower types is shown schematically in Figures 2.1, 2.2, and 2.3. The details of this design procedure are given in the body of this report, and complete design examples for 5.0-MW hybrid, all-concrete, and all-steel towers are given in Appendix B**.**

The dynamic requirements for the towers considered were developed based on [10–12] combined with input from representatives of Global Energy Concepts.

The general dimensions of the tower designs developed are shown in the schematic tower drawings given in Figures 1.1–1.11.

1.5 Objective

The overall result of this work is an evaluation of the cost effectiveness of using hybrid steel/concrete or full-height prestressed concrete towers in conjunction with self-erecting schemes for large wind turbine applications as part of the LWST project, compared to baseline all-steel tubular towers. The consequences to the cost of energy are determined, and the actions necessary to ensure the viability of implementing this approach in a manner that both captures the cost-saving potential and meets all of the requirements as a wind turbine support system are outlined.

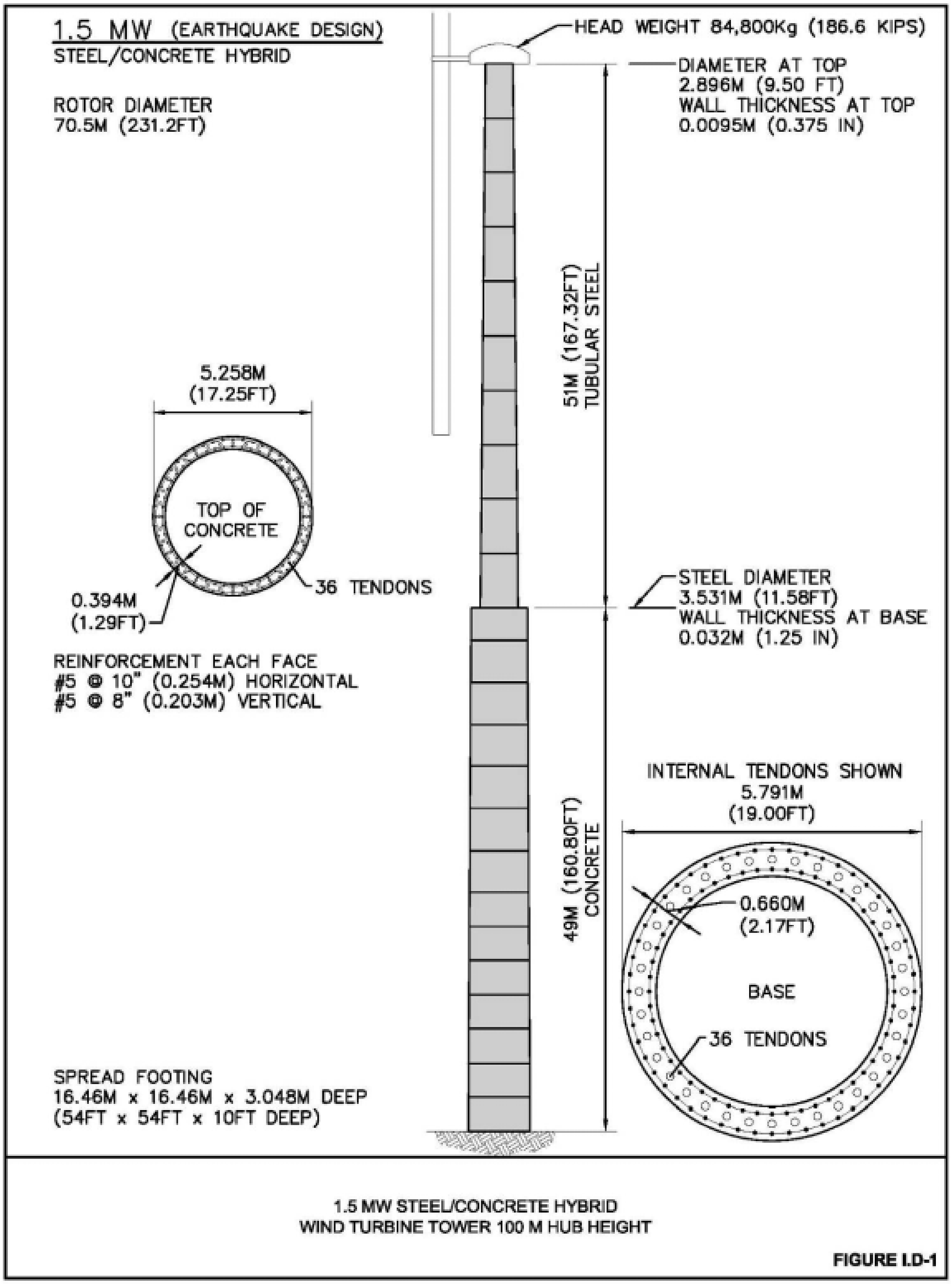


Figure 1.1 1.5-MW (earthquake design) steel/concrete hybrid wind turbine tower—100-m hub height

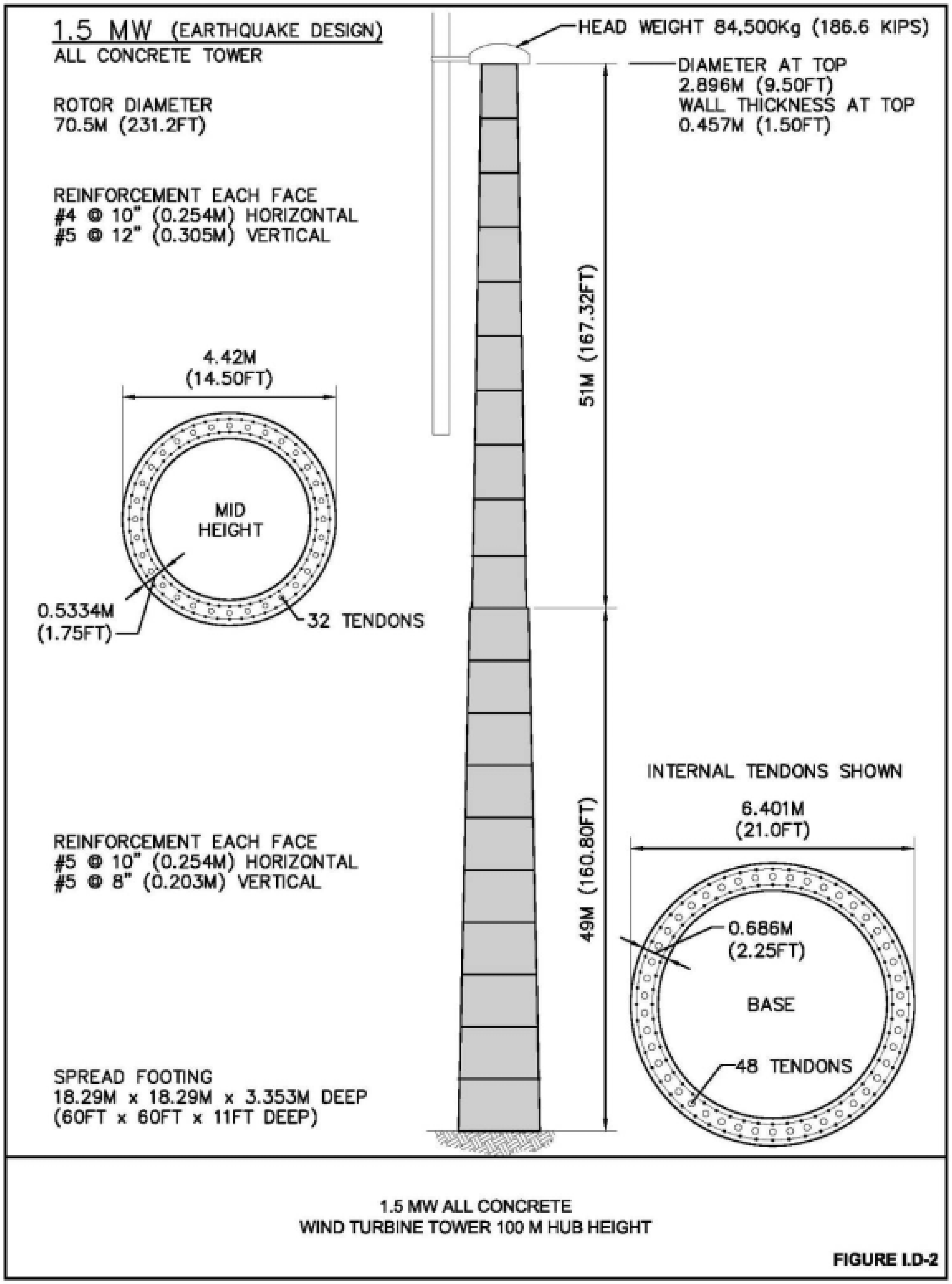


Figure 1.2 1.5-MW (earthquake design) all-concrete wind turbine tower—100-m hub height

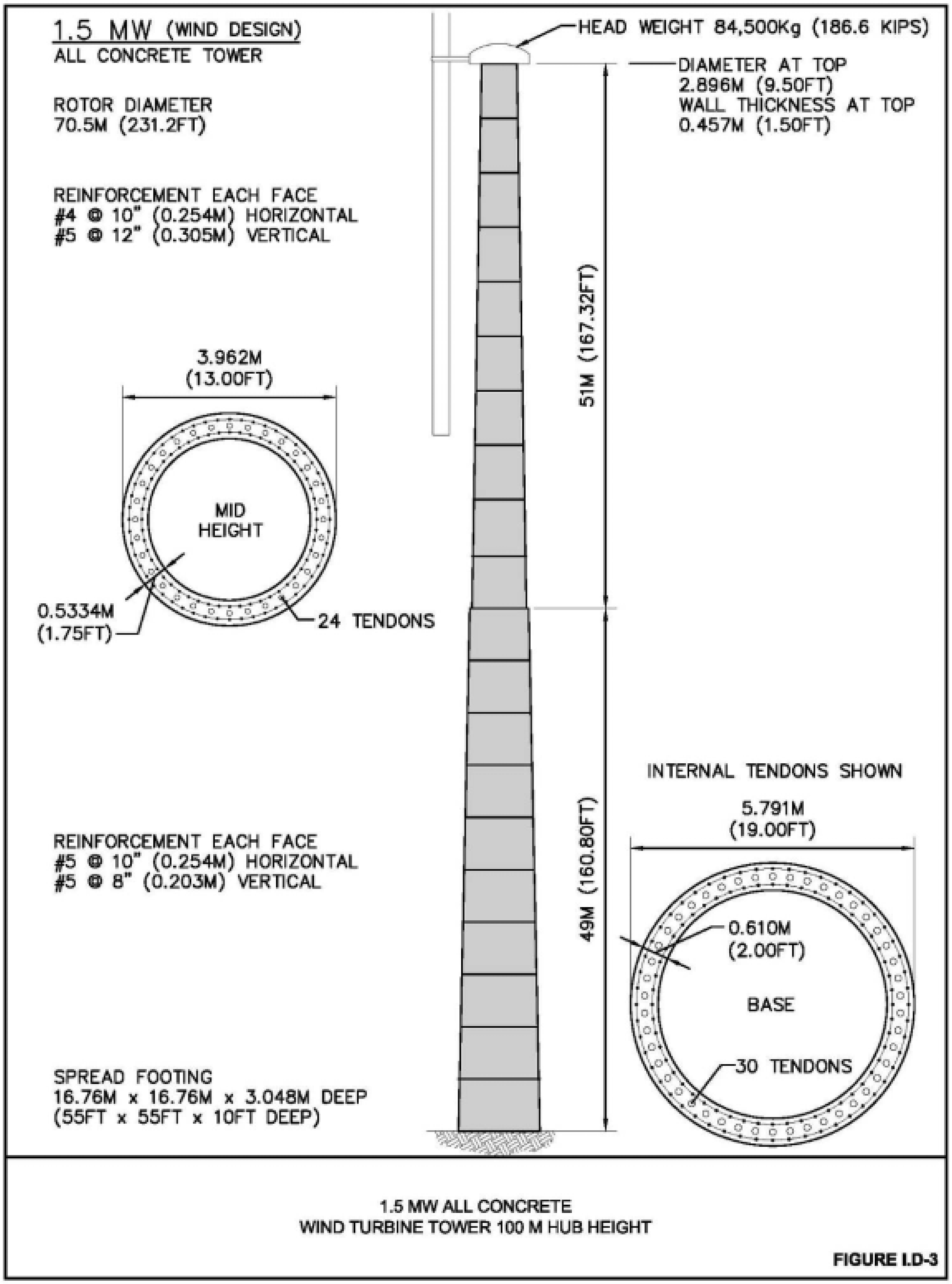


Figure 1.3 1.5-MW (wind design) all-concrete wind turbine tower—100-m hub height

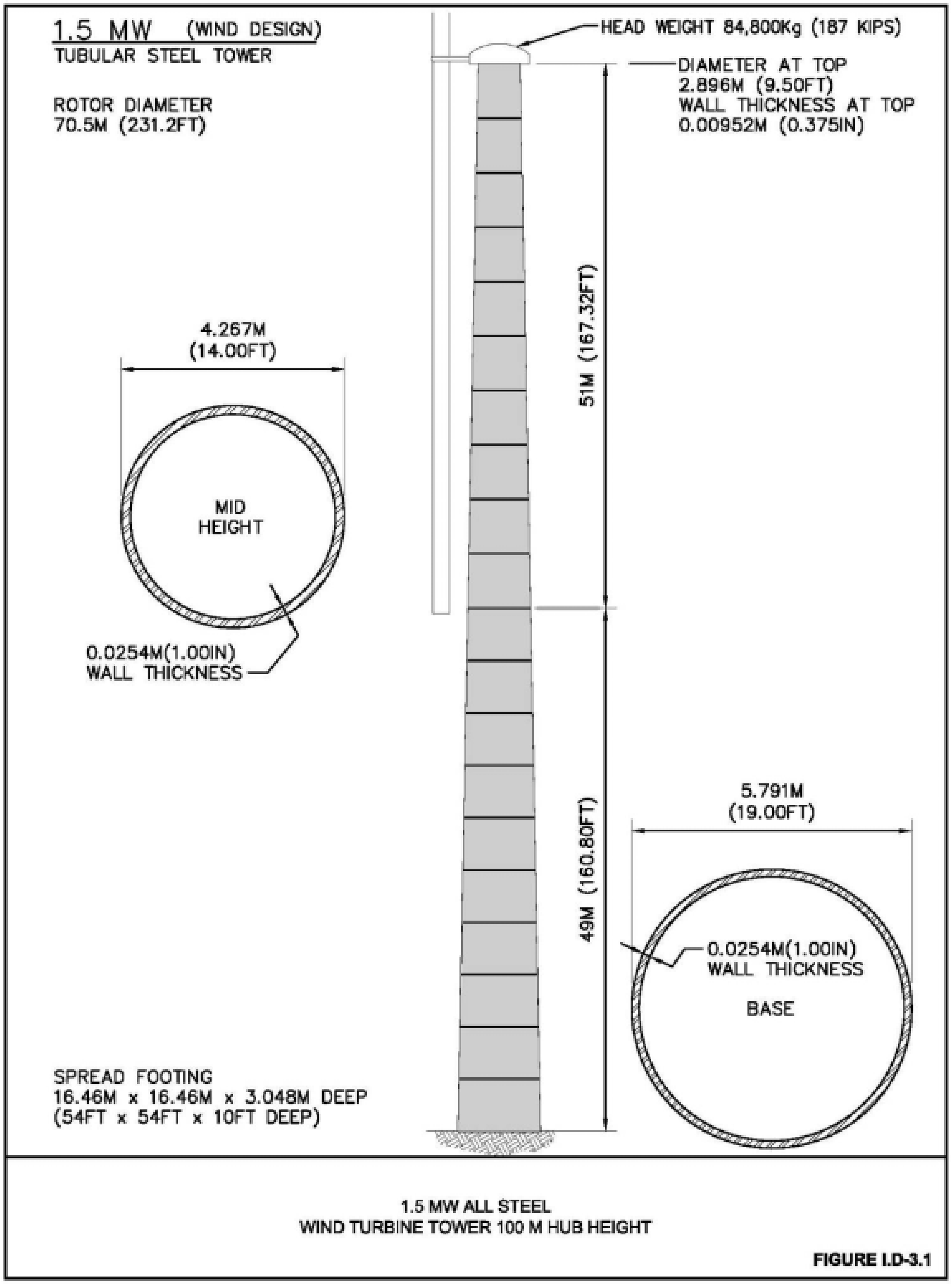


Figure 1.4 1.5-MW (wind design) all-steel wind turbine tower—100-m hub height

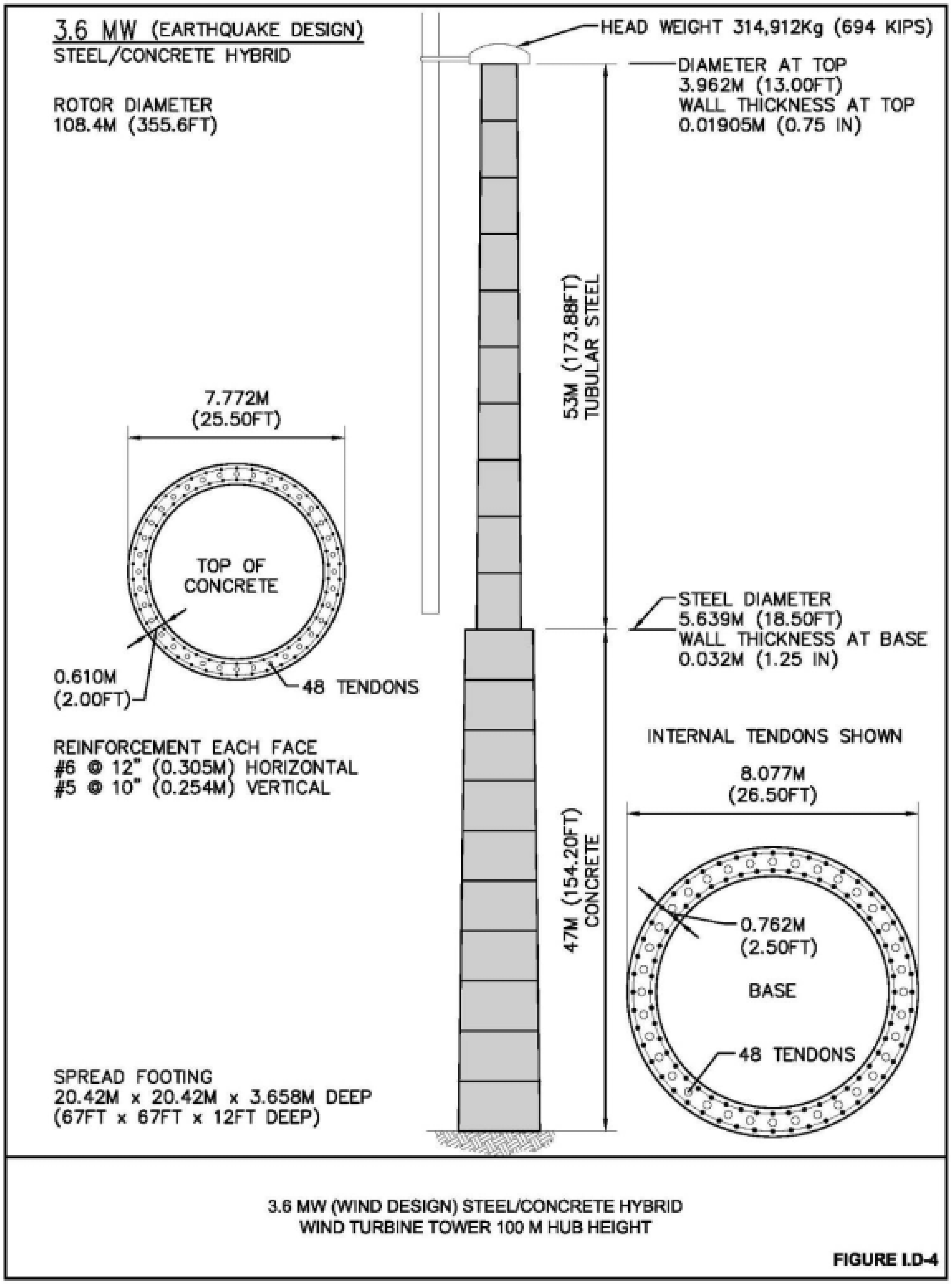


Figure 1.5 3.6-MW (earthquake design) steel/concrete hybrid wind turbine tower—100-m hub height

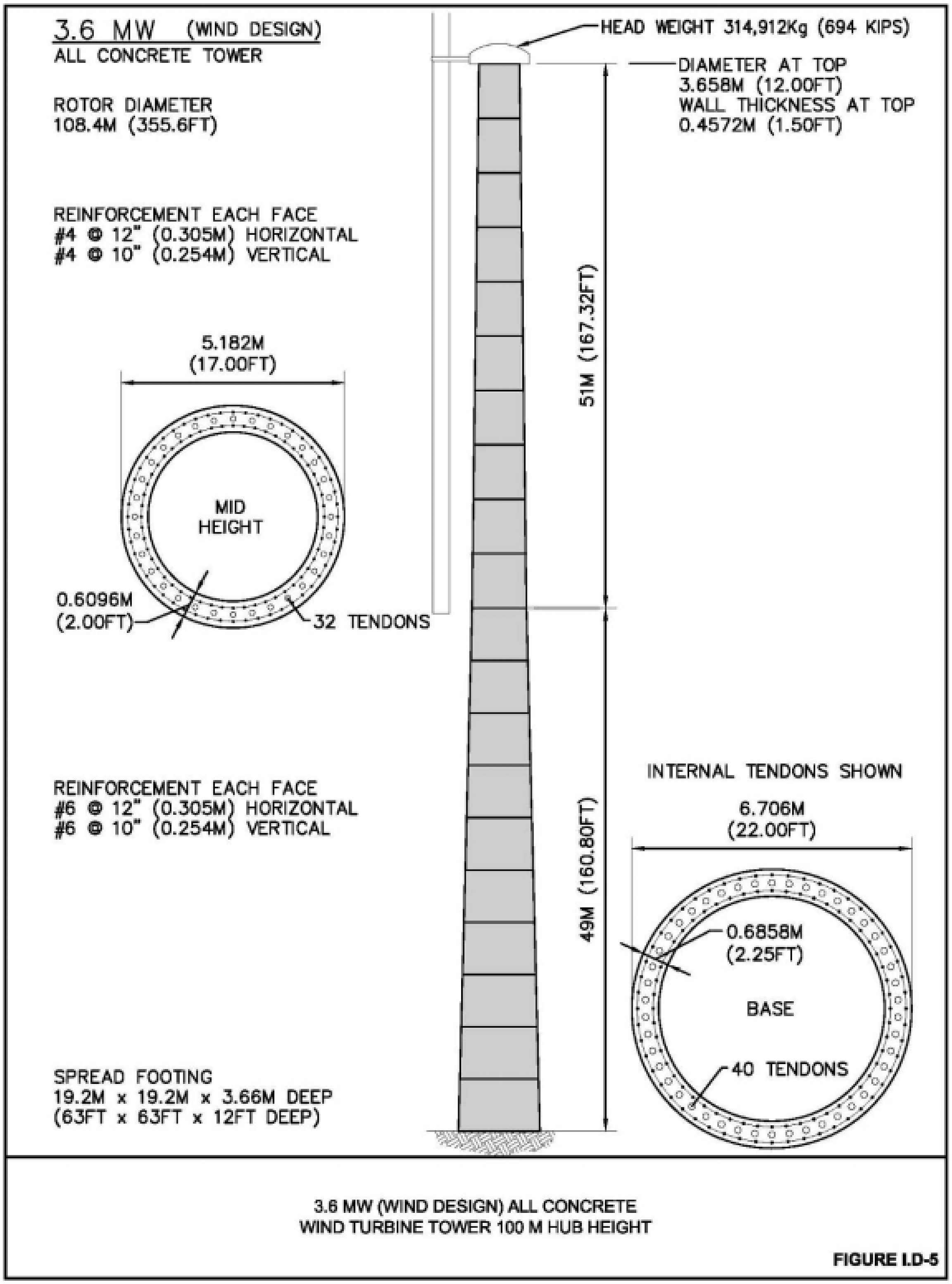


Figure 1.6 3.6-MW (wind design) all-concrete wind turbine tower—100-m hub height

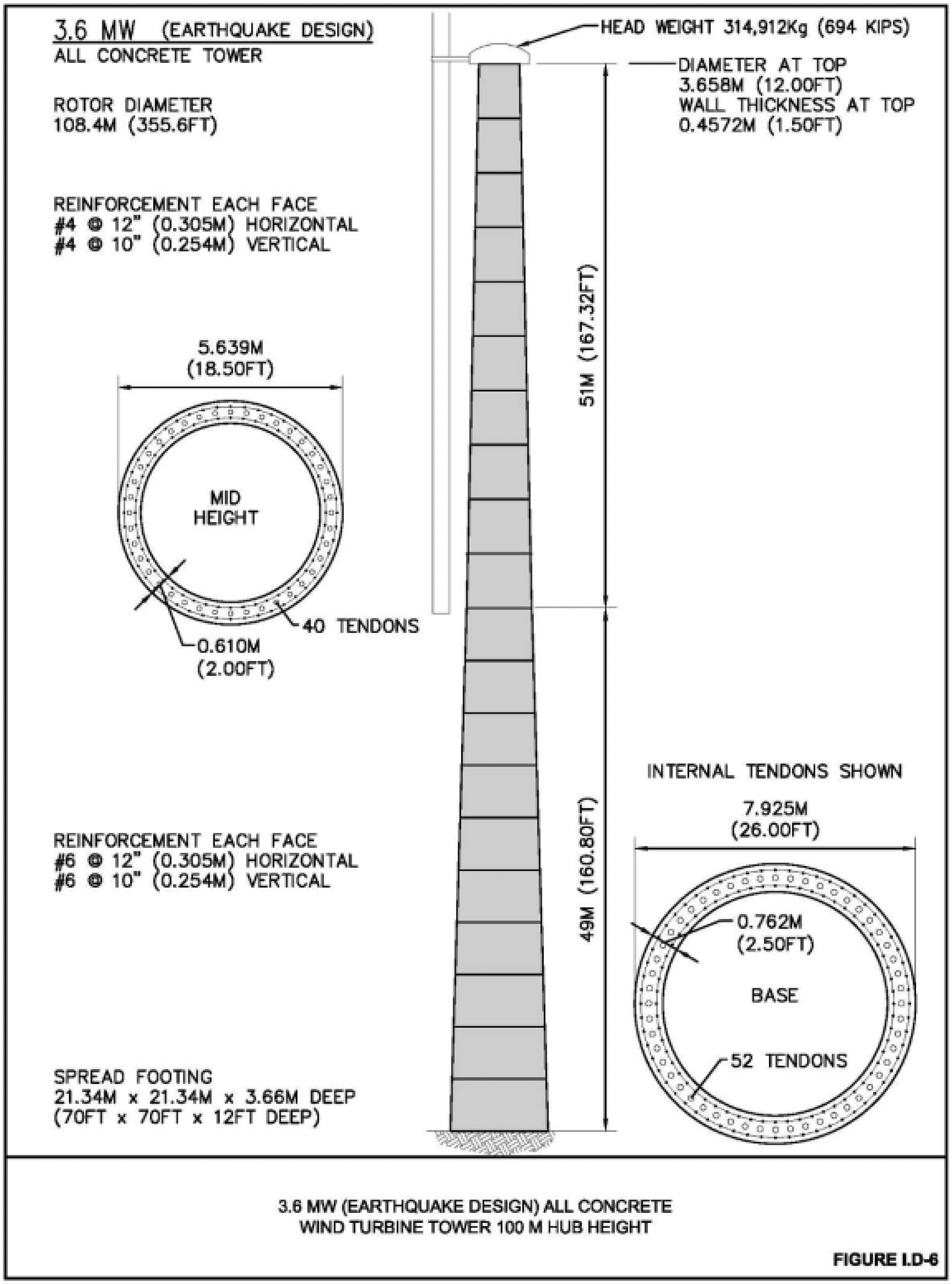


Figure 1.7 3.6-MW (earthquake design) all-concrete wind turbine tower—100-m hub height

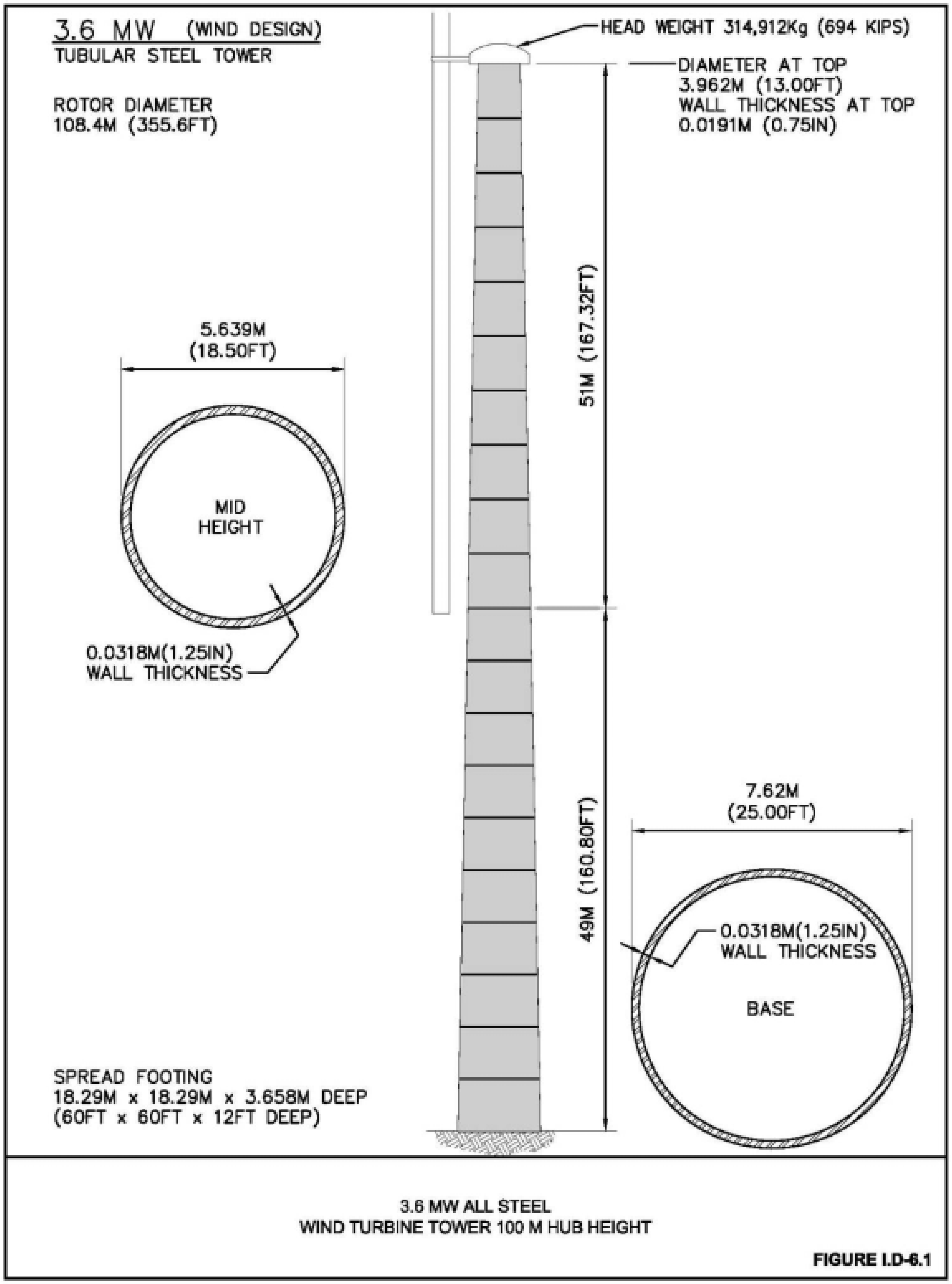


Figure 1.8 3.6-MW (wind design) all-steel wind turbine tower—100-m hub height

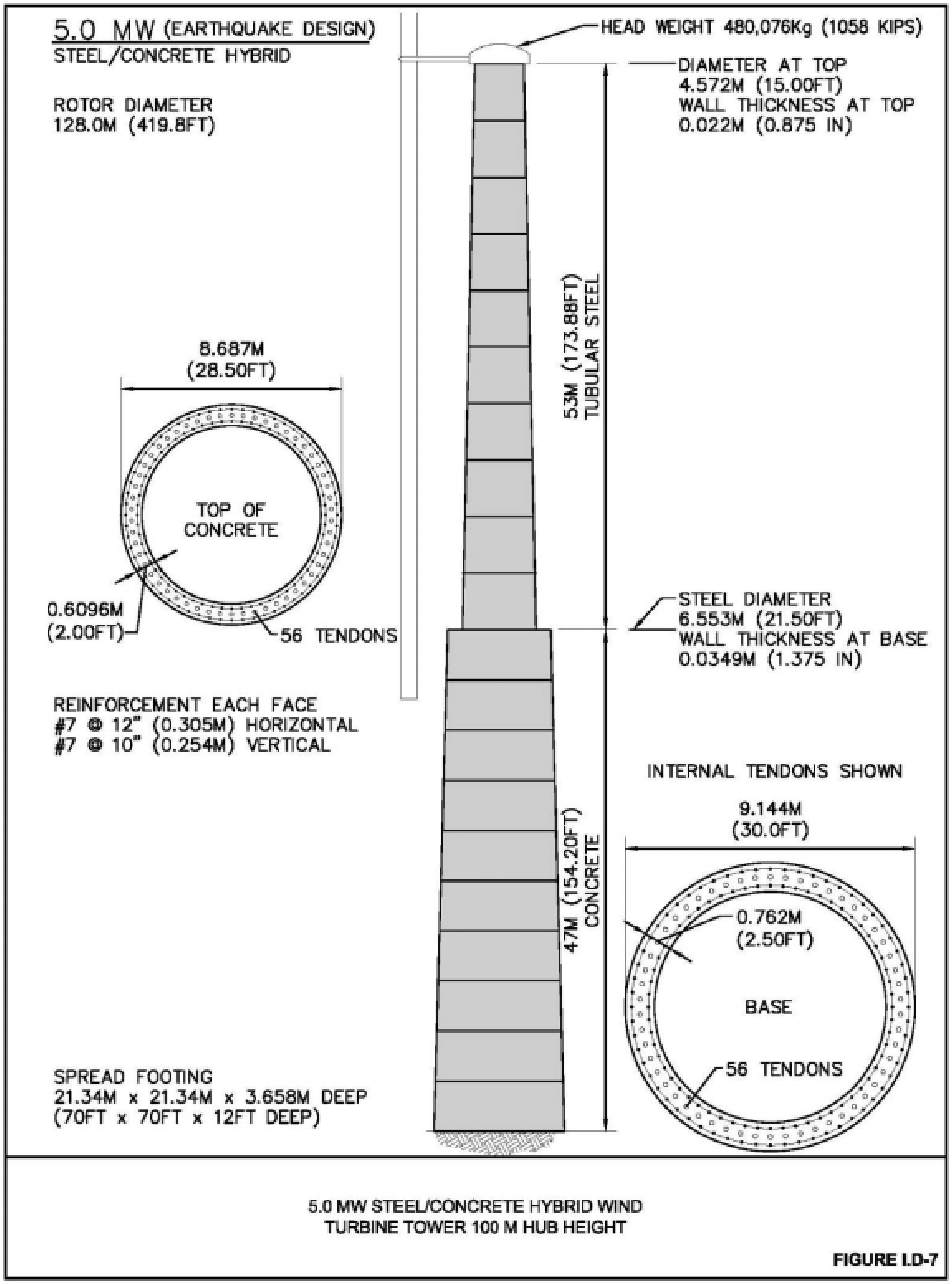


Figure 1-9 5.0-MW (earthquake design) steel/concrete hybrid wind turbine tower—100-m hub height

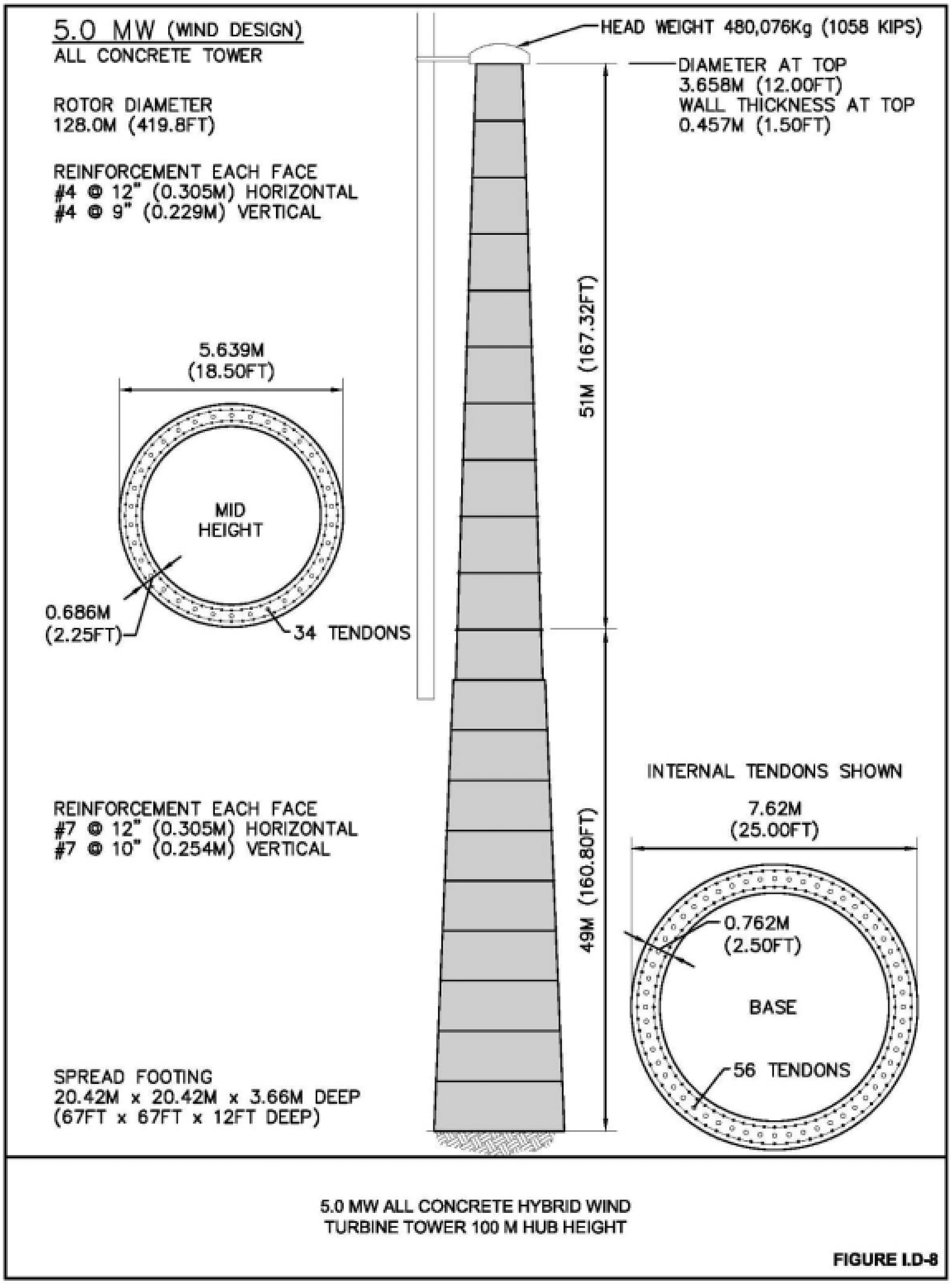


Figure 1.10 5.0-MW (wind design) all-concrete wind turbine tower—100-m hub height

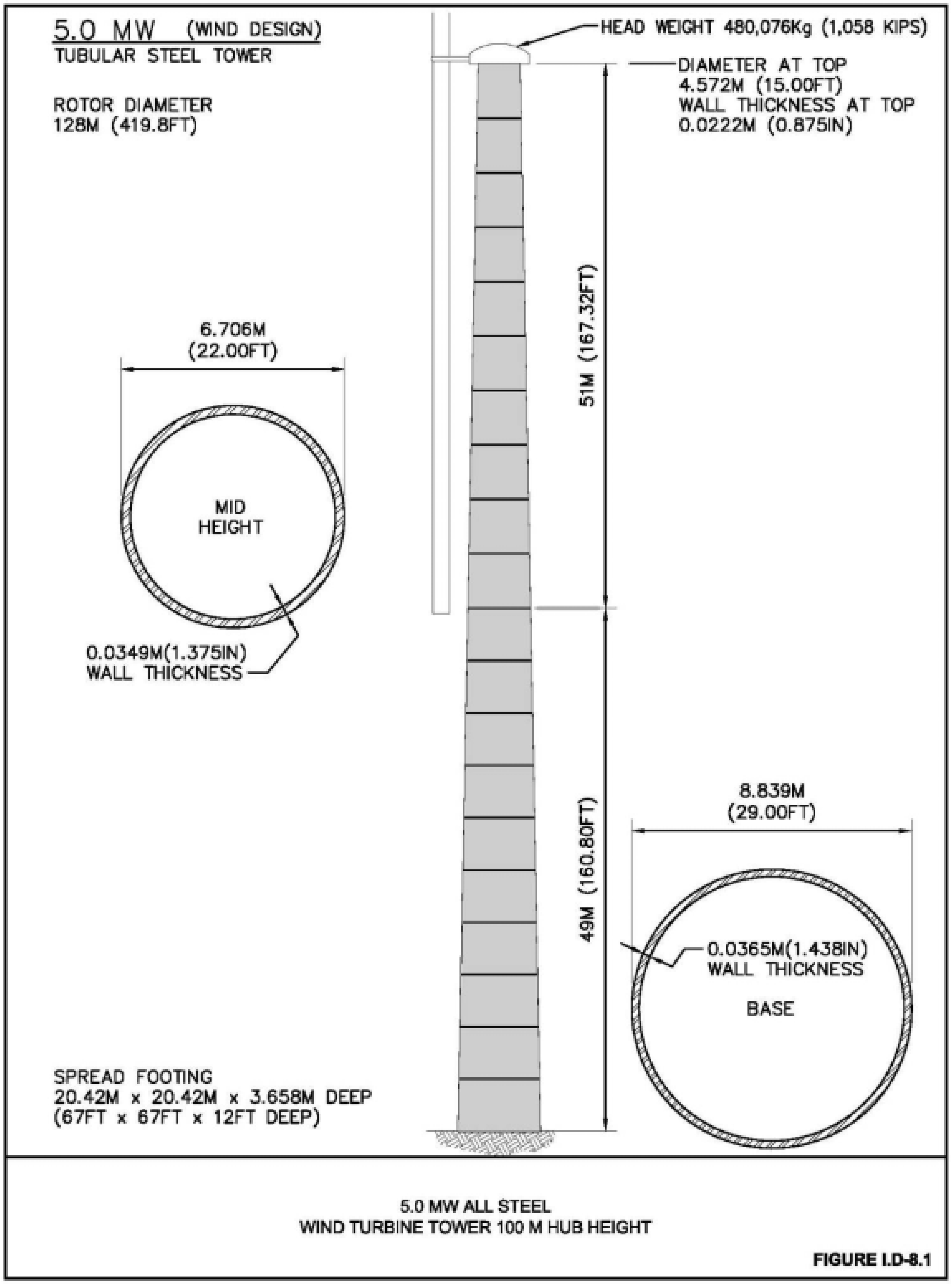


Figure 1-11 5.0-MW (wind design) all-steel wind turbine tower—100-m hub height

2.0 Analysis and Design Methodology for Wind Turbine Tower

Large concrete chimney structures of sizes similar to the wind turbine towers considered in this study have been in successful service for many years. The construction methods used for building these structures have been refined over time and have been proven to produce structures that are cost competitive with steel chimneys for the larger sizes. The primary differences between the design requirements for a concrete wind turbine tower and those of a chimney relate to the significantly larger magnitude of applied lateral force and overturning moment at the top of the tower, resulting in higher applied bending moments and shears, and the number of fatigue loading cycles associated with the rotational effects of the turbine blades. These effects are addressed in the designs developed here by the use of high-strength steel strands to post-tension (precompress) the tower concrete, increasing the structure's bending strength, shear strength, and its resistance to fatigue effects. The use of post-tensioning and the combined use of an upper steel tower and a lower concrete tower in the hybrid concept are the major departures from chimney design and construction technology.

The general design approach for the tower structures presented in this report (Figures 2.1–2.3) was to first size the tower cross section and taper to achieve the desired dynamic characteristics required for the different turbine sizes. Then, the post-tensioning of the concrete portion of the tower was designed to provide acceptable operational service load (characteristic load) level and ultimate strength level stresses in both the concrete and the post-tensioning tendons.

When an acceptable configuration was developed, the design was further evaluated for service level behavior (gross concrete section properties), for ultimate load behavior with the reduced section properties associated with a cracked section (applied moment exceeds the concrete cracking moment), and for fatigue strength. In this report, the civil engineering term *service level loading* is analogous to the wind industry terminology for *characteristic level loading*. Service level relates to terminology commonly used in U.S. codes such as the American Concrete Institute series of codes and standards.

In the case of the 1.5-MW hybrid steel/concrete tower, the concrete section was configured with a constant internal diameter to ease the jack-up process described in Section 10. The minimum internal diameter at the top of the concrete base section for the 3.6-MW and 5.0-MW hybrid steel/concrete towers was also controlled by the required diameter of the base of the upper steel section of the tower.

2.1 Literature Review and Design Criteria

The literature review for this study is outlined in the list of references cited in the References section at the end of this report. A special effort has been made to take advantage of related work that has been previously performed under NREL sponsorship. This specifically relates to the WindPACT series of studies [16–19,26].

We appreciate the input and insight from representatives of GE Wind Corporation primarily related to issues regarding commercially interesting turbine sizes to consider and the turbine hub height used. We also appreciate the input from representatives of Global Energy Concepts regarding appropriate WindPACT design loads and combination methods for use in the preliminary designs presented here. These aspects of the study were also coordinated with NREL representatives.

The basic design philosophy used for the prestressed concrete design of the wind turbine towers considered here was to design the tower structure for extreme load events based on ultimate strength design principles using accepted load factors on loads that are in use for concrete structures in the United States today. Where loads originated from operationally controlled turbine effects, wind-industry-accepted load factors were used. The detail dynamic behavior of the towers and the fatigue performance were evaluated using the principles of service load (characteristic load) design without the consideration of load factors (load factor = 1.00).

The issue of fatigue of the concrete and the prestressing steel materials has been specifically addressed, as the number of cycles of fatigue loading that typifies the wind turbine loading environment is an order of magnitude greater than that typical of most civil engineering structures.

2.2 Wind Turbine Tower Design Objectives

2.2.1 100-m Hybrid Steel/Concrete Tower

One design objective for the 100-m (328-ft) hybrid steel/concrete tower design is to develop a design that takes advantage of the favorable economics of tubular steel towers in the size range in which this advantage exists and replaces the steel tower with a prestressed concrete tower in that range in which the prestressed concrete tower economics are more favorable. A second design objective was to develop a design that could take advantage of self-erection concepts to reduce the cost and reliance on the large cranes necessary to erect the turbine machinery at the top of a 100-m (328-ft) tower.

The self-erection process proposed involves using a 51- to 53-m (167- to 174-ft) tall steel tower as a support for a small crane mounted on top of the tower that is used to erect the precast concrete elements of the lower tower to the full height of the concrete portion of the tower. When this work has been completed and the concrete tower post-tensioned to provide full design strength, the crane used to erect the precast is removed with a ground-based crane and the nacelle and rotors are installed using a ground-based crane. The ground-based crane is sized to make this lift at the 51-m (167-ft) level rather than the 100-m (328-ft) level. After the nacelle and rotor are installed at the 51-m (167-ft) level, the steel tower is jacked to the final 100-m hub height and the connection from the concrete tower to the steel tower at the 51-m (167-ft) level is completed and finalized. The outfitted steel tower is jacked up using a strand-jacking system that reacts against the top of the concrete tower. The concrete tower is used to support and stabilize the steel tower during the jacking process.

Because there is a step in the inside diameter at the transition from the concrete base to the upper steel portion of the tower, consideration must be given for any special measures necessary to service large items in the nacelle that may need to be lowered and raised within the access space inside the tower structure.

The cost differential for developing a full self-erecting approach is evaluated in Section 11. The conclusion of this evaluation is that, for the hybrid steel/concrete towers, it is more economical to use a pedestal crane sized to erect the precast concrete elements for the erection of the precast concrete tower and use a larger crane to set the nacelle, hub, and rotors, thus limiting the length of time this single larger crane must be rented.

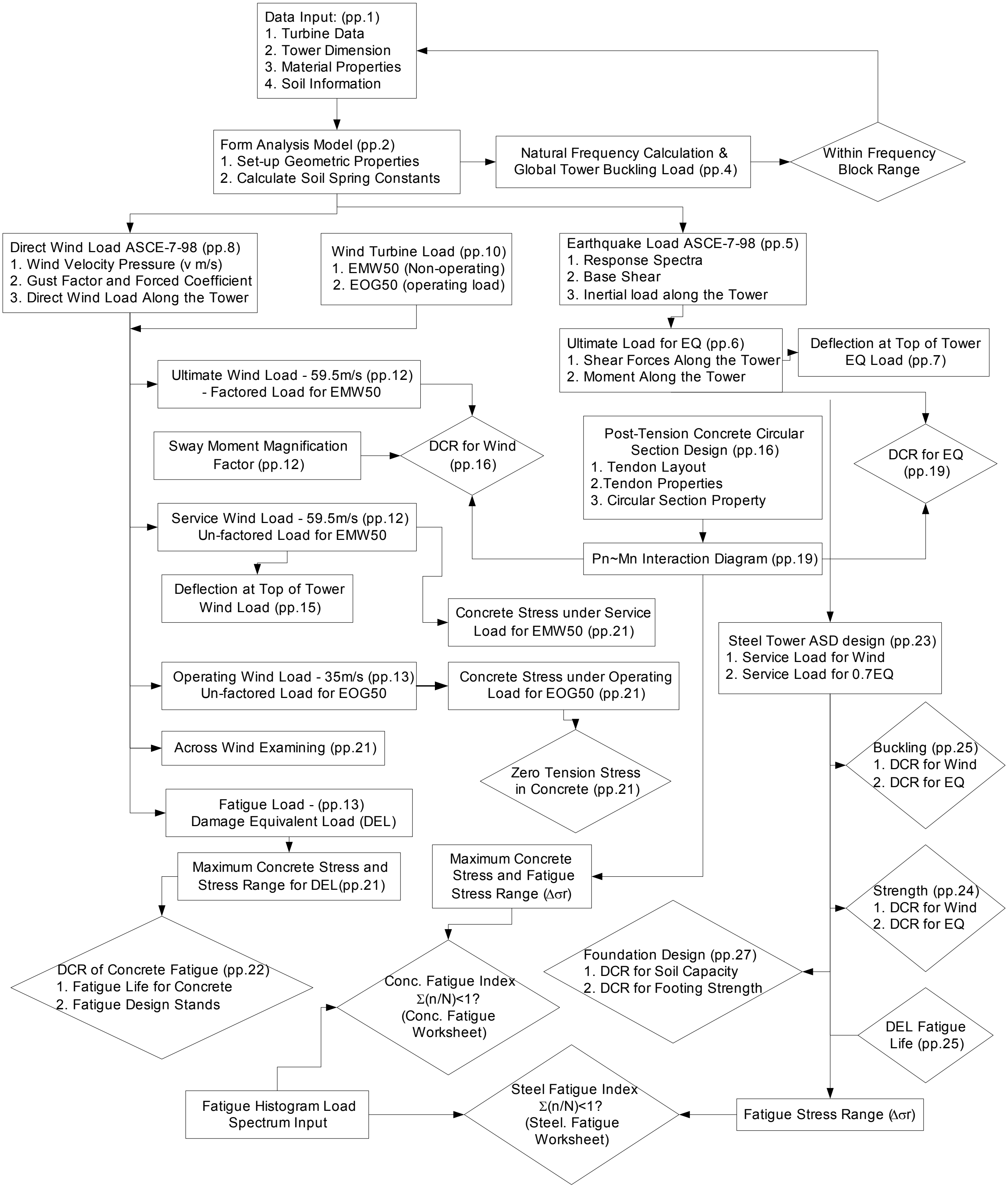


Figure 2.1. 100-m hybrid wind turbine tower design procedure flow chart
(page numbers refer to Appendix B Example Calculation page numbers)

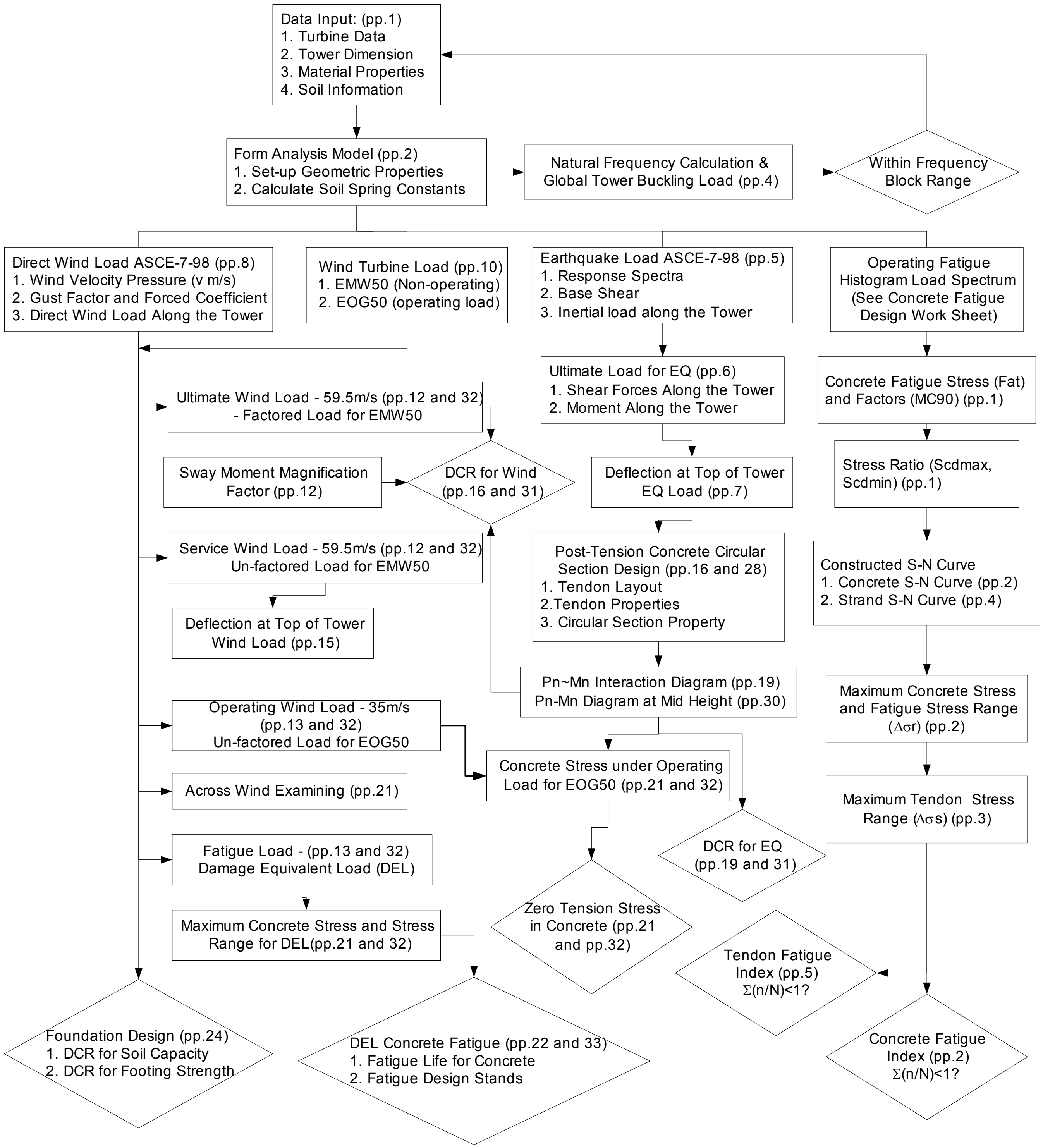


Figure 2.2. 100-m all-concrete wind turbine tower design procedure flow chart
(page numbers refer to Appendix B Example Calculation page numbers)

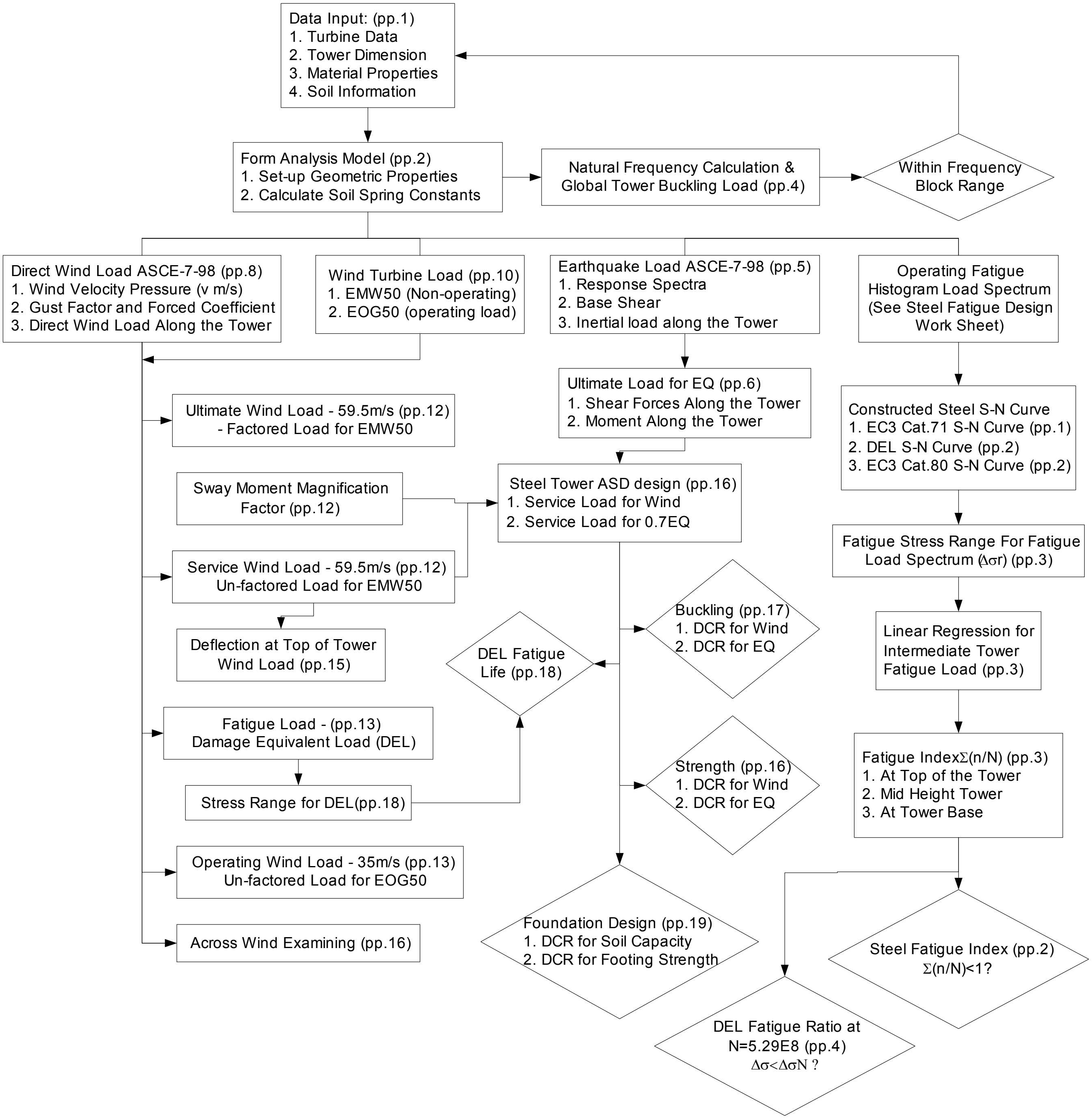


Figure 2.3. 100-m all-steel wind turbine tower design procedure flow chart
(page numbers refer to Appendix B Example Calculation page numbers)

A review of previous WindPACT work on tower self-erection indicates that the necessary transfer of local moments from a climbing self-erection crane to an uncompleted turbine tower (either steel or concrete) would likely require supplemental stiffening/strengthening at each point of force transfer to the tower structure (at increased cost). The erection concepts proposed in this study do not impose this requirement for supplemental strengthening of the tower structure.

A precast segmental design for the 1.5-MW hybrid tower was developed in some detail to identify and propose solutions for the design issues involved in the implementation of this concept. The drawings that describe this design and the associated construction process are given in Appendix D. A discussion of the construction process is given in Section 10.

The design of the 3.6-MW and 5.0-MW hybrid towers used the same basic dimensions for the split between concrete tower height and steel tower height. The reason is that the self-erection concept proposed is most easily implemented when the steel tower element of the hybrid tower is somewhat taller than the final height of the concrete tower that is constructed around the steel tower before jacking the steel tower to the 100-m (328-ft) height.

Review of the relative costs of these elements of the tower indicates that for a final design of the hybrid tower concept, the costs of temporarily supporting the steel tower at a higher bottom elevation (above the surface of the foundation) should be reviewed and traded off against the cost of different splits between the steel tower and concrete tower heights.

The concrete portion of the 1.5-MW hybrid steel/concrete tower has a somewhat larger diameter than the minimum required for strength purposes to provide necessary working space and clearance to allow the precast concrete erection and assembly operations and to provide clearance needed for the self-erection, jack-up operation. Also, to facilitate the jack-up operation, the inside diameter of the precast segments for the 1.5-MW hybrid tower was maintained from bottom to top. This approach will not be economical for the larger-diameter 3.6- and 5.0-MW towers, so an active hydraulically operated lower jack-up guide is proposed for these towers.

Although a cast-in-place concrete tower can be constructed around the steel tower portion of the hybrid tower, conventional chimney forming methods would have to be substantially revised. The potential cost effects of performing the hybrid concrete tower construction using a modification of the chimney construction methodology are discussed in Section 11.

2.2.2. 100-m Full-Height Concrete Tower

The full-height concrete towers can be constructed by continuing the segmental precast concrete concept to full height or by using a cast-in-place concrete approach similar to that used for chimney construction. Precast erection for the full concrete precast towers is envisioned being handled with a conventional mobile crane. The weight of the precast pieces is limited to balance the increasing cost of the crane required to lift fewer heavier elements with the increased cost of handling and integrating a larger number of smaller precast concrete segments. This area also merits further optimization study as part of a final tower design activity.

For the full-height concrete towers, we have assumed that the nacelle and rotor structure are erected at the 100-m (328-ft) level using a large crane mobilized for this purpose. We envision that most, if not all, the concrete towers would be completed and the nacelles and rotors all prepared for lifting before the large crane is mobilized to the site. The crane would then be kept in near constant service erecting one nacelle and rotor after another until all 50 are erected. In this way, the maximum use of the crane can be achieved, which will minimize the total time the crane is required on-site.

The 2001 WindPACT study on self-erection [18] indicates that the crane cost for tower assembly and erection and turbine installation for a 1.5-MW turbine installation at 100-m (328-ft) hub height is on the order of $100,000 per turbine, assuming that five turbines can be erected before the crane must be disassembled to move over difficult terrain. Thus, this approximately $5 million cost for a project of 50 turbine installations is the cost against which the cost of the self-erection concepts combined with the conventional crane erection costs of the nacelle and rotor must be compared. The cost studies are given in Section 11.

3.0 Design Loads

3.1 Wind Load

This element of the low wind speed technology program is focused on 100-m (328-ft) hub height turbines and their associated towers to access the increased amounts of wind energy available at this level. Operating in the 100-m (328-ft) high steady wind speed layer could subject large wind turbine towers to high speed wind gusts for the extreme load condition. Generally, for civil engineering structures, extreme and normal wind conditions are defined in terms of the highest wind speed condition occurring with 50-year and 1-year return periods, respectively. The wind load applied on the wind turbine tower is composed of the wind turbine loads and the effects of direct wind pressure on the tower. The ultimate strength design approach used for the tower designs presented here requires the design loads for the tower to be calculated as the appropriate summation of the products of each characteristic load and the appropriate load factor or safety factor. Those loads that occur simultaneously are appropriately combined.

3.1.1. Turbine Wind Loads

The forces that act on the rotor and hub that are transferred to the tower and finally to the foundation are attributable to the effects of wind, mass, and elastic forces. The different loads from these forces according to their time-related effect on the turning turbine rotor are grouped into the following categories:

- Aerodynamic loads from a uniform, steady wind speed and centrifugal forces generate a stationary load.
- A stationary, but spatially uneven flow field over the swept area causes cyclic load changes on the turning rotor.
- The mass forces that result from the rotating rotor blade weight cause periodic, nonstationary loads.
- In addition to the stationary and cyclic loads, the rotor is exposed to nonperiodic and random loads caused by wind turbulence.

Wind turbine design loads include inertia, mass, and aerodynamic forces acting on the rotor combined with acceleration and other dynamic reactions. Wind turbine machine manufacturers usually provide a design loads matrix based on the rated turbine power and location-specific design wind speeds. For this study, previous WindPACT studies provided the extreme wind turbine loads at the top of the tower for all six components of the loading matrix for a 1.5-MW and a 3.00-MW turbine. These loads varied with different wind directions. The extreme wind loads for the 3.6-MW and 5.0-MW turbines addressed in this study were scaled up according to the rotor sweeping area. The design assumes that those maximum component forces that are simultaneously applied on the top of the tower are appropriately combined for estimating maximum ultimate loads where the appropriate safety factors are also included.

3.1.2. Direct Wind Pressure on Tower

Direct wind load on the tower varies with tower dimension and, to a lesser extent, stiffness. In this report, the equivalent static lateral wind load acting on the tower is determined by ASCE 7-98 [9], wind load section. This approach was used as the ASCE 7 methodology and has been used for the wind load analysis of large industrial chimneys for some time, and it is considered to be applicable for these structures of similar size.

The extreme turbine loads are applied as static loads for the design of the towers for this study. It was felt that this would be slightly conservative. Thus, static lateral load methods were used according to current design code methods proposed by the ASCE standard to determine the direct wind load applied on the tower. The ASCE standard is the companion loads reference for the ACI 318 Building Code [6], the design code used for the design of the concrete towers.

The partial safety factor for limit load proposed by IEC 61400-1 standard for wind turbine design is 1.1DL + 1.35WL for normal and extreme load. The load factor from ASCE is: 1.2DL + 1.6WL, 19% higher than that of the International Electrotechnical Commission (IEC). In this study, the ASCE load factors for direct wind load on the tower structure were used because they were consistent with the code method used to calculate the direct wind load on the tower. The higher 1.6 (versus 1.35) load factor was also deemed appropriate because there is no opportunity to mitigate the effects of direct wind on the tower as there is with extreme loads applied to the actively controlled turbine rotors. The concrete towers are typically slightly stiffer and significantly heavier than the steel towers designed for the same tower top turbine loads.

For the extreme nonoperating condition, IEC condition EWM50, a nominal 3-s gust design wind speed of 59.5 m/s (133 mph) at 100 m (328 ft) was used for analysis purposes. For the extreme operating condition, IEC Condition EOG50, the nominal design 3-s gust wind speed at 100-m (328-ft) hub height is 35.0 m/s (78 mph).

It is important in using the ASCE design methodology to ratio the design wind speed typically given at the turbine hub height in the wind industry to the wind speed at 10 m (33 ft) above the ground, which is the reference elevation for ASCE equations. For the extreme direct wind that acts on the tower, associated with IEC nonoperating turbine condition EWM50, a wind shear exponent β of 0.1 to convert to the 10-m (33-ft) reference height was used, and for operational wind speed associated with the IEC extreme operating condition EOG50, a wind shear exponent β of 0.2 was used for this conversion.

Thus, wind distribution along the tower $v(z) = v\_hub\,(33ft/z)^{\beta}$.

The towers presented here are designed for direct wind exposure Category "D" to account for flat unobstructed area exposed to wind flowing over the open water or an expanse of flat terrain. An importance factor of 1.0 was selected for the low occupancies associated with wind turbine installations. The velocity pressure q_z on the tower is calculated by:

$$q_z = 0.00256 \cdot K_z \cdot K_{zt} \cdot K_d \cdot V^2 \text{ psf or, for SI units: } \quad q_z = 0.613 \cdot K_z \cdot K_{zt} \cdot K_d \cdot V^2 \, (\text{N/m}^2),$$

where the velocity of wind gust V is 59.5 m/s (133 mph) at 100 m (328 ft) height; the topographic factor K_{zt} is 1.0 for a flat open area; the wind directionality factor K_d is 0.95 for a round cylinder tower (see Table 6-6 of ASCE 7-98), and the terrain exposure coefficient K_z is determined either by Table 6-5 of ASCE 7-98 or by the following equation:

$$K_z(z) = \begin{cases} 2.01 \cdot \left(\dfrac{15ft}{z_g}\right)^{2/\alpha 1} & if \quad z < 15ft \\ 2.01 \cdot \left(\dfrac{z}{z_g}\right)^{2/\alpha 1} & otherwise \end{cases},$$

where z_g the nominal height of the atmospheric boundary layer is 213 m (700 ft) and $\alpha 1$ is 11.5 for exposure "D" from Table 6-4 of ASCE-7-98. z is the height above the ground in feet. The direct wind velocity pressure along the tower height is plotted in Figure 3.1. The 100-m hub height design wind speeds are converted to the ASCE7 reference wind speeds at 10 m (33 ft) above the ground surface.

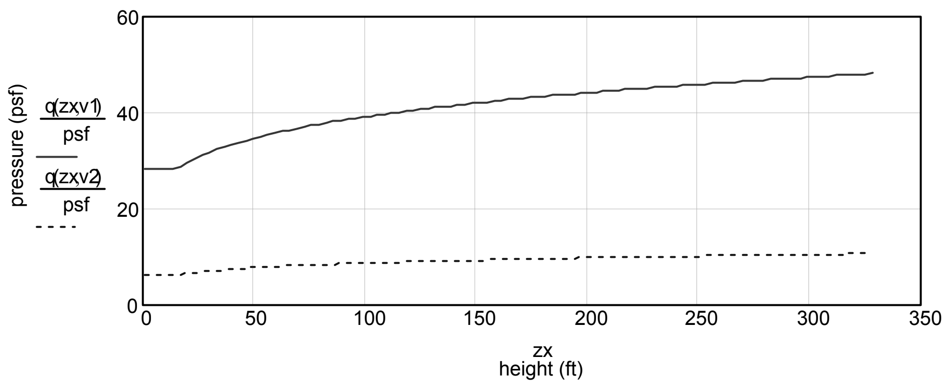


Figure 3.1. Velocity pressure along tower height (ft)
(v1 = 105.8 mph; v2 = 49.5 mph)

3.1.3. Direct Wind Load on Tower

The direct wind load on the tower (see Figure 3.2) depends not only on the direct wind pressure q_z on the tower but also on the gust effect factor G_f and force coefficient C_f. The gust effect factor is dependent on the flexibility of the tower structure. For a flexible turbine tower, the gust factor G_f can be calculated by

$$G_f = 0.925 \cdot \left(\frac{1 + 1.7 \cdot I_z \sqrt{g_Q^2 \cdot Q^2 + g_R^2 \cdot R^2}}{1 + 1.7 \cdot g_v \cdot I_z}\right) ,$$

where the intensity of turbulence, $I_z = 0.15\ (33ft/z)^{1/6}$, the background response Q, and the resonant response factor R are calculated by Equations 6-4 and 6-8 of ASCE-7-98; the peak gust factor for background response g_Q and for wind response g_v are equal to a value of 3.4. The peak gust factor for resonant response g_r is a function of tower frequency $n1$ and is computed by the following formula:

$$g_R = \sqrt{2 \cdot \ln(3600 \cdot n1} + \frac{0.577}{\sqrt{2 \cdot \ln(3600 \cdot n1}} .$$

The force coefficient C_f is a function of the structural shape (see Table 6-10 of ASCE-7-98). For the ratio of height to diameter of 11 typical of the towers under consideration here, C_f is approximately 0.62 for the moderately smooth round cylinder tower with $D\ q_z^{1/2} > 2.5$, where D is equal to the tower diameter.

The static lateral wind load $F_z(z)$ along the tower height z is calculated by the direct wind pressure on the projected area that varies with diameter $d(z)$:

$$F_z(z) = q_z\ G_f\ C_f\ d(z) .$$

The wind shear force $Vz(z)$ and the overturning moment $Mz(z)$ along the tower height z can be computed using the following:

$$Vz(z) = \int_z^h F_z(x) \cdot dx$$
$$Mz(z) = \int_z^h F_z(z) \cdot (x - z) \cdot dx \quad .$$

The tower deflection *Δ(z)* along the height (see Table 3.1) can be calculated by neglecting tower shear deformation and base translation and rotation:

$$\Delta(z) = \int_0^z \frac{Mz(x)}{E(x) \cdot I(x)} \cdot (z - x) \cdot dx \quad ,$$

where *E* is the modulus of elasticity; *I* is the moment of inertia of the tower cross section; both are varied along the tower height; and *x* is the integral variable along the tower height.

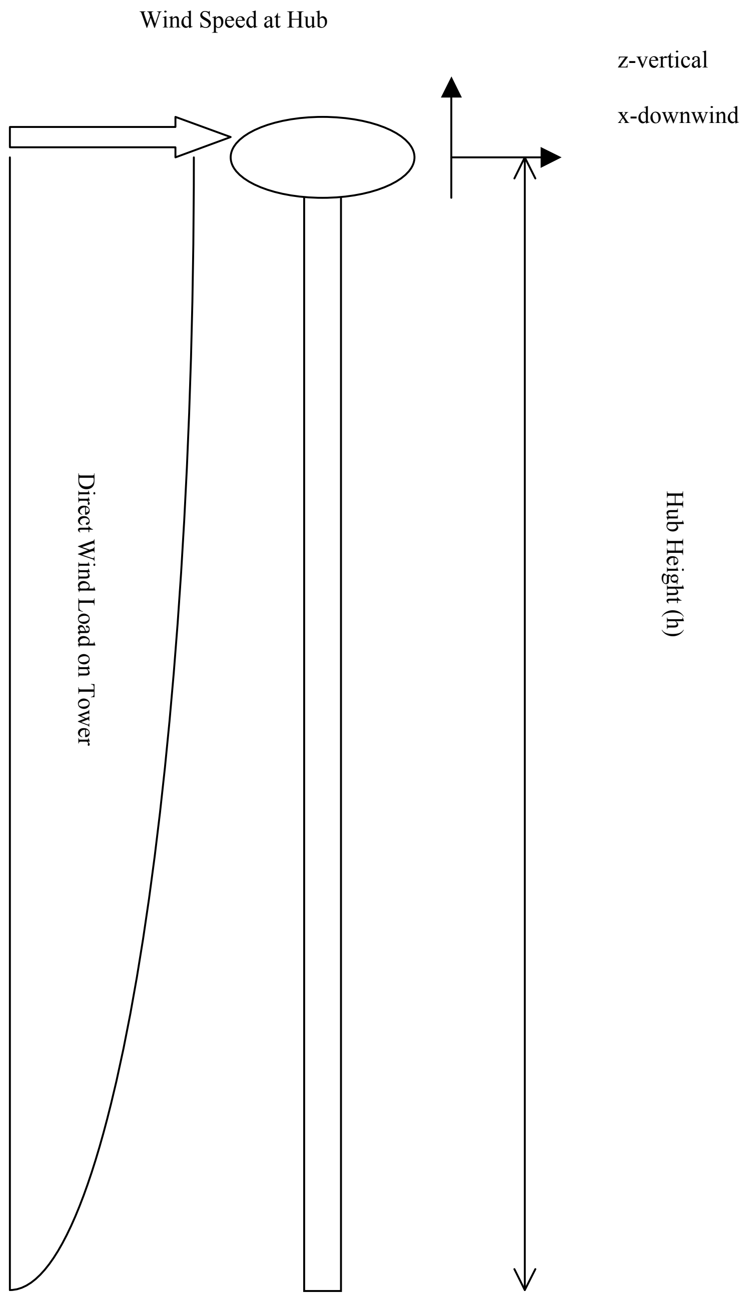


Figure 3.2 Distribution of direct wind load on tower

Table 3.1. Deflection at Top of 100-m Turbine Tower for Extreme Wind Load (EMW50)

Turbine Power	Hybrid Tower (EQ)		Conc. Tower (EQ)		Conc. Tower (Wind)		Steel Tower (Wind)	
1.5 MW	0.54 m	1.77 ft	0.27 m	0.90 ft	0.38 m	1.26 ft	0.92 m	3.01 ft
3.6 MW	0.47 m	1.53 ft	0.35 m	1.15 ft	0.51 m	1.66 ft	0.92 m	3.01 ft
5.0 MW	0.36 m	1.18 ft	0.27 m	0.88 ft	0.42 m	1.36 ft	0.61 m	1.99 ft

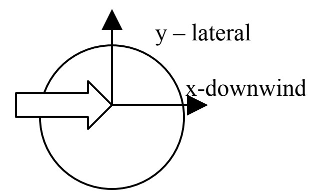
(EQ) = design controlled by earthquake (Wind) = design controlled by wind.

These deflections reflect consideration of the different directions of the EWM50 loads and the direct wind load on the tower structure.

3.1.4. Load Factors and Load Combinations for Ultimate Design Wind Load

For ultimate strength design, appropriate load factors are included in the design load combinations. Per the ASCE 7-98 recommendations, structures, components, and foundations shall be designed so that their ultimate design strength equals or exceeds the effects of the factored loads in the following combinations. (Note that wind turbine effects that use the IEC load factor of 1.35 have been added to these equations.)

- Partial Safety Factor γ_F: 1.35 for wind turbine loads (IEC)
- ASCE-7 Load Factor γ_{WL}: 1.60 for direct wind load on tower
  γ_{DL}: 1.20 for dead load



- Factored Load Combination for Extreme Load (EWM50):
  $\gamma_{DL}\, DL + \gamma_{WL}\, WL\_direct + \gamma_F\, TWL\_turbine$
- Characteristic Wind Load (Unfactored) Combination for EWM50 and EOG50:
  $DL + WL\_direct + TWL\_turbine$
- Fatigue Wind Load Combination:
  $DL + \Delta TWL\_turbine$ *(fatigue load)*

The summary of load conditions the towers are designed for is given below.

1. 1.4 *DL*
2. 1.2 *DL* + (1.35 *TWL* +1.6 *WL*)
3. 1.2 *DL* + *EQ*
4. 0.9 *DL* – (1.35 *TWL* + 1.6 *WL*)
5. 0.9 *DL* – *EQ*
6. 1.0 *DL* + Δ*WL* turbine (fatigue load)
7. 1.0 *DL* +1.0 *TWL* + 1.0 *WL*

where *DL* is dead load
TWL is the wind-induced turbine load
WL is direct wind load on the tower
EQ is earthquake load

Combinations *4* and *5* are used for uplift conditions. Total ultimate design wind load for tower shall be:

Ultimate design wind load = Extreme turbine wind load effects (with safety factor) + Factored direct wind load on the tower

3.1.4.1 Wind Load Combination Method

The total design wind load on the tower for a given load condition is determined as outlined below. In general, direct wind load on tower will add to wind turbine load on the tower along *x* direction.

A. Shear distribution along the tower on x or y direction

The total shear force along the tower: $Vx,y(z) = VTx,y + VDx\ (z)$,

where *VTx,y* is shear force on tower due to turbine load on either *x* or *y* direction
VDx(z) is direct wind load on *x* direction only varied along tower height

B. Moment distribution along the tower

Tower overturning moment *MTx,y(z)* along the tower *z* due to wind turbine load can be calculated by the linear interpolation method.

$$MTx,y(z) = [max(Mx,yT) - max(Mx,yB)]\ z/h + max(Mx,yB) ,$$

where *max(Mx,yT)* is maximum moment of *x* or *y* direction at top of the tower due to wind turbine load (given by Table 3.2).
max(Mx,yB) is maximum moment of *x* or *y* direction at tower base due to wind turbine load (given by Table 3.3)

C. Moment distribution along the tower on x and y direction

Total moment along the tower: $Mx,y(z) = MTx,y(z) + MDx(z)$,

where *MTx,y(z)* is overturning moment due to wind turbine load as calculated above
MDx(z) is overturning moment due to direct wind load on *x* direction

D. Wind load direction combination

The following methods of load combination are used for loads that act in different directions.

Absolute Summation -- > For loads applied on vertical (*z*) direction.

Vector Summation ---- > For loads applied on horizontal (*x* and *y*) direction for shear force and overturning Moment along the tower. (Although this method of combination is slightly conservative, not combining randomly applied loads acting in different directions is somewhat unconservative.)

Shear: $V(z) = (Vx(z)^2 + Vy(z)^2)^{1/2}$
Moment: $M(z) = (Mx(z)^2 + My(z)^2)^{1/2}$

The loads given in Table 3.2, associated with the turbines of the sizes considered here at 100-m (328-ft) hub height, were developed from the input used for the WindPACT Turbine Rotor Design Study [26] by representatives of Global Energy Concepts. The loads are given for the following conditions:

Ultimate design load condition (Extreme nonoperating load EWM50) with ultimate load factors.

Service or "characteristic" load condition (Extreme operating load EOG50 or EMW50 [whichever controls] with no load factors).

Table 3.2. Wind Turbine Tower Top Loads

		Turbine Wind Loads at Tower Top					
		PT(kN)	**PT(kips)**	**VT(kN)**	**VT(kips)**	**MT(kNm)**	**MT(k-ft)**
1.5 MW	Factored EWM50	999	225	519	117	53730	39630
	Unfactored EWM50	832	187	384	86	39800	29360
	Unfactored EOG50	832	187	402	90	33060	24380
3.6 MW	Factored EWM50	3796	853	1467	330	165900	122400
	Unfactored EWM50	3155	709	1087	244	122900	90640
	Unfactored EOG50	3129	703	1199	270	100700	74280
5.0 MW	Factored EWM50	6041	1358	781	176	189500	139800
	Unfactored EWM50	4998	1124	578	130	140400	103500
	Unfactored EOG50	4879	1097	1065	239	145500	107300

PT = load applied at the tower top in the z direction (along vertical axis of the tower)
VT = load applied at the tower top in the horizontal x (downwind) direction
MT = moment applied at the tower top

The resultant loads at the tower base for these same load conditions are summarized for direct wind loading on the tower and the total wind load, including turbine effects, in Tables 3.3–3.5. In these tables:

PD = tower dead load, not including the turbine head mass
VD = tower base shear resulting from the effect of direct wind on the tower
MD = tower base moment resulting from the effects of direct wind on the tower
P = total load applied at tower base, including tower dead load and turbine head mass
V = total tower base shear, including direct wind and turbine load effects
M = total tower base moment, including direct wind effects appropriately combined with turbine load effects

Table 3.3. 1.5-MW Wind Turbine Tower Loads at Tower Base—100-m Hub Height

Tower Base Resultant		Only Direct Wind Loads at Tower Base						Total Wind Loads at Tower Base (Direct Wind + Turbine Effects)					
		PD(kN)	PD(kips)	VD(kN)	VD(kips)	MD(kNm)	MD(k-ft)	P(kN)	P(kips)	V(kN)	V(kips)	M(kNm)	M(k-ft)
Steel	Factored EWM50	2772	623	1037	233	50720	37410	3771	848	1370	308	84060	62000
	Unfactored EWM50	2310	519	648	146	31700	23380	3142	706	902	203	57730	42580
	Unfactored EOG50	2310	519	119	27	5864	4325	3142	706	521	117	38850	28660
1.5 MW Concrete Wind Design	Factored EWM50	17390	3909	1022	230	49820	36750	18390	4133	1356	305	83350	61480
	Unfactored EWM50	14490	3257	639	144	31140	22970	15320	3444	894	201	57310	42270
	Unfactored EOG50	14490	3257	117	26	5721	4220	15320	3444	519	117	38710	28550
1.5 MW Concrete EQ Design	Factored EWM50	19990	4495	1059	238	51140	37720	20990	4719	1391	313	84390	62250
	Unfactored EWM50	16660	3746	662	149	31960	23580	17490	3933	915	206	57930	42730
	Unfactored EOG50	16660	3746	123	28	5955	4392	17490	3933	525	118	38940	28720
1.5 MW Hybrid	Factored EWM50	12500	2810	983	221	46620	34390	13500	3034	1319	297	80860	59640
	Unfactored EWM50	10420	2342	614	138	29140	21490	11250	2529	871	196	55830	41180
	Unfactored EOG5	10420	2342	115	26	5492	4051	11250	2529	517	116	38480	28380

Table 3.4. 3.6-MW Wind Turbine Tower Loads at Tower Base—100-m Hub Height

Tower Base Resultant		Only Direct Wind Loads at Tower Base						Total Wind Loads at Tower Base (Direct Wind + Turbine Effects)					
		PD(kN)	PD(kips)	VD(kN)	VD(kips)	MD(kNm)	MD(k-ft)	P(kN)	P(kips)	V(kN)	V(kips)	M(kNm)	M(k-ft)
3.6 MW	Factored EWM50	4842	1089	1353	304	66800	49270	8638	1942	2511	565	203200	149800
Steel	Unfactored EWM50	4035	907	845	190	41750	30800	7190	1616	1724	388	145400	107300
	Unfactored EOG50	4035	907	154	35	7654	5646	7164	1611	1353	304	108300	79890
3.6 MW	Factored EWM50	24480	5504	1243	280	61850	45620	28280	6357	2415	543	199900	147400
Concrete	Unfactored EWM50	20400	4587	777	175	38650	28510	23560	5296	1665	374	143400	105800
Wind Design	Unfactored EOG50	20400	4587	142	32	7100	5237	23530	5290	1341	301	107800	79480
3.6 MW	Factored EWM50	28410	6386	1285	289	62540	46120	32200	7239	2451	551	200300	147800
Concrete	Unfactored EWM50	23670	5322	803	181	39080	28830	26830	6031	1687	379	143700	106000
EQ Design	Unfactored EOG50	23670	5322	149	34	7297	5382	26800	6025	1348	303	108000	79630
3.6 MW	Factored EWM50	22670	5096	1351	304	64820	47810	26460	5950	2510	564	201800	148900
Hybrid	Unfactored EWM50	18890	4247	845	190	40510	29880	22050	4956	1723	387	144600	106700
	Unfactored EOG50	18890	4247	159	36	7645	5638	22020	4950	1357	305	108300	79880

Table 3.5. 5-MW Wind Turbine Tower Loads at Tower Base—100—m Hub Height

Tower Base Resultant		Only Direct Wind Loads at Tower Base						Total Wind Loads at Tower Base (Direct Wind + Turbine Effects)					
		PD(kN)	PD(kips)	VD(kN)	VD(kips)	MD(kNm)	MD(k-ft)	P(kN)	P(kips)	V(kN)	V(kips)	M(kNm)	M(k-ft)
5.0 MW	Factored EWM50	6398	1438	1515	341	74740	55130	12440	2796	1928	434	223500	164800
Steel	Unfactored EWM50	5331	1199	947	213	46710	34450	10330	2322	1268	285	160600	118500
	Unfactored EOG50	5331	1199	174	39	8626	6362	10210	2295	1238	278	153600	113300
5.0 MW	Factored EWM50	29420	6615	1320	297	64570	47620	35470	7973	1750	393	217700	160600
Concrete	Unfactored EWM50	24520	5513	825	186	40350	29760	29520	6636	1159	261	157200	116000
Wind Design	Unfactored EOG50	24520	5513	151	34	7425	5476	29400	6609	1215	273	152400	112400
5.0 MW	Factored EWM50	35810	8050	1390	313	66440	49000	41850	9408	1813	408	218700	161300
Concrete	Unfactored EWM50	29840	6708	869	195	41520	30630	34840	7832	1198	269	157800	116400
EQ Design	Factored EWM50	29840	6708	163	37	7790	5746	34720	7805	1226	276	152800	112700
5.0 MW	Unfactored EWM50	26100	5868	1506	339	72510	53480	32140	7226	1920	432	222200	163900
Hybrid	Unfactored EOG50	21750	4890	941	212	45320	33430	26750	6013	1263	284	159900	117900
	Factored EWM50	21750	4890	177	40	8565	6317	26630	5987	1241	279	153500	113200

In Tables 3.6–3.8, base shear and overturning moment for the ultimate design wind load are listed for a 100-m (328-ft) hub height with turbines of 1.5-, 3.6-, and 5.0-MW power ratings. The design wind velocity is 59.5 m/s (133 mph) at 100 m (328 ft). The value *z* at 49 m (160.8 ft) is the top of the concrete portion of the 1.5-MW hybrid concrete/steel tower.

Table 3.6. Factored Ultimate Tower Forces for Wind Load (EWM50)

Ultimate Tower Design Forces for Wind Load (EWM50)

Turbine Power	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	13500	3034	1319	297	80860	59640	1990	447	828	186	34900	25740
(EQ)	Conc. Tower	20990	4719	1391	313	84390	62250	8136	1829	890	200	35720	26340
	Steel Tower	3771	848	1370	308	84060	62000	1946	438	889	200	35740	26360
(Wind)	Conc. Tower	18390	4133	1356	305	83350	61480	7610	1711	880	198	35660	26300
3.6 MW	Hybrid Tower	26460	5950	2510	564	201800	148900	5688	1279	1920	432	106800	78750
(EQ)	Conc. Tower	32200	7239	2451	551	200300	147800	13840	3112	1902	428	103200	76100
	Steel Tower	8638	1942	2511	565	203200	149800	5617	1263	1940	436	103900	76660
(Wind)	Conc. Tower	28280	6357	2415	543	199900	147400	13270	2982	1902	428	103300	76180
5.0 MW	Hybrid Tower	32140	7226	1920	432	222200	163900	8505	1912	1238	278	125300	92390
(EQ)	Conc. Tower	41850	9408	1813	408	218700	161300	18400	4136	1182	266	120900	89170
	Steel Tower	12440	2796	1928	434	223500	164800	8447	1899	1258	283	122200	90130
(Wind)	Conc. Tower	35470	7973	1750	393	217700	160600	16750	3765	1174	264	120900	89180

Note: Forces for 3.6- and 5.0-MW hybrid tower are taken at tower height of 47 m versus 49 m.

The design wind tower height for the 3.6-MW wind turbine given by industry partner input is 94.5 m with hub height of 100 m. The remaining length is made up of the steel attachment section for the turbine nacelle. For the hybrid tower design that uses the jack-up construction method, the steel tower was made to be taller than the base concrete tower to allow installation of the turbine before jacking up the entire steel tower with turbine and rotor attached; therefore, the half of tower height for a 94-m tower (47 m) is the height of the concrete tower. The same allowance is assumed for the 5.0-MW hybrid tower. The loads given at 47 m are the tower top loads for the design of the concrete portion of the 3.6- and 5.0-MW hybrid steel/concrete towers.

3.1.5. Service (Characteristic) Wind Load

Service wind load is defined as the controlling unfactored load case (either EOG50 or EWM50). Hence, the unfactored service design wind load is simply expressed as:

Service wind load = Unfactored (EOG50 or WWM50) wind load + Unfactored direct wind load on the tower.

Table 3.8 lists the shear and moment effects of the unfactored wind loads from the wind turbine and design wind speed effects on the tower at the nonoperating extreme load condition EMW50, 59.5 m/s (133 mph). This condition was used **only** for the allowable strength proportioning of the tubular steel tower designs.

Table 3.7. Unfactored Tower Forces for Extreme Wind Load (EMW50)

(used only for preliminary proportioning of the tubular steel towers)

Unfactored Tower Forces for Extreme Wind Load (EWM50)

Turbine	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
Power		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	871	196	55830	41180	1659	373	571	129	25130	18540
(EQ)	Conc. Tower	22760	5117	974	219	60200	44400	8548	1922	633	142	26040	19210
	Steel Tower	3142	706	902	203	57730	42580	1622	365	608	137	25630	18900
(Wind)	Conc. Tower	15320	3444	894	201	57310	42270	6341	1426	603	136	25580	18870
3.6 MW	Hybrid Tower	22050	4956	1723	387	144600	106700	4732	1064	1364	307	78030	57560
(EQ)	Conc. Tower	26830	6031	1687	379	143700	106000	11530	2592	1353	304	75470	55660
	Steel Tower	7190	1616	1724	388	145400	107300	4673	1050	1376	309	75920	56000
(Wind)	Conc. Tower	23560	5296	1665	374	143400	105800	11050	2483	1353	304	75530	55710
5.0 MW	Hybrid Tower	26750	6013	1263	284	159900	117900	7051	1585	851	191	91750	67680
(EQ)	Conc. Tower	34840	7832	1198	269	157800	116400	15290	3438	817	184	88700	65430
	Steel Tower	10330	2322	1268	285	160600	118500	7003	1574	862	194	89490	66010
(Wind)	Conc. Tower	29520	6636	1159	261	157200	116000	13920	3129	812	183	88710	65430

Note: Forces for 3.6- and 5.0-MW hybrid tower are taken at tower height of 47 m shown in italics.

Table 3.8. Unfactored Tower Forces for Maximum Operating Wind Load (EOG50)

Operating Wind Load Tower Design Forces (EOG50)

Turbine	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
Power		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	517	116	38480	28380	1659	373	454	102	18780	13850
(EQ)	Conc. Tower	17490	3933	525	118	38940	28720	6780	1524	461	104	18920	13960
	Steel Tower	3142	706	521	117	38850	28660	1622	365	461	104	18920	13950
(Wind)	Conc. Tower	15320	3444	519	117	38710	28550	6341	1426	459	103	18890	13940
3.6 MW	Hybrid Tower	22020	4950	1357	305	108300	79880	4706	1058	1275	287	59770	44080
(EQ)	Conc. Tower	26800	6025	1348	303	108000	79630	11500	2586	1272	286	57760	42610
	Steel Tower	7164	1611	1353	304	108300	79890	4647	1045	1276	287	57890	42700
(Wind)	Conc. Tower	23530	5290	1341	301	107800	79480	11020	2478	1271	286	57760	42600
5.0 MW	Hybrid Tower	26630	5987	1241	279	153500	113200	6932	1558	1150	259	88270	65110
(EQ)	Conc. Tower	34720	7805	1226	276	152800	112700	15170	3411	1142	257	85410	63000
	Steel Tower	10210	2295	1238	278	153600	113300	6884	1548	1151	259	85680	63190
(Wind)	Conc. Tower	29400	6609	1215	273	152400	112400	13800	3103	1139	256	85380	62980

Note: Forces for 3.6- and 5.0-MW hybrid tower are taken at tower height of 47 m.

For the unfactored maximum operating load condition given in Table 3.9, the design criteria have been set to stipulate zero tension concrete stresses in the post-tensioned concrete tower at the loading associated with load condition EOG50, 35 m/s (78 mph) wind speed. This level of loading was deemed appropriate to associate with the zero concrete tension design condition from a review of the distribution of loading magnitudes and relative frequency of occurrence from the WindPACT loads [26]. In other words, the joints between concrete segments (precast concrete tower design) remain under compression at 35 m/s (78 mph) wind speed, while some tensile strain is allowed across the joint at the extreme 59.5 m/s (133 mph) wind speed.

3.1.6. Temporary Construction Wind Loads

A temporary design wind velocity of 40 m/s (90 mph) at 100-m hub height is used to determine the temporary construction design wind load. The temporary construction wind load is lower than the extreme load because of the lower probability of high wind loads during the limited time period of the construction stage. The turbine wind load is scaled down from load case EMW50 by the ratio of the square of wind speed accordingly. This load level is used for checking temporary construction conditions.

3.1.7. Operational Wind Fatigue Loading

The primary focus of the fatigue design of the towers studied here was on the concrete towers. For the fatigue design of these towers, WindPACT fatigue loads as outlined in Appendix J were used. The fatigue design of the steel towers was done with a damage equivalent load (DEL) approach found to give reasonable results. The less rigorous approach used for the steel towers was taken as these designs have been prepared for comparison purposes only. In a final design of a steel tower, a detailed fatigue analysis would be required.

For both the steel tower and concrete tower fatigue analyses, the effects of direct wind on the tower are not added to the turbine effects fatigue loading, in conformance with current industry practice. The fatigue moment along the tower was calculated as outlined below, and fatigue was checked at the tower base and midpoint. For a final design, additional sections would be checked on those towers controlled by the effects of fatigue.

3.1.7.1 Damage Equivalent Load for Steel Tower

The following describes how the DEL was used for this study.

Figure 3.3 shows the SN curve for category 80 from Euro Code 3 (1993) (EC3 Cat.80), which is a commonly used fatigue strength for details in wind turbine tower designs. This curve can be combined with the histogram of predicted stress cycles to determine the fatigue damage that will occur during the design lifetime of a tower.

In circumstances where the full histogram of fatigue cycles is not available but only a DEL is specified, the following method can be used to evaluate fatigue effects. The DEL will be accompanied by a value of the SN slope (m = 4 used in this case) and a number of cycles (*Ne*). The steps below constitute a “rule of thumb” that is acceptable for using the DEL to check the fatigue integrity of a steel tower design.

Step 1. Draw a line with slope m = 4 that passes through the point with coordinates N=2E6 and S=80 MPa (see Figure 3.3).

Step 2. Determine the allowable fatigue stress range *Se* value on this line, where *N* = *Ne* (9.46E8 in Figure 3.3). This *Ne* value is for illustrative purposes only, as the design fatigue life for the towers in this study is 5.29×10^8.

Step 3. The Se value is the fatigue strength of the design detail under Ne cycles. If the stress range that results from the DEL < *Se*, then the design is safe for the design fatigue loading. If DEL > *Se*, then the design is not acceptable.

The fatigue load moment along the tower is calculated by linear interpolation as outlined below.

Total moment range along the tower [$\Delta Mx,y(z)$] was determined.

$\Delta Mx,y(z) = [max(\Delta Mx,yT) - max(\Delta Mx,yB)]\ z/h + max(\Delta Mx,yB)$.

max(ΔMx,yT) = Maximum moment range at tower top on *x* or *y* direction.
max(ΔMx,yB) = Maximum moment range at tower base on *x* or *y* direction.

The design moment range is taken as the maximum of either *ΔMx(z)* or *ΔMy(z)*. No vector summation is applied.

For checking the steel tower designs, the following criteria were used.

Safety Factor of DEL: 1.0

Consequence failure factor and material factor:

$$\gamma_{Sd} \cdot \gamma_C = 1.15 \times 1.1 = 1.265$$

Number of Cycles: $N = 5.29 \times 10^8$ for 1.5-MW turbine
(Assume the same number of cycles for 3.6-MW and 5.0-MW turbines)
This represents a 20-year lifetime.

Fatigue Slope	$m = 4$
Stress Range at 2×10^6 Cycles	$\Delta\sigma r = 80$ MPa
DEL Thrust:	ΔF *(kN)* = See Table 3.9
DEL Moment:	ΔM *(kN-m)* = See Table 3.9

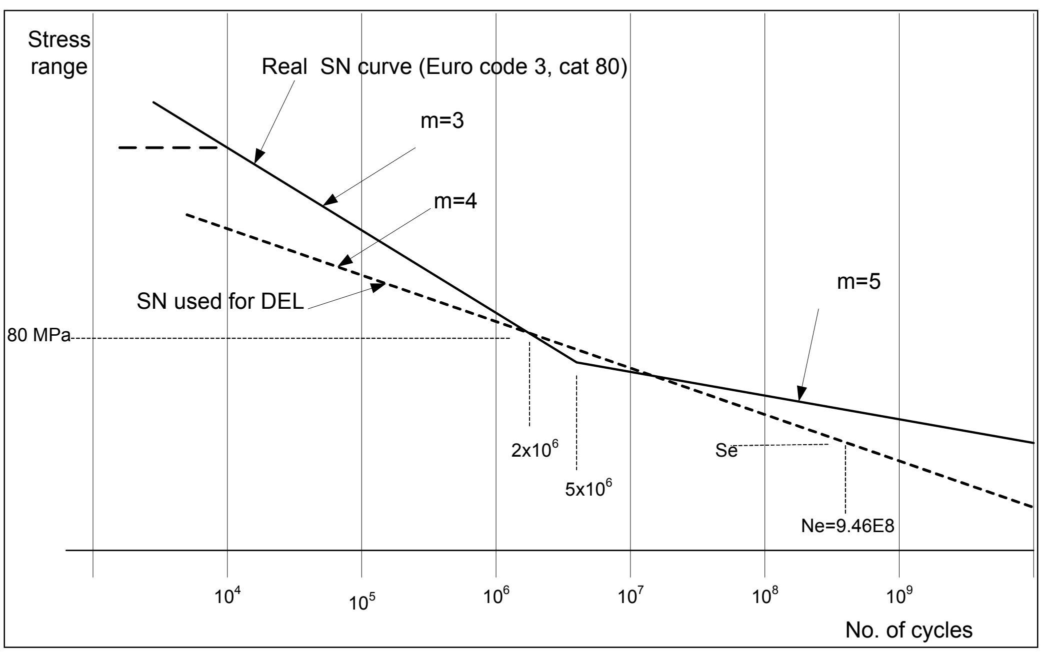


Figure 3.3. Applying the damage equivalent load to a steel tower design

Table 3.9. Unfactored Fatigue Wind Load Tower Forces (DELs) for Steel Tower Design

Fatigue Wind Load Tower Design Forces

Turbine	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
Power		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	57	13	8311	6130	1658	373	57	13	4510	3327
(EQ)	Conc. Tower	17490	3933	57	13	8311	6130	6779	1524	57	13	4510	3327
	Steel Tower	3142	706	57	13	8311	6130	1621	365	57	13	4510	3327
(Wind)	Conc. Tower	15320	3444	57	13	8311	6130	6341	1426	57	13	4510	3327
3.6 MW	Hybrid Tower	21980	4941	143	32	19770	14580	4665	1049	143	32	11500	8481
(EQ)	Conc. Tower	26760	6016	143	32	19770	14580	11460	2577	143	32	11150	8222
	Steel Tower	7123	1601	143	32	19770	14580	4606	1035	143	32	11150	8222
(Wind)	Conc. Tower	23490	5281	143	32	19770	14580	10980	2468	143	32	11150	8222
5.0 MW	Hybrid Tower	26460	5948	197	44	29890	22050	6761	1520	197	44	17540	12940
(EQ)	Conc. Tower	34550	7767	197	44	29890	22050	15000	3373	197	44	17020	12550
	Steel Tower	10040	2257	197	44	29890	22050	6713	1509	197	44	17020	12550
(Wind)	Conc. Tower	29230	6571	197	44	29890	22050	13630	3064	197	44	17020	12550

Note: Forces for 3.6- and 5.0-MW hybrid tower are taken at tower height of 47 m versus 49 m.

3.1.7.2 Fatigue Loads for Concrete Tower

The fatigue design approach outlined in CEB-FIB, Model Code 1990 [1] was used for the fatigue design of the all-concrete towers and the concrete portion of the hybrid steel/concrete towers. The details of this and other approaches are discussed in Section 6.

Fatigue Load Factors. The following combined safety factors (including partial safety factors on loads and material) were used:

- Fatigue check of concrete according to Model Code 90: $\gamma_F \cdot \gamma_{Sd} \cdot \gamma_C = 1.65$
- Fatigue check of reinforcement according to Model Code 90: $\gamma_F \cdot \gamma_{Sd} \cdot \gamma_C = 1.265$
- Fatigue check of embedded steel according to IEC 61400: $\gamma_F \cdot \gamma_M = 1.265$

where γ_F = factor for model uncertainties = 1.0
γ_{Sd} = partial factor on load = 1.1
γ_C = partial factor on concrete strength = 1.5
γ_M = material factor for steel = 1.15

Fatigue load range histograms (*Fx*, *Mx*, *My*, and *Mz*) associated with load cycles are from the input to the WindPACT Turbine Rotor Design Study [26] and were provided by GEC. These data are included in Appendix J.

Fatigue Data Assumptions. The following assumptions were made in the application of these data:

$$mean\ Fx = \Delta Fx / 2$$
$$mean\ Mx,y,z = \Delta Mx,y,z / 2$$
$$max\ Fx = mean\ Fx + \Delta Fx /2 = \Delta Fx$$

min Fx = mean Fx - ΔFx /2 = 0
max Mx,y,z = mean Mx,y,z + ΔMx,y,z /2 = ΔMx,y,z
min Mx,y,z = mean Mx,y,z - ΔFx,y,z /2 = 0

- It is assumed that the moment acting along the tower in the downwind direction (*x*) is independent of loads acting on the tower in the lateral direction. Loads that act in each direction are not correlated and do not occur simultaneously. Maximum fatigue moment range on either x direction or y direction will control the design for fatigue loads. (Here, moment about the *y* direction -*My*(*z*) obviously governs.)

Use of Fatigue Data. Fatigue moment at mid-height of the tower was calculated by linear interpolation:

ΔMx,y,z(z) = [max(ΔMx,y,zT) – max(ΔMx,y,zB)] z/h + max(ΔMx,y,zB)
max(ΔMx,y,zT) - Maximum moment range at tower top on x, y and z direction
max(ΔMx,y,zB) - Maximum moment range at tower base on x, y and z direction,

where the fatigue moment at the top and at the base of the tower are obtained by using linear regression as the function of *F(x)* = a ln(*x*+*b*) + *c* (see Figures 3.4–3.6).

Because about 40 data points of the fatigue load histogram are available and the data approximately span from 4 x 10^3 to 1.2 x 10^8 cycles, 40 fatigue load data points were interpolated and evenly distributed to estimate fatigue load at mid-height of the tower. The corresponding number of cycles can be estimated by $N_i = 10^{0.115(i-1)+3.6}$ and total number of the cycles $\Sigma N_i = 5.23 \times 10^8$.

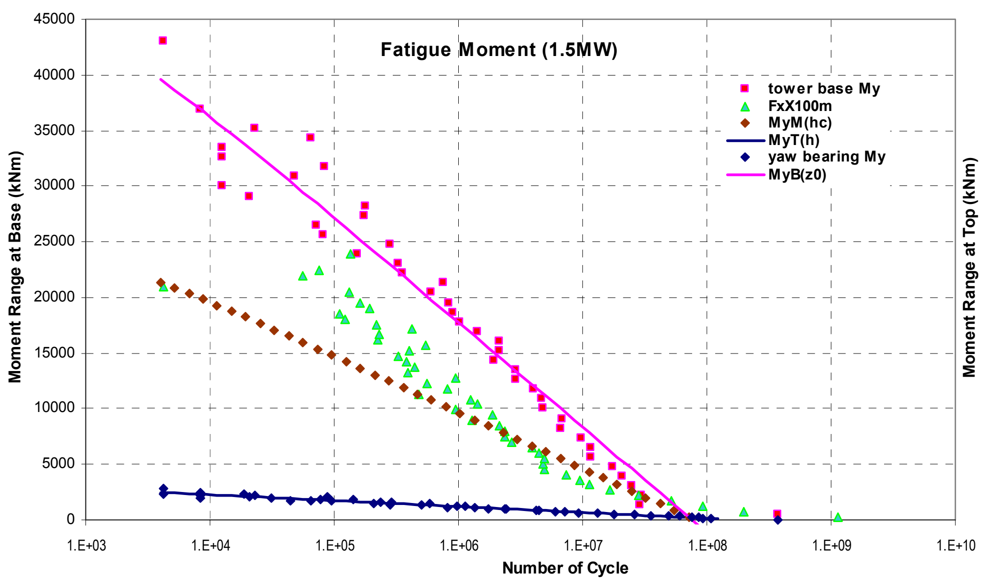


Figure 3.4. Fatigue moment at top and base of the 1.5-MW tower on x direction (My)

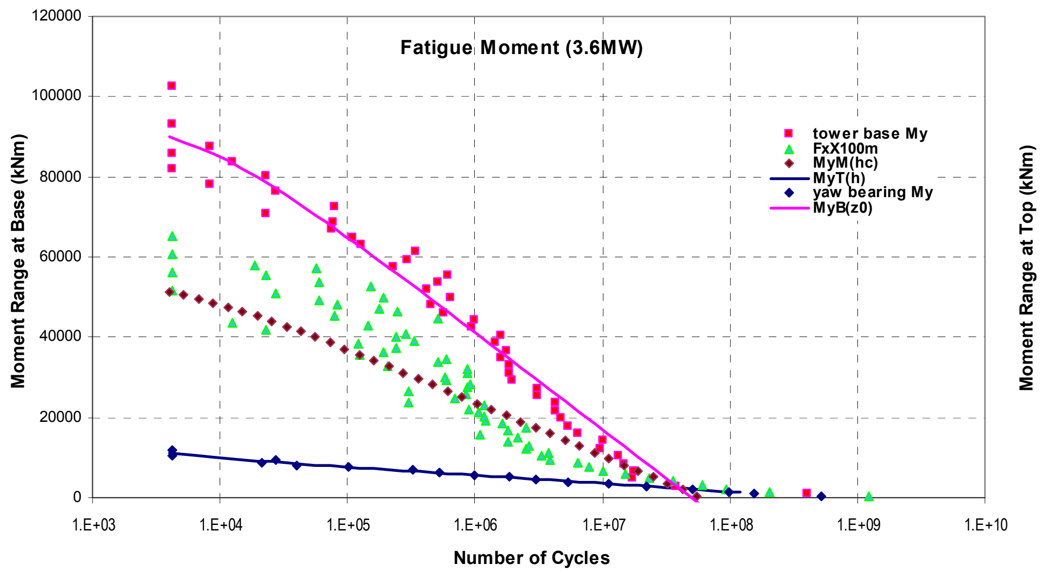


Figure 3.5. Fatigue moment at top and base of the 3.6-MW tower on x direction (My)

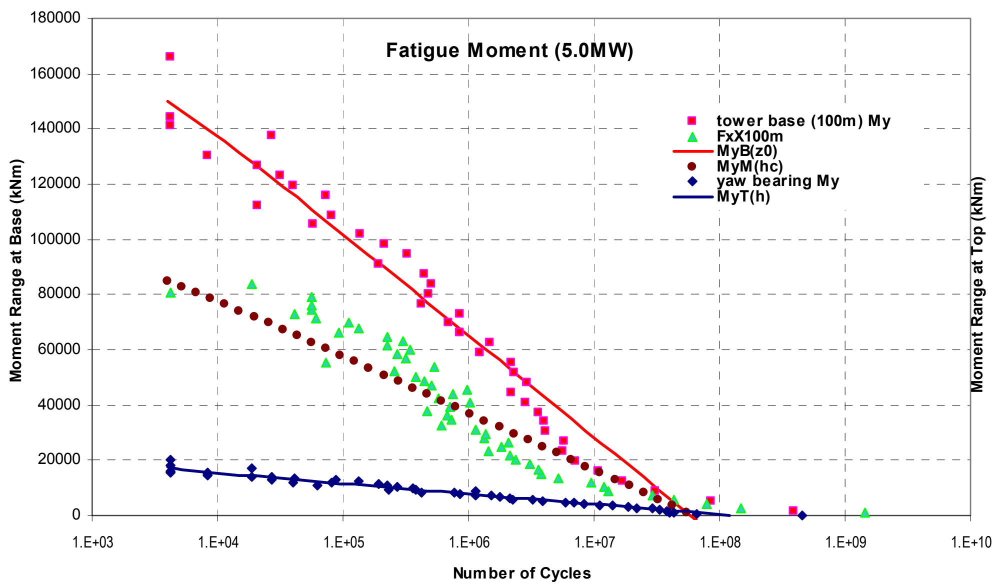


Figure 3.6. Fatigue moment at top and base of the 5.0-MW tower on x direction (My)

MyT(h):	Moment on *y* direction at top of the tower after linear regression
MyB(z0):	Moment on *y* direction at the tower base after linear regression
MyM(hc):	Moment on *y* direction at mid height *hc* of the tower after linear interpolation from *MyT(h)* and *MyB(z0)*

Yaw bearing *My*:	Moment on *y* direction at top of the tower obtained from fatigue histogram data
Yaw bearing *My*:	Moment on *y* direction at tower base obtained from fatigue histogram data
$Fx \cdot 100$m:	Moment on *y* direction at tower base calculated by fatigue thrust *Fx* obtained from fatigue histogram data on *x* direction multiplied by the tower height (100m) for comparison.

To show the relative magnitudes of design forces and moments, a comparison of the base shear and overturning moment of the wind turbine towers for 100-m (328 ft) 1.5-, 3.6-, and 5.0-MW hybrid towers at the base of the concrete towers are plotted in Figures 3.7–3.9.

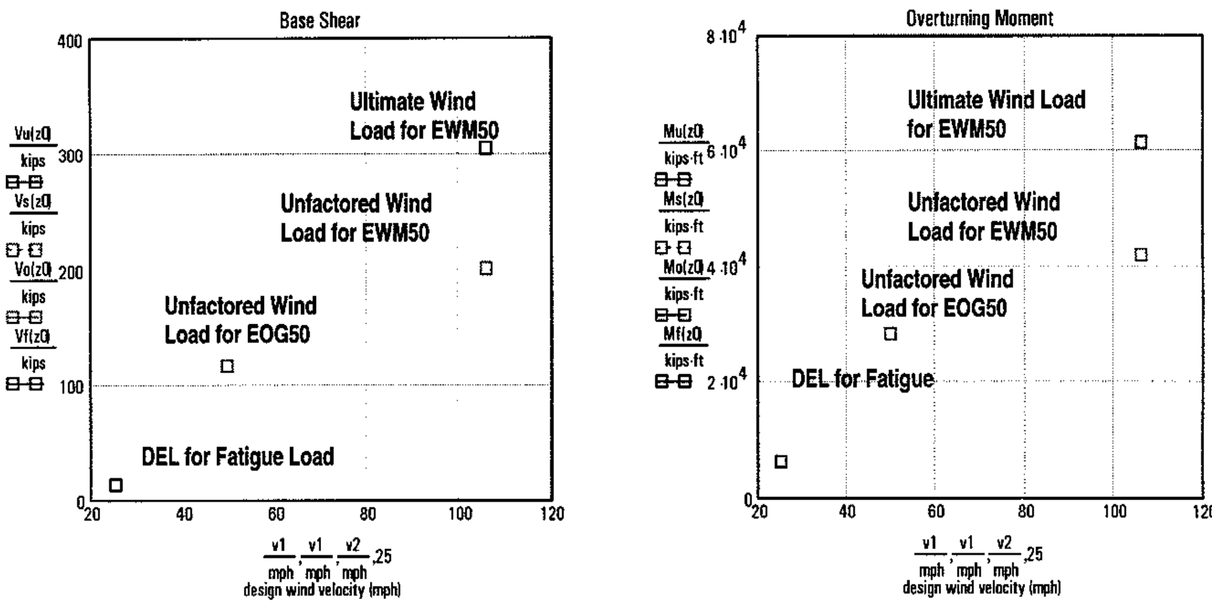


Figure 3.7. Resultant comparison at tower base for 1.5-MW concrete tower (wind)

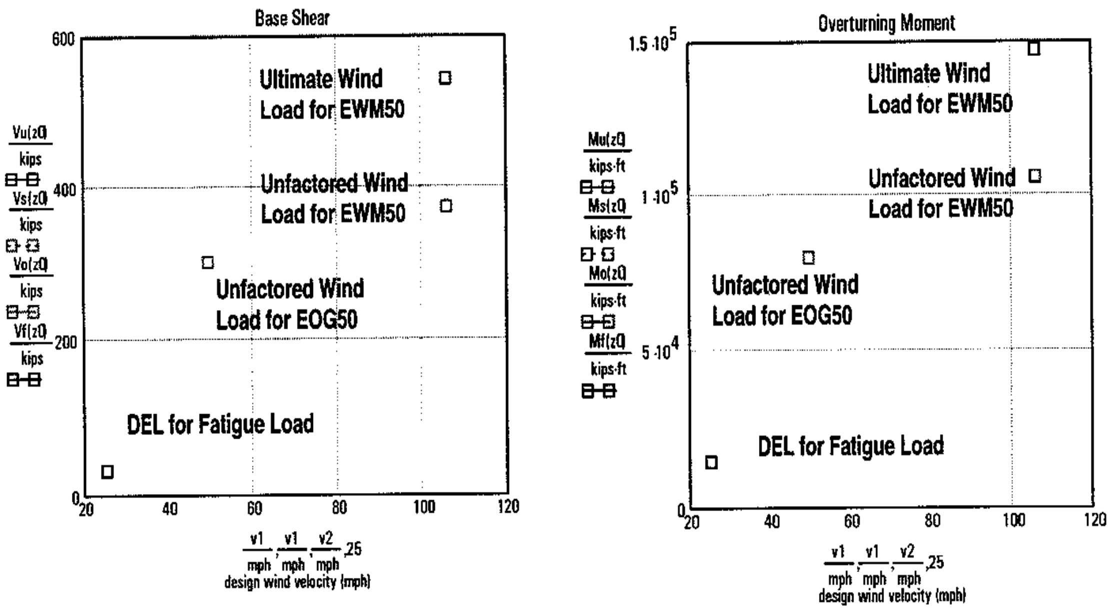


Figure 3.8. Resultant comparison at tower base for 3.6-MW concrete tower (wind)

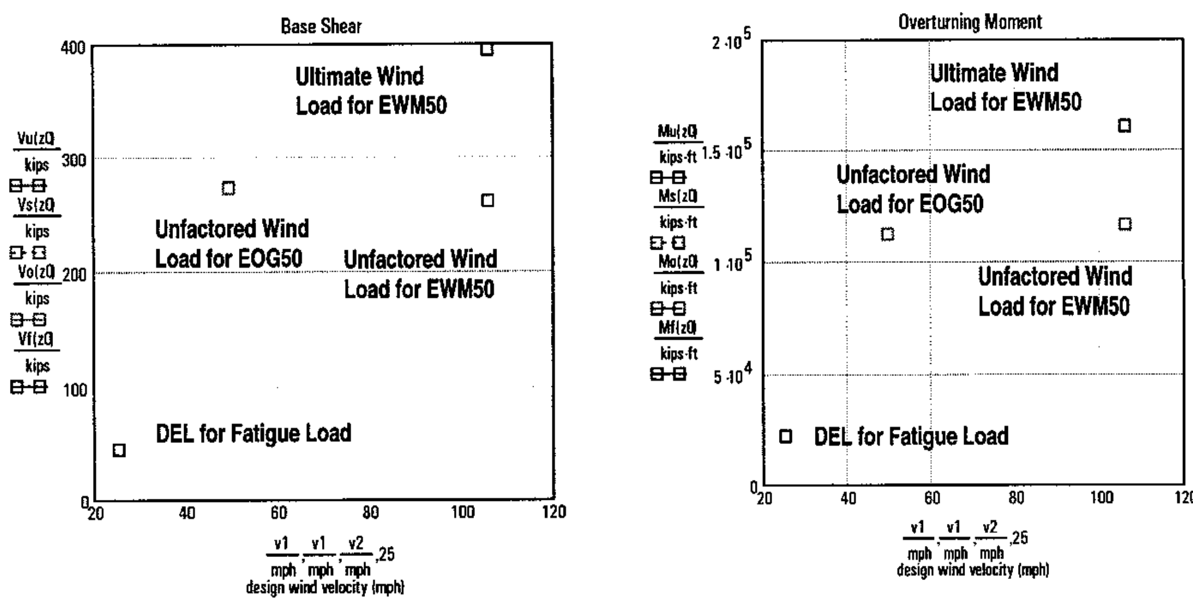


Figure 3.9. Resultant comparison at tower base for 5.0-MW concrete tower (wind)

3.1.7.3 Across-Wind Load on Wind Turbine Tower

Across-wind loads caused by vortex shedding on the wind turbine tower likely have similar characteristics to wind effects on chimney-type structures. According to Chapter 4 of ACI 307-98 [5], the across-wind response of cylindrical structures depends on the critical wind speed (V_{cr}). Across-wind load effects need not be considered if the wind speed at critical height (z_{cr}) is either less than $0.5V_{cr}$ or greater than $1.3V_{cr}$. Across-wind load effect for the first dynamic mode of the tower is examined because the first mode for the wind turbine tower is the dominant mode for dynamic analysis.

The critical wind speed at the height of $z_{cr} = 5/6h$ (h is the tower height) is calculated by

$$V_{cr} = f\, d(u) / S_t \ ,$$

where f is the natural frequency of tower
$d(u)$ is the mean outside diameter of the upper third of tower
the Strouhal number S_t is calculated as

$$S_t = 0.25\{0.333 + 0.206 \ln [h/d(u)]\} \ .$$

The mean hourly design wind speed V(z) at z_{cr} (5/6h) is computed as

$$V(z) = (1.47)\ V\ (z/33ft)^{0.154}\ (0.65) \ ,$$

where V is the nominal design wind speed, for example, the 1.5-MW, 100-m (328-ft) full-concrete turbine tower is examined for design wind speed 22.1 m/s (49.5 mph). The tower natural frequency is about 0.377 Hz. The wind speed at critical height ($z_{cr} = 5/6 \times 100 \times 3.28 = 273\ ft$) is

$$V(z_{cr}) = 1.47 \times 49.5\ mph \times (273/33)^{0.154} \times 0.65 = 65\ mph.$$

The average outside diameter $d(u)$ of the upper third of the tower is 3.6 m (11.8 ft). From the above formula, the Strouhal number $S_t = 0.255$. The critical wind speed V_{cr} can be computed

$$V_{cr} = 0.377 \times 11.8 / 0.255 = (12mph)\ (5.33\ \text{m/s}) < 0.5V(z_{cr}).$$

Thus, across-wind load effects need not be added to the design loads for the full concrete turbine tower. The hybrid tower has similar behavior.

3.2 Earthquake Loading

In some current steel tubular wind turbine tower analysis and design, earthquake loads may not be significant to the tower design because:

- Wind turbine towers often are placed in low seismic areas, wide-open areas, and high wind gust areas where the wind load from the turbine and direct wind pressure on the tower governs the design of the tower.

- Steel tubular tower structures usually are lighter than concrete structures, thus, they have less seismic inertial force than that of concrete towers.

For large wind turbine towers located in seismically active areas with increasing turbine head weight, the seismic load very likely becomes the governing loading case for a prestressed concrete tower and is a more significant effect for a large turbine steel tower, especially along the U.S. west coast high seismic zones. Seismic analysis and design have to conform to local seismic specifications and building codes such as the International Building Code and the Uniform Building Code. The earthquake load is considered as an extreme load condition. In ASCE 7-98 [9], the static equivalent earthquake load method is used for earthquake analysis.

3.2.1. Design Spectra

In this report, a LWST tower (presumably located in the Pacific Northwest) is used to illustrate the design earthquake load. From the earthquake geographic map, the maximum considered earthquake (MCE) ground motion for soil site Category B with 5% damping is 1.5 *g* (S_S) for structures with a period of 0.2 *s* and 0.6 *g* (S_1) for structures with a period of 1 s. The wind turbine towers are typically located in open areas away from population centers with very low occupancy. Therefore, the occupancy importance factor is equal to 1.0. For the post-tension concrete towers presented here, no reduction factor for tower seismic design forces is employed and Site Classification D is assumed. Site Classification D is typified by stiff soils with shear velocity (V_s in soil) typically 600–1,200 fps (183–366 m/s). For an actual site-specific design, the soil category will be determined from the results of a geotechnical investigation. The design earthquake spectral acceleration at short period, S_{DS} and 1-s period S_{D1} are determined by

$$S_{DS} = 2/3\ F_a\ S_S = 1.0\ g$$
$$S_{D1} = 2/3\ F_v\ S_1 = 0.6\ g,$$

where S_S is the mapped MCE spectral response acceleration at short periods
S_1 is the mapped MCE spectral response acceleration at 1second period
F_a is the site coefficient as a function of site class and short period MCE
F_v is the site coefficient as a function of site class and a 1 second period MCE
g is the acceleration caused by gravity.

The site factor for $F_a = 1.0$ and $F_v = 1.5$ are from Table 9.4.1.2 of ASCE 7-98. Design response spectra $S_a(T)$ are expressed and plotted in Figure 3.10.

$$S_a(T) = \begin{cases} \dfrac{S_{D1}}{T} & if \quad T > T_s \\ S_{DS}(0.4 + 0.6\dfrac{T}{T_0}) & if \quad T < T_0 \\ S_{DS} & otherwise \end{cases}$$

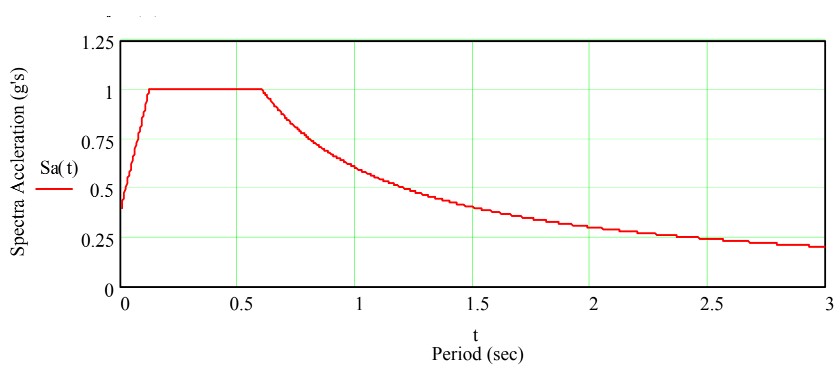


Figure 3.10. ASCE 7 design response spectra

In Figure 3.10, $T_S = S_{D1}/S_{DS}$ and $T_0 = 0.2\ T_S$. S_a is the design spectral response acceleration and T is the structural period.

3.2.2. Design Earthquake Load

The earthquake lateral load distributes along the tower height *h* according to its weight distribution. Defining axis *z* along the tower height and weight distribution *w(z)* as function of height, the total weight of tower *W* with turbine head weight:

$$W = \int_0^h w(z)dz + W_{HeadMass}$$

The base shear coefficient:

$$Cs(T) = Sa(t)\ I/R\ ,$$

where C_s is the seismic response coefficient and the importance factor I and reduction factor R are equal to 1.0 and earthquake base shear is

$$V = Cs(T)\ W\ .$$

The tower period T can be estimated either using the empirical formula $Ta = Ct\ h^{3/4}$, where Ct = 0.02 and T = 1.4 Ta (where C_t is the structural coefficient and T_a is the approximate fundamental period of the tower structure), or it can be calculated more accurately by the finite element model (FEM) method or other analytical methods (see dynamic properties, Section 4).

The lateral distribution forces *F(z)* can be defined as

$$F(z) = \frac{w(z)\cdot z^{k0}}{\int_0^h w(z) z^{k0} dz + W_{HeadMass} h^{k0}} V \quad ,$$

where *k0* is the exponent for the first mode profile:

$$k0 = \begin{cases} 1 & if \quad T < 0.5s \\ 2 & if \quad T > 2.5s \\ (0.5\cdot T + 0.75) & otherwise \end{cases} \quad .$$

The head mass concentrated force at the top of tower *Ft*:

$$Ft = \frac{W_{HeadMass} h^{k0}}{\int_0^h w(z) z^{k0} dz + W_{HeadMass} h^{k0}} V \quad .$$

The shear force - *Vz(z)* and overturning moment *Mz(z)* along the tower height can be calculated from:

$$Vz(z) = \int_z^h F(x)\cdot dx + Ft$$

$$Mz(z) = \tau(z)\cdot [\int_z^h F(z)\cdot (x-z)\cdot dx + Ft\cdot (h-z)] \quad ,$$

where the overturning moment reduction factor *τ(z)* is 1.0 for the tower top 30 m (98 ft) and 0.8 for the tower bottom 30 m (98 ft) or linear interpolation for the height between the top most and bottom most. Accordingly, tower deflection *Δ(z)* along the height can be calculated by following formula:

$$\Delta(z) = \int_0^z \frac{Mz(x)}{E(x)\cdot I(x)}\cdot (z-x)\cdot dx + \frac{Vz(z=0m)}{Kh} + \frac{Mz(z=0m)}{Kr}\cdot z \quad ,$$

where E is elastic modulus of the tower (see Section 4), *I(x)* is moment of inertia of the cross section of the tower, and *Kh* and *Kr* are the soil spring constants of translation and rotation.

Table 3.10. Deflection at Top of 100-m Turbine Tower for Earthquake Load

Turbine Power	Hybrid Tower (EQ)		Conc. Tower (EQ)		Steel Tower (Wind)	
1.5 MW	1.59 m	5.19 ft	1.25 m	4.10 ft	1.01 m	3.30 ft
3.6 MW	1.14 m	3.75 ft	1.01 m	3.30 ft	0.90 m	2.96 ft
5.0 MW	0.97 m	3.18 ft	0.88 m	2.87 ft	0.74 m	2.41 ft

(EQ)= controlled by earthquake (Wind) = controlled by wind

The calculation of the seismic deflection of the hybrid tower is dominated by the ASCE-7 seismic shear distribution requirements. A large portion of the relatively higher base shear associated with the inertia of higher mass of the concrete base tower must be applied to the more flexible steel portion of the tower.

3.2.3. Base Shear and Overturning Moment for Seismic Load

Table 3.11 shows seismic base shear and overturning moment for a 100-m (328-ft) high wind turbine tower of 1.5-, 3.6-, and 5.0-MW under prescribed seismic load.

Table 3.11. ASCE-7 Tower Ultimate Seismic Forces

Seismic Forces for Wind Turbine Tower

Turbine Power	Tower Type	Tower Weight kN	Tower Weight kips	Base Shear kN	Base Shear kips	Base Moment kNm	Base Moment kips-ft	Weight at 49m kN	Weight at 49m kips	Shear at 49m kN	Shear at 49m kips	Moment at 49m kNm	Moment at 49m kips-ft
1.5 MW	Hybrid Tower	11250	2529	3272	736	179700	132500	1658	373	1974	444	76650	56540
(EQ)	Conc. Tower	17490	3933	4863	1093	286400	211200	6779	1524	4024	905	121900	89940
	Steel Tower	3142	706	873	196	60030	44280	1621	365	789	177	30930	22820
(Wind)	Conc. Tower	15320	3444	4259	957	255000	188100	6341	1426	3584	806	110700	81660
3.6 MW	Hybrid Tower	21980	4941	6348	1427	395200	291500	4665	1049	4590	1032	199400	147100
(EQ)	Conc. Tower	26760	6016	7438	1672	468900	345900	11460	2577	6396	1438	219000	161500
	Steel Tower	7123	1601	1980	445	145200	107100	4606	1035	1875	422	79620	58720
(Wind)	Conc. Tower	23490	5281	6530	1468	418000	308300	10980	2468	5708	1283	198100	146100
5.0 MW	Hybrid Tower	26460	5948	7675	1725	499100	368100	6761	1520	5927	1332	261000	192500
(EQ)	Conc. Tower	34550	7767	9603	2159	614400	453200	15000	3373	8310	1868	292500	215700
	Steel Tower	10040	2257	2791	627	206600	152400	6713	1509	2658	598	114300	84290
(Wind)	Conc. Tower	29230	6571	8125	1827	529300	390400	13630	3064	7134	1604	256800	189400

Note: Forces for 3.6- and 5.0-MW towers are taken at tower height of 47 m versus 49 m.
(EQ)= controlled by earthquake
(Wind) = controlled by wind

The tower base shears and moments given in Table 3.11 are developed based on the ASCE 7 spectral response curve shown as Figure 3.13. The method of developing the base shear and applied base moment caused by earthquake is given in Section 3.2. This is not a peak earthquake load but rather a design load based on the dynamic properties of the tower/turbine structure.

An importance factor I of 1.0 and a seismic reduction factor R of 1.0 have been used. Using R of 1.0 means that the seismic forces have not been reduced to account for potential structural behavior that could mitigate the seismic forces or the consequences of seismic overload. $R = 1.0$ assumes elastic performance of the structure during a design seismic event. A more in-depth study that addresses the consequence of significant seismic overload on the behavior the turbine tower system, and consideration of soil structure interaction using actual site geotechnical conditions, may indicate that a seismic reduction factor greater than R = 1.0 is appropriate.

Because seismic loading results from inertial forces, the higher mass of the concrete towers, compared to the all-steel towers, results in higher seismic forces (base shears and overturning moments).

Figure 3.11 shows a comparison of base shears that result from design seismic loading in several major cities. Site seismicity varies considerably within a region, so large wind tower installations would benefit in design from a detailed consideration of site-specific seismic loading.

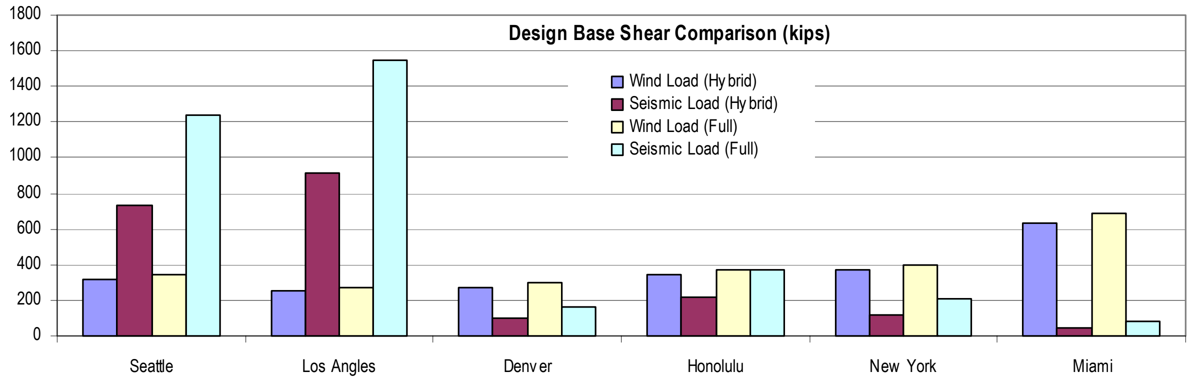


Figure 3.11. Base shear comparison of factored wind load and seismic load for 1.5-MW, 100-m hybrid steel/concrete and full-concrete towers

4.0 Analysis Modeling and Dynamic Characteristic Study

4.1. Foundation Flexibility Modeling

The flexibility of the foundation has a significant influence on the dynamic behavior of the tower. The most common method for modeling a footing is to use equivalent springs to represent soil stiffness. In general, the six components of displacement (three translational and three rotational) require six equivalent spring constants. Rigorously, there is coupling or interaction between the six components of displacement, but this coupling is negligibly small for shallow spread footings (typically, with embedment depth less than five times spread footing dimension). A special report for foundation spring modeling has been published in [14] by the Federal Highway Administration (FHWA) in 1986 as shown in Figures 4.1–4.3 (Figures 64–66 of [14]). In this study, the equivalent spring method recommended by FHWA is used for spring modeling of the tower spread footing.

Spring constants for shallow rectangular footings are obtained by modifying the solution for a circular footing, bonded to the surface of an elastic half-space. The equivalent radius for a rectangular section can be found as shown in Figure 4.1 (Figure 64 from [14]).

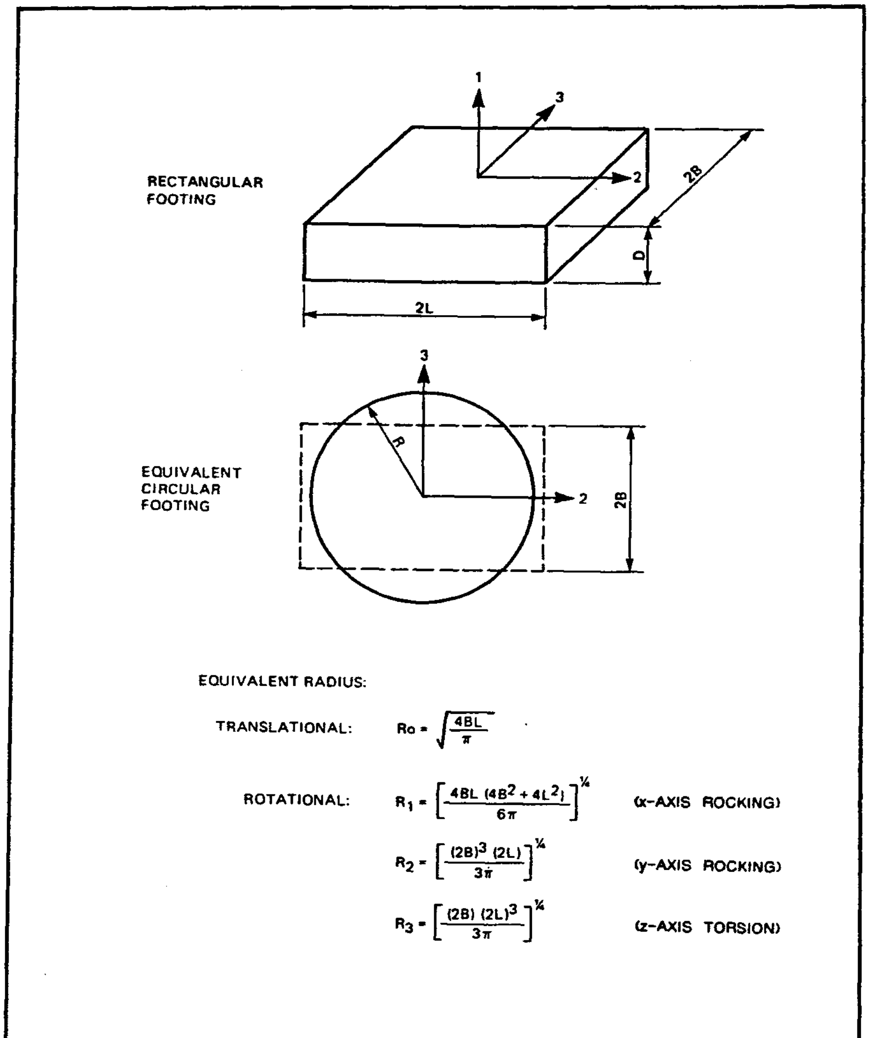


Figure 64: Equivalent Radii for Rectangular Footings (from Reference 6)

Figure 4.1. Equivalent radii for rectangular footings

The spring constants K can be defined by

$$K = \alpha \beta K_o ,$$

where α is the foundation shape correction factor; β is the embedment factor; and both can be interpolated in the following plot diagrams of Figures 4.2 and 4.3 (Figures 65 and 66 from [14]) and K_o is the stiffness coefficient for the equivalent circular footing. (See Tables 4.1 and 4.2.)

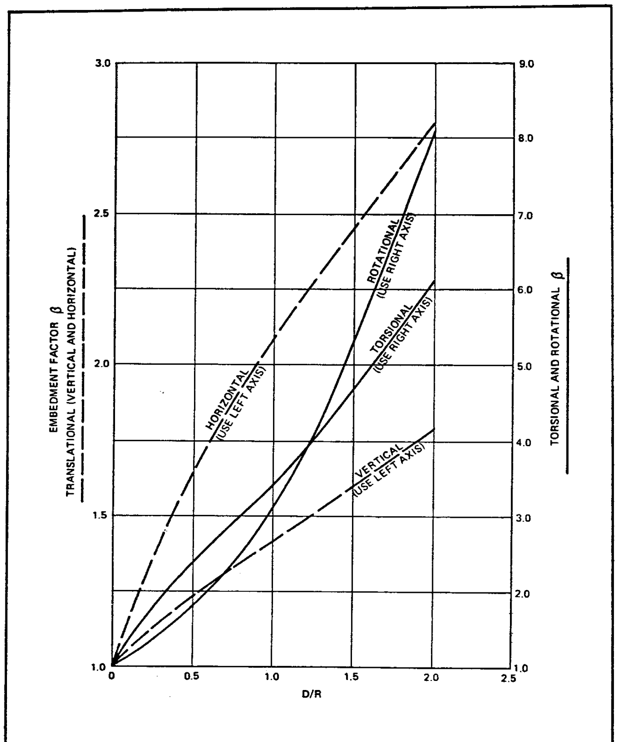


Figure 66: Embedment Factors for Footings (from Reference 6)

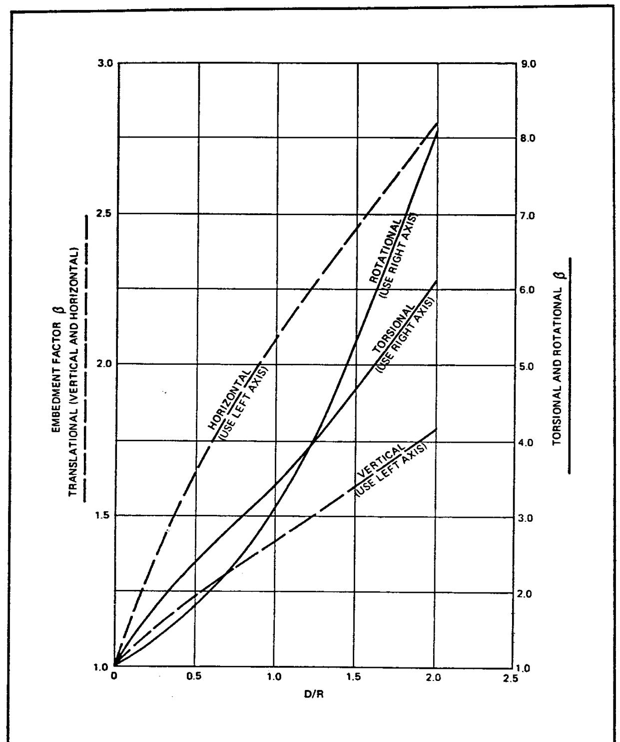


Figure 66: Embedment Factors for Footings (from Reference 6)

Figure 4.2. Shape factors for rectangular footings

Figure 4.3. Embedment factors for footings

Table 4.1. Stiffness Coefficient for a Circular Surface Footing

Displacement Degree of Freedom	Ko
Vertical Translation – Kv	4GR/(1-υ)
Horizontal Translation – Kh	8GR/(2-υ)
Torsional Rotation – Kt	$16GR^3/3$
Rocking Rotation – Kr	$8GR^3/[3(1-υ)]$

Note: G and υ are the shear modulus and Poisson ratio for elastic half space material
R is the radius of the footing

The sizes of spread footing and equivalent spring constants for 1.5, 3.6, and 5 MW are listed in Table 4.2. The assumed soil shear modulus *Gs = 20.7 MPa (3,000 psi)* and *υ = 0.35.* In a site-specific design, the soil shear modulus would be determined as result of a geotechnical investigation.

Table 4.2. Square Spread Footing Embedment Factors and Stiffness Coefficients

		1.5MW				3.6MW				5.0MW			
Square Footing		**Steel**	**Conc.(W)**	**Conc.(EQ)**	**Hybr.**	**Steel**	**Conc.(W)**	**Conc.(EQ)**	**Hybr.**	**Steel**	**Conc.(W)**	**Conc.(EQ)**	**Hybr.(EQ)**
Footing Width	B(m)	16.46	16.76	19.81	16.46	18.29	19.2	21.34	20.42	20.42	20.42	22.86	21.34
	B(ft)	54	55	65	54	60	63	70	67	67	67	75	70
Footing Depth	D(m)	3.048	3.048	3.658	3.048	3.658	3.658	3.658	3.658	3.658	3.658	3.962	3.658
	D(ft)	10	10	12	10	12	12	12	12	12	12	13	12
Imbed Factor	D/R1	0.3245	0.3186	0.3235	0.3245	0.3504	0.3337	0.3004	0.3138	0.3138	0.3138	0.3037	0.3004
Shape Factor	β_h	1.45	1.443	1.449	1.45	1.481	1.461	1.42	1.437	1.437	1.437	1.424	1.42
	β_t	2.001	1.986	1.998	2.001	2.065	2.024	1.94	1.974	1.974	1.974	1.949	1.94
	β_v	1.156	1.154	1.156	1.156	1.167	1.16	1.145	1.151	1.151	1.151	1.147	1.145
	β_r	1.473	1.463	1.471	1.473	1.518	1.489	1.433	1.455	1.455	1.455	1.438	1.433
Equivalent Radius	R0(m)	9.286	9.458	11.18	9.286	10.32	10.83	12.04	11.52	11.52	11.52	12.9	12.04
	R0(ft)	30.47	31.03	36.67	30.47	33.85	35.54	39.49	37.8	37.8	37.8	42.31	39.49
	R1,2,3(m)	9.394	9.568	11.31	9.394	10.44	10.96	12.18	11.66	11.66	11.66	13.05	12.18
	R1,2,3(ft)	30.82	31.39	37.1	30.82	34.24	35.96	39.95	38.24	38.24	38.24	42.8	39.95
Spring Constant	kv(kN/m)	1.41E+06	1.43E+06	1.69E+06	1.41E+06	1.58E+06	1.65E+06	1.81E+06	1.74E+06	1.74E+06	1.74E+06	1.94E+06	1.81E+06
	kv(k/in)	8037	8168	9671	8037	9018	9410	10320	9932	9932	9932	11070	10320
	kh(kN/m)	1.38E+06	1.40E+06	1.66E+06	1.38E+06	1.56E+06	1.62E+06	1.75E+06	1.69E+06	1.69E+06	1.69E+06	1.75E+06	1.75E+06
	kh(k/in)	7863	7969	9457	7863	8926	9245	9985	9669	9669	9669	10730	9985
	kt(kN/m)	1.92E+08	2.02E+08	3.35E+08	1.92E+08	2.72E+08	3.09E+08	4.06E+08	3.62E+08	3.62E+08	3.62E+08	5.01E+08	4.06E+08
	kt(k/in)	1.70E+09	1.78E+09	2.96E+09	1.70E+09	2.41E+09	2.73E+09	3.59E+09	3.21E+09	3.21E+09	3.21E+09	4.44E+09	3.59E+09
	kr(kN/m)	1.09E+08	1.14E+08	1.90E+08	1.09E+08	1.54E+08	1.75E+08	2.31E+08	2.05E+08	2.05E+08	2.05E+08	2.85E+08	2.31E+08
	kr(k/in)	9.63E+08	1.01E+09	1.68E+09	9.63E+08	1.36E+09	1.55E+09	2.04E+09	1.82E+09	1.82E+09	1.82E+09	2.52E+09	2.04E+09

Note: The Shape Factor for Square Footing: α_x = 1.02 α_y = 1.02 α_v = 1.03 α_r = 1.05

4.2 Dynamic Properties of Towers

Dynamic magnification effects can directly influence the fatigue loads to be considered in the design of the tower. Thus, it is very important to design the tower frequency to avoid the excitation of resonant oscillators that results from rotor thrust fluctuations at the blade passing frequency or, to a lesser extent, at the blade rotational frequency. Shown below are the plots of the desired working frequency for towers supporting 1.5-, 3.6-, and 5.0-MW turbines with the operating rotor rotational speeds as shown in Table 4.3 and Figure 4.4.

Table 4.3. Operational Frequency Ranges for 1.5-, 3.6-, and 5.0-MW Turbines

Frequency Analysis for 100-m Wind Turbine Tower

Turbine	Operation Speed		3P(op)	Working Freq. 1		Design Tower		
	rpm	Hz	Hz	Hzx1.1	Hzx2.6	Hybr.(Hz)	Conc.(Hz)	Stl(Hz)
1.5 MW(EQ)	20.5	0.342	1.025	0.376	0.888	0.4848	0.4355	0.4059
1.5 MW(Wind)	20.5	0.342	1.025	0.376	0.888		0.3774	
3.6 MW(EQ)	13.2	0.220	0.660	0.242	0.572	0.4813	0.4431	0.3693
3.6 MW(Wind)	13.2	0.220	0.660	0.242	0.572		0.3768	
5.0 MW(EQ)	11.2	0.187	0.560	0.205	0.485	0.4835	0.4621	0.3973
5.0 MW(Wnd)	11.2	0.187	0.560	0.205	0.485		0.384	

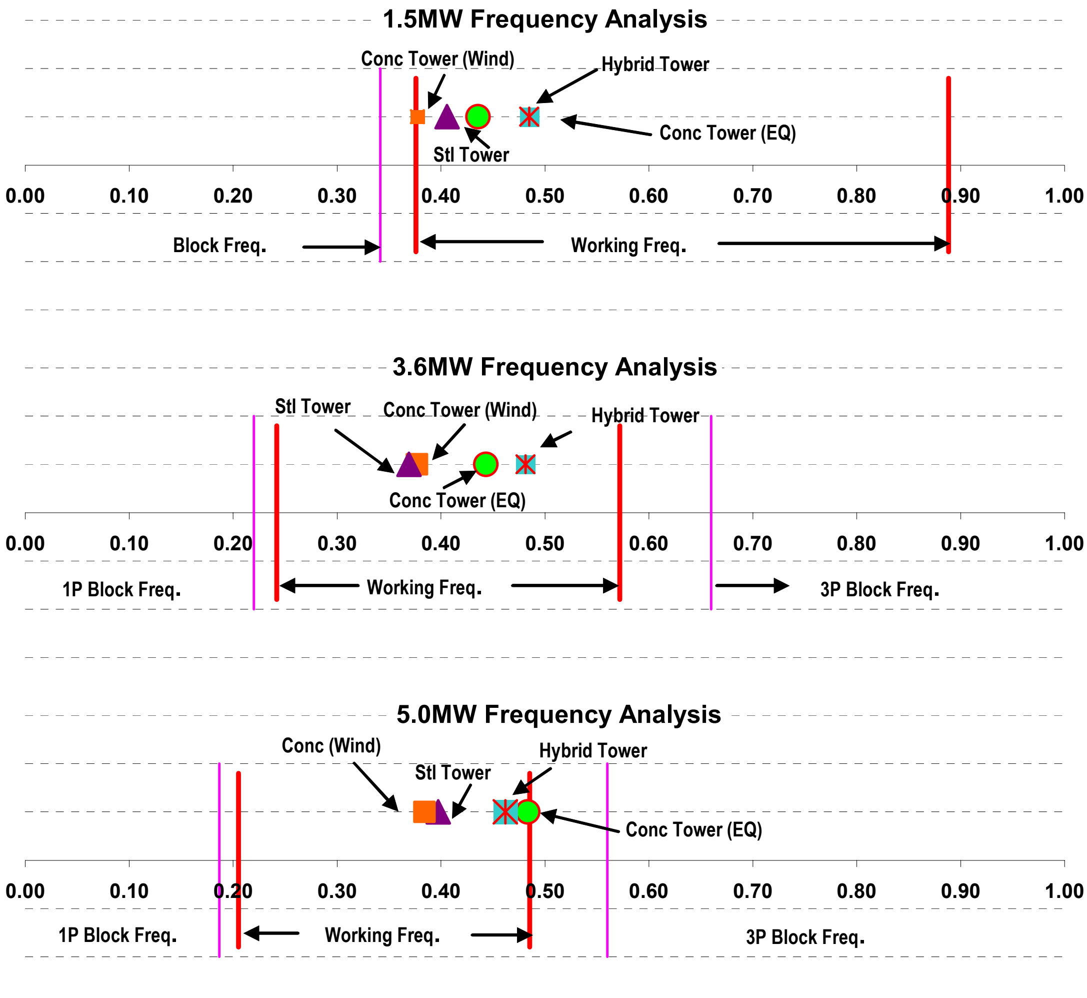


Figure 4.4. Operational frequency ranges for 1.5-, 3.6-, and 5.0-MW turbines

It is desired to block tower frequencies associated with the passing frequency (1P of a three-blade rotor) and the rotational frequency (3P of a three-blade rotor). The plots indicate that as the turbine rotors increase in diameter, with increasing generating capacity, the working frequency range decreases in value as the turbine size increases and the rotor rotational speed decreases. The desired working frequencies for the different sized turbines are shown in Table 4.3**.** This reduction in required tower natural frequency is contrary to the strength design of the tower that requires the towers for the larger turbines to be stronger and, thus, stiffer (higher natural frequency [ω_t]) to react to the higher peak loads associated with the larger turbines.

A soft tower design (natural frequency [ω_t] less than the 3P frequency range) for all the towers considered can be achieved. To avoid the requirement to design the 5.0-MW hybrid and all-concrete towers in seismic areas as stiff towers (ω_t above the 3P range), careful attention must be given to the dynamic properties of the tower. Consideration should be given to increasing the tower height to lower the ω_t changing the ratio of steel tower to concrete tower height in the hybrid tower design, or increasing the rotor speed to increase the operational frequency.

4.2.1. Vibration Induced by Rotor Rotation

The tower shall be designed to avoid the turbine steady excitation frequency under operation load. According to Germanischer Lloyd [20], the natural frequency of the tower can vary by ±5% as result of the uncertainties in calculating the fundamental frequency. In this study, a 10% variation of frequency has been considered. The dynamic magnification factor *D* shall be included and calculated by:

$$D = \frac{1}{\sqrt{(1 - \frac{{f_R}^2}{{f_0}^2})^2 + (2 \cdot \beta \cdot \frac{f_R}{f_0})^2}} \quad ,$$

where f_R is the rotor excitation frequency
f_0 is the tower natural frequency
β is critical damping.

For the ratio of rotor excitation and tower frequency (f_R / f_R) 0.9 and 1.1 with 10% tower structural damping, the dynamic magnification factor *D* is equal to 3.82 and 3.29, accordingly. Although the simulation-derived loads used in this study include the dynamic magnification effects, the 1.5- and 5.0-MW towers designed here should be refined in final design by adjusting tower height to provide a $\omega_{t,}$ closer to the center of the working frequency range to avoid any unwanted dynamic magnification effects.

4.2.2. Determining Tower Natural Frequency

The conventional methods for estimation of tower natural frequency use either FEM or an approximation analytical method (AAM). Accurate results can be achieved with commercially available FEM software; however, the FEM approach is time consuming for sizing the tower by trial-error. For the preliminary tower dynamic design, an AAM was developed in explicit form. The simple equations can allow designers to quickly and easily reach the solution for determining the section of the tower. For a simple straight cylindrical steel tower, the first natural tower bending frequency (in rad/s) is estimated by Harrison, Hau, and Snel [10] as:

$$\omega_t = 1.75 \sqrt{\frac{E \cdot I \cdot g}{H^3 (W_t + W_{tow} / 4)}} \quad ,$$

where ω_t is the estimated natural frequency of the tower
H is the height of the tower
E and I are elastic modulus and moment of inertia of the tower
Wt and *Wtow* are the weight of head mass and tower mass, respectively

Obviously, for the more complicated hybrid tower with a tapered section and with consideration of foundation flexibility, this simple AAM formula is not accurate. An analytical method based on the energy method (Rayleigh approximation) is introduced below to estimate the fundamental frequency for the hybrid and tapered tower.

4.2.3. Rayleigh's Method for Approximating the Fundamental Frequency

The Rayleigh approximation method is based on the energy conservation principle. Assume that the deflection curvature function of the member is given as

$$y(x,t) = Y(x) \cdot \sin(\omega \cdot t + \alpha) \ ,$$

where *Y(x)* is the assumed deflection curvature function along the tower axis *x* under simple harmonic motion. The maximum kinetic (T_{max}) energy is

$$T_{max} = \frac{\omega^2}{2} \int_0^h m(x) \cdot Y(x)^2 \cdot dx \ ,$$

where *m(x)* is mass distribution along the tower at height of *h*, and the maximum strain energy U_{max} is

$$U_{max} = \frac{1}{2} \int_0^h E(x) \cdot I(x) \cdot \left[Y''(x)\right]^2 \cdot dx \ ,$$

where *Y''(x)* is the second-order derivative of *Y(x)*, *E(x)* and *I(x)* are varied modulus and moment of inertia along the tower. According to the energy conservative principle, $T_{max} = U_{max}$, the natural frequency is

$$\omega^2 = \frac{\int_0^h E(x) \cdot I(x) \cdot [Y''(x)]^2 \cdot dx}{\int_0^h m(x) \cdot [Y(x)]^2 \cdot dx + \sum_i m_i \cdot Y(x_i)^2} \ ,$$

where $\sum m_i \, Y(x_i)^2$ is the summation of concentrated mass at *i* location. From the above equation, the mass *m(x)*, modulus *E(x),* and moment of initial *I(x)* can be varied along the height of tower. The accuracy of the calculated natural frequency of the tower largely depends on the extent of agreement of the actual deflected shape of the tower with the assumed prescribed deflection function.

4.2.4. Hybrid Tapered Cylindrical Tower

The diameter *d(x)* of the tapered section along the tower height can be described as

$$d(x) = \begin{cases} \dfrac{Dct - Dcb}{hc} \cdot x + Dcb & if\ x \le hc \\ \dfrac{Dst - Dsb}{h - hc} \cdot (x - hc) + Dsb & if\ hc < x \le h \end{cases} \ ,$$

where D_{cb} is the base diameter of concrete tower, D_{ct} is the top diameter of the concrete tower at height of *hc,* D_{sb} is the base diameter of steel tower, and D_{st} is the top diameter of the steel tower at height of *h.* Similar definition of the tower wall thickness *t(x)* along the tower height can be expressed as

$$t(x) = \begin{cases} \dfrac{Tct - Tcb}{hc} \cdot x + Tcb & if\ x \le hc \\ \dfrac{Tst - Tsb}{h - hc} \cdot (x - hc) + Tsb & if\ hc < x \le h \end{cases} \ ,$$

where *T* is the wall thickness. Thus, the moment of inertia *I(x)* and section area *A(x)* are

$$I(x)=\frac{\pi}{64}[d(x)^4-(d(x)-2\cdot t(x))^4]$$

$$A(x)=\frac{\pi}{4}[d(x)^2-(d(x)-2\cdot t(x))^2] \quad ,$$

the mass *m(x)* along the height and elastic modulus *E(x)* are accordingly written as

$$m(x)=\begin{cases} A(x)\cdot \rho c & if\ x\le hc \\ A(x)\cdot \rho s & if\ hc<x\le h \end{cases}$$

$$E(x)=\begin{cases} Ec & if\ x\le hc \\ Es & if\ hc<x\le h \end{cases} \quad ,$$

where ρ_c and ρ_s are the density of concrete and steel and E_c and E_s are the elastic modulus of concrete and steel, respectively. The deflection curvature function assumes – *y(a1,a2,x)* with the parameters *a1* and *a2*

$$y(a1,a2,x)=\begin{cases} a1\cdot[1-\sin(\frac{\pi}{2}\cdot\frac{x+hc}{hc})] & if\quad x\le hc \\ a2\cdot[1-\sin(\frac{\pi}{2}\cdot\frac{x+h-2\cdot hc}{h-hc})]+a1\cdot[1+\frac{\pi\cdot(x-hc)}{2\cdot hc}] & if\ hc<x\le h \end{cases} \quad ,$$

where *a1* and *a2* are modification parameters of the deflection function in units of the length. The first derivative *y'(a1,a2,x)* and second derivative *y''(a1,a2,x)* can be easily differentiated accordingly; the natural frequency of the tower can be described as

$$f(a1,a2)=\frac{1}{2\cdot\pi}\sqrt{\frac{\int_0^h E(x)\cdot I(x)\cdot[y''(a1,a2,x)]^2\cdot dx}{\int_0^h m(x)\cdot[y(a1,a2,x)]^2\cdot dx+\frac{Wh}{g}\cdot y(a1,a2,h)^2}} \quad ,$$

where *Wh* is the total turbine head weight and the frequency *f = min[f(a1,a1)]* can be obtained by plotting the tower frequency as a function of parameters *a1* and *a2.*

4.2.5. Foundation Flexibility Effect on Tower Fundamental Frequency

The flexibility of the foundation has a significant impact on the tower dynamic behavior. To include this factor, we here assumed that tower foundation has the horizontal spring constant *Kh* and rotation spring constant *Kr*. The deflection function *y(a1,a2,x)* can be revised as

$$ya(a1,a2,a3,x)=y(a1,a2,x)+a3\cdot[\frac{y(a1,a2,h)\cdot h^2}{Kr}\cdot\frac{x}{h}+\frac{y(a1,a2,h)}{Kh}] \quad ,$$

where the parameter *a3* is the third factor and has the same units as the spring constant *Kh*. The strain energy and kinetic energy shall be rewritten

$$U_{max}(a1,a2,a3)=\frac{1}{2}\int_0^h E(x)\cdot I(x)\cdot[y''(a1,a2,x)]^2\cdot dx+\frac{[a3\cdot y(a1,a2,h)]^2}{2\cdot Kh}+\frac{[a3\cdot y(a1,a2,h)\cdot h]^2}{2\cdot Kr}$$

$$T_{max}(a1,a2,a3)=\frac{\omega^2}{2}[\int_0^h m(x)\cdot ya(a1,a2,a3,x)^2\cdot dx+\frac{Wh}{g}\cdot ya(a1,a2,a3,h)^2] \quad .$$

The fundamental frequency of the tower can be calculated as

$$f = min[\frac{1}{2\cdot\pi}\sqrt{\frac{U_{max}(a1,a2,a3)}{T_{max}(a1,a2,a3)}}] \quad .$$

Another alternative method is to simply combine the frequencies with different motion in a series of springs. The rigid body rotation frequency *fr,* translation frequency *ft,* and tower flexure frequency *f(a1,a2)* can be obtained from following relation:

$$\frac{1}{f^2} = \frac{1}{fr^2} + \frac{1}{ft^2} + \frac{1}{f(a1,a2)^2}$$

4.2.6. Rayleigh's Method for Critical Buckling Load of the Tower

Another application for the Rayleigh energy method is to estimate the critical buckling load for the tower. For any possible deformations of the tower that satisfy its boundary conditions, the total potential energy Π shall be zero. Therefore, for a designated deflection of the tower, the global buckling load of the tower is the minimum of all possible axial compression loads. Based on this principle, the axial load work W_{max} including the self-weight can be determined by

$$W_{max}(a1,a2) = \frac{1}{2}[Pcr\int_0^h y'(a1,a2,x)^2\cdot dx + Wh\cdot\int_0^h y'(a1,a2,x)^2\cdot dx + \int_0^h m(x)\cdot g\cdot x\cdot y'(a1,a2,x)^2\cdot dx] \quad .$$

The first term is the work done by the tower critical load (*Pcr*), simplified as $Pcr\ \lambda_{max}$. The second and third terms are the work done by the turbine head weight and the tower self-weight, simplified as Ws_{max}. According to the minimum potential energy principle,

$$\Pi = U_{max} - W_{max} = 0 \quad .$$

For a prescribed deformation shape of the tower, the total potential energy is always above zero. The less potential energy the tower structure system has, the more accurate the deformation shape of the tower will be. Thus, the buckling load can be solved by minimizing the potential energy. Assume that the strain energy U_{max} is approximated without considering the flexibility of the foundation:

$$U_{max}(a1,a2) = \frac{1}{2}\int_0^h E(x)\cdot I(x)\cdot[y''(a1,a2,x)]^2\cdot dx \quad .$$

The critical buckling load can be determined by

$$Pcr = min(\frac{U_{max} - Ws_{max}}{\lambda_{max}}) \quad .$$

4.2.7. Remarks on Rayleigh's Method

The Rayleigh method for estimating the natural frequency of the tower is simple and computationally straightforward. It does not require a large amount of iteration compared to the FEM method using the SAP2000 commercial FEM software program. The accuracy of the fundamental frequency calculation from the Rayleigh's method depends on building an accurate deflection shape function. Also, it is limited to relatively simple structures and the fundamental frequency. The comparisons between FEM and Rayleigh's method for the tower with fixed restraint at base are listed in Table 4.4.

Table 4.4. Tower Natural Frequency in Hz, FEM and Rayleigh's Method for Tower Fixed at Base

Freq. Comparison (Hz)		Spring Base			Fixed Base		
	Tower Type	**SAP2000**	**Rayleigh**	**Diff.**	**SAP2000**	**Rayleigh**	**Diff.**
1.5 MW	STL	0.367	0.406	9.63%	0.379	0.424	10.56%
	Conc.(W)	0.356	0.377	5.76%	0.376	0.430	12.49%
	Conc.(EQ)	0.469	0.504	7.11%	0.546	0.618	11.68%
	Hybr.	0.480	0.485	0.96%	0.514	0.533	3.54%
3.6 MW	STL	0.334	0.369	9.45%	0.356	0.400	11.11%
	Conc.(W)	0.342	0.377	9.31%	0.386	0.443	12.89%
	Conc.(EQ)	0.412	0.443	7.05%	0.474	0.532	10.95%
	Hybr.	0.479	0.481	0.34%	0.536	0.553	3.16%
5.0 MW	STL	0.360	0.397	9.20%	0.391	0.441	11.26%
	Conc.(W)	0.356	0.384	7.19%	0.413	0.464	11.03%
	Conc.(EQ)	0.435	0.462	5.88%	0.518	0.579	10.40%
	Hybr.	0.480	0.483	0.58%	0.558	0.580	3.72%

The results of frequency given by the Rayleigh's method are consistently higher than those given by the FEM method. This is because the prescribed flexure curves are generally slightly stiffer than the towers.

According to minimum energy principle, the exact solution shall have the minimum energy. This characteristic also applies for the tower critical buckling load calculation. The results show that Rayleigh's method has good approximation for the tapered tower frequency estimation. It reduces the potentially large amount of time to target the right size of the tower by the trial-error method by using the FEM method.

5.0 Prestressed (Post-Tensioned) Concrete Tower Design

Steel and concrete materials are the most common construction materials for large civil engineering structures. Most wind turbine towers in North America are made of steel. Several concrete towers have been built, mostly in Northern Europe. Reports by European investigators show that the early tower designs in conventional reinforced concrete were vulnerable to cracking and thus, fatigue of the mild reinforcing steel was an issue. Prestressed concrete towers for smaller turbine sizes are more expensive than tubular steel towers.

This report focuses on the design of hybrid steel/concrete and all prestressed concrete towers for 1.5-, 3.6-, and 5.0-MW turbines, all with 100-m (328-ft) hub heights. Because prestressed concrete structures are economical in many similar applications, their design is investigated in some detail to determine the engineering requirements and resulting costs.

As the wind turbines become larger and the towers taller, the cost for tubular steel tower construction increases exponentially and the costs of construction logistics and complexities increase. To a large extent, the converse is true for concrete construction. Thus, prestressed concrete is likely to be a more economical construction material than steel for wind turbine towers as they become taller and support larger wind turbines. The proposed post-tensioned segmental and cast-in-place concrete towers in this report developed for LWST have the following advantages over tubular steel towers:

- Post-tensioned concrete towers of the same extreme load capacity are of similar stiffness as steel towers.

- A post-tensioned concrete tower has better fatigue properties because of the small stress range ratio (maximum stress range/applied post tensioning stress) compared to the applied stress on the concrete and post-tensioning tendons.

- There is no local buckling issue in the post-tensioned concrete tower such as may govern the design for larger steel towers.

- The material cost for a large concrete tower is less than that for a large steel tower.

The construction cost of a concrete tower largely depends on the erection/construction method, site conditions, equipment requirements, local transportation availability, and the number of the towers built at the same time at a wind farm installation. The rate of cost increase for post-tensioned concrete towers becomes more competitive than similarly loaded tubular steel towers as the wind turbine becomes larger and tower becomes taller.

5.1 Post-Tensioned Segmental Concrete Tower Section Design Criteria

The proposed post-tensioned segmental concrete tower consists of a number of arc segments that combine to form circular sections that are stacked on each other and made to act together in a monolithic manner by post-tensioned high-strength tendons that precompress the concrete so that it is nearly always in compression under applied loads. ACI-318 [6] Chapter 18 and Nawy [8] are the design guidelines used for the post-tension concrete tower design in this report. High-strength steel tendons and high-strength concrete are used. The cross-sectional dimensions of the concrete tower depend on the strength requirement and the stiffness requirement for the tower dynamic properties. The post-tensioned concrete towers are designed with sufficient strength for

- Resistance to the design earthquake or wind load at a speed of 59.5 m/s or 133 mph
- Zero-tension stress in the concrete under the service wind loads
- No fatigue failure resulting from the operation wind load over the 20-year design life of the structure
- No failure during construction for temporary wind loads at a speed of 40 m/s (90 mph) at 100-m hub height.

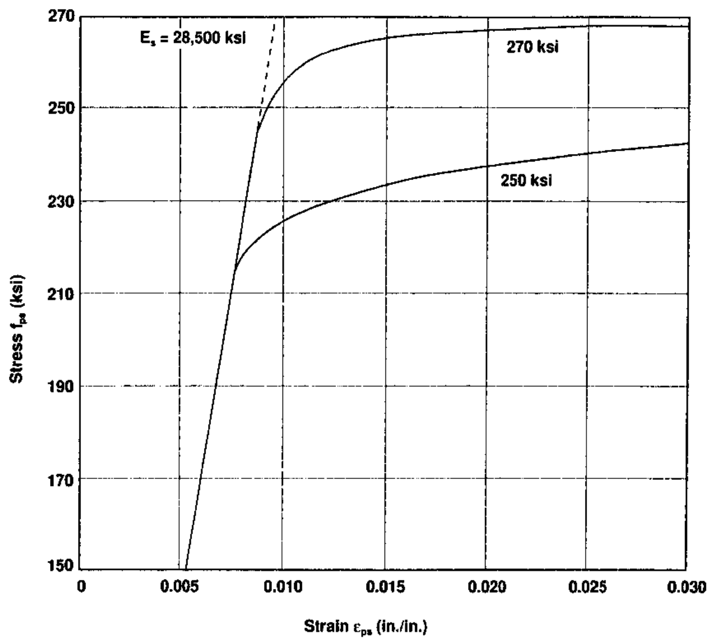
The material properties for concrete and post-tensioning tendons follow:

The compressive concrete strength:	f_c' = 7 ksi (48 MPa)
The tendon tensile strength: (*12-0.6 in. diameter - 7 wire low relaxation strands*)	f_{pu} = 270 ksi (1860 MPa)
The effective tendon stress after losses:	f_{se} = 160 ksi (1,100 MPa)
The ultimate concrete compressive strain:	ε_{cu} = 0.003
The nominal tendon yielding strain:	ε_{ps} = 0.0086 *(see 270 ksi strand stress – strain curve)*
The nominal strength of tendons: *(unbonded tendons are assumed)*	f_{ps} = 245 ksi (1,690 MPa)
The elastic modulus of post-tensioning tendons:	E_s = 28,500 ksi (196,500 MPa)

The stress strain relationships for prestressing strand are shown in Figure 5.1. The elastic modulus of concrete is determined from $Ec = 33w^{1.5}(fc')^{1/2}$,where w is density of concrete (150 lb/ft^3) (2403 kg/m^3).

We have qualitatively evaluated the consequence of using 34.4-MPa (5,000-psi) concrete for the tower construction to determine the effects on the tower design for locations where 48-MPa (7,000-psi) concrete may be difficult to produce reliably. Although 48-MPa (7,000-psi) concrete may be readily available in some locations and would ensure long-term durability, there may be some cost advantages to constructing the towers with 34.4-MPa (5,000-psi) concrete. This is especially true for the cast-in-place construction concept. Durable, long-lasting towers can also be built from 34.4-MPa (5,000-psi) concrete.

Design Aid 11.2.5 Idealized stress-strain curve, 7-wire low-relaxation prestressing strand



These curves can be approximated by the following equations:

250 ksi strand

$\varepsilon_{ps} \le 0.0076$: $f_{ps} = 28{,}500\,\varepsilon_{ps}$ (ksi)

$\varepsilon_{ps} > 0.0076$: $f_{ps} = 250 - \dfrac{0.25}{\varepsilon_{ps}}$ (ksi)

270 ksi strand

$\varepsilon_{ps} \le 0.0086$: $f_{ps} = 28{,}500\,\varepsilon_{ps}$ (ksi)

$\varepsilon_{ps} > 0.0086$: $f_{ps} = 270 - \dfrac{0.04}{\varepsilon_{ps} - 0.007}$ (ksi)

Figure 5.1. Material properties of prestressing steel

Using 34.4-MPa (5,000-psi) concrete versus 48-MPa (7,000-psi) concrete reduces the stiffness of the 1.5-MW hybrid tower 2%–3%. For example, for the ratio of concrete strength of 7 ksi (48 MPa) versus 5 ksi (34 MPa), the elastic modulus changes proportionally at ratio of $(7/5)^{1/2}$ and the resulting tower frequency changes at ratio of $(7/5)^{1/4} = 1.088$. This is actually beneficial from a dynamics point of view for the 3.6- and 5.0-MW tower designs considered here. The difference in the tower frequency is not large, but it is toward the lower favorable design frequency range for the 3.6- and 5.0-MW turbine towers.

For the all-concrete 1.5-MW tower, an increase in concrete quantity in the 3% range would be required with the lower-strength 34.4-MPa (5,000-psi) concrete. This may be a cost-effective action to take in a final design where the fatigue life consequences of the lower-strength concrete would also be evaluated.

The tower frequency was estimated based on Rayleigh method outlined in Section 4.2. The estimated change of the tower frequency noted above is the result of changing only modulus of concrete without changing the cross-section geometry of the tower.

5.2. Ultimate Strength for Post-Tension Concrete Circular Section

The wind turbine tower is designed functionally for wind loading in any direction. A circular-shaped tower is the most common selection for the tower for aerodynamic reasons. The following post-tensioned concrete design procedure for the circular cross section is similar in mechanical behavior to the rectangular section design procedure shown in Figure 5.2. Nominal mild reinforcement is provided for precast segment handling effects. This reinforcement will also serve as minimum temperature steel in the completed tower. Minimum mild reinforcement steel per ACI 307-98, the design standard for concrete chimney design [5] is provided in the cast-in-place tower designs. The temperature steel serves to limit the formation of concrete cracking that could result from temperature changes through the concrete section. Typically this amounts to #4 (0.5 in. diameter) (13 mm) reinforcing bars @ 12 in. (300 mm) on center each way and each face of the concrete shell.

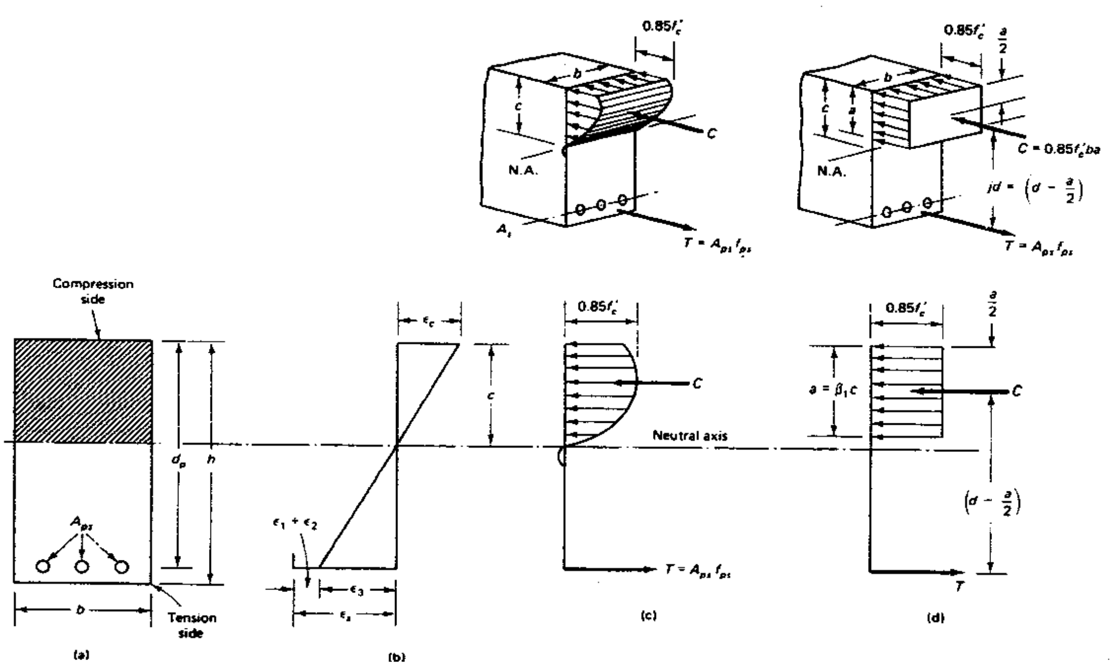


Figure 5.2. Concrete stress block assumptions

The mathematical functions of an outside circle with radius *R1* and an inside circle with radius *R2* can be expressed as;

$$f(x) = \pm (R1 - x)^{1/2}$$
$$g(x) = \pm (R2 - x)^{1/2},$$

where the *x* represents the horizontal coordinates. The *x* coordinates at the intersection of a horizontal line with the *y* coordinates are

$x1(y) = \pm(R1 - y)^{1/2}$ for the outside circle
$x2(y) = \pm(R2 - y)^{1/2}$ for the inside circle.

The area (*Areay(y)*) outward of the horizontal line can be written as the function of the y coordinates

$$Areay(y) = 2\int_{x2(y)}^{x1(y)} (f(x) - y)dx + \int_{-x2(x)}^{x2(x)} (f(x) - g(x))dx \quad .$$

Areay(0) is equal to half of the cross-section area. The neutral axis *YN(y)* for *Areay(y)* is obtained from

$$YN(y) = \frac{\int_{-x1(y)}^{x1(y)}\int_{y}^{f(x)} ydydx - \int_{-x2(y)}^{x2(y)}\int_{y}^{g(x)} ydydx}{Areay(y)} \quad .$$

For a total number of prestressing tendons *N* that are equally distributed along the circle at the average radius *R*, the coordinates for each *i-th* tendon (tx_i and ty_i) can be calculated from $tx_i = R \sin(i\, 2\pi/N)$ and $ty_i = R \cos(i\, 2\pi/N)$, respectively, with tendon area of At_i.

The tendon elongation strain is: $$\varepsilon_{pe} = \frac{\sum fse_i \cdot At_i}{\sum Es_i \cdot At_i}$$

The concrete elastic shortening: $$\varepsilon_{ce} = \frac{\sum fse_i \cdot At_i}{[Area - \sum At_i] \cdot Ec} \quad ,$$

where Es_i is the elastic modulus of the prestressing tendons, E_c is the elastic modulus for the concrete, and fse_i is the effective prestressing tendon stress after stress losses associated with axial shortening, shrinkage, and creep of the concrete.

The elastic shortening of the tendons after transferring stress to the concrete is computed by

$$\Delta\varepsilon_{py} = \varepsilon_{ps} - \varepsilon_{ce} - \varepsilon_{pe} \ ,$$

where ε_{py} is the strain of the prestressing tendons.

Assume *c* is the depth of the compression zone for concrete. According to the strain compatibility relation (see Figure 5.2 for rectangular section), the compression depth at the balance point can be described by following the triangular relationship

$$c = \frac{[\max(ty_i) + R1] \cdot \frac{\varepsilon_{cu}}{\Delta\varepsilon_{py}}}{(1 + \frac{\varepsilon_{cu}}{\Delta\varepsilon_{py}})} \quad ,$$

where ε_{cu} is the ultimate strain of the concrete, typically 0.003.

The concrete compression forces *Cn(c)* at the cross section can be calculated by

$$Cn(c) = 0.85\, fc'\, Areay\,(R1 - \beta 1\, c) \ ,$$

where the factor $\beta 1$ shall be taken as 0.85 for concrete strength $fc' \leq 4$ ksi (28MPa) and reduced continuously at a rate of 0.05 for each 1 ksi (6.895 MPa) of strength in excess of 4 ksi (28 MPa), but not less than 0.65. The tension force *Tsn(c)* is the summation of each of the tendon forces

$$Tsn(c) = \Sigma\{\varepsilon_{ce} + \varepsilon_{pe} + \varepsilon_{cu}\,[(R1 - ty_i)/c - 1]\}\, At_i\, Es \quad ,$$

The strain in {~} of the formula above shall be less than or equal to ε_{ps}. The nominal axial capacity *Pn(c)* is equal to

$$Pn(c) = Tsn(c) - Cn(c) \quad .$$

The nominal moment capacity *Mn(c)* can be derived accordingly:

$$Mn(c) = \Sigma\{\varepsilon_{ce} + \varepsilon_{pe} + \varepsilon_{cu}\,[(R1 - ty_i)/c - 1]\}\, At_i\, Es\, ty_i + Cn(c)\, YN(R1 - \beta 1\, c) \, .$$

The *Pn(c) ~ Mn(c)* interaction diagram is accordingly constructed and plotted with variation of the compression depth of concrete. The strength reduction factor $\phi(c)$ is calculated according to ACI 318 [6] Chapter 9.3 but is no less than 0.7.

$$\phi(c) = \frac{0.9 \cdot 0.1 \cdot fc' \cdot Area}{0.1 \cdot fc' \cdot Area + 0.2 \cdot Pn(c)} \quad .$$

The pure nominal compression capacity *Pn0* is expressed by

$$Pn0 = 0.85\, fc' \text{ Area} - \Sigma\, fse_i \text{ At}.$$

where Area is the cross-sectional area of the tower.

The demand capacity ratio (DCR) is calculated by $Mu/\phi Mn$ for a certain axial load from $\phi Pn \sim \phi Mn$ interaction diagram. Here, *Mu* is the ultimate applied moment and *Mn* is the nominal moment capacity of the concrete tower. The capacity of the cross section at the tower base and DCR values for turbine towers designed for wind are listed in Table 5.1.

5.3. Post-Tension Concrete Circular Section Design for Service Load

The concrete stress in compression at service loads (characteristics loads) for uncracked section properties, and after allowance for all prestress losses, shall not exceed 0.45 *fc'* 22 MPa (3.15 ksi) for prestress plus sustained load; 0.6 *fc'* 29 MPa (4.2 ksi) for prestress plus total sustained plus applied load. The total uncracked section modulus *Ix* is calculated by

$$Ix = Iz + (n-1)\, \Sigma At_i\, (ty_i)^2 \quad ,$$

where the *Iz* is the section moment of inertia for concrete and stiffness ratio *n* is defined by *Es/Ec*. The stresses in each *i-th* tendon fs_i under service loads (characteristic loads) can be computed by

$$fs_i = \pm Ms\, ty_i\, n / Ix + fse_i \quad ,$$

where the *Ms* is the bending moment at the investigated cross section under service loads (characteristic loads). The concrete stress *fc* is calculated by

Table 5.1. Section Capacity of Concrete Towers and Demand Capacity Ratios

		ϕPn(kN)	ϕPn(kips)	ϕMn(kN-m)	ϕMn(k-ft)	Mu/ ϕMn(W)	Mu/ ϕMn(EQ)
1.5 MW	Hybr. At Base	13443	3022	242994	179227	0.417	0.927
	Conc. (W) at Base	18403	4137	217096	160126	0.453	1.383
	Conc. (W) at Mid Height	7550	1697	100335	74005	0.396	1.228
3.6 MW	Hybr. At Base	26283	5909	500274	368991	0.458	0.896
	Conc. (W) at Base	28238	6348	336981	248550	0.669	1.397
	Conc. (W) at Mid Height	13245	2978	188236	138839	0.598	1.148
5.0 MW	Hybr. At Base	32057	7207	668155	492817	0.366	0.821
	Conc. (W) at Base	35447	7969	515107	379931	0.470	1.140
	Conc. (W) at Mid Height	16720	3759	228490	168529	0.570	1.213

$$f_c = \varepsilon_{ce} \pm \frac{Ms \cdot R1}{Iz} + \frac{Ps}{Area - \sum At_i} \quad .$$

The shear strength for plain concrete is $2(fc')^{1/2}$ (168 psi)(1.15 MPa). The moment of the area *Q* at the cross section is written by

$$Q = \frac{Area}{2}\left(\frac{4}{3\pi}\frac{R1^3 - R2^3}{R1^2 + R2^2}\right) \quad .$$

The maximum shear stress in the concrete for combined torsion moment *Ts* and shear forces *Vs* under service load (characteristic load) can be computed by

$$\tau s = \frac{Ts \cdot R1}{J} + \frac{Vs \cdot Q}{Iz \cdot 2 \cdot (R1 - R2)} \quad ,$$

where *J* is the polar moment of inertia of the cross section. Reinforcement for shear force is required if the shear force is larger than the concrete shear capacity. The maximum and minimum stresses of the post-tensioning tendon and concrete stresses under service loads (characteristic loads) for the 1.5-MW hybrid and full-concrete tower are shown in Tables 5.2–5.4.

The post-tensioning in the concrete tower is also designed to provide zero tension in the concrete under the service load (characteristic load) condition for the extreme operating condition E0G50. This means that all areas of the concrete cross section over the full height of the tower from foundation to the top of the tower concrete remain precompressed while resisting the applied bending moments associated with the service load (characteristic load) condition.

Table 5.2. Unfactored Concrete and Tendon Stress at Tower Base for Hybrid Tower

Turbine Size	Wind Load	Concrete Stress in Compression				Tendon Stress in Tension			
		fcmax	fcmax	fcmin	fcmin	fsmax	fsmax	fsmin	fsmin
		MPa	Ksi	MPa	Ksi	MPa	Ksi	MPa	Ksi
1.5 MW	Unfactored EWM50	11.91	1.727	2.826	0.41	1125.2	163.2	1081.1	156.8
	Unfactored EOG50	10.5	1.522	4.237	0.614	1118.3	162.2	1088	157.8
	Unfactored DEL	8.04	1.166	6.69	0.97	1106.4	160.5	1099.9	159.5
3.6 MW	Unfactored EWM50	11.3	1.639	1.435	0.208	1127.7	163.6	1078.6	156.4
	Unfactored EOG50	10.06	1.459	2.673	0.388	1121.6	162.7	1084.8	157.3
	Unfactored DEL	7.04	1.021	5.69	0.825	1106.5	160.5	1099.8	159.5
5.0 MW	Unfactored EWM50	10.65	1.545	2.422	0.351	1123.9	163	1082.4	157
	Unfactored EOG50	10.48	1.52	2.58	0.374	1123.1	162.9	1083.2	157.1
	Unfactored DEL	7.29	1.057	5.752	0.834	1107	160.6	1099.3	159.4

Under the design seismic load, the tower concrete in the lower portion of the tower will see tension stress above the cracking limit. We have performed a preliminary cracked section analysis to confirm that the tower section and proposed prestressing level is viable under this extreme condition. Under the extreme operating condition (EOG 50), the concrete towers are designed for zero tension stress in the concrete. This provides a substantial safety factor against flexural cracking of the concrete section at this load level. (The concrete would not be expected to crack until the stress in the concrete exceeded the tensile stress [six times the square root of the design compression strength of the concrete].) Under the extreme load associated with winds of 59.5 m/s (133 mph) and the design seismic loading, the design criteria allow tension stress to develop in the concrete that can result in cracking of the concrete and transfer of the tension stress in the concrete to the prestressing tendons on the tension side of the section.

Under this condition, the designer evaluates how far through the section the crack (tension stress above the tensile strength of the concrete) progresses to determine the resulting reduction in stiffness (cracked section properties versus gross section properties). In a final design for a site-specific project, this would be done precisely to ensure that sufficient prestressing is provided to limit the depth of the cracking in this condition. This ensures that the stiffness change and the extent of concrete cracking is within acceptable limits.

When the extreme load is removed, the elastic stress in the prestressing steel closes the cracks and, for service level loading, the tower behaves in accordance with its gross section properties again.

Table 5.3. Unfactored Concrete and Tendon Stress at Tower Base for Full-Concrete Tower

Turbine Size	Wind Load	Concrete Stress in Compression				Tendon Stress in Tension			
		fcmax	fcmax	fcmin	fcmin	fsmax	fsmax	fsmin	fsmin
		MPa	Ksi	MPa	Ksi	MPa	Ksi	MPa	Ksi
1.5 MW	Unfactored EWM50	12.1	1.755	2.269	0.329	1127.3	163.5	1079	156.5
	Unfactored EOG50	10.5	1.523	3.864	0.56	1119.5	162.4	1086.8	157.6
	Unfactored DEL	7.9	1.145	6.471	0.938	1106.7	160.5	1099.7	159.5
3.6 MW	Unfactored EWM50	15.65	2.27	-0.51	-0.074	1142.8	165.8	1063.5	154.2
	Unfactored EOG50	13.64	1.978	1.498	0.217	1133	164.3	1073.4	155.7
	Unfactored DEL	8.68	1.259	6.452	0.936	1108.6	160.8	1097.7	159.2
5.0 MW	Unfactored EWM50	14.3	2.074	2.036	0.295	1133.4	164.4	1073	155.6
	Unfactored EOG50	14.1	2.046	2.215	0.321	1132.5	164.2	1073.9	155.8
	Unfactored DEL	9.31	1.351	6.983	1.013	1108.9	160.8	1097.4	159.2

Table 5.4. Unfactored Concrete and Tendon Stress at Tower Mid Height for Hybrid Tower

Turbine Size	Wind Load	Concrete Stress in Compression				Tendon Stress in Tension			
		fcmax	fcmax	fcmin	fcmin	fsmax	fsmax	fsmin	Fsmin
		MPa	Ksi	MPa	Ksi	MPa	Ksi	MPa	Ksi
1.5 MW	Unfactored EWM50	14.77	2.142	3.048	0.442	1131	164	1075.4	156
	Unfactored EOG50	13.23	1.92	4.579	0.664	1123.7	163	1082.6	157
	Unfactored DEL	9.94	1.442	7.874	1.142	1108.1	160.7	1098.3	159.3
3.6 MW	Unfactored EWM50	16.49	2.391	-0.319	-0.046	1143.7	165.9	1062.6	154.1
	Unfactored EOG50	14.51	2.104	1.655	0.24	1134.2	164.5	1072.2	155.5
	Unfactored DEL	9.32	1.351	6.837	0.992	1109.1	160.9	1097.2	159.1
5.0 MW	Unfactored EWM50	14.75	2.139	-0.251	-0.036	1139.5	165.3	1066.8	154.7
	Unfactored EOG50	14.45	2.097	0.019	0.003	1138.1	165.1	1068.2	154.9
	Unfactored DEL	8.66	1.256	5.782	0.839	1110.1	161	1096.2	159

5.4 Moment Magnification Factor Due to P-Δ Effect

A slender tower subjected to combined axial load and bending, deforming laterally may develop additional moment. This is called the P-Δ effect and results in the possible requirement to magnify the applied forces. The wind turbine tower is structurally characterized as a cantilever column subject to lateral load combined with a gravity type of self-weight load. Moment magnification analysis is required for a slender column type of tower.

In the first-order analysis for moment magnification, because gravity loads do not contribute significantly to the moment along the tower, the tower is considered as a sway-type column structure with a length factor *k* of 2.0. The moment magnification factor δs is dependent on the slenderness of the tower, material stiffness *(E,* moment of inertia *I,* and the restrained condition, such that

$$\delta s = \frac{1}{1 - Pu/Pe} \geq 1 \quad ,$$

where Pu is the ultimate axial load on the tower and the tower buckling load *Pe* can be either determined by the Euler equation or approximated by the Rayleigh energy method for the complicated tapered section

$$Pe = \frac{\pi^2 \cdot E \cdot I}{(k \cdot L)^2} \quad ,$$

where the length of the column is equal to the tower height.

The second-order analysis for moment magnification factor is the P-Δ analysis. The additional moment is induced by lateral deformation with the effects of the gravity load. Additional moment δM can be calculated by

$$\delta M(z) = (\Delta(h) - \Delta(z)) \cdot HeadWeight + \int_z^h w(x) \cdot (\Delta(x) - \Delta(z)) dy \quad ,$$

where the deformations along the tower height $\Delta(z)$ are determined by wind load or earthquake load. $w(x)$ is the weight distribution along the tower. The analysis results show that moment magnification factor due to the P-Δ effect is less than 2% and, thus, negligible. Design results for the hybrid steel/concrete and all-concrete tower designs are given in Tables 5.5 and 5.6.

Table 5.5. Design Results—100-m Hybrid Steel/Concrete Wind Turbine Towers
(unfactored stresses given)

100m Hybrid Wind Turbine Tower (fc'=7ksi fy=50ksi)

	1.5MW (Wind/EQ)		3.6MW (Wind/EQ)		5.0MW(Wind/EQ)	
Rotor Diameter	70.5 m	231.2 ft	108.4 m	355.6 ft	128 m	419.8 ft
Total Head Weight	84800 kg	187 kips	314912 kg	694 kips	480076 kg	1058 kips
Additional Weight at Transition Connection	1500 kg	3.3 kips	3600 kg	7.94 kips	5000 kg	11 kips
Concrete Tower Height	49 m	161 ft	47 m	154 ft	47 m	154 ft
Outside Diameter at Base for Concrete Tower	5.791 m	228 in	8.077 m	318 in	9.144 m	360 in
Wall Thickness at Base for Concrete Tower	0.6604 m	26 in	0.762 m	30 in	0.762 m	30 in
Outside Diameter at Top for Concrete Tower	5.258 m	207 in	7.772 m	306 in	8.687 m	342 in
Wall Thickness at Top for Concrete Tower	0.3937 m	15.5 in	0.6096 m	24 in	0.6096 m	24 in
Outside Diameter at Base for Steel Tower	3.531 m	139 in	5.639 m	222 in	6.553 m	258 in
Wall Thickness at Base for Steel Tower	0.03175 m	1.25 in	0.03175 m	1.25 in	0.03492 m	1.375 in
Outside Diameter at Top for Steel Tower	2.896 m	114 in	3.962 m	156 in	4.572 m	180 in
Wall Thickness at Top for Steel Tower	0.009525 m	0.375 in	0.01905 m	0.75 in	0.02222 m	0.875 in
Spread Foot Width and Length	16.46 m	54 ft	20.42 m	67 ft	21.34 m	70 ft
Spread Foot Depth	3.048 m	10 ft	3.658 m	12 ft	3.658 m	12 ft
Steel Tower Weight	826.5 kN	185.8 kips	1577 kN	354.5 kips	2053 kN	461.6 kips
Concrete Tower Weight	9575 kN	2153 kips	17280 kN	3884 kips	19650 kN	4417 kips
Tendon Weight	23310 kg	51390 lb	29810 kg	65730 lb	34780 kg	76680 lb
Footing Reinforcement Weight	47160 kg	104 kips	97610 kg	215.2 kips	113500 kg	250.2 kips
Defection at Top of Tower for EQ Load	1.581 m	5.186 ft	1.142 m	3.746 ft	0.9679 m	3.176 ft
Defection at Top of Tower for Wind Load	0.5394 m	1.77 ft	0.4662 m	1.53 ft	0.3583 m	1.176 ft
Max. Conc Stress for Wind for EWM50	11.91 MPa	1.727 ksi	11.3 MPa	1.639 ksi	10.65 MPa	1.545 ksi
Min. Conc Stress for Wind for EWM50	2.826 MPa	0.4099 ksi	1.435 MPa	0.2082 ksi	2.422 MPa	0.3513 ksi
Max. Conc Stress for Wind at EOG50	10.5 MPa	1.522 ksi	10.06 MPa	1.459 ksi	10.48 MPa	1.52 ksi
Min. Conc Stress for Wind at EOG50	4.237 MPa	0.6145 ksi	2.673 MPa	0.3876 ksi	2.58 MPa	0.3742 ksi
Max. Conc Stress for Fatigue Load	8.042 MPa	1.166 ksi	7.039 MPa	1.021 ksi	7.291 MPa	1.057 ksi
Min. Conc Stress for Fatigue Load	6.69 MPa	0.9704 ksi	5.69 MPa	0.8253 ksi	5.752 MPa	0.8343 ksi
Max. Tendon Stress for Fatigue Load	1107.6 MPa	160.6 ksi	1107.6 MPa	160.6 ksi	1107.6 MPa	160.6 ksi
Min. Tendon Stress for Fatigue Load	1103 Mpa	160 ksi	1103 Mpa	160 ksi	1103 Mpa	160 ksi
Number of Tendon in Concrete Tower	36		48		56	
Tower Natural Frequency (Hz) (Rayleigh-SAP)	0.4848	0.4803	0.4813	0.4793	0.4835	0.4802
Base Shear & Mom. Comparison (EQ/Wind)	2.481	2.222	2.529	1.958	3.997	2.246
Mom. DCR of Conc. at Base (Wind - EQ)	0.417	0.927	0.458	0.896	0.366	0.821
Shear DCR of Conc at Base (Wind - EQ)	0.251	0.483	0.294	0.562	0.204	0.591
Max. Stress DCR for Steel (Wind - EQ)	0.328	0.684	0.413	0.712	0.365	0.633
Max. Buckling DCR of Steel (Wind - EQ)	0.356	0.663	0.433	0.741	0.385	0.666
Soil Bearing Capacity DCR (Wind - EQ)	0.656	0.775	0.839	0.873	0.848	0.986
Footing Shear Capacity DCR (Wind - EQ)	0.288	0.348	0.339	0.381	0.334	0.402
Steel Tower Fatigue DCR	0.954		0.902		0.991	
Conc. Fatigue DEL-log(N) & Σ(n/N) @Base	76.6	6.15E-08	85.4	1.73E-08	72.6	3.55E-06
Controlling Loading Case	STL Fatigue		STL Fatigue		STL Fatigue	

Table 5.6. Design Results—100-m Full Height Concrete Wind Turbine Towers
(unfactored stresses given)

100m All Concrete Wind Turbine Tower (fc'=7ksi)

	1.5 MW (EQ)		1.5 MW (Wind)		3.6 MW (EQ)		3.6 MW (Wind)		5.0 MW (EQ)		5.0 MW (Wind)	
Rotor Diameter	70.5 m	231.2 ft	70.5 m	231.2 ft	108.4 m	355.6 ft	108.4 m	355.6 ft	128 m	419.8 ft	128 m	419.8 ft
Total Head Weight	84800 kg	187 kips	84800 kg	187 kips	314912 kg	694 kips	314912 kg	694 kips	480076 kg	1058 kips	480076 kg	1058 kips
Additional Weight at Mid Height Tower	1500 kg	3.3 kips	1500 kg	3.3 kips	3600 kg	7.94 kips	3600 kg	7.94 kips	5000 kg	11 kips	5000 kg	11 kips
Mid Height of Concrete Tower (hc)	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft
Outside Diameter at Base for Concrete Tower	6.401 m	252 in	5.791 m	228 in	7.925 m	312 in	6.706 m	264 in	9.144 m	360 in	7.62 m	300 in
Wall Thickness at Base for Concrete Tower	0.6858 m	27 in	0.6096 m	24 in	0.762 m	30 in	0.6858 m	27 in	0.8382 m	33 in	0.762 m	30 in
Outside Diameter at Mid Height of Conc Tower	4.42 m	174 in	3.962 m	156 in	5.639 m	222 in	5.182 m	204 in	6.401 m	252 in	5.639 m	222 in
Wall Thickness at Mid Height of Conc Tower	0.5334 m	21 in	0.5334 m	21 in	0.6096 m	24 in	0.6096 m	24 in	0.6858 m	27 in	0.6858 m	27 in
Outside Diameter at Top of Conc Tower	2.896 m	114 in	2.896 m	114 in	3.658 m	144 in	3.658 m	144 in	3.658 m	144 in	3.658 m	144 in
Wall Thickness at Top of Conc Tower	0.4572 m	18 in	0.4572 m	18 in	0.4572 m	18 in	0.4572 m	18 in	0.5334 m	21 in	0.4572 m	18 in
Spread Foot Width and Length	18.29 m	60 ft	16.76 m	55 ft	21.34 m	70 ft	19.2 m	63 ft	22.86 m	75 ft	20.42 m	67 ft
Spread Foot Depth	3.353 m	11 ft	3.048 m	10 ft	3.658 m	12 ft	3.658 m	12 ft	3.962 m	13 ft	3.658 m	12 ft
Concrete Tower Weight	16650 kN	3742 kips	14470 kN	3254 kips	23640 kN	5314 kips	20370 kN	4579 kips	29790 kN	6697 kips	24470 kN	5502 kips
Tendon Weight	52650 kg	116100 lb	35600 kg	78490 lb	60630 kg	133700 lb	47470 kg	104600 lb	64570 kg	142300 lb	59180 kg	130500 lb
Footing Reinforcement Weight	76570 kg	168.8 kips	64960 kg	143.2 kips	129700 kg	285.8 kips	105000 kg	231.5 kips	157600 kg	347.4 kips	131600 kg	290.2 kips
Defection at Top of Tower for EQ Load	1.251 m	4.103 ft	1.596 m	5.236 ft	1.007 m	3.304 ft	1.323 m	4.342 ft	0.8754 m	2.872 ft	1.202 m	3.944 ft
Defection at Top of Tower for Wind Load	0.2737 m	0.898 ft	0.3828 m	1.256 ft	0.3501 m	1.149 ft	0.5046 m	1.656 ft	0.2675 m	0.8776 ft	0.4148 m	1.361 ft
Max. Stress at Tower Base												
Max. Conc Stress for Wind for EWM50	12.34 MPa	1.79 ksi	12.1 MPa	1.755 ksi	12.34 MPa	1.79 ksi	15.65 MPa	2.27 ksi	10.15 MPa	1.473 ksi	14.3 MPa	2.074 ksi
Min. Conc Stress for Wind for EWM50	5.067 MPa	0.7349 ksi	2.269 MPa	0.329 ksi	2.101 MPa	0.3047 ksi	-0.5103 MPa	-0.07401 ksi	2.578 MPa	0.3739 ksi	2.036 MPa	0.2954 ksi
Max. Conc Stress for Wind at EOG50	11.15 MPa	1.617 ksi	10.5 MPa	1.523 ksi	11.07 MPa	1.605 ksi	13.64 MPa	1.978 ksi	10.03 MPa	1.454 ksi	14.1 MPa	2.046 ksi
Min. Conc Stress for Wind at EOG50	6.258 MPa	0.9077 ksi	3.864 MPa	0.5604 ksi	3.374 MPa	0.4893 ksi	1.498 MPa	0.2173 ksi	2.693 MPa	0.3906 ksi	2.215 MPa	0.3212 ksi
Max. Conc Stress for Fatigue Load	9.224 MPa	1.338 ksi	7.896 MPa	1.145 ksi	7.922 MPa	1.149 ksi	8.68 MPa	1.259 ksi	7.07 MPa	1.025 ksi	9.314 MPa	1.351 ksi
Min. Conc Stress for Fatigue Load	8.181 MPa	1.187 ksi	6.471 MPa	0.9385 ksi	6.513 MPa	0.9447 ksi	6.452 MPa	0.9358 ksi	5.635 MPa	0.8173 ksi	6.983 MPa	1.013 ksi
Max. Tendon Stress for Fatigue Load	1111.6 MPa	161.2 ksi	1111.6 MPa	161.2 ksi	1106.2 MPa	160.4 ksi	1108.3 MPa	160.8 ksi	1105 MPa	160.3 ksi	1105 MPa	160.3 ksi
Min. Tendon Stress for Fatigue Load	1094.7 Mpa	158.8 ksi	1094.7 Mpa	158.8 ksi	1102.5 Mpa	159.9 ksi	1102 Mpa	159.8 ksi	1102.7 Mpa	159.9 ksi	1102.7 Mpa	159.9 ksi
Number of Tendon at Base and Mid Section	48	32	30	24	52	40	40	32	56	42	56	34
Tower Natural Frequency (Hz) [Rayleigh-SAP]	0.4355	0.4082	0.3774	0.3557	0.4431	0.4118	0.3768	0.3419	0.4621	0.4350	0.384	0.3564
Base Shear & Moment Comprison (EQ/Wind)	3.497	3.393	3.141	3.059	3.034	2.341	2.704	2.092	5.296	2.809	4.643	2.432
Mom. DCR of Conc. Tower at Base (Wind - EQ)	0.279	0.946	0.453	1.383	0.422	0.987	0.669	1.397	0.341	0.956	0.470	1.140
Shear DCR of Conc at Base (Wind - EQ)	0.215	0.604	0.265	0.650	0.290	0.657	0.390	0.747	0.177	0.664	0.240	0.736
Soil Bearing Capacity DCR (Wind - EQ)	0.655	0.901	0.694	1.230	0.814	0.907	0.946	1.214	0.833	0.960	0.932	1.285
Footing Shear Capacity DCR (Wind - EQ)	0.300	0.416	0.326	0.463	0.398	0.475	0.390	0.465	0.362	0.455	0.409	0.517
Section Forces at Mid Height of Concrete Tower (hc)												
Shear & Moment Comprison for EQ/Wind	4.523	3.414	4.076	3.105	3.362	2.122	3.000	1.918	7.029	2.419	6.077	2.124
Mom. DCR of Conc. Tower (Wind - EQ)	0.274	0.935	0.396	1.228	0.446	0.947	0.598	1.148	0.401	0.972	0.570	1.213
Shear DCR of Conc (Wind - EQ)	0.345	0.970	0.407	0.971	0.510	1.032	0.582	1.006	0.289	1.046	0.357	1.027
Max. Conc Stress for Wind for EWM50	14.75 MPa	2.14 ksi	14.77 MPa	2.142 ksi	15.84 MPa	2.298 ksi	16.49 MPa	2.391 ksi	13.17 MPa	1.911 ksi	14.75 MPa	2.139 ksi
Min. Conc Stress for Wind for EWM50	5.713 MPa	0.8287 ksi	3.048 MPa	0.4421 ksi	2.07 MPa	0.3002 ksi	-0.3194 MPa	-0.04633 ksi	2.04 MPa	0.2959 ksi	-0.2514 MPa	-0.03646 ksi
Max. Conc Stress for Wind at EOG50	13.57 MPa	1.968 ksi	13.23 MPa	1.92 ksi	14.22 MPa	2.063 ksi	14.51 MPa	2.104 ksi	12.96 MPa	1.879 ksi	14.45 MPa	2.097 ksi
Min. Conc Stress for Wind at EOG50	6.894 MPa	0.9999 ksi	4.579 MPa	0.6642 ksi	3.683 MPa	0.5341 ksi	1.655 MPa	0.2401 ksi	2.237 MPa	0.3245 ksi	0.01887 MPa	0.002737 ksi
Max. Conc Stress for Fatigue Load	11.03 MPa	1.599 ksi	9.94 MPa	1.442 ksi	9.967 MPa	1.446 ksi	9.317 MPa	1.351 ksi	8.652 MPa	1.255 ksi	8.659 MPa	1.256 ksi
Min. Conc Stress for Fatigue Load	9.437 MPa	1.369 ksi	7.874 MPa	1.142 ksi	7.932 MPa	1.15 ksi	6.837 MPa	0.9916 ksi	6.516 MPa	0.945 ksi	5.782 MPa	0.8386 ksi
Max. Tendon Stress for Fatigue Load	1106.4 MPa	160.5 ksi	1106.4 MPa	160.5 ksi	1108.3 MPa	160.7 ksi	1111.7 MPa	161.2 ksi	1110.1 Mpa	161 ksi	1110.1 Mpa	161 ksi
Min. Tendon Stress for Fatigue Load	1102.7 Mpa	159.9 ksi	1102.7 Mpa	159.9 ksi	1101.4 Mpa	159.8 ksi	1100.3 Mpa	159.6 ksi	1096.2 Mpa	159 ksi	1096.2 Mpa	159 ksi
Conc. Fatigue (z=hc,z=0) DEL-Log(N)	42.17	85.83	38.68	73.73	39.15	74.41	34.84	42.23	44.3	79.82	32.16	37.2
Conc. Fatigue (z=hc,z=0) 0 (n/N)	2.49E-04	1.13E-09	9.89E-03	1.84E-07	5.51E-03	1.61E-07	9.80E-02	1.60E-02	4.49E-03	4.64E-07	8.87E-01	1.39E-01
Controlling Loading Case	EQ Strength		Tower Frequency		EQ Strength		Conc Fatigue		EQ Strength		Conc Fatigue & Ten. Str.	

6.0 Fatigue Design for Concrete Elements

During operation, every blade rotation causes a small stress change in the wind turbine tower. As a result of operational loading in a 20-year-design life, the tower will experience approximately 5.29 x 10^8 fatigue load cycles. This is a very high number of cycles for a civil engineering type structure. Though the stress range is small, fatigue could become a critical design criterion for the prestressed concrete of the wind turbine tower because of the high number of stress cycles superimposed on a typically higher level of sustained concrete stress.

The consideration of fatigue degradation of concrete is rather new and has developed with the use of higher strength concrete, and the associated designs to take advantage of this strength that require the concrete to perform at higher stress levels. Fatigue design in typical concrete applications in bridge, building, and offshore structures typically consider less than 10 million load cycles, though these cycles can be associated with high-stress ranges. Because this area of design technology is still changing, several prevalent approaches to fatigue design, as represented by the provisions of the leading international design codes, are discussed as to their applicability to prestressed concrete wind turbine tower fatigue design.

Structures subjected to higher frequency vibration because of wind or machine-induced vibration, such as wind turbines, can be exposed to hundreds of millions of cycles and are seldom covered under the current codes. Only the Norwegian standard [2] explicitly considers fatigue of concrete at the high load cycle numbers typical of the wind turbine loading. A more useful document for the design for concrete fatigue is the Model Code 1990 (MC90) [1] from the International Federation for Prestressing (CEB-FIP). The MC90 will be the base for the new Eurocode 2. In the following sections, a selection of guides for fatigue design is presented and their applicability to the concrete wind turbine tower is discussed.

6.1 Fatigue Design According to the Model Code 1990

The MC90 [1] was established by the CEB-FIP to build a common base for setting up codes for the design and construction of buildings and civil engineering structures based on scientific and technical developments that have occurred over the past decade in the safety, analysis, and design of concrete structures. The model code was originally published in 1978 and has since been revised to a first draft in 1990 and been released for publication as CEB-FIP MC90 in 1993. Since its first release, the model code had a considerable impact on the national design codes in many countries. In particular, it has been used extensively for the harmonization of national design codes and as basic reference for Eurocode 2. The Eurocode 2 (officially EN 1992) was scheduled to become available in 2003.

At present, the MC90 is the only official guideline to cover a complete fatigue design procedure for concrete, mild steel, and prestressed steel subjected to more than 10^8 load cycles. It is, therefore, currently the most suitable design base for wind turbine towers made of prestressed concrete.

The fatigue design is addressed in MC 90 Chapter 6.7 Ultimate Limit State of Fatigue, which offers three methods with increasing refinement and complication.

6.1.1. Simplified Fatigue Design Procedure

The simplified method applies only to structures subjected to less than 10^8 load cycles. The fatigue requirement is met with the following formulas:

For steel:

$$\gamma_{Sd} \cdot max\, \Delta\sigma_{Ss} \leq \Delta\sigma_{Rsk} / \gamma_{s,fat} \quad ,$$

where $max\ \Delta\sigma_{Ss}$ is the maximum calculated stress range
$\Delta\sigma_{Rsk}$ is the characteristic fatigue strength at 10^8 cycles as tabulated in the code for mild and prestressed steel reinforcement
γ_{Sd} = 1.1 is the partial factor on load
$\gamma_{s,fat}$ = 1.15 is the partial factor on steel strength.

The characteristic fatigue strength $\Delta\sigma_{Rsk}$ is 125 MPa (18 ksi) for a straight Ø16 mm (5/8 in.) reinforcement bar and 95 MPa (14 ksi) for a straight prestressed strand. Bent and welded reinforcement bars have a lower fatigue strength.

The effect of differences in bond behavior of prestressing and reinforcing steel has to be taken into account for the stresses in the mild reinforcing steel. Using a linear elastic model for the stress calculation fulfilling strain compatibility, the stress in the mild reinforcement can be multiplied by the following factor:

$$\eta_s = \frac{1 + \left(A_p / A_s\right)}{1 + \left(A_p / A_s\right)\sqrt{\zeta (\phi_s / \phi_p)}} \geq 1 \ ,$$

where
η_s is the stress redistribution factor for mild steel reinforcement
A_s is the area of reinforcement steel
A_p is the area of prestressing steel
ϕ_s is the smallest diameter of reinforcing steel in the relevant section
ϕ_p is the diameter of prestressing steel (for bundles an equivalent diameter has to be chosen $1.6\sqrt{A_p}$)
ζ is the ratio of bond strength of prestressing steel and reinforcement steel and is tabulated in the code. The ratio is 0.4 for strands in post-tensioned members and 0.6 for strands in pre-tensioned members.

For concrete:

$$\gamma_{Sd} \cdot \sigma_{c,\max} \cdot \eta_c \leq 0.45 f_{cd,fat} \qquad \text{for concrete in compression and}$$

$$\gamma_{Sd} \cdot \sigma_{ct,\max} \leq 0.33 f_{ctd,fat} \qquad \text{for concrete in tension,}$$

where $\sigma_{c,max}$ is the maximum calculated compression stress

$\sigma_{ct,max}$ is the maximum calculated tension stress

$\gamma_{Sd} = 1.1$ is the partial factor on load

η_c is a factor that takes the effect of stress redistribution due to creep under consideration

$$\eta_c = \frac{1}{1.5 - 0.5|\sigma_{c1}| / |\sigma_{c2}|}$$

where $|\sigma_{c1}|$ is the lower and $|\sigma_{c2}|$ the larger absolute value of the compressive stress within a distance no more than 300 mm (12 in.) from the surface under the same relevant load combination. For a concrete section primarily under compression, η_c is about 1.

$f_{cd,fat}$ is the fatigue reference design strength and is dependent on the strength and age of the concrete:

$$f_{cd,fat} = \frac{0.85\beta_{cc}(t)}{\gamma_c}\left[f_{ck}\left(1 - \frac{f_{ck}}{25 f_{cko}}\right)\right].$$

For a concrete of f'_c of 48 MPa (7 ksi) at an age of 60 days, the concrete fatigue reference design strength is about 24 MPa (3.5 ksi) or 0.49 f_c'.

f_{cko} is a reference strength and is equal to 10 MPa (1.45 ksi).

f_{ck} is the characteristic concrete cylinder strength and is comparable to f'_c in ACI 318 [6]

$\beta_{cc}(t)$ is a coefficient which depends on the age of the concrete t in days when fatigue loading starts

$$\beta_{cc}(t) = e^{0.2\left(1 - \sqrt{28/t}\right)}$$

For a concrete age of 60 days, $\beta_{cc}(t{=}60)$ equals 1.065.

$f_{ctd,fat}$ is the fatigue reference design tensile strength and is $f_{ctk,min}/\gamma_c$

$f_{ctk,min}$ is the lower bound value of the characteristic tensile strength. In the absence of more accurate data, the following estimation can be used:

$$f_{ctk,\min} = f_{ctko,\min}\left(\frac{f_{ck}}{f_{cko}}\right)^{2/3}$$

$f_{ctko.min}$ = 0.95 MPa (0.138 ksi)

$\gamma_c = 1.5$ is the partial factor on concrete strength.

6.1.2. Refined Fatigue Design Procedure

A more refined procedure allows design for more than 10^8 load cycles. The procedure evaluates a maximum design life in number of cycles for a given stress pair at maximum and minimum load level. The method is based on characteristic SN curves for mild steel, prestressed steel, and concrete. The required lifetime (number of cycles) shall be less than or equal to the maximum design life.

The fatigue requirements for steel are met with the following formulas:

$$\gamma_{Sd} \cdot max\, \Delta\sigma_{Ss} \leq \Delta\sigma_{Rsk}(n) / \gamma_{s,fat} \quad ,$$

where
- $max\ \Delta\sigma_{Ss}$ is the maximum calculated stress range
- n is the foreseen number of cycles in the required design lifetime
- $\gamma_{Sd} = 1.1$ is the partial factor on load
- $\gamma_{s,fat} = 1.15$ is the partial factor on steel strength
- $\Delta\sigma_{Rsk}(n)$ is the fatigue strength for n cycles evaluated from characteristic SN curves as defined in the code for mild and prestressed steel reinforcement.

The characteristic fatigue curves are bilinear curves in a double logarithmic scale (Figure 6.1).

$$log\left(\Delta\sigma_{Rsk}(n)\right) = log\left(\Delta\sigma^{*}_{Rsk}\right) - \frac{1}{k_1} \cdot log\left(n - N^{*}\right) \text{ if } n \leq N^{*}$$

$$log\left(\Delta\sigma_{Rsk}(n)\right) = log\left(\Delta\sigma^{*}_{Rsk}\right) - \frac{1}{k_2} \cdot log\left(n - N^{*}\right) \text{ if } n > N^{*}$$

Table 6.1. Fatigue Exponents for Steel Features of Concrete Towers

		exponent		$\Delta\sigma_{Rsk}$ (MPa)	
	N^*	k_1	k_2	at N^*	at 10^8
Straight mild steel Ø16 mm	10^6	5	9	210	125
Straight prestressed strand	10^6	5	9	160	95
Welded bars, mech. couplers	10^7	3	5	50	30
PT coupler or anchor	10^6	3	5	80	30

For more cases, see MC90

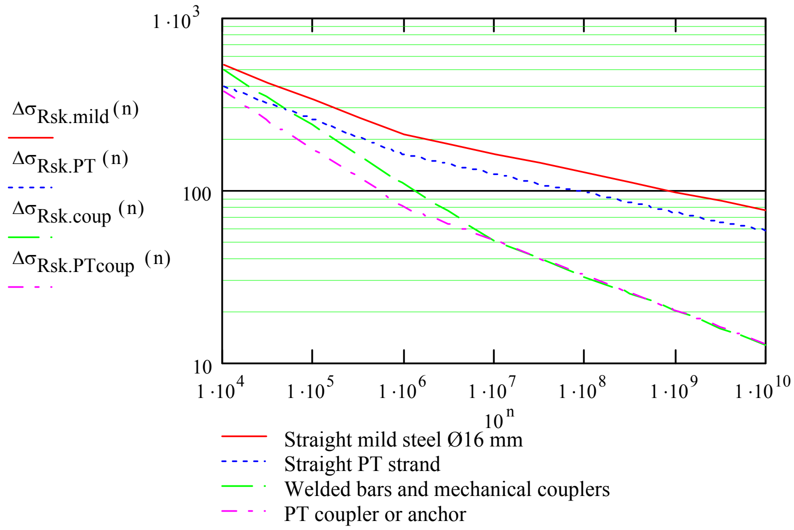


Figure 6.1. SN curves for steel reinforcement by MC90

The fatigue requirements for concrete are met with the following formulas (Figure 6.2):

$$n \leq N$$

for concrete in compression:

$$\log N_1 = (12 + 16\, S_{cd,min} + 8\, S^2_{cd,min})\,(1 - S_{cd,max})$$
$$\log N_2 = 0.2 \log N_1\,(\log N_1 - 1)$$
$$\log N_3 = \log N_2\,(0.3 - 3/8\, S_{cd.min}) / \Delta S_{cd}$$

if $\log N_1 \leq 6$, then $\log N = \log N_1$
if $\log N_1 > 6$ and $\Delta S_{cd} \geq (0.3 - 3/8\, S_{cd,min})$, then $\log N = \log N_2$
if $\log N_1 > 6$ and $\Delta S_{cd} < (0.3 - 3/8\, S_{cd,min})$, then $\log N = \log N_3$,

where $S_{cd,max} = \gamma_{Sd}\ \sigma_{c,max}\ \eta_c / f_{cd.fat}$
$S_{cd,min} = \gamma_{Sd}\ \sigma_{c,min}\ \eta_c / f_{cd.fat} \leq 0.8$.
$\Delta S_{cd} = S_{cd,max} - S_{cd,min}$

For concrete in compression-tension ($\sigma_{ct,max} \leq 0.026|\sigma_{c,max}|$):

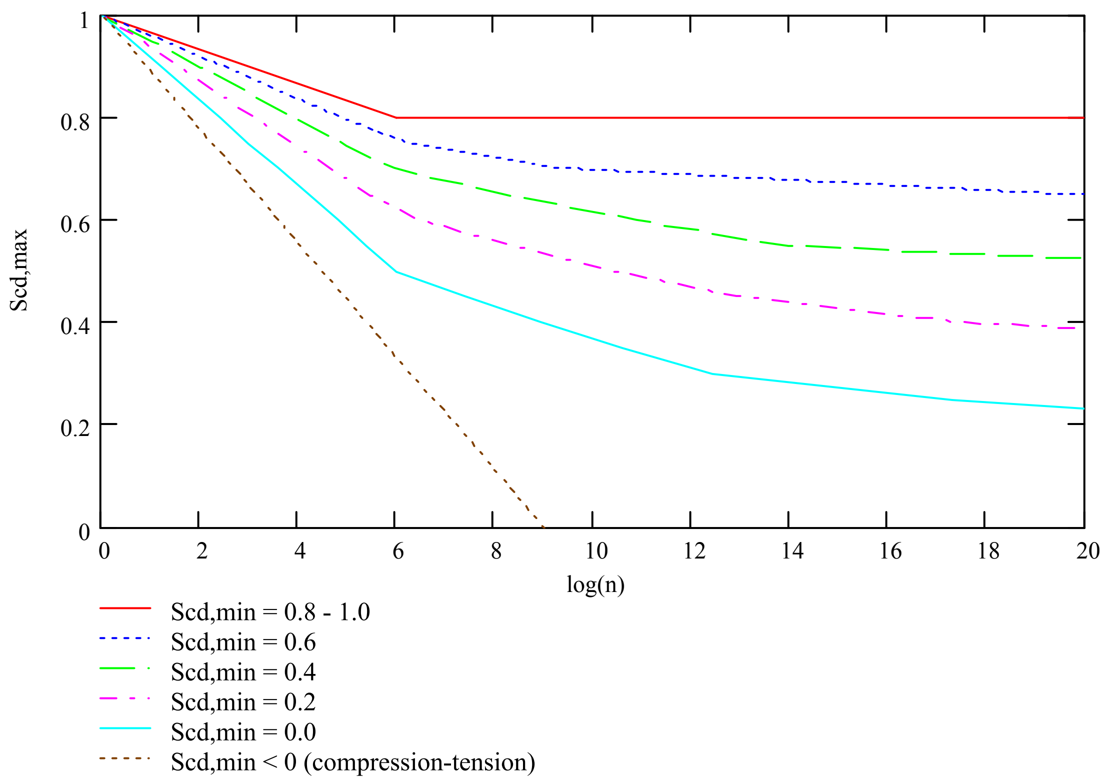
$$\log N = 9\,(1 - S_{cd,max})\ .$$

For concrete in pure tension or tension-compression ($\sigma_{ct,max} > 0.026|\sigma_{c,max}|$):

$$\log N = 12\,(1 - S_{td,max})\ ,$$

where $S_{td,max} = \gamma_{Sd}\ \sigma_{ct,max} / f_{ctd.fat}$

Clearly the fatigue lifetime of concrete in any form of tension is very limited.



($S_{cd,min} = \gamma_{Sd}\, \sigma_{c,min}\, \eta_c / f_{cd.fat}$)

Figure 6.2. SN curves for concrete in compression according to MC90

6.1.3. Fatigue Design Procedure for Load Spectra

The third design approach allows the designer to consider a spectrum of load levels by accumulating the damage according to the Palmgren-Miner hypothesis. The fatigue damage D is calculated as follows:

$$D = \sum_{i=1}^{j} \frac{n_{Si}}{N_{Ri}} \quad ,$$

where n_{Si} is the number of actual stress cycles within block i of the spectrum
N_{Ri} is the number of resisting stress cycles for the stress pair associated to block i of the spectrum
j is the number of blocks that divide the stress spectrum.

The spectrum counts the numbers of stress cycles n_{Si} within each stress category i for a total of j categories. A stress category i is defined by the average stress from the load cycles assigned to the category.

In the case of steel fatigue design, the stress category is defined as a stress range $\Delta\sigma_{Ssi}$. The corresponding number of resisting stress cycles N_{Ri} is derived from the SN curve for steel by using the increased numerical stress range $\gamma_{Sd}\gamma_{s,fat}\Delta\sigma_{Ssi}$, hence, from $\gamma_{Sd}\gamma_{s,fat}\Delta\sigma_{Ssi} = \Delta\sigma_{Rsk}(N_{Ri})$.

In the case of concrete fatigue design, the stress category is defined as a stress pair $\sigma_{c,max,i}/\sigma_{c,min,i}$. The stress spectrum for concrete can therefore be two-dimensional. The corresponding number of resisting stress cycles N_{Ri} is directly obtained by the refined fatigue design procedure.

The fatigue requirement is met if each material satisfies the damage criteria $D \leq D_{lim}$. Using an appropriate counting method (e.g., rainflow method) a value of $D_{lim} = 1$ can normally be used.

6.1.4. Fatigue Design of Concrete in Shear

The fatigue design lifetime of concrete in shear without shear reinforcement is calculated according to the following formula:

$$log\, N = 10\,(1 - V_{cd,max} / V_{Rd1})\ ,$$

where $V_{cd,max}$ is the maximum design shear force under the relevant representative values of permanent loads, including prestress and maximum cyclic loading

V_{Rd1} is the transverse design shear resistance of the concrete and may be described by an appropriate shear model.

For a single cyclic load case, the fatigue criteria can be expressed with a factor for the shear strength degradation of the concrete caused by cyclic loading:

$$V_{cd,max} \leq S_{vd,fat}(n)\ V_{Rd1}\ ,$$

where $Svd,fat(n) = (1 - 0.1\ log\ n)$ is the concrete shear strength degradation factor due to n load cycles

For concrete with shear reinforcement, the code recommends to use strut-and-tie models with compression struts that are less inclined and have a lower compression strength than struts for a static shear analysis. Both measures have the effect of decreasing the shear resistance of the concrete and increasing the strength demand of the shear reinforcement.

The inclination of the compression strut shall be chosen

$$tan\,\theta_{fat} = \sqrt{tan\,\theta}\ ,$$

where θ is the inclination of the compression strut used for a static shear analysis and lays between 18.4° and 45°

θ_{fat} is the inclination of the compression strut used for the fatigue analysis and is limited to 30° to 45°

The compression fatigue strength of the strut is evaluated by the simple or refined fatigue design procedure. The reference concrete fatigue design strength $f_{cd,fat}$ is thus reduced by an additional factor of 0.7. The fatigue strength of the tension tie can be calculated by the corresponding design procedures for reinforcement steel, under consideration of the small bending radius of the stirrups.

6.2. Fatigue Design According to NS 3473

The Norwegian Standard describes the fatigue analysis of reinforced concrete in the Code NS 3473 [2] for concrete structures in Chapter 13. The approach for the concrete fatigue design is similar to the one of MC90 as it calculates a resisting lifetime for a given stress pair and compares it to the required lifetime. The method, however, is much simpler than in the model code and produces a nearly linear curve in the Goodman diagram, allowing high concrete stresses at small stress ranges. The fatigue design for reinforcement steel is determined by means of SN curves similar to the MC90 approach. Fatigue of prestressed steel is not addressed in the code.

For fatigue loading caused by randomly variable forces such as wind, waves, and traffic, the code allows the designer to omit a detailed fatigue analysis if the calculated fatigue life for the largest force amplitude at 2 x 10^6 cycles meets the fatigue limit state requirement. Otherwise, a cumulative damage analysis according to the Miner hypothesis has to be done. Thereby, the ratio of fatigue utilization for concrete is reduced to 1/2 for loading histories with not nearly constant amplitude, which adds an additional safety factor of 2.

The Norwegian Standard uses different load and strength reduction factors than the MC90 or the German Institute for Standards (DIN). The characteristic concrete strength f_{ck} is further reduced by 20%–30% to an in-situ concrete strength f_{cn}, dependent on the design concrete strength. The partial safety factor on concrete is only 1.2. The reduction plus partial factor yield to a combined material safety factor of 1.5–1.7 over the characteristic concrete cylinder strength, which is comparable to the material safety factor of 1.5 of the MC90. The partial safety factor on the fatigue loading is 1.0.

The NS 3473 does not apply a redistribution factor for stresses between concrete and reinforcement steel or between prestressed and mild steel.

The fatigue life of concrete is calculated according to the following formulas:

$$log\,N = C_1 \frac{1-\sigma_{c,max}/f_{rd}}{1-\sigma_{c,min}/f_{rd}}$$

where	$\sigma_{c,max}$	is the numerically largest compressive stress
	$\sigma_{c,min}$	is the numerically least compressive stress
	$f_{rd} = \alpha f_{cd}$	is the reference stress for the type of failure in question and is typically equal to the concrete design strength f_{cd} for concrete primarily under compression.
	α	$= 1.3 - 0.3\,\beta > 1.0$
	β	is the ratio between the numerically smallest and largest stresses acting simultaneously in the local concrete zone within 300 mm and is practically 1 for the compressed concrete in the wind tower application
	$f_{cd} = f_{cn}/\gamma_c$	is the concrete design strength
	f_{cn}	is the concrete in-situ strength and is tabulated for different concrete strengths. A concrete with a characteristic cylinder strength of 48 MPa (7 ksi) yields by interpolation an in-situ strength f_{cn} of about 35.5 MPa (5.1 ksi)

γ_c = 1.2 is the material reduction factor for concrete under fatigue loading

C_1 is a factor taking into account the environment of the structure and is 12.0 for structures in air.

The design life may be increased by a factor C_2 if $log\, N > x$,

where $$x = \frac{C_1}{\left(1 - \sigma_{c,min} / f_{rd} + 0.1 \cdot C_1\right)}$$

$$C_2 = (1 + 0.2\,(log\, N - x)) > 1.0$$

These formulas are for the fatigue design of concrete under bending and axial force. The code also gives the option to apply this formula to concrete under shear and to the design of reinforcement anchorage and splicing.

The design life of reinforcement subjected to cyclic stresses is calculated according to the following SN curve:

$$logN = C_3 - C_4\, log\, \Delta\sigma_{Ss} \ ,$$

where $\Delta\sigma_{Ss}$ is the stress variation of the reinforcement in N/mm^2

C_3 and C_4 are factors dependent on reinforcement type and are C_3 = 19.6 and C_4 = 6.0 for straight reinforcement bars.

An infinite design life of reinforcement steel is assumed for calculated values of N greater than 2×10^8 cycles.

6.3 Fatigue Design According to DIN 1045

DIN addresses the design for fatigue of reinforced concrete in DIN 1045 [3], Chapter 10.8. The code offers two approaches for the fatigue design. The fatigue check for mild and prestressed steel is based on the fatigue endurance limit or on SN curves similar to MC90. The two approaches on concrete fatigue stress check are based on Goodman diagrams at 1 million cycles but do not explicitly limit the number of load cycles. If a fatigue stress check on concrete had to be performed on more than 1 million cycles, then the design stresses would have to be converted into an equivalent stress pair that causes equivalent fatigue damage at 1 million cycles to make the formula applicable. However, the code gives no approach for that conversion. The approach is, therefore, not suitable for the design of the concrete wind turbine tower.

The first design approach is based on SN curves for mild and prestressed reinforcement and on a nonlinear Goodman diagram for concrete stresses. As in the MC90, the stresses are redistributed between mild and prestressed steel by a factor η to account for the different bond behavior of the reinforcement. The factor is a function of the mild and prestressed steel area, the bar diameters, and the ratio between the bond coefficient of mild and prestressed steel. The tabulated ratios are slightly different than the ones in the MC90 and distinguish between normal and high-strength concrete embedment.

$$\eta = \frac{A_s + A_p}{A_s + A_p \sqrt{\zeta \left(d_s / d_p \right)}}$$

where A_s is the area of the mild steel reinforcement
A_p is the area of the prestressed steel
d_s is the diameter of the mild steel reinforcement
d_p is the diameter of the prestressed steel
ξ is the ratio between the bond coefficient for mild and prestressed steel reinforcement and is tabulated in the code for different rod types and concrete embedment.

Similar to the MC90, the SN curves for mild and prestressed steel reinforcements are tabulated as trilinear curves in the double logarithmic scale. The curves for mild steel reinforcement distinguish between straight, bent, and coupled or welded bars. The curves for prestressed steel differentiate between prestressed and post-tensioned steel in straight or bent steel or plastic ducts. The tabulated values are slightly less conservative than those of MC90.

The fatigue stress check on steel is done according to the following formula:

$$\gamma_{F,fat} \cdot \gamma_{Ed,fat} \cdot \Delta\sigma_{s,equ} \leq \frac{\Delta\sigma_{Rsk}(N)}{\gamma_{s,fat}} \quad ,$$

where $\Delta\sigma_{Rsk}(N)$ is the ultimate stress range for N load cycles taken from the SN curve
$\Delta\sigma_{s,equ}$ is the stress range causing equivalent damage to the steel as the design service stress range.

The safety factor applied on the fatigue load $\gamma_{F,fat} = 1.0$, the factor for model uncertainties $\gamma_{Ed,fat} = 1.1$, and material reduction factors applied on reinforcement $\gamma_{s,fat} = 1.15$ and concrete $\gamma_{c,fat} = 1.5$ are the same as in MC90.

For complex stress histories in the steel, the code proposes to apply the damage accumulation hypothesis by Palmgren-Miner using the SN curves similar to MC90.

The stress check on the concrete is done using a nonlinear Goodman diagram basing the input maximum and minimum fatigue stresses on 1 million cycles only. The diagram can be formulated as follows:

$$S_{cd,\max,equ} \leq 1 - 0.43\sqrt{1 - S_{cd,\min,equ} / S_{cd,\max,equ}} \quad ,$$

where $S_{cd,max}$ $= \sigma_{cd,max,equ} / f_{cd,fat}$

$S_{cd,min}$ $= \sigma_{cd,min,equ} / f_{cd,fat}$

$f_{cd,fat}$ is the concrete fatigue reference design strength,

$$f_{cd,fat} = \frac{\beta_{cc}(t)}{\gamma_c}\left[f_{ck}\left(1 - \frac{f_{ck}}{250}\right)\right]$$

f_{ck} is the characteristic concrete cylinder strength in MPa

$\beta_{cc}(t)$ is a coefficient that depends on the age of the concrete t in days when fatigue loading starts,

$$\beta_{cc}(t) = e^{0.2\left(1-\sqrt{28/t}\right)}$$

$\sigma_{cd,max,edu}$ and $\sigma_{cd,min,edu}$ are the numerical upper and lower stresses of the stress range during $N = 10^6$ load cycles, and cause equivalent damage as the design fatigue service stresses.

The concrete fatigue reference design strength $f_{cd,fat}$ is defined similarly to the MC90 and is dependent on concrete strength and age. However, it does not have an additional reduction factor of 0.85 as MC90 does for lower loading frequencies. For a concrete with f'_c of 48 MPa (7 ksi) at an age of 60 days, the concrete fatigue reference design strength is about 27 MPa (4 ksi) or 0.57 f_c'.

The second approach for the fatigue stress check is simplified. The formulas are independent of the number of load cycles. Therefore, the stress check cannot be optimized by the accumulated damage hypothesis and is valid only for load cycles up to 1 million cycles.

The procedure limits the stress range of unwelded mild steel reinforcement bars to 70 MPa and limits prestressed steel and welded reinforcement bars to zones with concrete under compression. For concrete, the approach uses a Goodman diagram to limit the maximum and minimum concrete fatigue stresses, not limiting the number of cycles for which the approach is applicable.

$$S_{cd,max} < 0.5 + 0.45\, S_{cd,min} < 0.9$$

6.4 Fatigue Design According to ACI 215R

ACI 215R [4] has only limited design recommendations for fatigue and bases ACI 215 on a description of the fatigue phenomena, experimental testing, and design conclusions from a series of references.

ACI bases the concrete fatigue strength on testing of concrete to up to 10 million cycles as there seems to be "no limiting value of stress below which the fatigue life of concrete will be infinite." "The fatigue strength of concrete for a life of 10 million cycles – for compression, tension, or flexure – is roughly about 55% of static strength." That would be with a stress range of 0%–55% of the static strength and would yield a 50% probability of fatigue failure. For beam design, ACI recommends to decrease the fatigue strength to 40% of the static strength at a lower failure probability. For design at a smaller stress range, ACI recommends a Goodman diagram (see Figure 6.3), which "reduces the stress range linearly as the minimum stress is increased, so that the permitted stress range is zero when the minimum stress is 0.75 f_c'," It can be formulated as

$$\Delta\sigma_{Rc} = 0.4 f_c' \,(1 - \sigma_{cd,min} / 0.75 f_c') \; ,$$

where $\Delta\sigma_{Rc}$ is the resisting stress range and $\sigma_{cd,min}$ is the minimum numerical stress that is smaller than 0.75 f_c' .

Or, it can be interpreted as follows (Figure 6.3):

$$S_{d,max} < 0.53 + 0.47\, S_{d,min} < 1.0$$

$$S_{d,max} = \sigma_{cd,max} / f_{cd,fat}$$

$S_{d,min} = \sigma_{cd,min} / f_{cd,fat}$

$f_{cd,fat} = \phi\, 0.75\, f_c'$,

where $\sigma_{cd,max}$ and $\sigma_{cd,min}$ are the maximum and minimum numerical fatigue stress, respectively, and $f_{cd,fat}$ is the concrete fatigue design reference strength. A material strength reduction factor ϕ is not proposed. Fatigue failure of concrete is announced by cracking of the concrete. However, ultimately it is a brittle concrete failure, so that the strength reduction factor ϕ should be somewhere between 0.7 and 0.75.

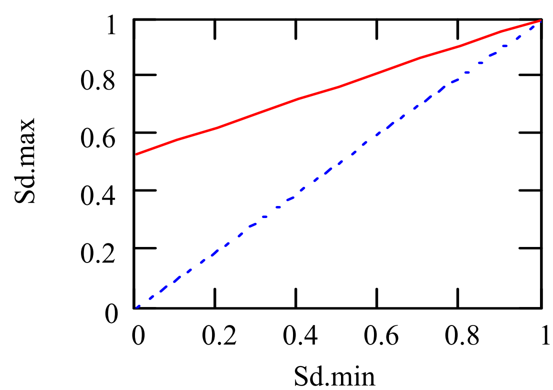


Figure 6.3. Goodman diagram for concrete according to ACI

ACI does not provide an SN curve type description of the fatigue life of concrete, which would relate the fatigue strength of the concrete to the stress range as well as the number of load cycles (Wöhler curves). A fatigue design beyond 10 million load cycles is, therefore, not covered by ACI, and the accumulative damage hypothesis by Miner to design for more complex load histories cannot be applied. However, concrete fatigue failure in compression at stresses below $0.4 f_c'$ is considered unlikely.

Mild steel reinforcement and prestressed steel reach an endurance limit at about 1 million load cycles. ACI provides some SN curves for mild reinforcement and prestressing steel summarized from different references but bases their design recommendations for concrete beams on the fatigue endurance of the steel. For nonprestressed members, ACI recommends to use a Goodman diagram to define the fatigue stress limitation in straight mild steel reinforcement (Figure 6.4):

$\Delta\sigma_{Rs} = 161 - 0.33\ \sigma_{s,min} \geq 138$ MPa in MPa

($\Delta\sigma_{Rs} = 23.4 - 0.33\ \sigma_{s,min} \geq 20$ ksi in ksi) ,

where $\Delta\sigma_{Rs}$ is the ultimate stress range and $\sigma_{s,min}$ is the minimum numerical stress. $\sigma_{s,min}$ is negative if the bar is in compression and positive if the bar is in tension. $\Delta\sigma_{Rs}$ needs not to be taken less than 138 MPa (20 ksi). For bent bars or bars to which auxiliary reinforcement has been tack welded, the stress range computed from the above equation should be reduced by 50%. ACI does not propose a material strength reduction factor ϕ for fatigue design.

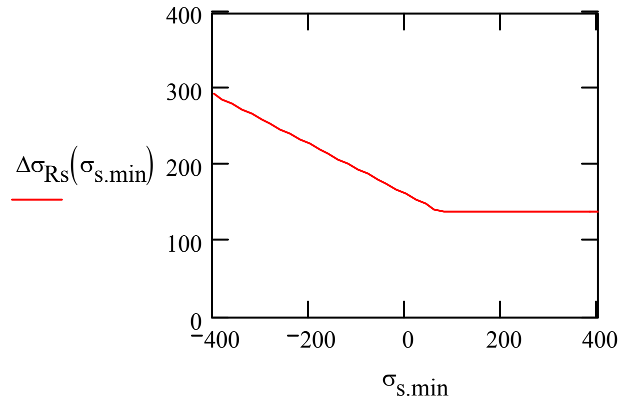


Figure 6.4. Stress range versus minimum reinforcement steel stress according to ACI

For the fatigue behavior of prestressing steel, ACI cautions to apply SN curves from strands tested in air to be applied to strands embedded in concrete, because the embedded strands encounter a variety of effects that are not subject to those tests. Such effects include cyclic creep, differential shrinkage effects, and localized stresses in vicinity of concrete cracks, which all typically increase the stress range over time, and fretting fatigue.

ACI recommends the following criteria to be used for the fatigue design of beams with prestressed reinforcement:

> The stress range in prestressed reinforcement that may be imposed on minimum stress levels up to 60% of the tensile strength shall not exceed 0.06 f_{pu} based on cracked section analysis if the nominal tensile stress in the precompressed tensile zone exceeds 3 $\sqrt{f_c'}$ psi under a realistic estimate of service loadings. f_{pu} is the ultimate strength of the prestressing steel.

ACI has some additional recommendations on anchorages and couplers of unbonded prestressing tendons and on deflected tendons to address fretting fatigue.

6.5 Comparing Fatigue Design Approaches

The MC90 is the only document of the considered design guides that fully covers the fatigue design of concrete, mild, and prestressing steel at high loading cycle numbers. It is, thus, the recommended approach for fatigue design of the concrete wind turbine tower. The Norwegian code lacks fatigue design recommendations for prestressing steel, and the German standard and the ACI recommendation do not explicitly cover the fatigue design of concrete for loading histories beyond 10^7 cycles.

All considered documents typically relate the fatigue strength of steel to SN curves, which makes the design life a function of the stress range independent of the stress level of the load. Only the recommendation by ACI makes the fatigue life dependent on the stress level as well. Because the stress range of the mild and prestressing steel in the wind turbine tower is relatively small, fatigue of the steel is apparently not a critical design parameter even for coupled or welded reinforcement steel (Figure 6.5).

The fatigue lifetime of concrete is typically formulated as a function of minimum and maximum stress level that results from the fatigue load. This complicates the damage accumulation analysis for superposed load cases, because the load history has to be converted into a spectrum of two rather than just one stress value over frequency. The concrete fatigue life can be plotted as a series of SN curves for given stress levels or as a series of Goodman graphs for given lifetime expectations.

Such a Goodman diagram is plotted in Figure 6.6 for all considered design approaches. The graph plots the maximum allowable design stress as a function of the minimum numerical design stress as a ratio of the characteristic concrete strength f_{ck} or $f'c$, where f_{ck} is 48 MPa (7 ksi). Where the design approach allowed, graphs were plotted for a series of applicable design lifetimes.

Comparing graphs for a design lifetime between $N = 10^6$ and 10^8, all curves except those of MC90 are fairly linear from around 0.3 f_{ck} at zero minimum stress to 0.5 f_{ck} at zero stress range. The curve according to MC90 seems more conservative and flattens considerably for smaller stress ranges compared to the other design approaches. For longer design lifetimes, the curves are slightly lower.

In the wind turbine tower application, the concrete stress range is relatively small compared to the design stress level. The numerical values for the concrete stresses are, therefore, close to the $f_{min} = f_{max}$ curve. If the numerical stress range is smaller than 20% of the maximum design stress, as they are in the design examples developed for the towers considered in this report, then the maximum design stress could be up to 33% of f_{ck} and still achieve a design life of 10^{10} even with the most conservative design approach by MC90.

The criteria used for design of the prestressed concrete towers requires prestressing force sufficient to result in a “zero tension in the concrete” criteria under the 35 m/s (78 mph) unfactored extreme operational wind loading condition EOG50 or the unfactored extreme nonoperational condition EWM50 (whichever controls). Although these loading conditions result in a very low stress change in the post-tensioning tendons at the operational loading level, fatigue loading of the basic tower cross section is still a controlling parameter for the prestressed concrete tower designs for the 3.6- and 5.0-MW towers designed for wind as the controlling ultimate load condition.

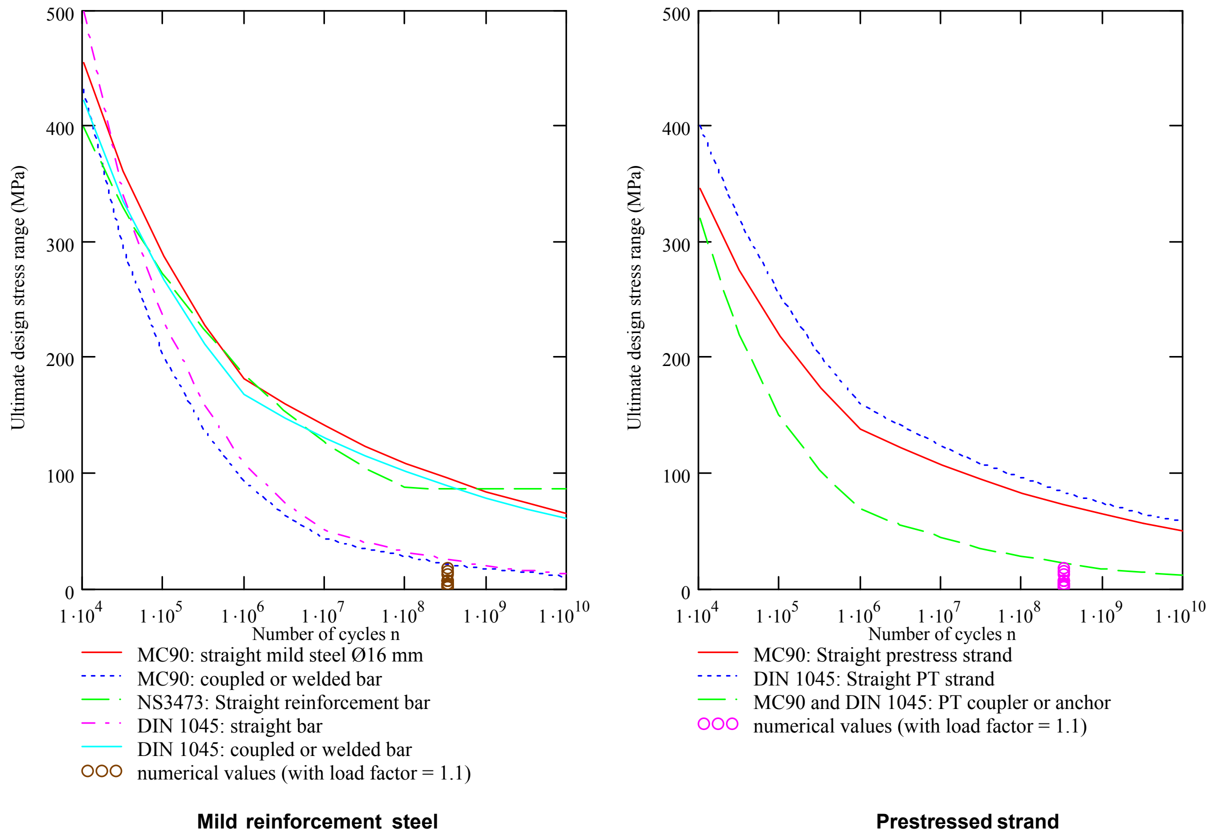


Figure 6.5. SN curves for mild reinforcement steel and prestressed strands

6.6 Fatigue Considerations for Concrete Connections

The general approach to fatigue design of concrete connections for the towers considered here has been to minimize connections that do not emulate cast-in-place concrete. Other than at the tower top post-tensioning anchor plate, tension is carried in high-strength, post-tensioning strand and compression is carried in high-strength, high-quality concrete. Mild reinforcing is used only for local temperature and shrinkage effects and is not relied on to resist major design loads and fatigue loading.

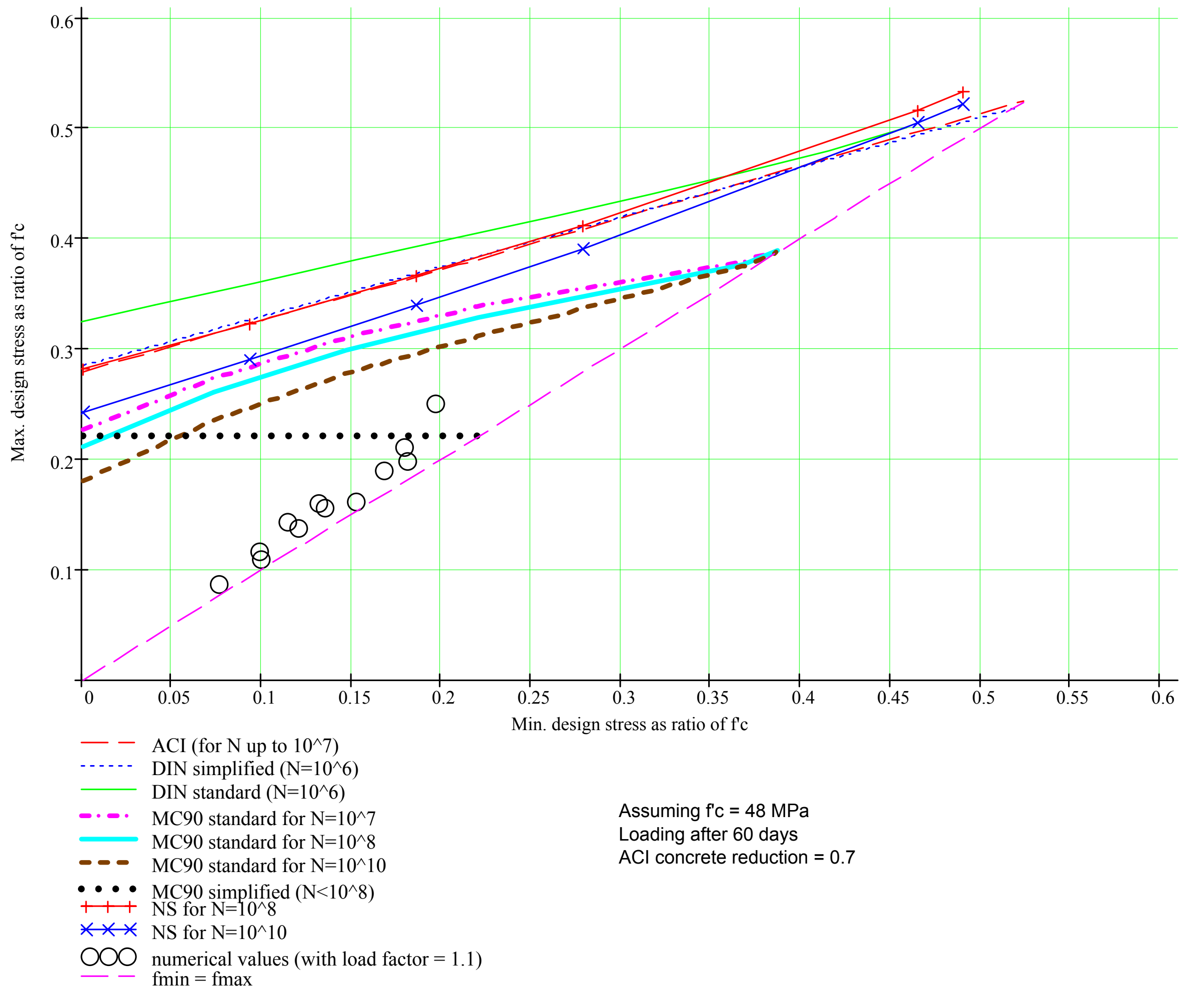


Figure 6.6. Maximum versus minimum fatigue design stresses in concrete in compression according to different codes (Goodman diagram)

6.7 Stress Discontinuities in Concrete

The primary concern for stress discontinuities in the tower structure concrete are at the top post-tensioning anchor plate and at the access door opening at the base of the tower.

6.7.1 Tower Top Post-Tensioning Anchor Plate

In the hybrid steel/concrete towers, and to a lesser extent in the all-concrete towers, there are significant shears, axial loads, and moments transferred from the steel tower or the steel turbine to the tower transition section to the top of the concrete tower through the connection between the steel and concrete towers at this location. (See Figure 6.7.) A number of design approaches were considered for this connection. The approach selected and shown in Figure 6.6 and in the Appendix D drawings is the use of a heavy stiffened steel ring that is stiff enough to avoid local high concentrations of load on the concrete as result of the transfer of bending moments between the steel and the concrete towers.

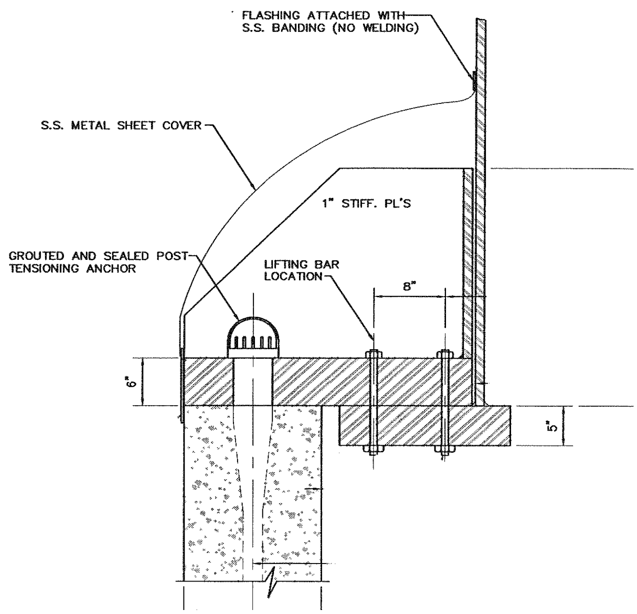


Figure 6.7. Concrete tower to steel tower connection for a steel/concrete hybrid tower

This ring will be fabricated to match the bottom support flange on the steel tower. It is shown fabricated in three sections and bolted together at the site. The ring is machined flat on the underside after the stiffeners are welded in place and the sections bolted together. It is then disassembled for shipment and reassembled at the site before it is lifted into place. The ring is held in place atop the concrete tower by the axial load from the tower post-tensioning anchors that seat directly against its top surface. The bolted connection between the steel flange on the base of the steel tower and the tower top post-tensioning anchor plate uses high-strength bolts that react the applied axial loads and bending moments in bolt tension and the applied shears as a friction connection. Enough bolts are used to minimize the fatigue load cyclic stress in the bolts.

After completion, this entire assembly is coated with corrosion protective coatings and covered with a watertight flashing to protect it from the elements.

6.7.1.1 Access Door Opening

The access door opening in the base of the tower represents a discontinuity in the concrete structure. Post-tensioning tendons will be curved to allow space for the opening. At some distance above the door the effect of the discontinuity will dissipate. The detail design of the opening must be further addressed in a final design of the tower. The principles that the detail design should address follow:

- Deviate the post-tensioning tendons around the opening and design for the effects of the deviation. This includes providing adequate reinforcing to resist the splitting force that will result at the location where the post-tensioning tendons are deviated.

- Include replacement axial load capacity to make up for the concrete missing from the opening. This can be handled either by the combination of a heavy structural door frame and supplemental reinforcing steel or by thickening the concrete in the region adjacent to the door.

- Provide adequate material either in the door frame or as thickened reinforced concrete to resist the radial compression forces that will result from the opposing curvature of the post-tensioning tendons as they are straightened before anchoring them in the foundation.

6.8 Grouted Joints between Tower Elements

Grouted joints are used to ensure full mating of precast elements to one another and to accommodate the casting and erection tolerances associated with the production and erection of the precast elements.

6.8.1 Precast Option

For the precast concrete towers, there are three primary locations of potential stress discontinuities in the concrete structure: at the top of the tower, where the post-tensioning tendons are anchored; at the bottom of the tower, where the precast elements are supported on the top of the footing, and at each of the horizontal joints between the precast segments.

The horizontal joints at the tower base and the typical joints up to the top joint are handled in the same manner with an approach that involves erection shims to align and level each segment as it is installed and high-quality grout that is pumped into the joint clearance space to ensure 100% contact between the precast element surfaces. (See joint grouting details in Appendix D.) The grout is allowed to cure and gain strength for 12–16 hours, and then the temporary prestressing bars used for erection are tensioned, putting the grout into compression. When the tower concrete erection is completed, the overall tower final post-tensioning adds to this initial compression in the grout. The grout then remains under compression for all but the most extreme loads applied to the tower. In these instances, a portion of the grout in the horizontal connections may become unloaded to zero compression for the short duration of the extreme load.

The seating of the post-tensioning anchor plate at the top of the tower is handled in the same manner as the typical horizontal joints, except that a higher quality machine grout will be used to interface the heavy steel anchor plate with the concrete section that supports it.

This approach ensures that any discontinuities at joints in the concrete are minimized to levels that have an insignificant effect on the local stresses in the concrete.

6.8.2 Cast-in-Place Option

For the cast-in-place concrete towers, there are two locations of potential stress discontinuities in the concrete structure: at the top of the tower, where the post-tensioning tendons are anchored, and at the bottom of the tower, where the tower structure is supported on the top of the footing. The cold joints between cast-in-place concrete placements are of less concern than the horizontal joints in the precast approach because of the self-tolerance adjusting nature of carefully constructed concrete cold joints.

The joint between the footing top and the tower concrete structure is specially inspected to ensure that the footing top concrete is sound and that reinforcing and post-tensioning ducts that extend from the footing and into the tower concrete are properly positioned. An important focus for the cast-in-place work is to ensure a sound interface between concrete placements at this location.

Cold joints between cast-in-place concrete segments are inspected to ensure that the concrete interface being cast against is sound and free of debris. Additional preparation of this joint is not required.

The top of tower interface with the post-tensioning anchor plate is handled in the same manner as for the precast option, except that special attention will be given to ensuring that the top surface of the last cast-in-place concrete segment is level and at the proper elevation.

6.9 Concrete Post-Tensioning Tendon Anchors

Two configurations for the post-tensioning tendons are considered. One configuration termed the "internal tendon" configuration has the post-tensioning tendons located within the concrete section. As the concrete is cast, hollow ducts are included in the casting. At the conclusion of the concrete construction (whether precast or cast-in-place), high-strength steel strands are threaded through the ducts and then post-tensioned. With internal tendons, the tendons are usually grouted for corrosion protection and to make the tendons integral with the concrete surrounding them. With this configuration, the post-tensioning anchors carry only the initial tensioning load. After curing the tendon grout, any changes in stress resulting from cyclic loads on the tower are transferred directly to the tendons through bond of the tendon grout from the surrounding concrete to which the tendons are bonded. Thus, fatigue loading of the tendon anchors with bonded internal tendons is usually not an issue of concern. Although the local steel stress in bonded tendons at the crack locations that can develop under extreme loads will be somewhat higher than in the external tendon approach, this may not to be a significant problem for the internal tendon design.

The second configuration considered for the post-tensioning tendons is termed the "external tendon" configuration. In this configuration, the post-tensioning tendons are located outside the concrete section immediately adjacent to the inside diameter of the concrete cross section. These tendons are enclosed in a plastic sheath that is pumped completely full of a corrosion-inhibiting, grease-like material. In this configuration, the tendons are anchored only at the top of the concrete tower and at the foundation. The tendons are not bonded to the tower concrete as in the internal tendon configuration. The result of this approach is that the tendon anchors carry both the initial tensioning load and any changes in load that result from cyclic loads on the tower. Thus, these anchors are subject to fatigue loading. However, because the service level cyclic stress levels in the post-tensioning tendons are small, it is unlikely that fatigue of the post-tensioning anchors will be a design issue. This will be further investigated in final design.

The external tendon design allows the strain associated with loading of the tower after the stressing of the post-tensioning strands to be accommodated within the entire length of the post-tensioning strands (approximately 100 m). The resulting stress change associated with this strain in the post-tensioning steel is thus very small. Under fatigue loads, the superimposed stresses in the post-tensioning tendons are very low.

In this situation, in which the design allows concrete cracking at the extreme load, with external tendons it is possible to develop fewer (potentially one) larger width flexural cracks in the concrete section rather than many smaller width distributed cracks, as is the case with internal bonded tendons. Any concrete cracks from a previous extreme load event do not open at service level loading as result of the pre-compression of the concrete from the post-tensioning force.

Either the internal or the external tendon prestressing method can result in a successful tower design. In a severe overload (above the extreme design load) the performance of a tower with internal bonded tendons is judged to be somewhat more predictable than one with external tendons.

If it is desired to reduce the cyclic load on the post-tensioning anchors for the unbonded external tendons, the likely solution would be to grout the portion of the tendon located within the foundation and make the top section or two of the concrete tower with internal tendon ducts and grout the top 3–6 m (10–20 ft) of the tendons. This would greatly reduce any cyclic loads applied to the tendon anchors.

Currently, for a 20- to 30-year design life, conventional post-tensioning systems are being considered. If an enhanced corrosion protection of the prestressing tendons associated with a significant extension in design life were wanted, one may consider the emerging technology of double encapsulated, electrically isolated post-tensioning tendons. This technology, originally developed for high-strength ground anchor systems, is now being applied to provide enhanced tendon corrosion resistance for post-tensioned concrete structures subject to exposure in very harsh and corrosive environments and for structures in which a greatly extended lifetime is desired.

6.10 Fatigue Results for Concrete Tower Designs

Figures 6.8–6.10 show the fatigue stresses in the concrete towers plotted on the concrete SN curves developed from MC90 [1]. The concrete fatigue strength of each tower is shown on the SN curve as the envelope between the plots of $S_{cd,min}$ for the towers. $S_{cd,min}$ is the minimum concrete stress as a result of fatigue loading of the tower section divided by the fatigue reference design stress that is constant for the *f'c* 48 MPa (7,000 psi) concrete used in the design. The stress resulting from the various levels of WindPACT fatigue loading from the data given in Appendix J are plotted for the mid height of the concrete tower, the base of the concrete tower, and the base of the hybrid tower. In every instance, the fatigue stress ranges fall below the applicable curves. This indicates that the tower concrete fatigue strength exceeds that required for the tower designs developed in this study.

The fatigue of the post-tensioning tendons and the tendon anchorages is shown in Figure 6.5 as defined by the different codes and in Figure 9.1 as defined by Euro Code 3, as outlined in [12] and [1].

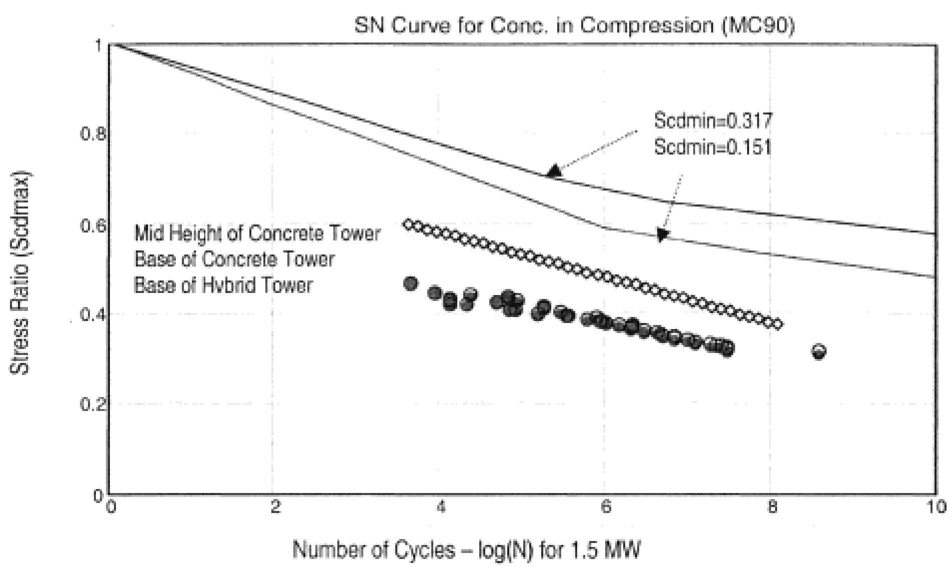


Figure 6.8. SN curve for 1.5-MW concrete tower

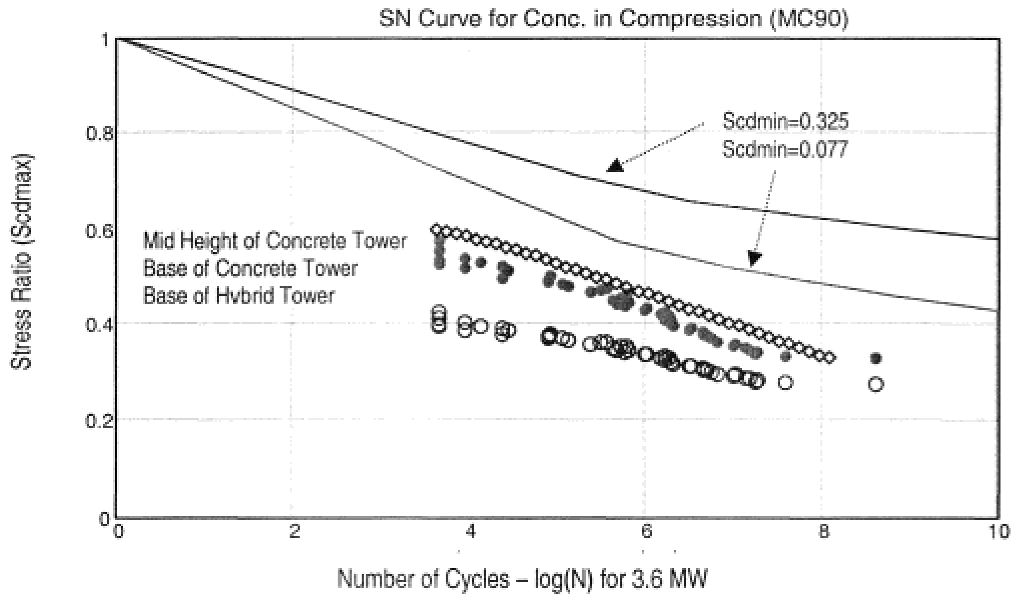


Figure 6.9. SN curve for 3.6-MW concrete tower

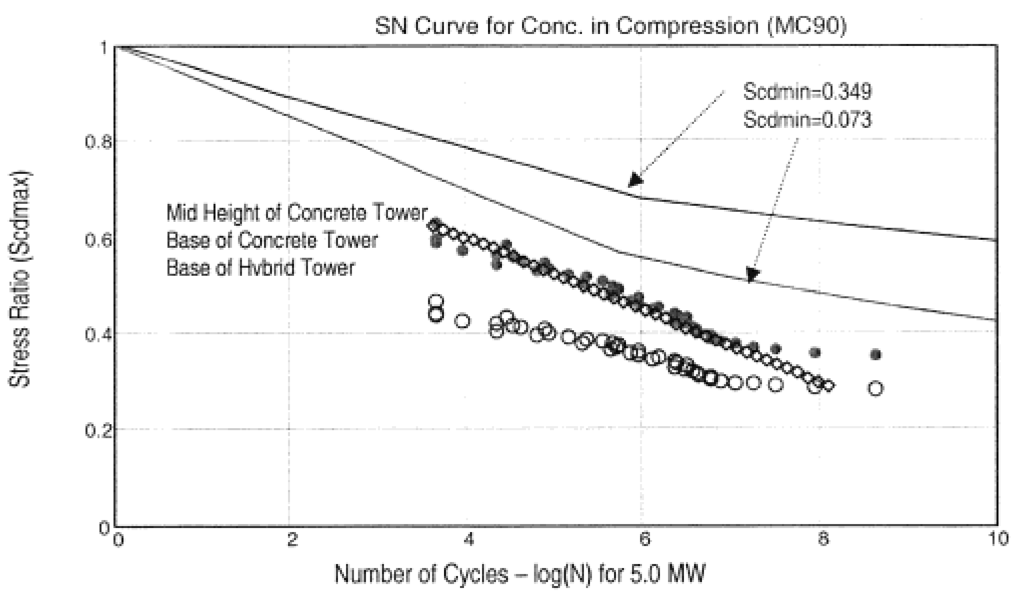


Figure 6.10. SN curve for 5.0-MW concrete tower

To estimate the fatigue life for a spectrum of fatigue loads, the Palmgren-Miner summation may be applied. Fatigue failure can be avoided if the fatigue index D is less than or equal to 1.

$$D = \Sigma(n/N)$$

where n is the number of fatigue cycles applied
N is the number of fatigue cycles to failure

Table 6.2 shows that the fatigue index for the tower designs developed here are all less than unity as required for both the concrete material and the post tensioning tendon material.

Table 6.2. Fatigue Index *Σ(n/N)* for Prestressed Concrete Towers

	Concrete Fatigue Index			Post-tension Tendon Fatigue Index		
	Conc Base	**Mid Height**	**Hybr Base**	**Conc Base**	**Mid Height**	**Hybr Base**
1.5 MW	1.839E-7	9.884E-3	6.145E-8	2.426E-11	9.451E-9	6.497E-12
3.6 MW	0.016	0.099	1.731E-8	1.863E-7	4.073E-7	1.112E-11
5.0 MW	0.139	0.886	3.554E-6	1.791E-6	2.868E-5	6.946E-10

Fatigue Index $\Sigma(n/N)$ for accumulated damage shall be less than unity according to Miner's rule.

7.0 Foundation Design

The design of wind turbine foundations is largely driven by the tower base overturning moment under the extreme load conditions and by local geotechnical conditions. Because of the dependence on local site-specific soil conditions, we have not attempted to optimize the generic foundation designs presented here. Usually, the reinforced concrete spread footing is a simple and economical solution for the tower and is thus widely used. Spread footings are typically applied at normal site conditions with good soil bearing capacity. Pile foundations, drilled shafts, caissons, or other types of foundation are typically used for weak soil and unusual site conditions, such as limited space, sloped terrain, and off-shore sites. Special foundation structures may apply for foundation design. For typical on-shore soils, the dynamic impact and fatigue life of foundation design considering the dynamic load spectrum are normally not governing design parameters. Rectangular and hexagonal concrete spread footings were analyzed and designed for the wind turbine tower.

7.1 Spread Footing Design

The overturning moment applied to a spread footing is resisted by an eccentric reaction to the weight of the turbine, tower, foundation, and overburden surcharge. Therefore, the dimensions of spread footings are determined by soil bearing capacity and extreme load conditions. The spread footing should be designed to meet the stability and strength requirement for shear and flexural loads. Tie-down rock anchors or micropiles may be applied to reduce the size of the spread footing. For this study, we have assumed a competent soil that has 6,000 psf f_{so} (29,300 kg/m^2) bearing capacity and safety factor γ_{eq} of two for earthquake load. 4,000 psi *fc'* (28 MPa) normal strength of concrete is used for the spread footing. The rectangular spread footings, subjected to eccentric load, have three design load cases (see Figure 7.1).

The soil contact area A_f is equal to the length of the footing *L* multiplied by the width of the footing *S*. The moment of inertia of area *I* is $SL^3/12$, and *c* is the distance toward the footing edge. For the maximum soil bearing stress at the edge of the footing, *c* is equal to half of the footing length. The eccentricity of load on the spread footing ($e = M/P$) is defined as the ratio of the overturning moment *M* to the tower axial load *P*, and shall be inside the footing perimeter ($<L/2$) to ensure the stability of the footing. If the eccentricity is within the compression kern ($<L/6$), the soil bearing stresses under the footing will be in compression. Otherwise (as shown in Case 3), the maximum soil stress can be expressed

$$P_{max} = \frac{2 \cdot P}{3 \cdot S \cdot (\frac{L}{2} - e)} \quad .$$

The maximum soil bearing stress P_{max} must be less than the soil-bearing capacity f_{so} for the service design wind load. The short-term soil bearing capacity can usually be increased by the safety factor γ_{eq} for the earthquake load. The depth *D* of the spread footing is determined by the concrete shear strength of the footing and the depth required to resist the applied shear. According to the soil stress distribution shown above, calculate the ultimate shear force V_u with load factor at the location 1.0 depth of the footing away from the tower base perimeter. The footing shall meet the shear strength requirement as follows:

$$V_u \leq \phi \cdot 2\sqrt{f'c}S \cdot D \quad ,$$

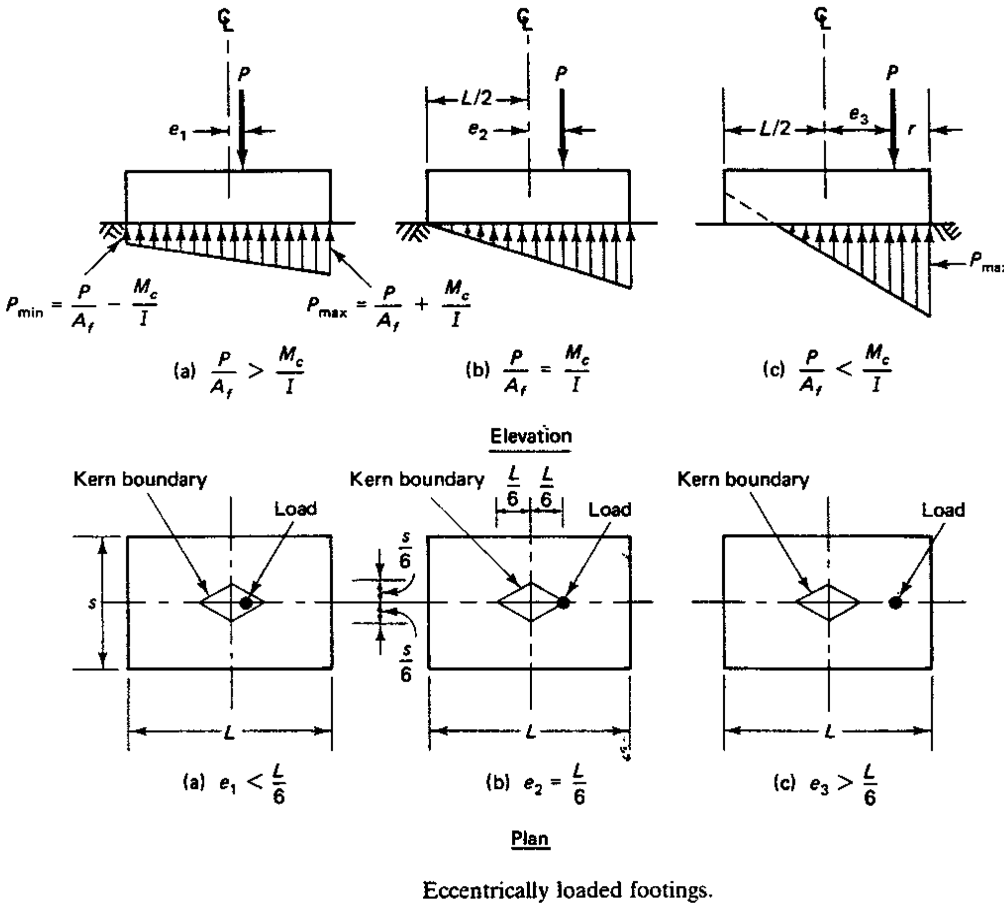


Figure 7.1. Footing design loading cases

where $f'c$ = the design compressive strength of the concrete and the material reduction factor ϕ is 0.85. The thickness of the concrete cover shall be subtracted for the depth D. The required reinforcement ratio ρ_s of the spread footing can be determined by

$$\rho_S = \frac{\phi \cdot fc'}{fy}\left(1 - \sqrt{1 - \frac{2 \cdot Mu}{\phi \cdot fc' \cdot S \cdot D^2}}\right) ,$$

where fy is the yielding stress of the reinforcement, typically 60 ksi. The ultimate moment Mu is calculated at the face of the tower according to bearing stress distribution. The minimum reinforcement ratio ρ_s shall be 0.0018.

7.2 Multi-Equilateral Spread Footing Design

For circular towers, wind load can be applied from any direction and multi-equilateral footings such as those of hexagonal, octagonal, or even circular shape are more economical to use. The multi-equilateral shape is typically easier to form than the circular shape during concrete construction. The area of the footing *Af* can be described as

$$Af = a^2\ n\ /4\ tan(\alpha)\ ,$$

where the *a* and α are the lateral length and angle (see Figure 7.2) and *n* is the number of equilateral sides for a hexagonal shape *(n=6)*. The outer *(ρ1)* and inner *(ρ2)* radius are

$$\rho 1\ = a\ /\ 2\ sin(\alpha)$$
$$\rho 2\ = a\ /\ 2\ tan(\alpha)\ .$$

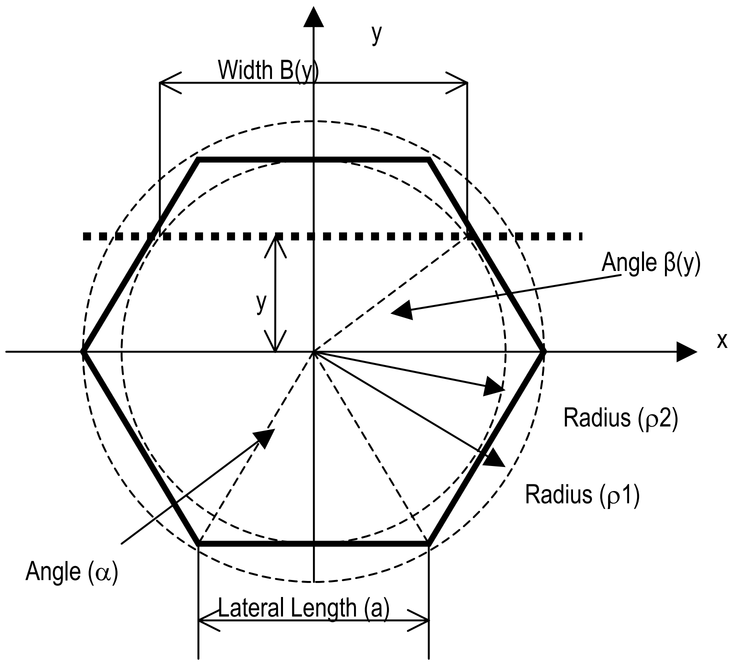


Figure 7.2. Hexagonal foundation

For a hexagonal shape, the cut-off width *B(y)* is the function of the distance from center *y*. The angle *β(y)* and *B(y)* are accordingly calculated as

$$\beta(h) = a\tan\left(\frac{y}{\rho 1 - \dfrac{|y|}{\tan(2\alpha)}}\right)$$

$$B(y)\ = 2\ y\ /tan(\beta(y))\ .$$

The moment of inertia *If* of the footing about *x-x* direction can be simplified as:

$$If = Af\ (6\ \rho 1^2 - a^2)/24\ .$$

The maximum soil pressure *Pmax* can be evaluated by the applied axial load *Pf* and bending moment *Ms* assuming no tension stress of soil occurs (*Pmin>0*):

$Pmax = Pf / Af + Ms\ \rho 1 / If$
$Pmin = Pf / Af + Ms\ \rho 1 / If$.

If the analysis indicates tension stress of the soil exists or minimum stress of the soil (*pmin*<0) mathematically, zero stress should be applied for the tension zone of the footing. The soil pressure for given cut-off line at the distance of *z* can be expressed as the function of any line *y* along the y-axis:

$$p(y,z,pt\,max) = \begin{cases} \dfrac{P\,max - P\,min}{2\rho 2}(y-\rho 2) + P\,min & if \quad P\,min > 0 \\ \dfrac{pt\,max(z-y)}{z+\rho 2} & otherwise \end{cases},$$

where the *ptmax* is the maximum soil stress with zero stress in the tension zone and can be calculated by combining the vertical and moment equilibrium equations:

$$Pf = \int_{-\rho 2}^{z} p(y,z,pt\,max)B(y)dy$$

$$Ms = -\int_{-\rho 2}^{z} p(y,z,pt\,max)B(y)ydy \quad .$$

The design moment and shear of the hexagonal-shaped footing can be easily calculated accordingly. The results show that the square type of footing is less conservative than the hexagonal shape of footing for the same volume of concrete in the spread footing.

We are aware that, for specific geotechnical conditions, solutions other than traditional spread footing foundations have proven to be economical for the overturning controlled wind turbine tower foundation requirement.

For example, the use of a Henderson-type foundation or other special foundation systems is not precluded. The foundation type selection largely depends on site and soil conditions. For silt and soft soil with bearing capacity in the lower range, a large drilled shaft with caisson (Henderson type) and pile group foundations are likely good solutions. For high-bearing capacity soils and rock, a spread footing is usually appropriate. This can be even more economical if spread footing concepts are combining with rock anchors to provide uplift-tension capacity.

The foundations for the large towers considered here will be very large. Thus, the required size of a single caisson-type foundation may be too large to be drilled with a single large drill.

Because the foundations are costly, it will make good economic sense to use the most economical approach consistent with the local geotechnical conditions. Because this study is not site specific, no attempt has been made to fine tune the foundations. The foundation sizes developed here are similar in size to those in the WindPACT Technical Area 4 - Balance of Station study.

8.0 Transition Detail Design between Steel Tower and Concrete Tower

The design of the transition detail between the steel tower and the concrete tower for the hybrid tower design was discussed initially in Section 6. It was determined that with regard to the tower design this connection and the connection from the tower to the turbine structure are the two places where close-tolerance, bolted connections should be used.

This connection is shown for the 1.5-MW turbine on Drawings D-28–D-30 and D-37 in Appendix D. The concept developed for the 1.5-MW turbine is scalable for the larger turbine sizes. The constraints on this connection are that it must handle the extreme load and fatigue load conditions, and it must be able to be efficiently constructed 50 m off the ground without large equipment that is not needed for other aspects of the tower construction.

After a number of alternatives were considered, the conventional and proven bolted flange connection to the steel tower structure was chosen. This connection is now used to connect tubular steel towers to embedded anchor bolts in the foundation. A heavy stiffened steel ring was selected to transfer axial loads, shears, and moments from the steel tower to the top of the concrete tower structure. This ring is made sufficiently stiff so that applied bending moments do not cause high local loads in the concrete section at the top of the concrete tower.

The load-transfer ring is also used as the top anchor plate for all the tower post-tensioning tendons. This adds structural redundancy to the post-tensioning system and provides a single element that can be carefully fabricated in a shop environment to meet the close tolerance requirements of this connection. It is envisioned that the tower top post-tensioning anchor ring and the steel tower bottom flange plate will be fabricated together and that one will be used as the drilling template for the other. This will provide certainty in the compatibility of the tolerances between these two elements.

The tower top post-tensioning anchor plate is fabricated in three sections that are bolted together at the site. After the stiffeners are welded to this plate, the plate sections are bolted together and the bottom face is machined flat. The plates are then disassembled for shipment to the site and reassembled at the site before being hoisted to the tower top for installation.

At the fabrication facility, a mating tower base flange is fabricated for each tower top ring. For the larger tower sizes, this ring will be fabricated in sections and welded to the base steel tower segment at the site. The tower top post-tensioning anchor plate will be used as a positioning template for welding the tower base flange plate and ensuring that the top surface of the flange plate remains flat and within tolerance after the welding process is completed. (See Drawing D-27, Appendix D.)

At their lower end, the tower jack-up strand tendons terminate in pintel-like guide elements that align with guide holes in the tower top post-tensioning anchor plates. (See Drawing D-36, Appendix D.) When these pintels are engaged in the guide holes, the connection bolt holes will all line up within tolerance to allow the installation to the connection bolts without the requirement to ream the holes in place.

The connection is designed to react the axial loads and bending moments from the steel tower as tension in the connection bolts and shear is carried across the connection as a friction connection. The number of bolts and the bolt size are selected to keep the fatigue stress range in the bolts to an acceptable level.

9.0 Steel Tubular Tower Design Considerations

The most common tower type currently in use for wind turbines is the cantilever steel tube. Typical tubular steel towers are built as tapered cylindrical tubes in which the diameter and wall thickness decrease from the base of the tower to the top. The typical tubular steel towers are assembled cost efficiently with prefabricated conical tubes shipped to the site from an off-site fabrication facility. The stiffness of both steel and concrete towers designed for similar loads allow each type to be designed for dynamic considerations as “soft” towers.

The dimensions and shapes of the steel towers depend primarily on maximum strength, stiffness, local buckling, and fatigue strength requirements. In this report, to compare steel tower costs with post-tensioned concrete tower solution costs, the steel towers for the larger wind turbine are also studied and designed to satisfy these requirements. The stiffness requirements for the steel tower to handle the turbine operational frequency requirements were discussed in Section 4.2.

9.1 Allowable Stress Design

The steel towers were initially sized to meet the AISC [13] strength design criteria. Allowable stress design method (ASD) is used as per AISC-89 for the steel tubular tower design. The load combination method for the service load (characteristic load) condition is suggested by ASCE-7-98 [9]. A 0.7 load factor is applied for the earthquake load accordingly. The allowable bending stress *Fb* for noncompact section is 0.6 *Fy*, where the yielding stress *Fy* of the steel tubular structure is typically 344 MPa (50 ksi). The allowable shear stress *Fv* is 0.4 *Fy*. The allowable compression stress *Fa* is determined by

$$Fa = \frac{\left[1 - \frac{(K \cdot L/r)^2}{2 \cdot Cc^2}\right] \cdot Fy}{\frac{5}{3} + \frac{3(K \cdot L/r)}{8 \cdot Cc} - \frac{(K \cdot L/r)^3}{8 \cdot Cc^3}} \quad ,$$

where the *KL/r* is the slenderness ratio of the steel tower, *K* = 2 for the cantilever type of structure, and *L* and *r* are the length of the tower and radius of section, respectively. The material coefficient *Cc* is calculated by

$$Cc = \sqrt{\frac{2 \cdot \pi^2 \cdot E}{Fy}} \quad ,$$

where the *E* is the steel modulus. When *KL/r* is greater than *Cc*, the allowable compression stress *Fa* should be recalculated by

$$Fa = \frac{12 \cdot \pi^2 \cdot E}{23 \cdot (K \cdot L/r)^2} \quad .$$

Typically, the ratio of the applied axial compression stress *fa* to the allowable compression stress *Fa* of the steel tower is less than 0.15. The combined stress for the applied bending stress *fb* acting on the steel tower shall be satisfied with interaction equation

$$\frac{fa}{Fa} + \frac{fb}{Fb} \le 1 \quad .$$

The applied shear stress *fv* from the torsion and the shear force on the tower shall also be less than the allowable shear stress *Fv*.

9.2 Fatigue Design Considerations for Tubular Steel Towers

In addition to the stiffness and strength requirements for the steel tower, the fatigue loading for the tower design is crucial because of the large number of cyclic repetitive loads that result from the wind turbine's routine operation. Fatigue loads will likely govern the steel tower design in most cases. Fatigue is a local material deterioration caused by repeated variations of stresses or strains. Low- and high-cycle fatigue may be distinguished. Low-cycle fatigue is associated with nonlinear material and geometric behavior and may be excluded from consideration in this instance. High-cycle fatigue is mainly governed by elastic behavior. Therefore, the analysis model can be elastic. Criteria are given to determine whether fatigue assessment is needed.

Except for cases where the fatigue strength of members is determined in specific tests with a load-time history close to the actual loading to which the members are subjected, the fatigue behavior of structural members is generally studied for regulatory code purposes by simplified tests. In these tests, the test specimens are typically subjected to constant amplitude load variations, until excessive deformations or fractures (which are caused by cracking) occur. This relationship may be modeled by a standardized linear, bilinear, or bilinear line in double logarithmic scale, so-called SN curves. When stress-time histories representative of the fatigue action on a given detail are available, any stress-time history may be evaluated with the reservoir-counting method or rain-flow counting method. These methods enable stress ranges and the corresponding numbers of cycles to be determined, together with the associated mean stresses when these are relevant. The stress ranges and the number of cycles may be ordered in stress-range frequency distributions or stress-range spectra.

The stress-range frequency distributions or stress–range spectra may be transformed to fatigue-damage-equivalent constant-amplitude stress-range spectra using Miner's rule, into DEL (as discussed in Section 3).

The safety verification for fatigue at the limit state equal to the total fatigue loading over the life of the tower may be carried out by:

- A damage calculation, where the damage caused by the fatigue actions is related to an ultimate damage representing the limit state

- A fatigue life verification, where, for a representative level of stress range, a damage equivalent number of load cycles caused by the fatigue action is related to an ultimate number of cycles that represent the limit state

- A stress range verification, where, for a representative number of stress cycles, the magnitude of the damage equivalent stress range caused by the fatigue action is related to an ultimate stress range resistance that represents the limit state.

In general, the design of a structure susceptible to fatigue should be such that it is damage tolerant. To be damage tolerant, the structure should be capable of sustaining all loads with sufficient reliability until any cracks that may form can be detected by regular inspections and appropriate remedial measures can be undertaken before structural failure occurs. For structures that can be verified to be damage tolerant, the safety factor on the fatigue resistance side of the equation may be taken as 1.0. For structures for which the damage tolerance cannot be verified, the safety factors have to be chosen such that they take account of the uncertainties in defining the fatigue actions, the fatigue action effects, and the fatigue resistances, and the possible decrease of resistances caused by corrosion or other time-dependent phenomena, with due regard for the consequences of a failure without prewarning.

For the welded base metal of tubular steel towers, the fatigue curve typically specified is Euro Code 3 Category 71 (EC3 Cat.71) [12]. Category 80 (1993)-(EC3 Cat.80) is used as a common fatigue strength for details in wind turbine tower design. These curves can be combined with the histogram of predicted stress cycles to determine the fatigue damage that will occur during the design lifetime.

If the full histogram of fatigue cycles is not available, only the DEL may be specified. This DEL will be accompanied by a value of the SN curve slope (steel tower designs typically use m = 4) and a number of cycles *Ne* at 2 x 10^6 that has the associated stress range $\Delta\sigma_r$ 80 MPa. (11.4 ksi). The allowable stress range at 5.29 x 10^8 cycles for 20 years fatigue design life can be accordingly calculated and compared with the fatigue stress produced by DEL.

9.2.1. Comparison of Material Fatigue Properties

The comparisons of applicable SN curves are shown in Figure 9.1. Post-tension (PT) tendons and steel anchors/couplers as plotted by Mode Code 90 [1] are also shown in the figure.

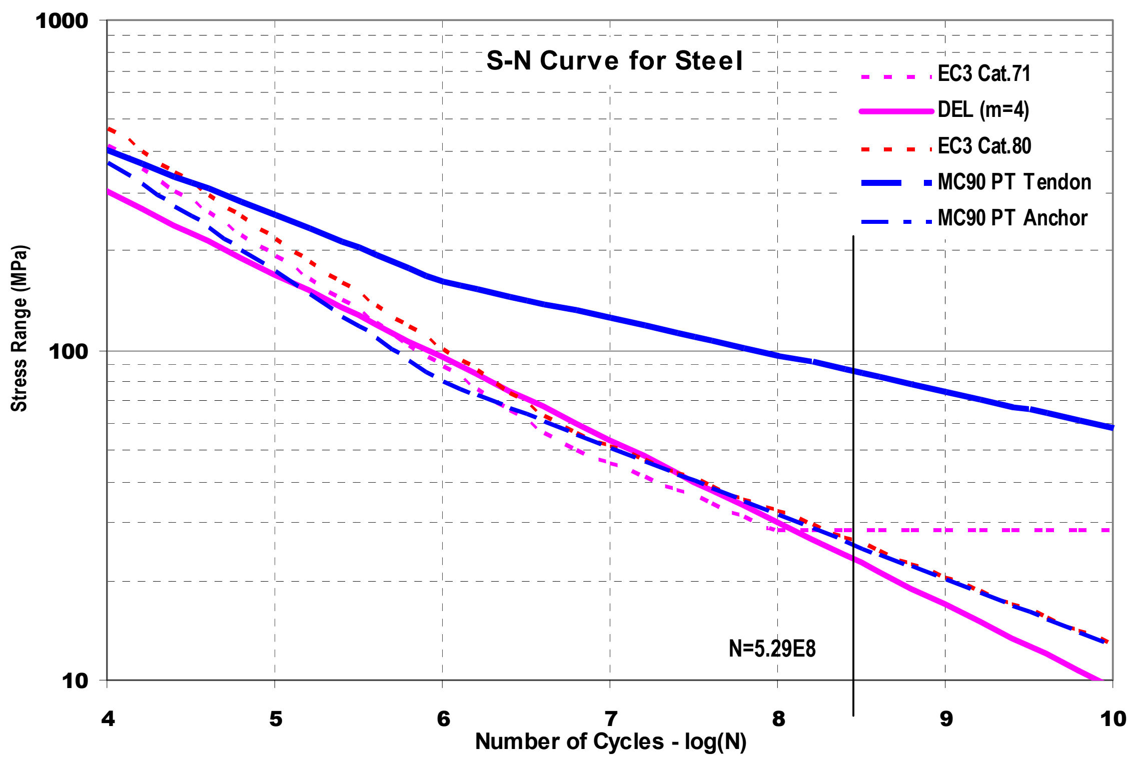


Figure 9.1. Comparison of SN curves for welded steel and post-tensioning material

The allowable fatigue stress ranges for the number of cycles in the design life of the tower (N = 5.29 x 10^8) are compared in Table 9.1.

Table 9.1. Allowable Fatigue Stress Range for Varying Numbers of Cycles

Stress Range	$\Delta\sigma_{sr}$ at N = 10E4		$\Delta\sigma_{sr}$ at N = 2x10E6		$\Delta\sigma_{sr}$ at N = 5.29x10E8	
	Mpa	ksi	Mpa	ksi	Mpa	ksi
EC3 Cat.71	414	60.05	70.79	10.27	28.65	4.155
DEL (m=4)	301	43.66	80.04	11.61	19.85	2.879
EC3 Cat.80	468	67.88	80.03	11.61	23.21	3.366
MC90 PT Tendon	401.9	58.29	148.1	21.49	79.71	11.56
MC90 PT Anchor	371.3	53.86	69.64	10.1	22.82	3.31

Table 9.1 shows that post-tensioning tendon strands have obviously a higher endurance limit for the same stress range than the steel welded structures. Thus, the post-tensioning tendons typically do not govern the fatigue design for the prestressed concrete towers considered here. The tendons should, however, be internal and grouted for a length near the post-tensioning anchors to lower stress at the anchor to ensure that the tendon stress at the anchor does not control the design. The SN curves for steel welded structures in Euro Code 3 Category 71 (EC3 Cat.71) can be constructed as

$$log[\Delta\sigma s(n)] = log(414\text{MPa}) + (10^4\text{-}n)/3 \qquad \text{for } 10^4 < n < 5 \text{ x } 10^6$$
$$log[\Delta\sigma s(n)] = log(52\text{MPa}) + (5 \text{ x } 10^6\text{-}n)/5 \qquad \text{for } 5 \text{ x } 10^6 < n < 10^8$$
$$\Delta\sigma s(n) = 29\text{MPa} \qquad \text{for } n > 10^8$$

The SN curve for Euro Code 3 Category 80 (1993) (EC3 Cat.80) used to evaluate tower details is obtained in similar way.

The DEL method is a simple and quick way to determine the steel tower preliminary dimensions in instances where fatigue load histogram data are not available. The SN curve for the DEL method can be expressed by

$$log[\Delta\sigma s(n)] = log(80\text{MPa}) + (2 \text{ x } 10^6\text{-}n)/m\ ,$$

where m, the slope ratio, here is equal to 4. The number of cycles corresponding to the endurance limit along the tower height z can be calculated by using DEL method:

$$N(z) = \left(\frac{Mf(z)}{\Delta\sigma_{r\max} S(z) \cdot \sqrt[m]{N_0}}\right)^{-m} ,$$

where
- $Mf(z)$ is the moment produced by the fatigue DEL thrust along the steel tower
- $S(z)$ is the section modulus that varies along the height of the tower
- $\Delta\sigma_{rmax}$ is the maximum allowable stress range at N_0 cycles (typically 10^4)
- m is the slope of the curve.

If the fatigue load spectrum is available, the fatigue index $\Sigma(n/N)$ can be calculated. The resulting index value must be calculated to be less than unity according to Miner's rule for fatigue design. The fatigue design index for different SN curves is shown in Table 9.2. A linear regression solution (Section 3) of the fatigue load spectrum at the tower base is also calculated for comparison. The fatigue design index determined by the DEL method are also included. The results show that the fatigue strength will govern the steel tower design.

Table 9.2. Fatigue Design Index *Σ(n/N)* for Steel Towers Computed by Indicated Methods

Wind Turbine Size		1.5 MW	3.6 MW	5.0 MW
Fatigue Load Spectrum Tower Base *Σ(n/N)*	EC3 Cat.71	0.579	0.971	0.548
	DEL (m=4)	0.414	0.603	0.548
	EC3 Cat.80	0.36	0.581	0.536
Fatigue Load Spectrum Linear regression Tower Base *Σ(n/N)*	EC3 Cat.71	0.4	0.571	0.632
	DEL (m=4)	0.308	0.396	0.438
	EC3 Cat.80	0.257	0.356	0.397
Fatigue Load Spectrum Linear interpolation Tower Mid Height *Σ(n/N)*	EC3 Cat.71	0.41	0.726	0.74
	DEL (m=4)	0.317	0.494	0.506
	EC3 Cat.80	0.263	0.454	0.464
Max Fatigue Index along Tower DEL for *(n/N)*	EC3 Cat.71	0.067	0.078	0.072
	DEL (m=4)	0.758	0.803	0.78
	EC3 Cat.80	0.323	0.348	0.335
Max Stress Ratio along Tower DEL for *Δσ/ΔσN* at 5.29E8	EC3 Cat.71	0.646	0.656	0.651
	DEL (m=4)	0.933	0.947	0.94
	EC3 Cat.80	0.798	0.81	0.804

9.3 Local Buckling Stress

There was some concern about the buckling stability of the thin plates at the larger diameters involved for the tubular steel towers considered in this study, so this issue was assessed specifically to determine whether local buckling was a controlling design parameter. The strength of the tubular steel tower in axial compression is the lesser of the yield strength and the elastic critical buckling stress σ_{cr} given by

$$\sigma_{cr} = 0.605\, E\, t/r \,,$$

where *r* is the cylinder radius and *t* is the wall thickness. However, the presence of imperfections, particularly those introduced by welding, will significantly reduce the tower wall resistance to buckling. According to [12], steel tower design, the reduction coefficient α_0 for axial load is introduced by

$$\alpha_0 = \begin{cases} \dfrac{0.83}{\sqrt{1+0.01\cdot r/t}} & if \quad r/t < 212 \\ \dfrac{0.70}{\sqrt{0.1+0.01\cdot r/t}} & if \quad r/t > 212 \end{cases} .$$

The reduction coefficient α_B for bending load is calculated as

$$\alpha_B = 0.1887 + 0.8113\ \alpha_0 \quad .$$

The buckling stress σ_u can be computed in terms of the yielding stress *Fy:*

$$\sigma_u = \begin{cases} Fy\left[1-0.4123\cdot(\dfrac{Fy}{\alpha_B\cdot\sigma_{cr}})^{0.6}\right] & if \quad \alpha_B\cdot\sigma_{cr} > Fy/2 \\ 0.75\cdot\alpha_B\cdot\sigma_{cr} \quad if \quad \alpha_B\cdot\sigma_{cr} < Fy/2 \end{cases} .$$

The maximum applied stress σ_a combined with normal stress and shear stress is calculated by

$$\sigma_a = \sqrt{(fa+fb)^2 + 3\cdot fv^2} \quad .$$

The demand and capacity ratios for 100-m steel towers for 1.5-, 3.6-, and 5.0-MW turbines are listed in the following table. Usually, wind load governs the design for the steel tower because the tower masses are relatively low compared to seismic load.

The unity ratio for combined stresses is defined as follows. Because the tower is subjected to combined stress with axial compression and bending moment, the steel tower is designed to satisfy the combined stress check. This check is called the unity check interaction equation according to the AISC manual (ASD 9th Edition).

$$\text{Unity} = fa/Fa + fb/Fb \le 1.0 \quad \text{for } fb < 0.15\ Fb \quad ,$$

where *fa* is the applied compression stress and *Fa* is the allowable stress; *fb* is the applied bending stress and *Fb* is the allowable bending stress as defined in Section 9.

Table 9.3. Demand Capacity Ratio (DCR) for 100-m Tapered Steel Tubular Towers

Wind Turbine Size	1.5 MW		3.6 MW		5.0 MW	
Load Condition	Wind Load	EQ Load	Wind Load	EQ Load	Wind Load	EQ Load
Strength Unity Ratio for Combined Stress(<1)	0.492	0.374	0.575	0.429	0.494	0.40
Stress Ratio ($\sigma a/\sigma u$)	0.370	0.279	0.449	0.324	0.379	0.304

9.4 Earthquake Design of Tubular Steel Towers

A check of earthquake design requirements for tubular steel towers against the seismic loading requirements outlined in Section 3.2 indicates that seismic loading does not govern the design of the tubular steel towers considered in this study.

9.5. Design Summaries for Tubular Steel Towers

The design summary for the steel towers developed in 344-MPa (50-ksi) yield strength steel for the different turbine sizes at 100-m hub height are given in Table 9.4. WindPACT Technical Area 2 Appendix A-5 uses a design stress of 272.7 MPa (39.5 ksi) for tower sizing. Industry sources indicate that current practice is to fabricate tubular steel towers from 344-MPa (50-ksi) yield strength steel.

Table 9.4. Design Results—All-steel Wind Turbine Towers
***Fy* = 344 MPa (50 ksi)**

100m Steel Wind Turbine Tower (50ksi)

	1.5MW		3.6MW		5.0MW	
Rotor Diameter	70.5 m	231.2 ft	108.4 m	355.6 ft	128 m	419.8 ft
Total Head Weight	84800 kg	187 kips	314912 kg	694 kips	480076 kg	1058 kips
Additional Weight at Transition Connection	1500 kg	3.3 kips	3600 kg	7.94 kips	5000 kg	11 kips
Steel Tower Mid Height	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft
Outside Diameter at Base for Steel Tower	5.791 m	228 in	7.62 m	300 in	8.839 m	348 in
Wall Thickness at Base for Steel Tower	0.0254 m	1 in	0.03175 m	1.25 in	0.03651 m	1.438 in
Outside Diameter at Mid Height of Steel Tower	4.267 m	168 in	5.639 m	222 in	6.706 m	264 in
Wall Thickness at Mid Height of Steel Tower	0.0254 m	1 in	0.03175 m	1.25 in	0.03492 m	1.375 in
Outside Diameter at Top of Steel Tower	2.896 m	114 in	3.962 m	156 in	4.572 m	180 in
Wall Thickness at Top of Steel Tower	0.009525 m	0.375 in	0.01905 m	0.75 in	0.02222 m	0.875 in
Spread Foot Width and Length	16.46 m	54 ft	18.29 m	60 ft	20.42 m	67 ft
Spread Foot Depth	3.048 m	10 ft	3.658 m	12 ft	3.658 m	12 ft
Steel Tower Weight	2296 kN	516.1 kips	4000 kN	899.2 kips	5282 kN	1188 kips
Footing Reinforcement Weight	23330 kg	51.44 kips	34570 kg	76.2 kips	43100 kg	95.02 kips
Defection at Top of Tower for EQ Load	1.005 m	3.296 ft	0.9011 m	2.956 ft	0.7356 m	2.413 ft
Defection at Top of Tower for Wind Load	0.9185 m	3.013 ft	0.9183 m	3.013 ft	0.6078 m	1.994 ft
Tower Natural Frequency (Hz) [Rayleigh-SAP]	0.4059	0.3669	0.3693	0.3341	0.3973	0.3605
Base Shear & Mom Comparison for EQ/Wind	0.638	0.714	0.789	0.715	1.447	0.925
Max. Stress DCR for Steel (Wind - EQ)	0.492	0.374	0.575	0.429	0.494	0.400
Max. Buckling DCR of Steel (Wind - EQ)	0.370	0.279	0.449	0.324	0.379	0.304
Soil Bearing Capacity DCR (Wind - EQ)	0.561	0.315	0.895	0.474	0.780	0.486
Footing Shear Capacity DCR (Wind - EQ)	0.243	0.172	0.235	0.160	0.267	0.207
Max. Fatigue DCR of Steel Tower	0.758		0.803		0.780	
Controlling Loading Case	STL Fatigue		STL Fatigue		STL Tower Fatigue	

10.0 Construction Methodology

10.1 Background

In this study, the construction methodology necessary to construct the 1.5-MW, 100-m (328-ft) hybrid steel/concrete wind turbine tower was developed in some detail to allow the various issues associated with this construction approach to be evaluated and conceptually priced. Preliminary drawings that describe the construction process are included in Appendix D. The construction process developed for the hybrid tower uses precast concrete segments to construct the lower concrete portion of the tower; conventional steel fabrication is used for the upper tubular steel section of the tower. The concrete and steel portions of the tower are configured to allow the precast segments to be erected with a pedestal crane mounted atop the steel tower before jack-up and a semi-self-erection, jack-up method to finalize the tower outfitted with the turbine and rotors at the 50-m height, thus avoiding the use of the very large crane needed to lift the nacelle to the 100-m (328-ft) level. The construction methods developed for the 1.5-MW hybrid tower were then applied to the 3.6- and 5.0-MW tower designs to determine their applicability to the larger tower sizes associated with the larger turbines.

The configuration of the concrete portion of the 1.5-MW hybrid tower was optimized for the steel tower jack-up operation by designing the precast concrete segments with a constant internal diameter from top to bottom. This allows the use of passive roller horizontal guide assemblies beneath the steel tower to stabilize it as it is being jacked up into final position. For the 1.5-MW tower, this approach results in acceptable tower dynamic characteristics and is feasible with only a minor material cost premium. For the larger turbine sizes and correspondingly larger tower diameters, the internal diameter of the concrete portion of the tower is made variable for reasons of dynamic tower properties and for economy of material. This necessitates the use of an active lower horizontal guide assembly during the steel tower jack-up process. We envision this to be a series of 8–12 roller-type units mounted on the ends of hydraulic actuators that are in turn mounted on the steel frame support structure that supports the steel tower during the jack-up process. A cost for the design and fabrication of this assembly is included in the pricing for the 3.6- and 5.0-MW hybrid towers.

The all-concrete tower designs were considered for construction in two ways. First, the segmented precast concrete approach developed for the hybrid steel/concrete towers was extended to all-concrete towers. For the different turbine sizes, the precast segment sizes used in the assembly are limited in size to pieces less than 27,000 kg (60 kips). This was accomplished by limiting the heights of the precast concrete segments. Each ring of the tower is made up of three-arc sections to stay within the established weight limit. Erection for the all-concrete precast towers is handled by a crane that picks and places the precast concrete segments. A conventional crawler crane is used for pricing purposes. For an installation of 50 towers, it is likely that a smaller crane would be used to erect precast concrete segments to the 50-m (164-ft) level and a larger crane would be used to handle the erection of the precast concrete segments near the tower top.

The second construction approach considered is a jump-formed, cast-in-place concrete approach similar to that used for large industrial chimneys. This approach may also be applicable to the construction of the hybrid steel/concrete towers. The approach was not considered here for the hybrid towers, as the currently used construction methods for which cost information exists are not consistent with the presence of the steel top tower in the center of the cast-in-place concrete tower construction activity. In the cast-in-place concrete jump-formed approach it is assumed that tower construction is completed for most of the towers before the large crane necessary to erect the nacelle, hub, and rotors at the 100-m (328-ft) height is mobilized to the site. This allows the crane to move from one tower to the next as the nacelles, hubs, and rotors are erected, with no down time between lifts. This minimized the time this large crane must be kept on site.

10 2 Project Construction Organization

The project to construct 50, 1.5-MW, 100-m (328-ft) wind turbine towers is significant and involves construction costs in the area of $65 million, not including turbines and rotors. Installation costs for 3.6- and 5.0-MW towers will be larger. This is a significant construction project size that will involve several entities. The way the project is organized can have a significant effect on the overall project cost in that the layers of contracting and subcontracting are associated with layers of cost markups to address the cost of involving the different entities. The concerns and capabilities of all the entities involved must be appropriately considered in the development of the final project implementation plans for the project to be optimally successful from cost, schedule, and performance points of view. For example, considering the cost implications of the project organization may be as important as refining the costs of some tower elements through improved design. Consider that an additional 10% overall markup from an additional organizational level or the comparable savings from one less organizational level involves $6.5 million in project cost associated with the tower construction alone.

A development general contractor (DGC) will have overall responsibility for the construction of the installation within the established budget and schedule. He will likely be responsible to the installation owner for all procurement, site development, and construction until the installation goes into operation.

A turbine and blade manufacturer (TM) will supply the complete turbine assemblies and likely many or all of the electrical components necessary for collecting and conditioning the power from the wind farm installation. This entity will have a major interface with the tower design and construction. Turbine design loads and required dynamic characteristics of the towers will be prescribed by the turbine system supplier.

There will be a tower engineer of record (EOR) for the tower designs. In addition to tower design, this individual or firm will be responsible for verifying that the design intent is carried through in the construction operations. The EOR will prepare construction documents for the towers, including the quality assurance requirements that must be addressed in the construction activity. He will review the results of quality control inspections and determine how significant construction quality discrepancies will be resolved.

A precast supplier (PS) will supply the precast concrete segments to the project site. This entity will be responsible for delivering completed precast segments to the project site on a schedule consistent with the overall project construction schedule. Several alternatives for handling the precast manufacture are addressed in Section 10.1. The DGC will likely be responsible for the erection and integration of the precast tower segments.

A steel fabricator (SF) will fabricate the tubular steel tower elements for assembly under the direction of the DGC. This entity will be responsible for delivery of tower elements to the site on a schedule consistent with the overall project construction schedule. The DGC will likely be responsible for the erection and integration of the steel tower elements.

An electrical contractor will be responsible for installing all of the project electrical facilities, including those within the tower installation. The electrical design and construction activities will have an interface with the tower and foundation designs and construction.

A concrete supplier (CS) will supply the concrete for the foundations and possibly the precast concrete segments. Alternatives for concrete supply are addressed in Section 10.3.

10.3 Construction of Hybrid Steel/Concrete Wind Turbine Towers

The construction approach selected for the 1.5-MW hybrid tower combines the advantages of high-quality precast concrete for the lower half of the 100-m (328-ft) tower and the advantages of shop-fabricated steel tubular construction for the upper half.

For the top 50-m (164-ft) steel tube of the 1.5-MW hybrid tower, the diameters of the shop-fabricated steel sections are manageable for delivery, erection, and field welding. Extrapolating the steel tower to the full 100 m (328 ft) results in tube sections significantly in excess of the 4.27-m (14-ft) deliverable width, incurring either additional fabrication costs to segment the tube section vertically for shipment or more costly and time-consuming delivery expenses. Similarly, erection and field welding of 100-m (328-ft) steel tubes requires large cranes and rigging that are costly.

Construction for a full 100-m (328-ft) concrete tower involves costs that increase with tower height:

- Larger foundation monoliths, or pile foundations
- Increased strength requirements (volume of concrete and post-tensioning). This carries higher penalties in seismic regions
- Higher erection costs for precast segments; or alternatively, potential schedule and logistical cost penalties for cast-in-place tapered towers.

The hybrid tower solution seeks to produce a 100-m (328-ft) tower with a minimum combined structural steel/concrete material and assembly cost. The costs involved with the construction process are significant compared to the basic material costs for this type of a structure. The upper steel tube, at 50 m (164 ft), is shop-fabricated in three sections of manageable weight and width for truck shipment. The lower concrete tower, at 50 m (164 ft), lends itself to reasonably sized precast concrete segments (three per ring). Precise forming and production techniques will result in efficient erection and closure joint construction.

Rings and ring segments for the 1.5-MW hybrid tower are shown at 3.20 m (10.5 ft) high for the lower rings and 3.81 m (12.5 ft) high for the upper rings. The inside diameter is constant at 4,470 mm (176 in), and the outside diameter varies from 5,791 mm (228 in) at the bottom to 5,257 mm (207 in) at the mid-height where the concrete mates with the upper steel tube. A constant internal diameter allows the lower guide roller assembly to stay in contact with the concrete surface as the steel tower is being jacked up without any requirement to adjust it to accommodate a reducing diameter, as would be required with a tapered internal cross section. For the larger towers, we have included the development and fabrication cost of an active (hydraulic) guide assembly that can adjust to the varying diameter while under load as the steel tower is jacked up. This guide assembly for the 1.5-MW tower is shown in Figure 10.1 and in Drawings D-32 and D-33.

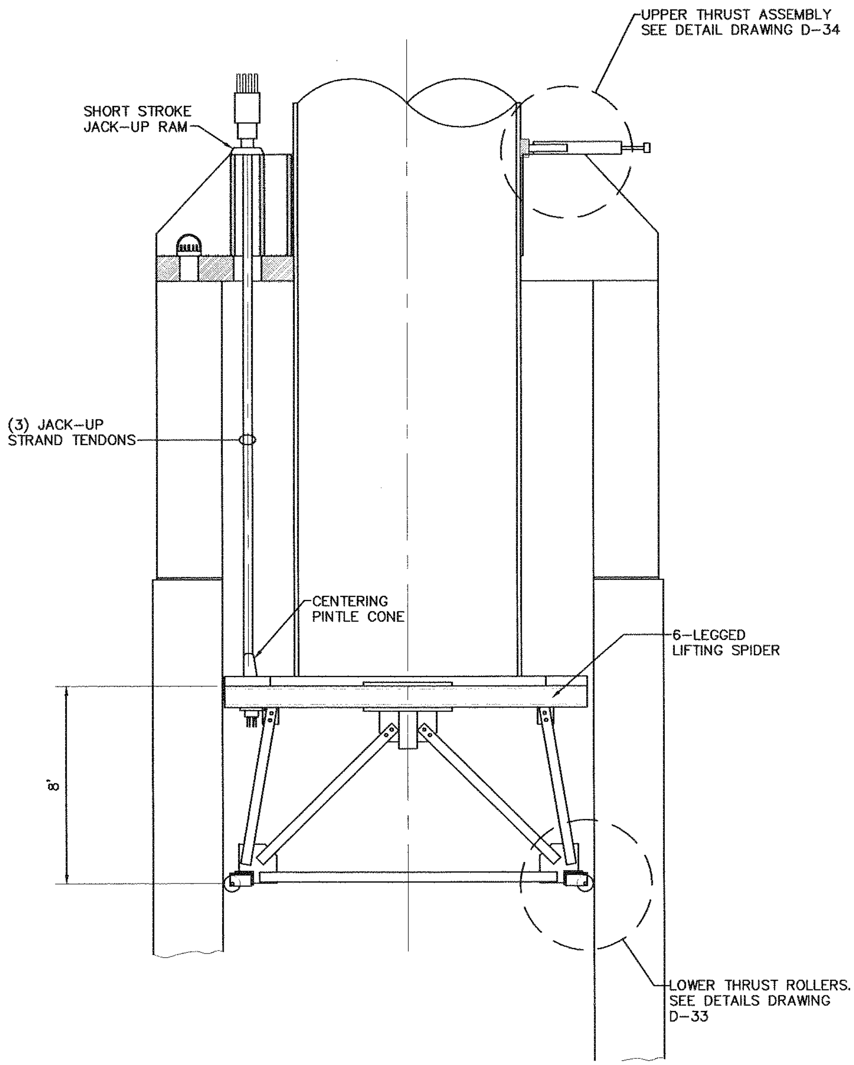


Figure 10.1. Hybrid steel/concrete tower jacking arrangement

Each ring is made of three 108° precast segments and three 12° cast-in-place closure joints. The horizontal joint between rings is a grouted joint, nominally 19 mm (0.75 in.) thick. Bending strength is provided by vertical post-tension tendons that bend 90° in the mass footing and terminate at post-tensioning tendon anchors located on the six vertical sides of the hexagon-shaped footing.

A significant feature of the hybrid tower design is the erection method for the steel and concrete towers:

The steel tube sections are erected and butt-welded together first, vertically on top of the foundation pad, supported by a 2.44-m (8-ft) high steel framework and temporarily held down to the foundation by A-490 bolts that provide base bending capacity against wind on the tower without the turbine installed and construction loads during the precast concrete tower field erection.

With the steel tube erected, the concrete tower is constructed around the tube with 14 rings of 3 precast concrete segments each. A custom-built pedestal crane, mounted on top of the completed steel tube, is used to erect the concrete segments, handle forms and place concrete for the three closure joint pours per ring, and assist in post-tensioning operations.

When the concrete tower is completed and post-tensioned, the pedestal crane is removed from the top of the steel tube. The tube is then is outfitted with the turbine nacelle, hub and rotor at the 50-m (164-ft) height. Then, the steel tube is jacked up inside the concrete tower by means of three post-tension strand tendons, each with short-stroke hydraulic rams, pumps, gauges, and controls. This controlled raising of large loads is a well-established procedure with competent engineering, precision equipment, controls, and supervision.

When the steel tube is jacked up to its full height, a heavy bolted connection is executed at mid-height between the steel flange ring on the bottom of the steel tower tube and a mating steel tower-top connection ring that has been connected by post tensioning to the top of the concrete tower. The preliminary design of this connection and preliminary details are shown in Appendix D, Drawings D-26 through D-30.

The following task lists, with associated comments and recommendations, describe the separate fabrication of the steel sections and precast concrete, the erection of the steel and concrete elements of the 1.5-MW hybrid towers in the field, and the final jack-up of the steel tube and mating connection at mid-height. Construction sketches in the drawing package (Appendix D) illustrate the principal construction tasks.

Task List 1: Procure and Mobilize

This area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 1.1 Develop site, access road, and utilities
Task 1.2 Design and order precision forms for precast ring segments
Task 1.3 Select precast segment supplier
Task 1.4 Select fabrication shop for steel tube, annular flange, and connection ring
Task 1.5 Design and fabricate special pedestal crane for erecting concrete segments
Task 1.6 Evaluate options for concrete supply
Task 1.7 Move equipment and support services to site

Comments and Recommendations

Task 1.1 Site development activities can be grouped into "general" and "site specific." General site development includes utilities, communications, material laydown, material storage, office trailers, employee parking, and other requirements common to any major construction project. The WindPACT Technical Area 4 -Balance of Station Cost Study [19] provides insight into the variables associated with differing site development scenarios.

Site-specific development tasks include access roads and bringing construction support utilities from nearest power, water, and communications supply points. In cases of very remote land sites or offshore platform sites, site development could include housing trailers and food service facilities for employees who would live in a construction camp environment for the duration of the construction project. For these reasons, it is not possible to determine meaningful cost and schedule estimates applicable to all generic project sites.

Task 1.2 Form design and procurement of the precision forms for the precast concrete segments deserve special attention. Whereas the concrete ring segments are not complicated, they must be cast in extremely precise forms to ensure that successive three-piece rings can be erected to tighter tolerances than is normal to precast construction. The key to success in producing and erecting precision segments is the design and fabrication of segment forms by a form fabricator experienced in meeting similar requirements. In the United States, a number of companies specialize in the design and fabrication of custom precision form work for specialized precast concrete applications. The Precast Concrete Institute (PCI) lists a number of precast concrete form companies active in this business in its Annual Directory [23] each year.

Precast concrete producers turn to these specialty form designer/fabricators when faced with requirements for precise, heavily built forms capable of reliably forming close-tolerance precast segments.

The forms should be procured and owned by the DGC, and provided to the precast supplier for use on each project. There are three reasons for this nonstandard procedure:

- The DGC can control the design and fabrication of the forms and ensure that precast segment tolerances are met.
- Providing a forming system with the proven capability to meet specified project tolerances will help ensure that an increased number of potential precast suppliers are capable of and interested in competitively bidding on the work.
- The forms can be reconditioned and made available for a subsequent project.

Task 1.3 In selecting a precast supplier for the precast concrete tower segments, the DGC has several options:

- Negotiate with and select an established precast concrete company with an excellent performance record. This is the best option if the company is fully qualified, is within economical delivery distance (~ 300 miles or less), and is fairly pricing its product.
- Precast concrete suppliers that participate in the PCI Plant Quality Certification program have established quality assurance/quality control programs in place. These plants are regularly subjected to external quality audits to ensure compliance with quality standards. The use of an established plant mobilizes a management, quality assurance organization, and a functioning manufacturing facility. Thus, if such a plant is within supply range of the project it has the potential of greatly simplifying the procurement of the precast concrete segments.
- Choose the established, qualified precast concrete company, and pay the precaster to set up a special-purpose precast concrete segment manufacturing operation within a much shorter delivery radius from the project. An obvious choice is to set up the temporary precast operation on land held by a local, top-quality, ready-mix concrete plant. This option enables the DGC to acquire the skills and established quality-control procedures of the experienced precast supplier without the cost penalty of long-haul deliveries. This approach has a somewhat higher quality and productivity risk than the first option.
- The DGC can to set up his own precast operation dedicated to production, curing, and delivery of the precision ring segments. This option is viable only if the DGC is willing

to hire experienced, qualified precast concrete plant managers, supervisors, and quality-control personnel. There must be a local source of quality concrete and experienced labor. Finally, if the DGC sets up his own plant, it must be far enough away from the project site to avoid the high labor costs and "work rules" that are likely at the main construction site. The size of this dedicated precast operation is not large. Precasting (four) segments per day for the 1.5-MW hybrid towers, for example, can be done with 12–15 experienced workers plus two supervisors and two quality-control technicians. The towers for the larger turbines and the all-precast-concrete towers would require a larger precast concrete fabrication operation. This option has the highest quality and productivity risk of the three options considered.

Task 1.4 Selecting a qualified steel fabricator is more problematic with the limited number of shops experienced in forming, fitting, and welding precision-tapered, heavy-plate tube sections. Setting up a fully qualified welding facility near the project site is probably not economically feasible for the 1.5-MW towers, so the DGC should expect to deal with a truck delivery radius of 500 miles (or more in the western United States, where major steel fabrication shops are scarce).

As outlined in [17], fabricated tubular tower sections for the larger turbine tower sizes must be shipped in sections. Fatigue issues associated with bolted connections for the vertical segment joints may require that these joints be accomplished by welding. Thus, an on-site (or very near site) welding facility may be necessary for final assembly of the larger 3.6- and 5.0-MW tubular steel tower elements. Equally limited are heavy fabrication shops with metal working equipment to handle the welding, milling, and drilling of the heavy annular tower base flange ring and tower top connection ring.

Task 1.5 For the hybrid tower design concept presented here, we propose erecting the steel tower on raised supports centered on the foundation, then erecting precast concrete ring segments encircling the erected steel tube (see construction Tasks 4.1 and 6.2). This study uses a custom designed and fabricated pedestal crane mounted on top of the steel tower tube to handle the precast erection, joint closures, post-tensioning, and other tasks for construction of the concrete tower. Justification for this special crane is provided under Task 6.0. Because this pedestal crane is a special, long-lead-time item, it is identified here in the mobilization tasks.

Task 1.6 Each concrete foundation for the 1.5-MW Hybrid tower requires 825 cubic meters (1,080 cubic yards) of 27.6 MPa (4000 psi) concrete. This is based on an assumed high-bearing-capacity soil for which spread footings are appropriate. If the nearest ready-mix concrete supplier lies outside the practical delivery radius, the DGC should consider setting up an on-site concrete plant. If the DGC is also considering precast concrete supply (see Task 1.3 above), a combination concrete plant for both the precast concrete segments and tower foundations should be considered.

Task 1.7 As the date approaches for starting work at the project site, equipment, tool trailers, and support shops (e.g., carpentry, maintenance), as well as office and administration trailers will be moved in and set up.

Task List 2: Construct Tower Foundation

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 2.1 Excavation for foundation (Drawing D-2)
Task 2.2 Prepare for concrete placement
Task 2.3 Install all embedments
Task 2.4 Pour and cure foundation concrete
Task 2.5 Cool the concrete

Comments and Recommendations

The foundation design and construction sketches shown in this report are based on a gravity-type concrete footing. For the 1.5-MW hybrid tower, the plan is hexagonal, 3 m (10 ft) deep, and requires 826 m^3 (1,080 yd^3) of concrete. The specific project site may dictate other designs such as pile-supported, rock-supported footings or footings that incorporate ground anchors or rock anchor tension elements. In such cases, the size of the footings and the anchorage details for the vertical post tension tendons would change.

These tasks are generally self-explanatory. The following comments are added for clarification:

Task 2.1 If site conditions allow, excavation for the footing should provide a 3-m (10-ft) wide access aisle around the perimeter of the concrete footing to permit a small truck to maneuver around the completed concrete monolith for ease of forming and servicing the post-tensioning and grouting operations.

Task 2.2 The shape of the foundation plan proposed is hexagonal to accommodate the (36) vertical post-tensioning tendons. In six groups, the post-tensioning tendons fold 90° under the center of the foundation and daylight in the opposite wall (Drawing D-2). This shape significantly simplifies the placement of the post-tensioning anchors. A circular foundation would work equally well, but a square plan does not work well with the six-tendon-group concept.

The DGC should consider prefabricating all or part of the foundation rebar and post-tensioning duct in a single cage at a central rebar cage assembly station on the project site. This would not only improve the efficiency of rebar tying, but it offers better dimensional control for installing and securing the post-tensioning ducts and anchors. The procedure would be to set the cage first, erect the forms, and install post-tensioning anchors through windows in the side forms. It may also be advantageous to preinstall the post-tensioning anchorages bolted to the side forms, and connect them to the post-tensioning ducts after the forms are set up. The steel "spider" fixture location template can be used as a strong-back for handling the completed rebar/duct cage.

Task 2.3 The DGC will design and fabricate a custom steel "spider" template to hold the anchor bolts, post-tensioning ducts, bar post-tensioning anchors, and embedments daylighting out of the top of the footing. Location of post-tensioning ducts and erection rods for the segments must be held to ± 3 mm (± 1/8 in.) tolerance to match requirements for erection of the precast concrete segments. Additionally, there will be embedded A-490 anchor bolt sleeves and other hardware for positioning and holding the steel tube tower.

Task 2.4 Because the supports for the template must span across the form, the size and cost of this "spider" template are greater than typical anchor bolt templates. However, because it can be reused on every footing, it will be cost effective to invest in a durable fixture that is quick and easy to install and adjust and that will reliably position all embedded fixtures within the required tolerances.

Task 2.5 With the mass of these foundation pours, special low heat of hydration mix designs and cooling of the concrete may be required in summer pours. Special concrete placement and consolidation procedures are necessary to avoid damage to the post-tensioning ducts during placement and vibration of the concrete.

Task List 3: Fabricate Steel Tube, Annular Base Flange Ring for Tube, and Annular Tower Top Connection Ring

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 3.1 Qualify welding procedures, welders, and nondestructive testing (NDT) systems
Task 3.2 Cut and roll steel shells and prepare edges for welding (Drawing D-3)
Task 3.3 Fabricate annular base flange ring (Drawing D-27)
Task 3.4 Fabricate annular concrete tower top connection ring (Drawing D-26)
Task 3.5 Mate annular base flange and annular connection ring (Drawing D-5)
Task 3.6 Bolt base flange and top connection rings together (Drawing D-4)
Task 3.7 Fit and weld tapered tube in three sections (Drawing D-6)
Task 3.8 Prepare top and bottom of each section for field weld (Drawing D-3)
Task 3.9 Install internal ladders and platforms in each section (Drawing D-3)
Task 3.10 Ship (three) fabricated sections by truck to site

Comments and Recommendations

Task 3.1 The circular butt welds, including the bottom weld to the flange ring, are subjected to the same reversible fatigue loading as the steel tower shaft itself. Thus, the welding procedures, equipment, journeyman qualifications, and NDT systems must be developed and implemented in the strictest conformance with the project specifications. The welding quality required to resist the very high numbers of fatigue cycles involved in a typical tower 20-year lifetime is much higher than that typically specified for heavy civil construction. The methods to attain this level of quality, especially for any welds made at the site, will require special attention to procedures and use of automated equipment in protected enclosures, in combination with a high level and frequency of quality control and NDT.

Task 3.2 In the steel fabrication shop, steel plate will be cut, rolled into shape, and welded into 2.4-m (8-ft) high “cans” for fabricating the tapered steel tube (Drawing D-3).

Task 3.3 To fabricate the 130-mm (5-in.) thick annular base flange ring: cut 120° segments; butt weld to form ring; stress relieve; mill top face for flatness; fit and weld on 6-mm x 25-mm (1/4-in. x 1-in.) backing bar for flange-to-tube butt weld (Drawing D-27).

On the annular base flange ring, the tensile and compression stress from the tube shell flows through the butt weld and enters the 130-mm (5-in.) flange metal perpendicular to the plane of the plate steel. Therefore, special precautions must be taken to ensure that the flange plate material is completely free from plate rolling inclusions that can lead to lamellar weakness and tearing failures. Grade 50Z plate steel with enhanced through-thickness properties [25] (specified steel for use in offshore structures) is a good candidate material for this application. Ultrasonic qualification of plate stock will be necessary before fabrication. Testing of through-plate steel coupons shall be done to ensure ductility in excess of 25% for the plate steel on each flange ring.

Task 3.4 To fabricate the concrete tower top connection ring: cut 120° segments with holes for tendons; fit and weld vertical stiffeners; stress relieve; mill end stiffeners for verticality, and drill for alignment pins and bolts; bolt segments into full ring; and mill bottom surface for flatness while bolted. This plate element is subject to the similar loading and has the same concerns and quality requirements as outlined for the flange ring in Item 3.3 (Drawing D-26).

Task 3.5 In the steel fabrication shop, mate the annular base flange ring and tower top connection ring and match-drill 38-mm (1.5-in.) diameter holes; fit and weld on (three) alignment cones matched with female sockets in the tower top connection ring. The purpose of match drilling is to avoid the requirement of excessively tight hole location tolerances that would be required if match drilling were not used.

For both annular rings, stress relieving and surface milling are indicated so that the two mating ring surfaces are in full contact when bolted together in the final installation. This is an important design feature for carrying the axial load and bending stresses from the base of the steel tube into the post-tensioned concrete at the top of the concrete tower. After shop clamping of the two rings and match drilling of the 38-mm (1.5-in.) diameter bolt holes, the two rings shall be marked and used as matched pairs throughout construction of the steel tube and concrete tower (Drawing D-5).

Task 3.6 In the steel fabrication shop, bolt the base flange ring and tower top connection ring together with 50% of the 38-mm (1.5-in.) diameter A-490 bolts. Fit first tube "can" onto annular base flange; apply seal weld; and apply full penetration butt weld. Cool slowly before unbolting the two ring assemblies (Drawing D-27). For the larger towers associated with the larger turbine sizes, the larger-diameter steel tube base flange will have to be welded to the tube can sections at or near the site for transportation reasons.

The purpose of bolting the annular tube flange ring to the larger, stiffened tower top connection ring prior to welding to the tube element is to hold the ring flange flat and square during the application of the butt weld to the first tubular can section. By cooling this weld slowly, the stresses induced by this butt weld have time to dissipate so that the flange remains unwarped after unbolting it from the heavier ring.

Task 3.7 In the steel fabrication shop, weld tapered tube sections together to form three sections 14.6 m (48 ft) with attached base flange, 17.1 m (56 ft) and 19.5 m (64 ft) with attached top flange for shipment. Complete and resolve all dimensional and weld quality assurance and quality control before shipment to site.

Task 3.8 In the steel fabrication shop, prepare tube can sections for welding to each other. Bevel bottom edge for full penetration butt weld; add backing bar on inside of top edge; add tab clips on top edge for guiding in next section during erection (Drawing D-3).

Task 3.9 In the steel fabrication shop, preinstall internal ladders and platforms in each of the sections. Ensure that ladder and platform details do not interfere with weld locations. Additional provisions for electrical (such as conduit runs and the like) may also be installed at this time. A tolerance-insensitive method of completing the conduit runs across joints must be incorporated in the conduit run designs.

Task 3.10 Ship via truck to site. Overweight and overwidth permits and escorts may be required. The bottom tube section, with the annular flange ring, is 4.32 m (14.25 ft) wide, exceeding the 4.26 m (14 ft) width limit used in many states (for manufactured home sections). This will require special permitting and escort cars, with an associated cost premium for transport of these sections.

Task List 4: Erect Steel Tube on Site

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 4.1 Install tube base support frame structure (Drawings D-7 and D-8)
Task 4.2 Attach 24 roller-type horizontal guide assemblies (Drawings D-8, D-32, and D-33)
Task 4.3 Erect first tube section on base frame
Task 4.4 Install temporary hold-down bolts to the foundation (Drawing D-8)
Task 4.5 Hang ring scaffold near top of first section (Drawing D-6)
Task 4.6 Erect second tube section, fit to top of first (Drawing D-6)
Task 4.7 Weld tube sections together (Drawing D-6)
Task 4.8 Verify weld quality with approved NDT procedures
Task 4.9 Erect third tube section, and butt weld (Drawing D-6)
Task 4.10 Install pedestal erection crane on top of steel tube (Drawing D-6)

Comments and Recommendations

Task 4.1 Install a 2.4-m (8-ft) high steel frame structure, centered on the concrete foundation, to serve as a support and lateral stabilization for subsequent jack-up erection of the 51-m (167-ft) tapered steel tube (Drawings D-7 and D-8). The bolted steel frame has six posts with crossed X-bracing. The top is a six-spoke lifting frame with three jack-up tendon connections on the ends of alternate spokes. The design, fabrication, and installation of the tubular steel tower base support frame and A-490 hold-down bolts at the bottom of the steel tube must meet all the following requirements:

- It must incorporate a six-legged, jack-up frame with anchor points for the three jack-up tendons, and have the structural capacity to support the dead load of the steel tube and special pedestal crane mounted on top.

- The support frame and hold-down bolts must provide the temporary axial load, moment, and shear connection between the base of the tube and the concrete foundation for construction period wind loads on the assembled steel tube and erection loads as the pedestal crane lifts and installs the precast concrete ring segments.

- A work platform suspended about 7 ft below the flange ring must provide a safe support for workers during jack-up and mating with the top connection ring on top of the concrete.

- The support frame must deal with potentially large horizontal forces at the bottom from horizontal roller thrust guides to resist overturning from wind loads on the tower tube, turbine, and nonoperating rotors during the jack-up operation. These thrust loads increase significantly when the jack-up is near completion as the moment arm between the lower and upper thrust guides decreases to 3 m (10 ft).

- The support frame and jack-up frame should be constructed so that, after jack-up and fastening of the steel tube, they can be lowered to the ground and removed though the access door in the base of the concrete tower for subsequent reuse.

Task 4.2 At the bottom of the steel frame support structure, attach 24 roller-type horizontal guide assemblies to a perimeter set of heavy angles. These guides provide the lower reaction against the inside of the hollow concrete tower during the jack-up of the steel tube (Drawings D-8, D-32, and D-33). The configuration of the concrete portion of the 1.5-MW hybrid tower was optimized for the steel tower jack-up operation by making the concrete segments with a constant internal diameter from top to bottom. This allows the use of passive roller horizontal guide assemblies beneath the steel tower as it is being jacked up into final position. For the 1.5-MW tower, this approach results in acceptable tower dynamic characteristics and is feasible with only a minor cost premium.

For the larger turbine sizes, the internal diameter of the concrete portion of the tower is made variable for reasons of dynamic tower properties and economy of material. This necessitates the use of an active lower horizontal guide assembly during the jack-up process. We envision this to be a series of 8–2 roller-type units mounted on the ends of hydraulic actuators, which are in turn mounted on the steel frame support structure that supports the steel tower during the jack-up process. A cost for the design and fabrication of this assembly is included in the pricing for the 3.6- and 5.0-MW hybrid towers.

Task 4.3 Erect the first tube section on the base frame. The tube flange must be precisely centered and oriented rotationally, so that the three alignment cones are properly positioned for jack-up. These alignment cones will be required to mate with female sockets located on the tower top connection ring. This erection activity is accomplished using a crawler crane.

Task 4.4 Install temporary A-490 hold-down bolts to the foundation, connected to the base flange ring of first tube section. Torque these bolts to provide the specified “clamping” force of the steel tower flange through the support frame to the concrete foundation (Drawing D-8).

Task 4.5 Hang the ring scaffold near top of the first section, and clamp on the circular track for the automatic welding machine (Drawing D-6).

Task 4.6 Erect the second steel tube section, fit to the top of the first, and manually lay in a root weld. Install the automatic welding machine on a circular track. Erection of the three steel tube sections, with attached temporary scaffold rings and ladders, is handled by a crawler crane with sufficient boom. The same crane also sets the bull ring, support track, and custom-built erection crane on top of the completed tube assembly (Drawing D-6).

Task 4.7 Lay down the submerged-arc butt weld with the track-mounted machine (Drawing D-6). Automated welding on-site is recommended to achieve the required weld quality for fatigue-rated welds.

Task 4.8 Verify weld quality with approved NDT procedures specific to each weld type. Type of inspection and frequency of inspections will be developed consistent with the requirement to reliably produce fatigue-rated welds.

Task 4.9 Repeat scaffold and circular track installation, erect the third tube section and butt weld (Drawing D-6).

Task 4.10 Install pedestal crane bull gear, support track, rotation pin, and custom-built erection crane on top of the completed steel tube for erecting the precast concrete ring segments. The custom crane is a pedestal crane designed specifically to hoist and erect the 108° precast concrete segments that comprise the 3.2-m (10.5-ft) and 3.8-m (12.5-ft) high concrete rings for the post-tension tower.

Mounting the crane on top of the steel tower requires bolting on a circular support turntable, which consists of a circular track, bull gear, and vertical rotation pin. The DGC will use the large crawler crane for installing the support turntable and pedestal crane. Erection and post-tensioning of the concrete tower are described in Task List 6. The precast concrete erection and post-tensioning process is estimated to take 20–22 days, which is a long and costly commitment for the 250-ton crawler crane; thus, the use of the pedestal crane is proposed (Drawing D-6).

The justification for the custom-designed pedestal crane is that its use will be less expensive than the use of the larger crawler crane, and it releases the crawler crane for erecting other steel tubes and other work on the 50-tower project. If the project site has a small number of towers, economics will favor the use of the crawler crane to erect and post-tension the concrete; but for a large project, one or two pedestal cranes are justified. An increased number of pedestal cranes will be required for 50 tower installations that involve the larger towers for the 3.6- and 5.0-MW turbines, all of which involve erecting increased numbers of precast concrete segments.

Task List 5: Precast Operation

Two precision steel concrete forms are used to manufacture the precast concrete segments for the 1.5-MW hybrid tower. Form "A" is used to fabricate segments for Rings 1–7 with height of segment = 3.20 m (10.50 ft); Form "B" is used to fabricate segments for Rings 8–14 with height of segment = 3.81 m (12.50 ft). Appendix F shows photos of precast arc segment production.

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 5.1 Install forms for production (Drawing D-14)
Task 5.2 Install rebar and hardware into forms (Drawings D-10–D-13 and D-15)
Task 5.3 Mount outer wall forms (Drawing D-14)
Task 5.4 Place concrete into forms
Task 5.5 Cure precast concrete segments overnight
Task 5.6 Strip precast segments from their forms
Task 5.7 Stockpile segments for continued curing

Comments and Recommendations

The key to rapid, accurate assembly of the segmented precast concrete rings is precasting and curing dimensionally precise segments with precisely located embedded items and alignment features. Three segments make up each tower ring (108° segments plus three 12° vertical cast-in-place closure joints). Each ring is rotated 60° from the one below it so that the vertical closure joints are staggered. The horizontal joint between rings is nominally 19 mm (0.75 in.) thick and is injected with self-leveling, high-strength cement grout (Drawings D-9, D-17, and D-20).

If the project schedule is based on completing one 1.5-MW hybrid tower per month (21 work days), then one "A" form and one "B" form, each with 21 castings per concrete tower, exactly matches the project usage rate. If the project schedule calls for completion of a tower every 10 or 11 days, two “A” forms and two “B” forms are required for a precasting schedule of four segments per day. A larger number of forms will be required to produce a 50-tower installation that involves either all precast concrete towers or the larger towers for the 3.6- or 5.0-MW turbines.

Task 5.1 Install and brace forms to level the form base and plumb the inside wall of the form to within 25% of the larger final tolerance allowed on the precast concrete segments. The tolerance on segment height must be held to ±3 mm (±1/8 in.), and the top and bottom location of post-tension ducts, alignment pins, and connector bars must be held to ±1.5 mm (±1/16 in.) of true location. Finally, the inside wall of the precast segment form must be precisely perpendicular to the bottom plane of the precast segment. This is so that, when all three 108° segments are set on leveled supports and the alignment pintels are engaged, the inside surface is cylindrical and forms the exact same circular plane at the top and bottom of the ring (Drawing D-14).

To achieve these precise dimensional requirements, the forms for the segments shall be designed and fabricated by a specialty precast form fabricator and shall have the following features:

- The bottom form plate shall be a stiff, dimensionally stable flat-rolled plate (9.5 mm [3/8 in.] typical) supported by straight, true base wide-flanges. The plate shall be sufficiently stiff and supported so that it will deflect only a negligible amount when the form is filled with concrete and vibrated.

- The inside radius skin form shall be 6 mm (1/4 in.), with vertical stiffeners, braced to form a precisely plumb cylindrical surface. The inside stiffened skin form shall be permanently connected to the bottom stiffened skin plate at exactly 90° angles. The plate shall be sufficiently stiff and supported so that it will deflect only a negligible amount when the form is filled with concrete and vibrated.

- The outer stiffened radius skin is removable to provide access to the interior of the form for installation of rebar, duct, and hardware. Its position is adjustable to accommodate the decreasing wall thickness of the segments from ring to ring.

- Post-tension ducts, alignment sockets, and erection bar ducts are positioned on the bottom plate by hard rubber plugs permanently fixed to the bottom plate so that their locations are closely within tolerance and nonchanging from segment to segment. At the top of these vertical ducts and bars, similar positioning plugs are located by precise fixtures that bolt to holes in the inner form skin.

At the precast concrete production plant, the forms are installed, leveled, braced, and check-surveyed to ensure that flatness tolerances of the form bottom and plumbness of the inside wall form are satisfied.

Task 5.2 Install rebar, vertical duct, and embedded hardware in forms using preset plugs and bolt holes, to hold the bottom of ducts and hardware in precise location. At the top of the form, hold the precise location of the embedded items with jigs mounted on the inside of the wall form. Methods of prefabricating the reinforcing cages and duct assemblies to allow rapid and accurate placement within the form should be employed to speed production and ensure that tolerances are reliably met (Drawings D-10–D-13 and D-15).

Task 5.3 Mount outer wall forms. The movable outer forms should be designed to allow the frequent move into place and subsequent stripping without damage or wear to the form that would compromise precast segment tolerances (Drawing D-14).

Task 5.4 Place concrete from top, using form vibrators to consolidate concrete. Consider using self-consolidating concrete to mitigate the problem of placing the concrete without dislocating any of the embedded items. Concrete will be subject to quality-control testing as outlined in [22]. Concrete test results will be monitored regularly and, if necessary, the concrete mix will be adjusted to ensure that project concrete material parameters (strength, shrinkage, permeability, etc.) are being met.

Task 5.5 Cure overnight using steam or electric heat to accelerate curing to achieve a 24-MPa (3,500-psi) stripping strength. In some temperature conditions or with some concrete mixes, it may not be necessary to add heat to the concrete to achieve the required stripping strength. Maximum curing temperatures as permitted by the PCI [22] shall not be exceeded. In hot summer conditions, measures to cool the concrete and forms to avoid exceeding maximum allowable curing temperature may be necessary.

Task 5.6 The following morning, remove the outer forms and strip the precast segments from their forms. As the initial segments are produced, and after any forms are adjusted or relocated or new forms are introduced into the production, dimensionally check the precast segments against required tolerances to ensure that all necessary tolerances are being achieved. A program of statistically significant dimensional checking and dimensional records analysis should be developed to allow monitoring of the production to ensure that tolerances are being met and to provide advance warning regarding effects of form wear, form damage, and the need for form repairs or adjustments.

As the initial segments on the project are produced, a mock-up mating of the segments should be done to ensure that mating features properly mate and the desired proper alignment is achieved.

Task 5.7 Stockpile segments in vertical position on level dunnage. Cover units for seven days to prevent rapid drying. Special provisions are required to minimize dimensional changes in the precast segments that can be caused by unequal drying of the concrete segments during the first days of curing after stripping the segments from the form. Likewise, for long-term storage in hot climates, shading of the stored pieces is indicated to prevent potential bowing or warping, which can be caused by solar-radiation-produced thermal gradients as the result of the sun shining on one surface every day.

Task List 6: Field Erection of Precast Concrete Tower Encircling Steel Tube

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 6.1 Deliver precast concrete segments upright on truck trailers
Task 6.2 Perform typical daily operation for constructing each ring
Task 6.2.1 Remove fixtures and forms from previous day’s pour (Drawings D-19, D-22, and D-23)
Task 6.2.2 Set three leveling shims per segment (Drawing D-18)
Task 6.2.3 Install perimeter grout gaskets (Drawing D-24)
Task 6.2.4 Rig precast concrete segment for hoisting (Drawing D-18)
Task 6.2.5 Erect first precast segment using pedestal crane (Drawing D-18)

Task 6.2.6 Install and stress post-tensioning bars in first segment (Drawings D-24 and D-25)
Task 6.2.7 Repeat erection process for second and third precast segment
Task 6.2.8 Install positioning fixtures on erected segments (Drawings D-16, D-17, and D-19)
Task 6.2.9 Install rebar in three vertical closures (Drawings D-20 and D-21)
Task 6.2.10 Set forms for closure joint pours (Drawings D-22 and D-23)
Task 6.2.11 Install duct sealing assemblies (Drawing D-25)
Task 6.2.12 Inject grout in horizontal joint (Drawings D-24 and D-25)
Task 6.2.13 Place concrete in vertical closure joints (Drawing D-19)
Task 6.3 Install staged strand post tensioning at Ring No. 6, and later at Ring No. 10
Task 6.4 Install tower top steel connection annular ring:
Task 6.4.1 Install leveled steel support pads and grout gaskets
Task 6.4.2 Hoist steel ring segments and set on support pads (Drawing D-29)
Task 6.4.3 Align ring segments with alignment pins (Drawing D-28)
Task 6.4.4 Inject leveling grout beneath tower top connection ring (Drawing D-30)
Task 6.4.5 Install, stress, and grout erection bars (Drawing D-30)
Task 6.4.6 Install and stress vertical post tensioning tendons (Drawing D-30)
Task 6.5 Grout vertical tendons

Comments and Recommendations

This report suggests the use of the custom-built pedestal crane temporarily mounted on top of the steel tube for erecting the concrete segments, constructing the closure joints, and post-tensioning. This crane is similar in concept to a tower crane, designed to hoist the 108° ring segments with partial scaffold rings, for a maximum weight of 27,000 kg (60 kips). The hoisting radius is 10.7 m (35 ft) to allow the crane to lift the segment directly off the delivery truck spotted next to the foundation monolith. After hoisting, the segment is erected on the ring below, with a load radius of about 2 m (6.5 ft), which poses a significant challenge for the design of the pedestal crane.

Task 6.1 Deliver the 108° precast concrete segments loaded upright on truck trailers. If the precast manufacturing facility is close enough to the tower site, it is desirable to deliver the precast segments to the tower site for erection as they are needed. This avoids both the requirement to develop a storage area on site and double handling of the pieces. If the precast manufacturing facility is located further from the site such that reliable delivery times are difficult to predict, it may be possible to deliver pieces the day before they are needed and leave them on the truck trailer overnight, positioned for picking up by the erection crane, with the tractor returning to the fabrication facility for another load and exchanging trailers each day.

Task 6.2 Typical daily operation for constructing each ring (three segments + three closures) involves the following subtasks.

This series of subtasks must be executed for each three-segment ring. The objective is to complete the erection, bolting, horizontal joint grouting, closure pour rebar placement, closure joint form setting, joint concrete placement, and curing of the horizontal joint grout and the closure joint concrete in a 24-hour cycle. Therefore, all the tasks must be completed in two, 8-hour shifts to allow curing time for the closure joint concrete and horizontal joint grout. Insulated forms will likely be required for the closure joint to enable the joint concrete to reach a stripping strength of 17.2 MPa (2,500 psi) in 8 hours. In cold weather, either special low-temperature curing mixes or heating provisions will be required to achieve the desired strength while supporting the 24-hour turnaround cycle.

Composite crews that consist of carpenters, iron-workers, welders, and concrete laborers are required. The sequence of subtasks is repeated 14 times for each concrete tower, so the crews will have the opportunity of many repetitions to perfect the operation.

Task 6.2.1 Remove the three top positioning fixtures and vertical closure joint forms from the previous day's pour (Drawings D-19, D-22, and D-23).

Task 6.2.2 Set three leveling shims per segment using an optical level, working on top of the previously completed ring (Drawing D-18).

Task 6.2.3 Install perimeter grout gaskets on top of the previous ring (Drawing D-24).

Task 6.2.4 Attach 108° scaffold 3 feet down from top of first precast concrete segment before hoisting (Drawing D-18).

Task 6.2.5 Erect the first 108° precast concrete segment using pedestal crane. Align segment with tapered male pins in previous ring into female sockets in incoming segment (Drawing D-18).

Task 6.2.6 Install and stress four post-tensioning bars in the first segment, coupling to bars in the ring segment below. Jack post-tensioning bars to force segment down hard against the steel shims, compressing grout gaskets, and holding segment upright. Adjust, if necessary, for precise plumbness of inside of wall (Drawings D-24 and D-25).

Task 6.2.7 Repeat precast concrete segment erection and post-tensioning bar installation for second and third precast concrete segments.

Task 6.2.8 Install three positioning fixtures at the top of (3) erected segments to hold tops of precast segments in a perfect circle (Drawings D-16, D-17, and D-19).

Task 6.2.9 Install rebar in three vertical closures (12° wide), including welding horizontal splice hoop bars (Drawings D-20 and D-21).

Task 6.2.10 Clean, oil, and reset inner and outer vertical forms for three closure joint concrete pours (Drawings D-22 and D-23).

Task 6.2.11 Install and inflate tubular sealing hose assemblies down from the top of the segments to seal vertical post-tensioning ducts at the horizontal grout joint (Drawing D-25).

Task 6.2.12 Inject high-strength, self-leveling, rapid-curing grout in the horizontal gasketed joint at the bottom of three segments, using previously installed injection and bleeder tubing (Drawings D-24 and D-25).

Task 6.2.13 Place concrete in the three vertical closure joints. Consolidate with internal vibrators. Use a concrete mix that will reliably provide 17.2 MPa (2,500 psi) overnight strength (Drawing D-19).

Task 6.3 At the top of Ring No. 6, interrupt concrete segment erection to install 12 vertical strand post-tensioning tendons, and stress to foundation. Similarly, install and stress six vertical tendons anchored on top of Ring No. 10. Extra days are scheduled at the top of Ring Nos. 6 and 10 to install, and stress vertical tendons that terminate at those two rings.

Task 6.4 On top of the concrete tower (Ring No. 14), install the three-segment steel tower top connection annular ring. After concrete Ring No. 14 has been installed and the closure joint has been poured, the three-piece annular steel connection ring is installed, bolted together, grouted, and post-tensioned to the top of the concrete. This bolted steel ring must mate with the flange welded on the base of the steel tube, thus, it is critical that the three-piece steel connection ring, after bolting, leveling, grouting, and post-tensioning, is precisely located in the correct radial location and is square to the axis of the completed concrete tower. Otherwise, the steel tube will bolt-up out of plumb. It is also necessary that the three jack-up and mating sockets on the connection ring are vertically aligned with the match-marked alignment cones welded to the steel tube base flange.

Task 6.4.1 Install three precisely leveled steel support pads for each of the three connection ring segments, and glue compressible foam gaskets on top of the concrete to retain the grout (Drawing D-29).

Task 6.4.2 Hoist the 120° steel ring segments with the pedestal crane and set them on support pads and gaskets (Drawing D-29).

Task 6.4.3 Align the three segments with alignment pins at the three joints, and bolt the segments together with A-490 bolts. Recheck levelness of bolted ring (Drawing D-28).

Task 6.4.4 Inject leveling grout into the horizontal joint between the top of the concrete and the tower top steel connection ring annulus (Drawing D-30).

Task 6.4.5 When the leveling grout has reached 34.4 MPa (5,000 psi), install, stress, and grout 12 erection bars, anchoring on top of the steel tower top connection ring annulus (Drawing D-30).

Task 6.4.6 Install, stress, and grout 18 vertical tendons full height from the top of the steel connection ring to the foundation footing (Drawing D-30).

Task 6.5 Grout all vertical strand tendons: Grout from bottom upward in stages with interim grout vents and injection points every 10 m (32 ft). Grouting tendons from below will require high grout pump pressure and plasticizing admixture. Add thixotropic admixture to prevent grout segregation problems in vertical tendons.

All vertical tendons are grouted in one final operation. Vertical tendons stressed to Ring Nos. 6 and 10 are not grouted until all tendons are installed and stressed. This avoids the remote possibility of tendon grout migrating from the tendon being grouted to an empty duct.

Task List 7: Jack-Up Steel Tube Inside Completed Concrete Tower

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 7.1 Prepare for jack-up operation
Task 7.1.1 Install three jack-up tendons (Drawing D-8)
Task 7.1.2 Install upper guide skid assemblies (Drawings D-8, D-32, D-34, and D-35)

Task 7.1.3 Remove pedestal crane from top of steel tube
Task 7.1.4 Erect transition pedestal and turbine nacelle on the steel tube (Drawing D-3)
Task 7.1.5 Erect and connect turbine hub and blades to nacelle (Drawing D-31)
Task 7.1.6 Set up instrumentation to monitor jack-up process
Task 7.1.7 Remove hold-down anchor bolts at base flange of steel tube (Drawing D-8)
Task 7.2 Operate jack-up
Task 7.2.1 Test jack-up hydraulic system.
Task 7.2.2 Jack-up steel tube (Drawing D-32)
Task 7.2.3 Adjust guide skid assemblies during erection (Drawings D-32, D-34, and D-35)
Task 7.2.4 Monitor jack-up process
Task 7.2.5 Before final jack-up lifts, inspect alignment (Drawing D-36)
Task 7.2.6 Jack up tight against the steel connection ring (Drawing D-37)

Comments and Recommendations

Task 7.1 Preparation for a jack-up operation, such as is proposed here, requires the input of a firm specializing in this type of lift. While this is a feasible proven technology, the systems used to accomplish the lift must be sufficiently reliable and have sufficient redundancy and fail safety to reduce the risk of such a lift to acceptable levels. Similarly, the crews actually performing the lifts must be adequately trained in the operation of the systems involved. The assembly and testing of such a system for an installation of 50 towers is certainly practical and economically viable. As the number of towers in an installation decreases, the economic viability of doing all the things necessary to result in a low-risk lift of this sort will become more problematic.

Task 7.1.1 Install three, 9-strand, 15-mm (0.6-in.) diameter jack-up tendons, each with short stroke jack and pump at the top of the concrete tower. Jack-up force is applied by three 9 - 0.6-inch strand tendons stressed with short-stroke post-tension hydraulic jacks, each with a separate hydraulic pump, precision gauge, and controls. One operator at a central panel operates all three rams while monitoring pressure and elongation gauges. Using 360 kips combined weight of the steel tower plus the turbine module and blades, the 27, 15-mm (0.6-in.) diameter prestressed strands provide a safety factor of 4 with all strands equally loaded. The contractor may elect to use more strands to increase the safety factor (Drawing D-8).

Task 7.1.2 Install 18 upper guide skid assemblies bolted to top of the steel tower top connection annulus atop Concrete Ring No. 14. The fixtures shown are mechanically operated guides that are backed off before each 0.3-m (12-in.) jack-up lift. A hydraulically operated guide system, even though more costly to initially develop, may allow a more economical jack-up operation. This issue would be further explored in a final design for a site-specific application (Drawings D-8, D-32, D-34, and D-35).

Task 7.1.3 Remove the pedestal crane and support turntable from the top of the steel tube. This activity is performed with an appropriately sized crawler crane. The Manitowoc 4100W series or the LTL 600 series crane is used for this work.

Task 7.1.4 Erect the transition pedestal and turbine nacelle on top of the steel tube. Use the Lampson LTL 600 series crane to make these lifts to the 50-m (164-ft) level. By lifting these elements only to the 50-m level, the cost of mobilizing and renting a larger crane is avoided and the overall time required for the lift is reduced (Drawing D-31).

Task 7.1.5 Erect the hub and connect the turbine blades to the hub. Use the Lampson LTL 600 series crane to make these lifts to the 50-m (164-ft) level. By lifting these elements only to the 50-m level the cost of mobilizing and renting a larger crane is avoided (Drawing D-31).

Task 7.1.6 Set up instrumentation to monitor plumbness and rotational location of the steel tower as it is raised. In the final design of the jack-up system, it may be determined that a supplemental guide system that is engaged at, say, the 75% point of the jack-up process may be desirable. At this point, the rotational position of the tower could be easily adjusted.

Task 7.1.7 Loosen and remove the A-490 hold-down anchor bolts connecting the base flange of steel tube to the foundation. This can be done once the upper and lower reaction rollers and plates are engaged to react overturning loads (Drawing D-8).

Task 7.2 Jack-up Operation (Weight: Steel Tube + Turbine Module = 150,000 kg [330 kips]): The jack-up operation should not be planned for a day when high winds are expected. Although the system will be designed to be safe in the event the jack-up operation is exposed to high winds, performing this operation in high winds will be more difficult and prone to problems than if the operation is performed in low-wind conditions.

Task 7.2.1 Test the jack up hydraulic system by preloading jacks to 11,400 kg (25 kips) each. All the redundant and emergency lock-up systems for the jack-up system should be checked at this time as well.

Task 7.2.2 Jack-up the steel tube in 0.3-m (12-in.) ± lifts in round-the-clock operation, taking care to stay within wind speed limits. Assuming three minutes per 0.3-m (12-in.) jacking stroke plus 3 minutes to retract the hydraulic ram and check the thrusters results in 6 minutes per 0.3-m (12-in.) lift, or 3 m (10 ft) lift per hour. Thus, the jack-up operation, assuming no delaying problems, would take 10–12 hours, plus 2 more hours to install and tighten enough bolts in the tower top connection to stabilize the connection to handle normal wind loads. If high winds or other unexpected problems arise, the jack-up operation is reversible. The three post-tensioning rams can be used to lower the load (Drawing D-32).

Task 7.2.3 To accommodate the taper in the steel tube, it is necessary to back off the upper guide skid thruster assemblies approximately 5 mm (3/16 in.) before each 0.3-m (12-in.) jack-up lift to prevent binding of the thruster assemblies. Two sets of horizontal thrusters are employed to resist the wind loads on the steel tower plus turbine module during jack-up. The upper thrusters are attached to the steel tower top connector ring anchored to the top of the concrete tower. The lower thrusters are mounted on a frame connected to the underside of the steel tube flange ring (Drawings D-32, D-34, and D-35).

During jack-up, the upper and lower sets of thrusters provide the moment couple to resist lateral moment caused by wind loads on the steel tower and turbine module. As the jack-up of the steel tube progresses, the potential applied wind moment increases and the moment arm between the two thruster sets decreases. To avoid overloading the upper and lower horizontal thrusters, wind loads on the tower during jack-up must be carefully controlled as follows:

Disconnecting the steel tower from the foundation and commencing jack-up shall not commence when sustained wind speeds > 30 mph (or predicted during the 12–16 hour jack-up operation)

During jack-up, the lift shall not proceed beyond 80% of the full lift when sustained wind speeds > 20 mph.

Task 7.2.4 Monitor steel tube plumbness with transits and other instrumentation; adjust as required with upper guide skid thrust assemblies.

Task 7.2.5 Before the final 600-mm (24-in.) jack-up lifts, inspect from the underside platform to determine that the tapered centering cones on the tube flange are lined up with the female sockets on the steel tower top connection ring mounted atop Concrete Ring No. 14. During the final 300 mm (12 in.) of jack-up, three tapered cones stab into precisely matched sockets to ensure the precise mating of the annular tower flange ring with the annular tower top connection ring mounted on top of the concrete. This mating is designed to line up the match-drilled bolt holes in the two annular rings so that the connecting bolts can be quickly installed and tightened (Drawing D-36).

Task 7.2.6 Jack up the final 600 mm (24 in.), tight against the underside of the steel connection ring, and lock off the strand tendons (Drawing D-37). At this point, the connection between the steel tower and the concrete tower is ready for bolting.

Task List 8: Complete the Concrete/Steel Hybrid Tower

This task area involves the following tasks and activities. Drawings referenced are in Appendix D.

Task 8.1 Install connection bolts (Drawings D-28 and D-37)
Task 8.2 Install connection cover for the tower top connection ring
Task 8.3 Lower and remove the interior platforms and staging (Drawing D-32).
Task 8.4 Install interior access ladder and platforms inside concrete tower
Task 8.5 Remove temporary scaffolds/ladder system from concrete tower (Drawing D-18).

Comments and Recommendations

Not included in these final tasks is the installation of the electrical conductors, operation controls, and commissioning the wind turbine and generator system. The DGC and electrical contractor may connect electrical conductors and other wiring to the turbine module and inside the steel tower before the jack-up operation so that these payout from bottom spools as the tower and module are raised.

Task 8.1 With the steel tower flange jacked up tight against the underside of the steel connection ring, install A-490 connection bolts and torque them to the specified tension (Drawings D-28 and D-37).

Task 8.2 After tensioning and inspecting the bolts, touch up all steel with specified paint and cover the top of the connection annular ring with a segmented stainless steel sheet-metal cap to provide weather protection (Drawing D-37).

Task 8.3 Unbolt and lower the platform and hardware suspended under the jacked-up steel tower. When at the bottom, unbolt the components and remove them from inside the concrete tower through the access manway (Drawing D-32).

Task 8.4 Install interior access ladder and platforms inside the concrete tower by manhandling short sections through the lower access manway and hoisting them up inside the tower. Connect them to the interior concrete by drill-in inserts. The access ladder and platform system installed inside the concrete tower connects to the access ladder and platform system preinstalled inside the steel tube. This provides uninterrupted worker access from the manway at the bottom of the concrete all the way to the turbine module mounted atop the steel tube.

Task 8.5 Remove the bolt-on scaffolds/ladder system from outside the concrete tower (Drawing D-18).

The sizes and number of precast concrete rings required for each tower type and size are given in Appendix H.

10.4 Erection Crane Considerations

The WindPACT Technical Area 2 Study [17] was used as a guide for selecting the appropriate cranes to support the tower erection effort. Mobile crane costs used for the estimates developed in this study are from [17]. The estimate for the pedestal crane cost was developed as part of this study. Table 10.1 shows the crane selection for the various operations. The general crane philosophy for this study follows:

10.4.1. Hybrid Steel/Concrete Tower

The hybrid towers all use mobile cranes of the appropriate size to erect the partial-height steel tubular tower on the foundation. This same crane is used to set the pedestal crane atop the temporarily erected steel tubular tower at the approximately 50-m level. The precast erection is handled by the tower top pedestal crane. Before jack-up, the nacelle, hub, and rotor are erected at the approximate 50-m height by a mobile crane of appropriate size for the lift to this level.

Table 10.1. Crane Data Used for Selection of Mobile Cranes for Tower Construction

	B/A Study Tower Head Mass (Kg)	WindPACT Area 2 Tower Hd Mass (kg)	WindPACT Area 2 Nacelle Mass (kg)	Precast Segment Max Weight (kg)	B/A Study Tower Ht. (m)	WindPACT Area 2 Tower Ht. (m)	WindPACT Area 2 Crane Selection	B/A Study PC Segment Crane Selection	B/A Study NacelleCrane Selection	Rated Radius (m)	Rated Max Load @ rated radius (kg)
0.75MW		45428	31081	NA	NA	65.1	4100W	NA	NA	23	36400
							4600W			16	64000
1.5 MW Hybrid	84,800	91,747	61,517	26,045	51	86.0	LTL-600	4100W	LTL-600	30	170,500
1.5 MW All concrete	84,800	91,747	61,517	26,045	100	86.0	LTL-600	LTL-600	LTL-850	34	207,400
2.5 MW	NA	174,091	111,065	NA	NA	110.5	LT-850		NA		
3.6 MW Hybrid	314,912	262,708	164,049	26,772	53	130.2	LTL-1100	4100W	LTL-850	34	207,400
3.6 MW All Concrete	314,912	262,708	164,049	27,181	100	130.2	LTL-1100	LTL-600	LTL-850	34	207,400
5.0 MW Hybrid	480,076	416,815	254,102	25,681	53	156.1	LTL-1200	4100W	LTL-1100*	32	213,500
5.0 MW All Concrete	480,076	416,815	254,102	25,681	100	156.1	LTL-1200	LTL-600	LTL-1100*	32	213,500
	* increased load capacity at reduced radius should be adequate for the reduced lift heights in this study.										

Crane Costs from WindPACT Area 2	Mob De Mob	Basic Monthly Rental (assume 12 mo,)	Loaded Hourly Crane Costs (40 hrs/wk) $/hr	Days to Assemble (Per Turbine)	Labor Cost to Assemble (Per Turbine)	Days to Relocate (Per Turbine)	Labor Cost to Relocate (Per Turbine)	Cribbing Cost (Per Turbine)	Meals and Lodging (Per Turbine)	Fuel Cost (Per Month)	
4100	$66,416	$13,000	$374	1.05	$1,365	0.60	$780	$131	$248	$1,429	
4600	$123,833	$27,733	$490								
LTL-600	$415,091	$78,000	$920	1.89	$3,685	0.80	$1,560	$538	$605	$4,222	
LTL-850	$484,727	$86,667	$910	3.76	$7,332	1.40	$2,730	$808	$1,161	$4,222	
LTL-1000	$976,118	$108,333	$1,030								
LTL 1100	$1,107,036	$121,333	$1,125	5.28	$10,296	2.50	$4,875	$943	$1,751	$4,547	
LTL 1200	$1,605,782	$151,667	$1,259								

10.4.2. All-Precast Concrete Tower

The all-precast towers are assumed to be erected by a mobile crane of the appropriate size. Upon completion of the tower, the nacelle, hub, and rotor are erected atop the tower at the 100-m height using a mobile crane of the appropriate size for the lift.

10.4.3. All-Cast-in-Place Concrete Tower

Materials and personnel movements are handled by a ground-based hoist system and a tower-mounted derrick that climbs as the tower construction progresses. Upon completion of the tower, the nacelle, hub, and rotor are erected atop the tower at the 100-m height using a mobile crane of the appropriate size for the lift.

10.4.4. All-Tubular-Steel Tower

The all-tubular-steel towers are assumed to be erected in sections and the horizontal joints welded after erection. The tower sections are erected using a mobile crane of appropriate size for the load and lift height. Upon completion of the tower, the nacelle, hub, and rotor are erected atop the tower at the 100-m height using a mobile crane of the appropriate size for the lift.

The total cost of cranes for each of the tower construction approaches considered is given in Table 10.2. The observation that stands out is that, because of the high crane costs associated with erecting the precast concrete pieces for the all-precast concept, there is significant opportunity for cost reduction in this tower concept if a purpose-built tower crane can be developed to support only the precast erection. It appears that self-erection for the nacelle, hub, and rotor are likely to be more costly than the use of a mobile crane for erection of these elements at the 100-m level.

Table 10.2. Crane Costs for the Tower Construction Concepts

50 Tower Project Crane Costs - Design, Development, Mobilization + Rental & Operational Cost For Duration Needed								
	Pedestal Cranes	Steel Tower Erection Cranes	Precast Erection Cranes	Nacelle Erection Crane	Total Crane Costs	Total Costs Per Tower	% of Tower Cost	Crane Costs $/KW
1.5 MW -100 m Hub Height								
Hybrid Steel Concrete	$900,000	$1,234,475		$1,474,489	$3,608,964	$72,179	5.1%	$48
All Precast Concrete			$11,028,165	$2,052,323	$13,080,488	$261,610	17.1%	$174
All Cast in Place Concrete				$2,265,967	$2,265,967	$45,319	3.8%	$30
All Tubular Steel		$6,497,993		$2,052,323	$8,550,316	$171,006	12.5%	$114
3.6 MW - 100 M Hub Height								
Hybrid Steel Concrete	$1,150,000	$1,603,900		$2,209,784	$4,963,684	$99,274	4.1%	$28
All Precast Concrete			$13,663,250	$2,479,612	$16,142,862	$322,857	16.4%	$90
All Cast in Place Concrete				$2,693,257	$2,693,257	$53,865	3.5%	$15
All Tubular Steel		$8,886,412		$2,479,612	$11,366,024	$227,320	9.0%	$63
5.0 MW - 100 m Hub Height								
Hybrid Steel Concrete	$1,650,000	$2,342,750		$4,266,126	$8,258,876	$165,178	4.9%	$33
All Precast Concrete			$13,549,256	$4,266,126	$17,815,382	$356,308	15.2%	$71
All Cast in Place Concrete				$4,555,650	$4,555,650	$91,113	5.5%	$18
All Tubular Steel		$11,028,165		$4,266,126	$15,294,291	$305,886	9.8%	$61

The cost advantage of the jack-up system that allows installing the nacelle, hub, and rotor at the 50-m level is small ($12,000 per tower) in relation to the total tower cost. The real cost advantage from a crane-cost point of view of this jack-up concept stems from the lower cost involved with erecting the reduced number of precast pieces involved using the tower top-mounted pedestal crane.

10.5 Construction of All-Precast-Concrete Wind Turbine Towers

The construction of the all-precast-concrete wind turbine towers is similar to the construction of the concrete tower portion of the hybrid steel/concrete towers described in detail in Section 10.4. The sizes and number of precast concrete rings and segments involved for each tower type and size are given in Appendix H. The primary differences are that the erection of the precast elements is assumed to be by mobile crane and the installation of the large tower top connection ring that joins the steel and concrete towers is not needed. The turbine nacelle is assumed to connect to the reduced size concrete tower top steel plate through a short tubular steel transition section that is match drilled with the tower top ring in a manner similar to that described in Section 10.4 for the tubular tower base flange ring and the tower top connection ring.

After the precast concrete tower construction is complete, the turbine nacelle, hub, and rotor are erected at the 100-m height using a mobile crane of appropriate size for the lift.

10.6 Construction of All-Cast-in-Place Concrete Wind Turbine Towers

Hamon Custodis, an experienced industrial chimney contractor, developed a construction plan and cost estimate for the all-cast-in-place 100-m (328-ft) full-height towers. They did not address the construction of the hybrid towers at this time, as a significant redesign of their customary construction method would be required to allow construction around the pre-erected steel tube as envisioned in the hybrid concept. They also did not price the addition of post-tensioning to the tower structure. The cost of the post-tensioning has been added to the Hamon Custodis estimate by BERGER/ABAM. Similarly, we have added the cost of the foundation, erecting the nacelle, hub, and rotor, and have added site mobilization costs and site development costs to make the all-cast-in-place concrete estimates consistent with the estimates for the other concepts.

10.6.1 Safety

Because significant amounts of work are performed at significant distances above the ground, the issue of personnel safety demands special attention for a project such as this. The following items were outlined as included in the work plan and cost estimate developed by Hamon Custodis.

- Training – All Hamon Custodis employees are instructed in standard safety procedures as contained the Hamon Custodis *Safety Policies and Procedures Manual* in accordance with all applicable Occupational Safety and Health Administration (OSHA) and industry standards. Supervisory personnel receive in-depth annual refresher training. A full-time site safety officer will be assigned to the project.

  Before beginning the project, a Construction Health and Safety Plan (CHASP) will be developed. The job superintendent and site safety officer conduct a safety training review with all members of the assigned crew. New hires are furnished with a personal copy of the Hamon Custodis safety handbook and verbally instructed in all safety regulations applicable to the current project. A sign-off form is used to indicate that members are trained and topics are covered in each safety training session.

- Safety meetings – Reinforcement of the training will be given via toolbox safety talks. Job Hazard Analyses (JHAs) are prepared and reviewed daily. Before each new activity, a safety meeting is held to identify and discuss possible hazards addressed in the JHA. Safety meetings are documented on the Hamon Custodis safety meeting report form, which indicates the members present and topics discussed.

- In accordance with Hamon Custodis health and safety procedures, 100% fall protection techniques are required when personnel are exposed to potential falls greater than 2 m (6 ft). This policy is reviewed daily with the crew, and a sign-off form is used to confirm agreement to adhere to this policy.

- Safety equipment used during construction will consist of hard hats, safety glasses, welding/burning goggles, work gloves, full body harnesses with double lanyards for fall protection, appropriate clothing, two-way radios, other activity-specific safety equipment, and an intercom system to allow the hoist operator to maintain constant communication with the workers in the tower.

- Safety buffer – In accordance with Hamon Custodis safety requirements, a 15.2-m (50-ft) buffer zone will be established around the base of the tower with fencing or caution tape. Unauthorized personnel will be prohibited from entering this area unless prior permission is obtained from the job superintendent.

10.6.2 Facility Plan

- The safety buffer zone is required, in a 15.2-m (50-ft) radius from the exterior surface of the concrete tower.

- In this area, clear and unobstructed access to the base of the tower, free from any obstructions or the activities of other contractors, is required.

- A 30-m by 30-m (100-ft by 100-ft) laydown area adjacent to each tower foundation is required.
- Within the laydown area, a 3-m by 15.2-m (10-ft by 50-ft) office/change trailer with telephone, electrical service, and a first-aid station will be located.
- A 2.4-m by 12-m (8-ft by 40-ft) tool van area will be provided at the base of the tower.
- 220-V 3-phase power is required within 15.2 m (50 ft) of the base of the tower.
- A 2.4-m by 5-m (8-ft by 16-ft) concrete pad and wood frame shed to house the single drum diesel hoist will be constructed approximately 23 m (75 ft) from the base of the tower. The hoists will be used to transport personnel and lift materials.

10.6.3 Construction

The concrete tower will be constructed using the Hamon Custodis jump-form equipment whereby a 2.3-m (7.5-ft) vertical section of concrete is cast each day.

Once the initial site familiarization and orientation is complete, grade and reference lines are established on the foundation. The assembly of the derrick used to erect the concrete tower begins with the lower half of the derrick being constructed on the foundation center. The top half of the derrick, with outriggers, chain blocks, etc, is assembled to one side as area constraints allow. The top half of the approximately 18.3-m (60-ft) high derrick is then attached to the bottom half by raising it with a cherry picker and settling it over the derrick splice tubes and then bolting the pieces together. The assembled derrick is then guyed and secured.

Outside formwork is bolted together with the appropriate taper sheets installed. Various form hardware is attached. The forms are then centered and plumbed with a laser from a center point on the foundation to a center on a target at the form height. Tape measures are used to measure a prescribed radius, and the forms are adjusted to the required radius using adjusting bolts. Reinforcing steel for the initial section is installed and spaced from the outside form to provide specified concrete cover.

During the outside form and reinforcement installation activity, the timber work platform is constructed and raised 2.4 m (8 ft) using chain blocks connected to the derrick outriggers. The inside concrete forms are installed, and form walers are positioned and tightened. Concrete is placed into the formwork using a 0.48-m^3 (5/8-yd^3) concrete bucket hoisted by the cherry picker. The concrete is placed around the perimeter in approximately 0.46-m (18-in.) lifts while being vibrated continuously.

The next two concrete sections follow the same procedure, except that the inside and outside concrete forms are raised as compete units via chain blocks.

Once concrete for the fourth section of the tower is placed, the erection derrick is attached to previously embedded structural inserts that will act as supports for raising the derrick after each section of concrete is placed. The power-up and power-down construction hoist is then connected for the purpose of hoisting materials to the work deck. This hoist is also used to bring personnel to the working level via a man cage with safety clamps that activate if the main hoist cable breaks. Crew personnel will be hoisted in strict accordance with OSHA's standard for personnel hoisting.

The daily procedure for casting each subsequent section of concrete follows:

1. Raise, plumb, and secure the derrick at the new construction level.

2. Break loose the outside concrete forms, raise them to the next section elevation, and secure them in place. Center and plumb the forms with a laser from the center point on the foundation

3. Install reinforcement bars, opening blocks, post-tensioning ducts, and embedded items as required.

4. Raise and secure the inside forms.

5. Place the section of concrete.

6. Repeat the procedure. (Add an extra day for two elevation locations when interim post-tensioning anchors must be installed.)

Radio communications are also established from the operating engineer, to the bottom of the tower (foundation) and the top work area, using a talk-a-phone and two-way speakers.

All material and concrete hoisting is by the same construction hoist, with the man cage removed. This system allows for a very minimal hookup time of the man cage, should a situation arise where it is needed.

Upon completion of the tower, the formwork is removed and lowered to the ground. Temporary grillage work is placed on top of the tower to provide a means of lowering the derrick and material and personnel hoisting equipment.

10.6.4 Jump Forming versus Slip Forming

Hammon Custodis based its cost estimate on the use of jump-form construction. For the height and size of the towers proposed, jump forming is a more economical method of construction than slip forming. Slip forming would require more costly equipment and a larger crew. To be cost effective, slip forming usually requires a 24-hour-per-day operation. This would require around-the-clock access and support services at the site. In addition, concrete supply costs, whether procured from an off-site batch plant or an on-site batch plant, would be higher for slip forming because of the relatively small quantities of concrete required more or less continuously.

10.6.5 Concrete Supply

Hamon Custodis based the concrete supply cost on the cost of concrete furnished by an off-site commercial batch plant in the region. For the total quantity of concrete required for the towers and foundations, an on-site batch plant could be justified. Depending on the final location of the site, if a commercial batch plant is not located close enough to the site to reliably deliver ready-mixed concrete within the time limits and of the quality required for structural concrete, it may be necessary to set up an on-site batch plant.

10.6.6 Hybrid Concrete Tower Using Cast-in-Place Concrete Methods

Although Hamon Custodis did not investigate the cost of construction for cast-in-place concrete towers for the hybrid steel/concrete tower arrangement, the following comments are offered regarding the use of chimney construction methods for this concept.

Construction of the cast-in-place concrete tower around the steel tower would prevent the use of standard jump-form chimney construction equipment, which uses a central self-climbing derrick supported on the inside of the tower and an interior work platform. A revised approach that uses work platforms located on the exterior perimeter of the tower and interior forms that are very compact would be required to allow the cast-in-place construction of the concrete tower around the steel tube. A method of bracing the interior form system against the steel tube may be viable, but would require development to the same extent that the precast concrete construction concept has been developed in this study. The differential turbine nacelle, hub, and rotor erection crane costs of about $16,000 per tower for the 1.5-MW turbine hybrid steel/concrete concept (erection at 50 m) versus cast-in-place concrete concept (erection at 100 m) may not warrant this type of development.

10.7 Construction of the Steel Wind Turbine Towers

The all-tubular-steel tower for the 1.5-MW hybrid steel/concrete tower can be shipped to the site in three lengths that are shop prefabricated to the full circular section of the tower. We envision that the base section is erected on the foundation first, and then subsequent sections are erected and the horizontal welds completed as described in Section 10.4.

The larger-diameter tubular towers are envisioned being erected in a similar way. The larger-diameter towers will be shipped from the fabrication facility in truck-shippable lengths and will be sectioned into vertical quarter rounds that meet highway dimensional load limits. These quarter-round sections of plate will be welded together vertically at or near the construction site before being erected.

After the all construction is complete, the turbine nacelle, hub, and rotor are installed with a crane of the appropriate size for the lift.

11.0 Cost and Risk Analysis

The aggregate costs developed in this study have been noted to be higher than previously published in WindPACT studies. A question to be considered is, Are these tower cost estimates higher than the likely actual cost of construction?

The basic cast-in-place tower costs were developed by an established industrial chimney contractor experienced in the construction of structures of similar size and configuration. This study added the costs of prestressing and turbine erection to the basic costs from the chimney contractor. Thus, these costs represent a benchmark of reasonableness for the concrete tower concept. The fact that the all-precast-concrete and the precast concrete/steel hybrid towers are more costly than the cast-in-place concrete towers is reasonable, based on the construction operations associated with these concepts. It is possible that different precast concrete tower concepts could have costs lower than those estimated here.

As outlined below, we have included overhead and profit markups that total 30% on the total construction cost. This is to account for an assumed turnkey general contractor/subcontractor organization to build 50 towers. It may be possible to organize the project so that the total overhead and profit markup is significantly lower. It would require a project organization where the general contractor performs significant portions of the construction work.

There is a question as to whether the baseline steel tower costs are higher than the likely actual cost of construction. The currently produced sizes of tubular steel towers, 1.5-MW, 65-m hub height and smaller, have maximized the amount of off-site prefabrication, creating significant economy in the overall steel-tower construction process. The construction approach assumed for the large steel towers considered in this study is the one assumed in [17]. In this approach, large tower cross sections are shipped via highway to the site in quarter sections. This approach shifts substantial amounts of work previously performed in an efficient and economical factory environment into the field. Field fabrication costs are higher, and more supporting crane costs than are typical for smaller turbine/tower combinations are incurred with this approach. It is possible that more cost-effective fabrication procedures for large steel towers than those assumed in WindPACT Technical Area 2 and used in this study can be developed, resulting in a reduction in steel fabrication costs over those used in this study.

The WindPACT Turbine Rotor Design Study [26] notes the potential of significant reduction in the level of tower fatigue loading through active control of the turbine rotor. Because the steel tower designs are controlled by fatigue, this technology has the potential to reduce the quantity and cost of steel material needed in large tower designs.

The towers considered in this study were all set at 100-m (328-ft) hub height, as this was indicated to be a height of current industry interest. The WindPACT tower heights (1.5-MW, 84-m; 3.0-MW, 119 m; and 5.0-MW, 154-m) result in different relationships of tower cost to annual energy production than the towers considered here. The use of taller towers for the larger turbines may result in different conclusions relative to the tower effects on the total cost of energy.

Outlined below is a description of what has been included in the cost estimates prepared. Included in Appendix C are all of the background cost estimates that form the basis for the comparisons given. Although there is a large database of tower costs for tower sizes that are currently being built, there is only proprietary, generally unavailable, data for the few towers that have been built in the larger sizes addressed in this report. As the industry moves forward with design and construction of large wind turbine towers, it will be important to develop a cost database founded on actual construction costs that can be used to validate or refine the costs estimates developed here.

The design criteria used to size the concrete towers considered in this study, both dynamic and strength related, may be subject to future refinement. Generally, with new classes of structures, such as these large wind towers represent, design criteria starts off as somewhat conservative and related to other structures judged to be similar. The designs, including the criteria, are then refined and optimized over time using lessons learned from actual performance. The optimization is usually for cost minimization. This activity continues until failures or performance problems begin to occur and then the design criteria or the design methodology is revised to account for the causes of the failures or problems noted.

Because these towers are being designed for high extreme wind loads and high numbers of fatigue cycles, it may be many years before the performance of towers designed and constructed are actually tested against their extreme design conditions. For this reason, projects that involve instrumentation and calibration testing of large towers to provide performance data points that can be used to guide the design of large wind turbine towers will be of considerable value to the industry. This type of information is essential input to any efforts to refine the design methodology and design criteria used in development of both large-diameter steel towers and prestressed concrete towers.

11.1 Cost Study

In the development of cost estimates for the hybrid steel/concrete and the all-precast-concrete towers considered here, it is not possible to rely on the large background of construction cost-estimating tools and experience available for most types of construction in the United States. This is because similar tower structures of the scale considered here have not been built in the large numbers that allow the development of typical unit costs for the types of material and construction operations involved. Key elements of the cast-in-place concrete towers were estimated by an experienced industrial chimney contractor assuming the type of construction technology typically used for large industrial chimney construction.

The tower configurations for which costs are estimated here are the result of preliminary structural designs based on actual design loads and dynamic requirements for the turbine sizes involved. Thus, the tower cross sections developed and the prestressing and reinforcing steel used in the estimates are based on the actual structural requirements for the various different turbine sizes.

For this study, costs were developed for all the significant cost elements involved with constructing a wind turbine installation except the procurement costs of the turbine hub and rotor and the electrical work to move the power from the turbine into the power distribution grid. Thus, the tower costs include the cost of fabricating the tower elements at the factory; shipping them to the site; developing the site roadway system and contractor support offices, etc. necessary to support a large 50-tower construction project; construction of foundations; assembly of the tower elements on site; the labor and equipment necessary to support erection and integration of the tower elements; and the cranes and labor necessary to erect the turbine, hub, and rotor on the tower. Also included are markups for general contractor field overhead, administrative overhead, and profit.

As outlined, elements of the WindPACT work were used to estimate transportation to the site; balance of station elements necessary to support the tower construction; assembly of large tower elements on site; mobilization and rental of cranes and crews necessary to support the tower erection; and the erection of the turbine, hub, and blades.

All of these elements were included to provide a more complete assessment of how important various elements of the tower design and construction activity were to the overall project cost for 25 or 50 towers.

The estimates developed include some balance of station items associated with the construction of the towers. When tower costs are discussed in the WindPACT literature, the costs typically quoted are the freight on board (FOB) fabrication facility structural steel costs. The tower costs estimated in this study also include the cost for the labor and equipment associated with erecting the turbine nacelle, hub, and rotor. These costs are included so that the cost benefits of the semi-self-erection concept used for the hybrid towers and the consequence of the increased mass of the concrete towers can be assessed. Thus, these estimates include:

- Construction of a road to the tower locations
- Construction of site construction offices and furnishings
- Recruitment of management personnel and labor for the tower construction effort
- Design of any special construction equipment needed
- Mobilization, monthly rental, and operating costs for cranes
- Equipment move-in costs
- Construction project mobilization costs
- Foundation construction
- Steel tube tower fabrication, shipping, site assembly, and erection
- Precast concrete fabrication, shipping, site erection, and integration
- Semi-self-erection of hybrid steel/concrete tower
- Erection and installation of turbine nacelle, hub and rotor (but not the procurement cost for these elements)
- Final installation and touch up.

Costs associated with electrical and mechanical systems required to complete the wind farm installation are not included in the basic cost estimates used for cost comparisons. Costs for these items [26] are included in the cost of energy (COE) calculations given in Appendix I.

Items that are the same from one type of installation to the next have not been changed in cost from one tower estimate to another tower estimate; those items that vary with the different concepts have been estimated accordingly. The detailed cost estimate spreadsheets are given in Appendix C and summarized in Section 11.1.8.

11.1.1 Estimating Methodology

Preliminary designs were developed for all the tower concepts with the same design criteria for each turbine size considered so that the estimates developed are consistent from one tower concept to another. The approach to estimating the different tower concepts addressed in this study was to determine first the construction procedure required for the hybrid steel/concrete tower, which was deemed to have the most different operations involved. The involved operations, tasks, and equipment requirements were then defined, and levels of effort and durations for both labor and equipment were then estimated for all the defined tasks and operations. These tasks and operations are listed in some detail on the cost estimating spreadsheets provided in Appendix C.

All project construction for all turbine sizes and construction concepts for both the 50-tower and 25-tower-project sizes was assumed to take place in a 28-month period. Individual tower construction durations for the different tower types were estimated, and these durations were used in the project schedules developed for each tower type and size to determine the production rates for the various aspects of the work and the associated labor and equipment needed to support the estimated construction rates. These project schedules are provided in Appendix G.

- **Hybrid steel/concrete towers**. The hybrid steel/concrete tower was used as the baseline to develop the tower estimates. The construction requirements for this concept at the 1.5-MW turbine size were developed in some detail so that all the operations required to construct the design could be identified. The description of this construction activity is provided in Section 10.4.

- **All-precast concrete towers**. The all-precast-concrete towers were estimated with the same basic construction procedures developed for the hybrid steel/concrete tower. The erection was assumed to be entirely accomplished by mobile crane.

- **All-cast-in-place concrete Towers**. The basic cast-in-place towers were estimated by Hamon Custodis, an industrial chimney contractor. BERGER/ABAM modified these estimates to include the cost of post-tensioning and erecting the turbine on the towers.

- **All-tubular-steel towers**. The all-tubular-steel towers were estimated based on shop fabrication of the formed plate steel shells and delivery to the site for assembly and erection. The larger towers were assumed to be shipped to the site in quartered sections. Costs for material and shop fabrication of the tubular steel shells FOB the fabrication facility were developed from discussions with experienced steel tower fabricators. Costs for shipping, joining the quartered sections, and erection times to determine crane time and cost requirements were derived from [17].

11.1.2 Raw Material Costs

- **Concrete**. Concrete for the foundations and cast-in-place joints was assumed available from a local ready-mix concrete supplier within transit distance from the site. No on-site concrete batch plant is assumed. If an on-site batch plant is required, a small increase in the concrete cost is likely. The concrete for the precast segments is assumed to be produced by the plant precast supplier at or near the precast-concrete fabrication facility.

- **Reinforcing steel**. Reinforcing steel unit prices, including labor, were developed from experience and [23].

- **Prestressing steel**. Prestressing steel unit prices were developed from experience, supplier input, and recent project pricing history.

- **Tubular tower steel**. See Section 11.2 for comments on unit prices used for fabricated tubular tower steel.

- **Plates and connection steel**. Plates and connection steel were estimated at a fabricated price of \$1.50–\$2.50/lb (\$3.30–\$5.50/kg), depending on the complexity of the element involved.

- Table 11.2 shows the effect on tower cost of the significant escalation in plate steel, reinforcing steel, and prestressing steel prices that were in effect as of March 2004.

11.1.3 Labor Costs

Labor in the precast plant was estimated on the basis of crew hours for a typical precast plant crew, including supervision.

Site labor and crane crew operating labor were estimated at separate rates. Some material costs are given in place, such as placement of the foundation concrete, and include the cost effect of labor for placement.

11.1.4 Transportation Costs

- **Transportation of precast concrete segments**. Assumed delivered to the site 300 miles by truck with one segment per truck load.

- **Transportation of steel tower sections**. Based on [17].

- **Transportation of cast-in-place concrete**. Assumed from a local ready-mix concrete supplier within transit distance of the site. Transportation included in concrete cost.

11.1.5 Site Development Costs

This cost includes cost for an access road developed from information in [19]. It also includes an allowance for site offices and equipment, equipment and move-in allowance, and mobilization and miscellaneous site development costs.

11.1.6 Overhead and Profit Markups and Estimating Contingency

Overhead and profit markups in large projects often have a significant effect on the overall project cost. Generally speaking, larger, more complex projects require larger and more costly construction organizations to successfully handle the project construction activity. This increased cost shows up in the form of general contractor administrative and overhead charges to the project and in profit assumed. For this project, we have assumed a 10% field overhead, a 10% administrative overhead, and a 10% profit for a general contractor who will have turnkey responsibility for delivering the completed project. Overall, these markups result in a 30% markup to project costs.

We have not included either a design or an estimating contingency in the cost estimates prepared for this study. While the magnitude of the general contractor markups and the number of tiers of subcontractors involved (who also have markups) will be important elements to be determined as a large project is organized, it is felt that, absent estimating contingencies, the total 30% general contractor markup is appropriate.

11.1.7 Combined Effect of Differences in Estimating Inputs

This report focuses on the development of concrete and hybrid steel/concrete large-scale wind turbine towers. Preliminary designs of all-steel towers designed for the same applied loads were also prepared as a comparison cost baseline. The estimates prepared for this study are consistent for the various tower concepts considered and thus represent a reasonable basis for cost comparison among the concepts considered.

Comparison of the tower costs developed here with known costs for smaller towers and with published costs in studies of towers of this size must consider the differences in the purpose of the study involved, differences in material prices assumed, and differences in what is included or not included in the quoted "tower cost." In the basic estimates prepared here, we have included a number of cost items that are not typically considered "tower cost." This was done so that the cost significance of different aspects of the overall tower construction and turbine installation process could be evaluated as an indicator to cost risks and future final design optimization efforts. Section 11.3 discusses, in the context of the COE calculation, the combined effects of some of the differences in discount rate, material costs, overhead markup, etc., that must be considered when comparing the cost results of this study with those of other studies.

11.1.8 Cost Estimate Breakdown

The following items were included in the basic cost estimate model. Only items that applied to a particular tower concept were used in developing the costs associated with that concept. Detailed cost estimates are given in Appendix C.

11.1.8.1 Mobilization and Site Development for a 50-Tower Site

- Access road
- Site offices and office equipment
- Management and supervision, recruitment and relocation
- Design/develop special pedestal cranes, 30-ton capacity
    - Fabricate, assemble pedestal cranes for erecting precast elements
    - Equipment move-in and setup
    - Other mobilization and site development cost
    - Mobilize/demobilize element/tube erection cranes to site
    - Rental for element/tube erection cranes
    - Labor cost to assemble cranes per turbine
    - Labor cost to relocate cranes per turbine
    - Mobilize, demobilize turbine setting cranes to site
    - Rental for turbine setting cranes
    - Labor cost to assemble turbine setting cranes per turbine
    - Labor cost to relocate turbine setting cranes per turbine
    - Crane cribbing cost per turbine
    - Meals and lodging for crane crews per turbine
    - Crane fuel costs per month
    - Other equipment rental

11.1.8.2 Foundation Construction

- Survey layout and location
- Geotechnical investigation (per tower location)
- Excavation for foundation
- Supply and install concrete forms for foundation
- Supply, place, and consolidate foundation concrete
- Supply and install foundation reinforcing steel
- A-490 anchor bolts and couplers
    - Template for anchor bolts and post-tensioning anchors and ducts
    - Backfill and tamp around foundation
    - Install untamped backfill

11.1.8.3 Shop Fabrication of Steel Tower

- Tube section material
- Tube section fabrication, rolled and welded
- Base flange ring
    - Cut, weld, stress relieve
    - Drill holes, mill after welding to tube section

- Top flange ring
  - Cut, weld, stress relieve
  - Drill holes, mill after welding to tube section
- Concrete tower top connection ring
  - Cut, weld, stress relieve
  - Drill holes to match tower flange
  - Mill to match tube flange
- Fabricate and install internal galvanized ladders
- Surface preparation, prime, and paint
  - Two coats primer on interior surfaces
  - Primer and epoxy finish coats on exterior
- Truck delivery of tower to site

11.1.8.4 Field Erection of Steel Tube and Pedestal Crane

- Fabricate jack-up frame and base supports
- Install base support system and jack-up frame
  - Site weld quartered tube sections
- Rig, erect, and fit steel tube sections
- Weld horizontal field joints
- Grout and torque tower base
- Erect special pedestal crane on top of steel tube

11.1.8.5 Precast Concrete Operation

- Design and fabricate Type A forms
- Design and fabricate Type B forms
- Design and fabricate Type C forms
- Install forms and startup at precast plant
- Precast A, B, and C segments as required
- Daily strip and setup forms
- Supply end plates and weld to horizontal rebar
- Supply and install rebar
- Supply and install embedments, each segment
- Supply duct for erection post-tensioning bars
- Install strand post-tensioning duct sleeves, each segment
- Install bar post-tensioning anchor plates and trumpets
- Supply and place concrete for precast segments
- Strip, handle, cure, and store precast segments
- Precast supervision, quality control, maintenance shop overhead
- Precast general and administrative overhead and profit

11.1.8.6 Field Erection and Post-Tensioning of Precast Concrete Tower

- Truck delivery of precast segments
- Fabricate joint closure forms
- Erect precast segment rings
  - Strip clean and oil top fixtures and forms
  - Set shims with level and glue gaskets

- Hoist and set precast segments

- Supply post-tensioning bars and couplers
- Install and stress post-tensioning bars
- Install top positioning fixtures
- Place and weld rebar splices and ties in vertical joints
- Inject grout in horizontal joints
- Attach closure joint forms
- Supply, place, and vibrate closure pour concrete
- Hoist, install, and level and grout concrete tower top connection plate
- Install, stress, and grout vertical strand post-tensioning tendons
- Supply post-tensioning anchors
- Supply vertical post-tensioning ducts
- Supply and install post-tensioning strand
- Stress post-tensioning tendons in stages
- Grout post-tensioning tendons
    - Supervision, overhead, and profit for strand post-tensioning subcontractor
    - Allowance for material handling, unloading, and equipment

11.1.8.7 Cast-in-Place Concrete Tower Construction

- Direct material costs for cast -in-place concrete construction
- Direct labor costs for cast-in-place concrete construction
- Equipment and site overhead for cast-in-place concrete construction

11.1.8.8 Jack-Up Steel Tube Inside of Concrete Tower

- Prepare for jack-up operation
- Supply and install jack-up tendons
- Jack-up anchors top and bottom
- Fabricate upper thruster assemblies
- Install upper thruster assemblies
- Fabricate lower thruster assemblies
- Install lower thruster assemblies
- Remove special pedestal crane and prepare for reinstallation
- Erect transition section and turbine nacelle
- Supply, install, and torque hs bolts
- Erect hub and blades to turbine nacelle
- Disconnect base flange of steel tube from anchor bolts
- Jack-up steel tube with turbine and blades attached
- Jack-up equipment rental
- Monitor with control transits
- Allowance for equipment and small cranes

11.1.8.9 Complete Concrete-to-Steel Connection

- Remove upper and lower thruster assemblies
- Supply, install and torque hs bolts
- Remove jack-up tendons and anchors

- Lower and remove tower base support frame
- Install weather protective flashing over concrete-to-steel joint
- Hoist in and install ladders and platforms inside of concrete tower
- Remove exterior scaffold platforms and connecting towers
- Touch up paint on steel tube exterior

11.1.8.10 General Contractor Markups

- General contractor field overhead
- General contractor administrative overhead
- General contractor profit

11.2 Cost Comparisons

In comparing the cost results of this study with those of *WindPACT Technical Area 2 and 3* studies [17,18], the tower heights for this study are all 100 m (328 ft). The comparable WindPACT study tower heights are given in Table 11.1.

Table 11.1. Wind Turbine Height Comparisons

Turbine Size	BERGER/ABAM	WindPACT Area 2	Turbine Rotor Design Study
0.75 MW	NA	65.1 m (213.6 ft)	60 m (196.8 ft)
1.5 MW	100 m (328 ft)	86.0 m (282.2 ft)	84 m (275.6 ft)
2.5 MW	NA	110.5 m (362.5 ft)	NA
3.6 MW	100 m (328 ft)	(3.5 MW) 130.2 m (427.2 ft)	(3.0 MW) 119 m (390.4 ft)
5.0 MW	100 m (328 ft)	156.1 m (512.1 ft)	154 m (505.2 ft)

Although the estimates developed in this study are based on quantities developed from actual preliminary designs of the tower structures, they should still be considered concept-level cost estimates. Thus, the accuracy variance on these estimates is likely to be ±20%. This range is the result of a combination of design and production unknowns and variability in construction contractor bidding approaches that may be in effect at the time of the actual construction. Because the estimate is not site specific, an additional variance will be associated with actual site conditions. For example, depending on the tower type and size, the foundation cost accounts for 8%–20% of the total installed tower cost. We have made assumptions regarding the geotechnical conditions of the site and have not attempted to optimize the foundation design, as the final design of the foundations will depend significantly on the local geotechnical conditions.

We are reporting cost numbers down to the nearest dollar so that the reader can track the numbers from the cost estimates given in Appendix C. This is not to imply that the estimates are accurate to this level of precision.

11.2.1 Cost Comparison of Tower Concepts

Table 11.2 and Figures 11.1 and 11.2 show the designations used to define the different tower types.

Table 11.2. Estimated Installed Tower Costs and Chart Tower Type Designations
(50-Tower Installation)

Turbine/Tower Size/Construction Method	Chart Designation	Installed Cost	$/KW
1.5 MW Hybrid Steel Concrete (EQ)	1.5 H EQ	$1,402,721	$935
1.5 MW All Precast Concrete (Wind)	1.5 P W	$1,581,707	$1,054
1.5 MW All Precast Concrete (EQ)	1.5 P EQ	$1,943,472	$1,296
1.5 MW All Cast in Place Concrete (EQ)	1.5 CIP EQ	$1,394,300	$930
1.5 MW All Cast in Place Concrete (Wind)	1.5 CIP W	$1,188,150	$792
1.5 MW All Tubular Steel (Wind)	1.5 S W	$1,369,656	$913
3.6 MW Hybrid Steel Concrete (EQ)	3.6 H EQ	$2,380,653	$661
3.6 MW All Precast Concrete (Wind)	3.6 P W	$2,026,608	$563
3.6 MW All Cast in Place Concrete (Wind)	3.6 CIP W	$1,550,472	$431
3.6 MW All Tubular Steel (Wind)	3.6 S W	$2,293,759	$637
5.0 MW Hybrid Steel Concrete (EQ)	5.0 H EQ	$3,242,075	$648
5.0 MW All Precast Concrete (Wind)	5.0 P W	$2,402,928	$481
5.0 MW All Precast Concrete (EQ)	5.0 P EQ	$2,949,155	$590
5.0 MW All Cast in Place Concrete (Wind)	5.0 CIP W	$1,872,036	$374
5.0 MW All Cast in Place Concrete (EQ)	5.0 CIP EQ	$2,126,524	$425
5.0 MW All Tubular Steel (Wind)	5.0 S W	$2,956,356	$591

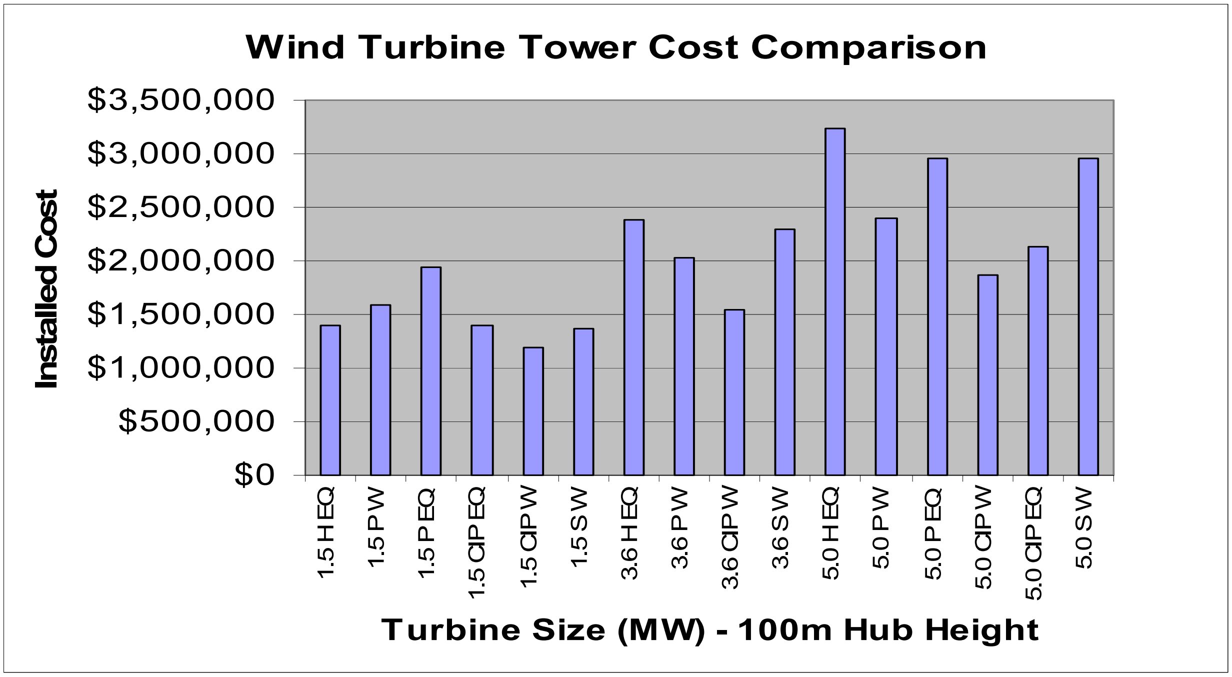


Figure 11.1. Wind turbine tower cost comparisons: installed cost

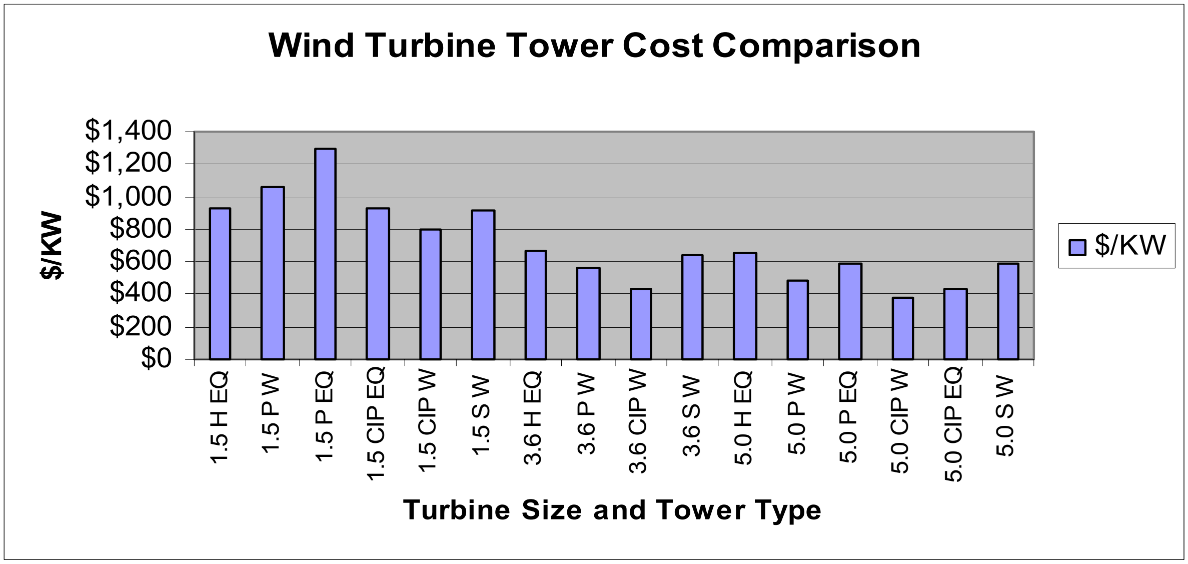


Figure 11.2. Wind turbine tower cost comparisons: cost/kW

11.2.1.1 Large Tubular Steel Towers

General Comments — The focus of this study is **not** steel wind turbine towers. Preliminary designs for steel towers were developed to provide a reference for dynamic properties and to provide a basis for cost comparison with the all-concrete and hybrid steel/concrete tower concepts. There is very limited experience or data regarding the fabrication costs, on a large-scale production basis, for the large, thick steel plate tube shells of the scale required for the 3.6- and 5.0-MW towers that must be ultimately joined into circular sections at the project site. Especially, there is missing cost information relative to the cost of performing, in a site environment, the large number of fatigue-rated welds necessary for these structures.

The fabricated steel costs (FOB fabricator's shop) developed for the steel tubular towers used in the hybrid steel/concrete and the all-steel towers given in this report are based on conversations with wind turbine tower fabricators regarding the total fabricated cost of the large heavy sections that will be required for these elements. We have reviewed and used the WindPACT studies [16–19] to develop costs for transportation, site assembly, and erection of these towers.

Table 11.3 shows the effect on the overall installed cost estimated for the hybrid steel/concrete, the all-steel tubular towers, and the all-concrete towers with the March 2004 price increases over the August 2003 basic unit costs used for material and fabrication of the structural steel tube elements, the reinforcing steel, and the prestressing steel used in the tower installation. The basic per-pound cost we have used in our estimates for material cost plus fabrication for the tubular steel elements is 119% of that quoted in [18] and 132% of that quoted in [26]. Using the March 2004 prices makes these costs higher still. Domestic fabricators indicated that towers are now being shipped into the United States from China and Korea, and this is forcing the prices down for fabricated towers in the 1.5-MW, 65-m (213-ft) height and smaller size ranges.

The WindPact Study [18] used $0.75/lb ($1.66/kg), which is the cost of current smaller-diameter tubular towers FOB the manufacturer's facility. These smaller-diameter towers can be fabricated and shipped typically as a complete circular cross section and are fabricated of thinner plate than that associated with the larger towers discussed here.

Table 11.3. Effects of Variation in Steel Cost on Installed Tower Costs

Effects of Steel Cost Variation for Towers - August 2003 prices and March 2004 prices for fabricated steel, reinforcing, and prestressing strand				
	March 2004 (These prices are used for high steel cost estimates)		August 2003 (These prices are used for baseline cost estimates)	
Material	Material cost $/lb.	Labor cost $/lb.	Material cost $/lb.	Labor cost $/lb.
Tower tube steel	$0.40	$0.72	$0.18	$0.72
Prestressing Strand	$0.45	$0.40	$0.28	$0.40
H. S. Post Tensioning Bars	$1.95	$0.50	$1.50	$0.50
Foundation reinforcing steel	$0.28	$0.26	$0.19	$0.26
Precast reinforcing steel	$0.28	$0.16	$0.19	$0.16
Weldments				
Heavy or complex	$0.40	$2.32	$0.18	$2.32
Medium heavy	$0.40	$1.82	$0.18	$1.82
Very heavy or simple	$0.40	$1.32	$0.18	$1.32
	Mar-04		**Aug-03**	
Turbine/Tower Size/Construction Method	Tower Cost	% of baseline	Tower Cost	% of baseline
1.5 MW -100 m Hub Height				
Hybrid Steel Concrete - Earthquake Design	$1,513,550	108%	$1,402,721	100%
All Precast Concrete - Wind Design	$1,600,446	101%	$1,581,707	100%
All Cast in Place Concrete - Wind Design	$1,226,822	103%	$1,188,150	100%
All Tubular Steel - Wind Design	$1,528,457	112%	$1,369,656	100%
3.6 MW - 100 M Hub Height				
Hybrid Steel Concrete - Earthquake Design	$2,571,998	108%	$2,380,653	100%
All Precast Concrete - Wind Design	$2,118,904	105%	$2,026,608	100%
All Cast in Place Concrete - Wind Design	$1,643,515	106%	$1,550,472	100%
All Tubular Steel - Wind Design	$2,566,670	112%	$2,293,759	100%
5.0 MW - 100 m Hub Height				
Hybrid Steel Concrete - Earthquake Design	$3,507,911	108%	$3,242,075	100%
All Precast Concrete - Wind Design	$2,512,240	105%	$2,402,928	100%
All Cast in Place Concrete - Wind Design	$1,962,998	105%	$1,872,036	100%
All Tubular Steel - Wind Design	$3,315,123	112%	$2,956,356	100%
Note: Material and labor costs are for shop fabrication of the tubular tower elements only and do not include shipping, field welding or erection (these items are accounted for separately in the cost estimates.).				

Representatives of three steel tower fabricators indicated in August 2003 that about $0.90/lb ($1.98/kg) would be an appropriate value for fabricated steel FOB their plant to use for larger tower elements of the plate thickness required for these towers. This study used $0.90/lb ($1.98/kg) in the cost estimates for the steel towers. This study also includes the additional costs to weld the shell sections together at the site using cost parameters developed in the WindPACT study.

In March 2004, raw steel plate prices increased from the August 2003 prices of $0.18/lb to $0.40/lb. Thus, the fabricated plate cost used in Table 11.3 shows the effect of steel price variation as $0.40 material plus $0.72 labor = $1.12/lb for fabricated tubular tower steel plating.

Several fabricators expressed a concern about the amount of site infrastructure that would be required to complete the fabrication on-site of large steel tower cross sections that would be shipped in quarter sections. The tower structures would have to be welded, then blasted and painted at the site. These are significant activities that require enclosures and extensive amounts of equipment to achieve the quality required to ensure long-term durability of these fatigue-loaded structures. Based on this input, the estimates we have used in this report for field welding and field painting of the steel towers may be low. The effects of using higher-yield-strength steel for the construction of tubular steel towers were evaluated. The steel towers have been designed with 344-MPa (50-ksi) yield strength steel, as this was indicated to be current industry practice.

With the larger turbine sizes, the effects of the tower top head weight composed of the nacelle, hub, and rotor increasingly dominate the seismic design of the towers. As shown in Table 11.4, the head weight, as a percentage of the all-steel tower weight, increases from about 27% for the 1.5-MW turbine to 44% and 47% for the 3.6- and 5.0-MW turbines, respectively. Seismic loads are among the most uncertain with regard to their actual magnitude and dynamic characteristic. This increasing influence of the tower top head weight represents an increased seismic risk that should be further considered as part of the final design in developing the seismic design criteria for these large steel turbine towers located in high seismic areas.

As outlined in 11.2, for the steel tubular towers we have preliminarily designed, the local buckling formula [12] has been used to check the tubular steel towers for buckling. The reference indicates that this formula includes the effects of welding and other imperfections. The final design of a large-diameter steel tower should investigate the issue of design against local buckling in more depth to ensure that this guidance applies to the large diameter/thickness ratios associated with the 3.6- and 5.0-MW towers. Should heavier plate, plate stiffeners, or diaphragms be required for local buckling, this will have an increasing effect on the costs for these towers and will pose additional fatigue design issues.

11.2.1.2 1.5-MW, 100-m Hub Height Tower

As shown in Table 11.5 and Figures 11.3 and 11.4, the cost estimates developed for this tower size indicate that the cast-in-place concrete tower developed here is the most economical of the tower construction concepts considered. The all-cast-in-place concrete concept designed for this size tower was estimated at 87% of the tubular steel tower cost. The premium for designing the cast-in-place concrete tower for earthquake appears to be about 17%, making the cost of this tower in a seismic area essentially equal to that of the 1.5-MW all-tubular-steel tower. There is no cost premium for the tubular steel tower designed for earthquake, as this tower design is controlled by wind loads, because of the lower mass of the steel tower.

Table 11.4. Comparison of Tower Head Weight to Overall Tower Weight

Comparison of Tower Head Weight to Overall Tower Weight	1.5 MW Hybrid (EQ)	1.5 MW All Concrete (EQ)	1.5 MW All Concrete (Wind)	1.5 MW All Steel (Wind)	3.6 MW Hybrid (EQ)	3.6 MW All Concrete (Wind)	3.6 MW All Steel (Wind)	5.0 MW Hybrid (EQ)	5.0 MW All Concrete (Wind)	5.0 MW All Steel (Wind)
Total tower head weight (kips)	187	187	187	187	694	694	694	1058	1058	1058
Head weight as a % of total tower weight	7.40%	4.76%		26.60%	14.07%	13.16%	43.56%	17.82%	16.13%	47.11%
Steel tower weight (kips)	185.8			516.1	354.5		899.2	461.6		1188
Concrete tower weight (kips)	2153	3742			3884	4579		4417	5502	
Total tower weight (kips)	2525.8	3929		703.1	4932.5	5273	1593.2	5936.6	6560	2246

Table 11.5. Tower Cost Breakdown: 1.5-MW, 100-m Hub Height

	1.5 MW Hybrid Steel Concrete Earthquake Design		1.5 MW All Precast Concrete Wind Design		1.5 MW All Precast Concrete Earthquake Design		1.5 MW Cast in Place Concrete Wind Design		1.5 MW Cast in Place Concrete Earthquake Design		1.5 MW All Tubular Steel Wind Design	
	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total
Mobilizaton & Site Development Including Crane Costs	$107,325	8%	$296,756	19%	$349,457	18%	$80,465	7%	$80,465	6%	$206,152	15%
Foundation Construction	$171,949	12%	$185,725	12%	$228,850	12%	$185,725	16%	$228,850	16%	$139,297	10%
Shop Fabrication of Steel Tube and Flange Rings	$302,431	22%	$28,264	2%	$28,264	1%	$28,264	2%	$28,264	2%	$638,102	47%
Field Erection of Steel Tube	$31,683	2%	$2,462	0%	$2,462	0%	$0	0%	$0	0%	$35,050	3%
Tower Concrete Fabrication	$166,656	12%	$290,217	18%	$358,818	18%	$432,817	36%	$481,881	35%	$0	0%
Field Erection of Precast and Post Tensioning	$219,117	16%	$360,248	23%	$474,101	24%	$133,664	11%	$200,052	14%	$0	0%
Jack-Up of Steel Tube within Hybrid Tower	$43,586	3%	$14,581	1%	$14,581	1%	$14,581	1%	$14,581	1%	$14,581	1%
Complete Concrete To Steel Connection and install Nacelle and Rotor	$36,270	3%	$38,445	2%	$38,445	2%	$38,445	3%	$38,445	3%	$20,400	1%
General Contractor Mark-ups	$323,704	23%	$365,009	23%	$448,494	23%	$274,189	23%	$321,762	23%	$316,074	23%
Total Cost	**$1,402,721**	100%	**$1,581,707**	100%	**$1,943,472**	100%	**$1,188,150**	100%	**$1,394,300**	100%	**$1,369,656**	100%
	118.1%		133.1%		163.6%		100.0%		117.4%		115.3%	

11.2.2.3 3.6-MW, 100-m Hub Height Tower

The natural frequency of the 3.6-MW hybrid steel/concrete and all-concrete towers designed for earthquake are calculated to be in the central portion of the working frequency range.

As shown in Table 11.6 and Figures 11.5 and 11.6, the all cast-in-place concrete towers designed for this turbine and height combination are the most economical of the concepts considered. The all-cast-in-place concrete towers designed for wind are estimated to be 68% the cost of the all-steel tubular towers.

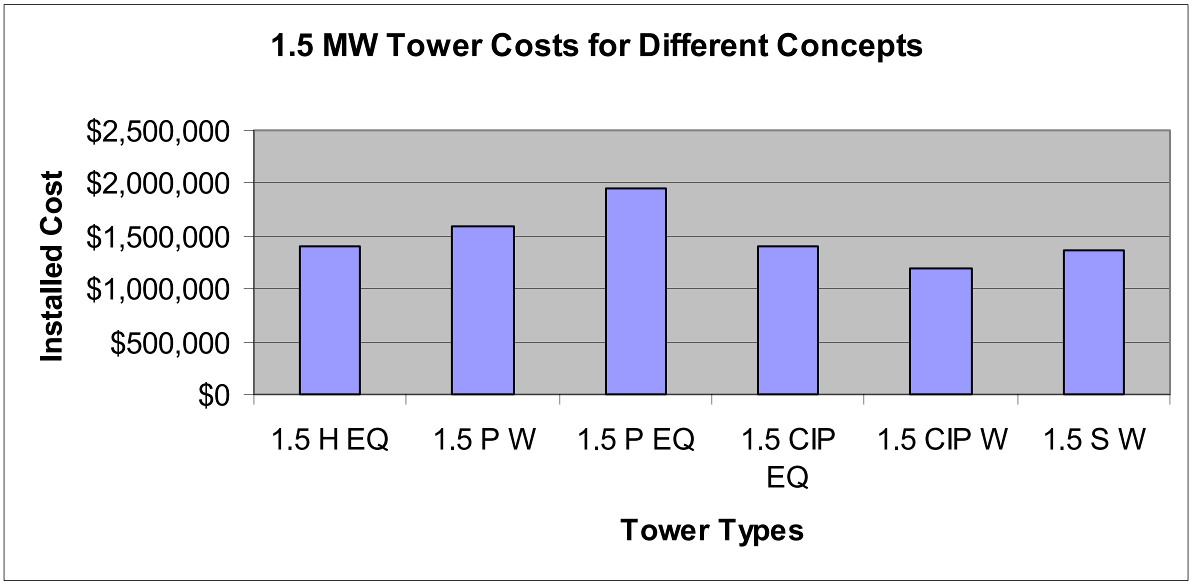


Figure 11.3. Wind turbine tower cost comparisons: 1.5-MW, 100-m hub height

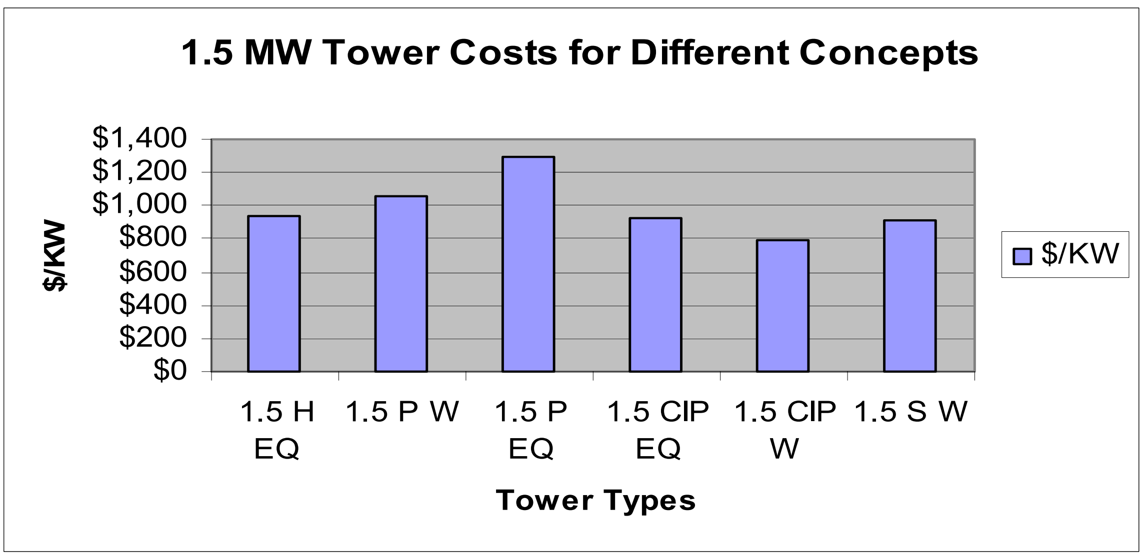


Figure 11.4. Wind turbine tower cost $/kW comparisons: 1.5-MW, 100-m hub height

Table 11.6. Tower Cost Breakdown: 3.6-MW, 100-m Hub Height

	3.6 MW Hybrid Steel Concrete Earthquake Design		3.6 MW All Precast Concrete Wind Design		3.6 MW Cast in Place Concrete Wind Design		3.6 MW All Tubular Steel Wind Design	
	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total
Mobilizaton & Site Development Including Crane Costs	145,081	6%	$358,003	18%	$89,011	6%	$262,466	11%
Foundation Construction	310,326	13%	$285,510	14%	$285,422	18%	$200,056	9%
Shop Fabrication of Steel Tube and Flange Rings	602,587	25%	$35,368	2%	$35,368	2%	$1,138,083	50%
Field Erection of Steel Tube	55,010	2%	$2,462	0%	$0	0%	$127,070	6%
Tower Concrete Fabrication	305,167	13%	$367,899	18%	$551,950	36%	$0	0%
Field Erection of Precast and Post Tensioning	317,625	13%	$450,482	22%	$171,715	11%	$0	0%
Jack-Up of Steel Tube within Hybrid Tower	53,084	2%	$16,510	1%	$16,510	1%	$16,354	1%
Complete Concrete To Steel Connection and install Nacelle and Rotor	42,392	2%	$42,695	2%	$42,695	3%	$20,400	1%
General Contractor Mark-ups	$549,381	23%	$467,679	23%	$357,801	23%	$529,330	23%
Total Cost	**$2,380,653**	100%	**$2,026,608**	100%	**$1,550,472**	100%	**$2,293,759**	100%
	153.5%		130.7%		100.0%		147.9%	

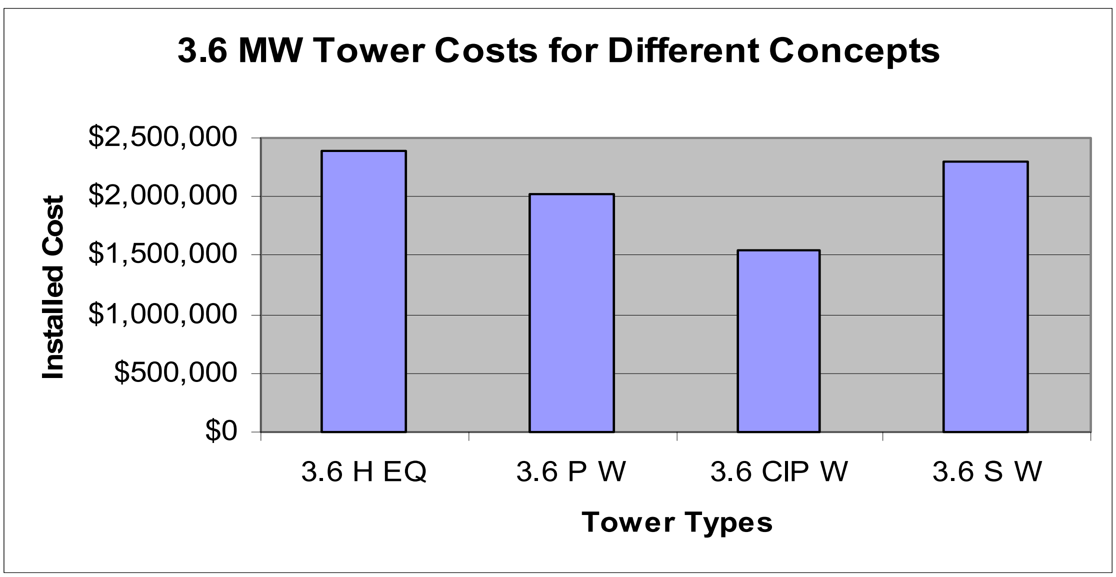


Figure 11.5. Wind turbine tower cost comparisons: 3.6-MW, 100-m hub height

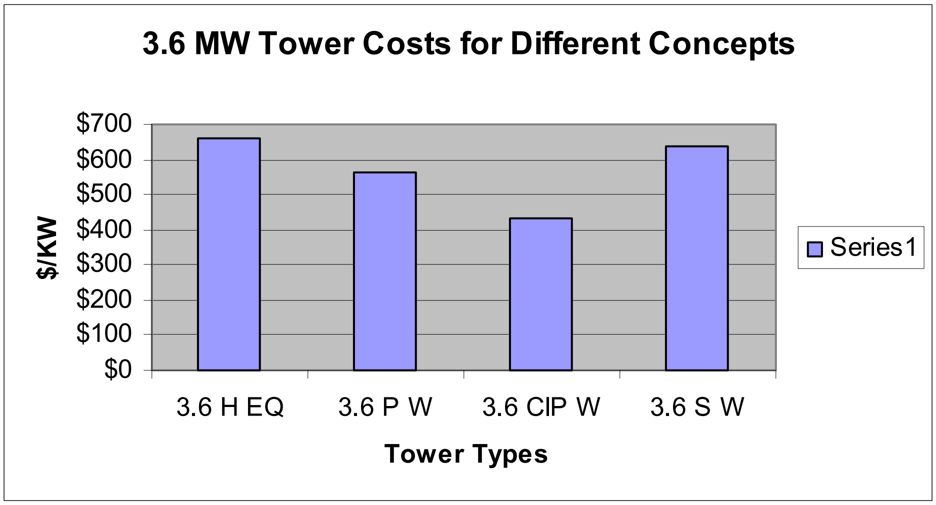


Figure 11.6. Wind turbine tower cost $/kW comparisons: 3.6-MW, 100-m hub height

11.2.2.4 5.0-MW, 100-m Hub Height Tower

The 5.0-MW towers designed here all fall in the upper range of the working frequency. In final design consideration should be given to tailoring the tower height and cross section to lower the frequency somewhat moving toward the center of the working frequency range.

The all-cast-in-place concrete towers designed for the 5.0-MW turbine and this height combination are estimated to be about 63% the cost of the all-tubular-steel tower concept (see Table 11.7 and Figure 11.7). Sample designs for the 5.0-MW towers are given in Appendix B.

Table 11.7. Tower Cost Breakdown: 5.0-MW, 100-m Hub Height

	5.0 MW Hybrid Steel Concrete Earthquake Design		5.0 MW All Precast Concrete Earthquake Design		5.0 MW All Precast Concrete Wind Design		5.0 MW Cast in Place Concrete Wind Design		5.0 MW Cast in Place Concrete Earthquake Design		5.0 MW All Tubular Steel Wind Design	
	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total	Cost	% of Total
Mobilizaton & Site Development Including Crane Costs	$213,824	7%	$476,697	16%	$391,454	16%	$126,259	7%	$126,259	6%	$341,032	12%
Foundation Construction	$350,204	11%	$426,564	14%	$336,037	14%	$333,584	18%	$426,556	20%	$245,745	8%
Shop Fabrication of Steel Tube and Flange Rings	$824,805	25%	$35,368	1%	$35,368	1%	$35,368	2%	$35,368	2%	$1,478,239	50%
Field Erection of Steel Tube	$144,503	4%	$2,462	0%	$2,462	0%	$2,462	0%	$2,462	0%	$170,899	6%
Tower Concrete Fabrication	$338,204	10%	$562,326	19%	$427,544	18%	$652,622	35%	$746,744	35%	$0	0%
Field Erection of Precast and Post Tensioning	$501,334	15%	$704,508	24%	$594,886	25%	$229,077	12%	$237,743	11%	$0	0%
Jack-Up of Steel Tube within Hybrid Tower	$76,559	2%	$17,961	1%	$17,961	1%	$17,961	1%	$17,961	1%	$17,805	1%
Complete Concrete To Steel Connection and install Nacelle and Rotor	$44,471	1%	$42,695	1%	$42,695	2%	$42,695	2%	$42,695	2%	$20,400	1%
General Contractor Mark-ups	$748,171	23%	$680,574	23%	$554,521	23%	$432,008	23%	$490,736	23%	$682,236	23%
Total Cost	**$3,242,075**	100%	**$2,949,155**	100%	**$2,402,928**	100%	**$1,872,036**	100%	**$2,126,524**	100%	**$2,956,356**	100%
	173.2%		157.5%		128.4%		100.0%		113.6%		157.9%	

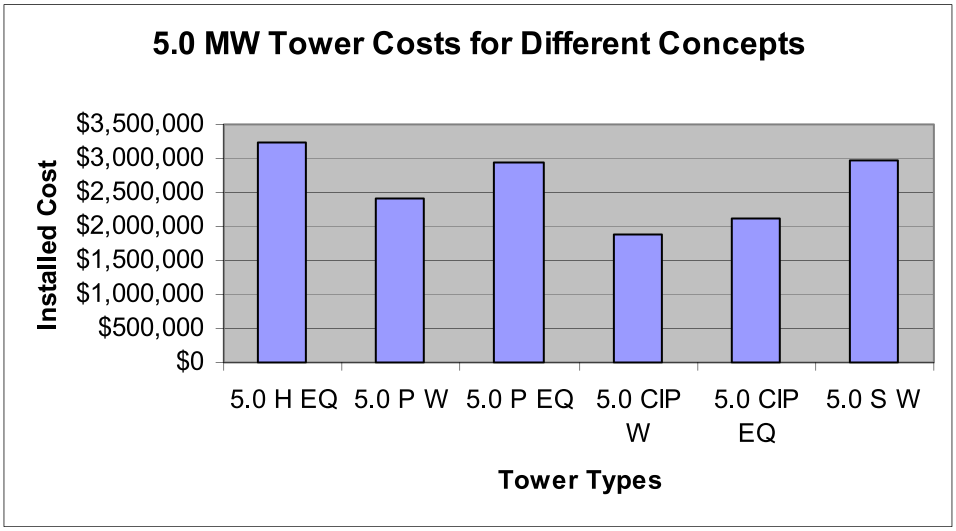


Figure 11.7. Wind turbine tower cost comparisons: 5.0-MW, 100-m hub height

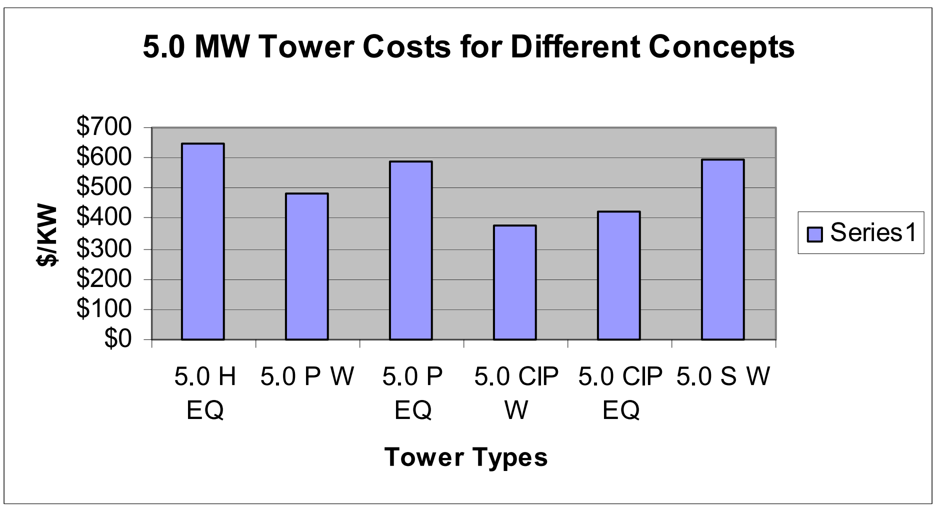


Figure 11.8. Wind turbine tower cost $/kW comparisons: 5.0-MW, 100-m hub height

11.2.3 Cost Effects of Earthquake Loading

As shown in Figure 3.11, in some parts of the country earthquake forces will control the design of the hybrid steel/concrete and all-concrete towers. With the current criteria used in this study, wind-related loads control the design of the all-tubular steel towers. As discussed in Section 3, if deployed in high seismic areas, the greater mass associated with the concrete towers results in high seismic forces that must be designed for. This affects primarily the post-tensioning design of the tower (quantity of post-tensioning materials) and the design of the foundation. The requirement to design the concrete towers for earthquake has a cost increasing effect in the 14% to 23% range for the concrete towers considered. The magnitude of that effect is shown in Table 11.8.

Table 11.8. Cost Effects of Designing Wind Turbine Towers for Earthquake

Relative Tower Costs - Wind Controls vs. Earthquake Controls			
Turbine/Tower Size/Construction Method	50 Tower Project Design for Wind	50 Tower Project Design for EQ	Percentage Cost Increase Due to Seismic
1.5 MW -100 m Hub Height			
Hybrid Steel Concrete		$1,402,721	Note 1
All Precast Concrete	$1,581,707	$1,943,472	122.9%
All Cast in Place Concrete	$1,188,150	$1,394,300	117.4%
All Tubular Steel	$1,369,656		Note 2
3.6 MW - 100 M Hub Height			
Hybrid Steel Concrete		$2,380,653	Note 3
All Precast Concrete	$2,026,608		Note 4
All Cast in Place Concrete	$1,550,472		Note 4
All Tubular Steel	$2,293,759		Note 2
5.0 MW - 100 m Hub Height			
Hybrid Steel Concrete		$3,242,075	Note 3
All Precast Concrete	$2,402,928	$2,949,155	122.7%
All Cast in Place Concrete	$1,872,036	$2,126,524	113.6%
All Tubular Steel	$2,956,356		Note 2

Note 1. Tower designed with constant ID. Strength exceeds that required for wind.
Note 2. Tubular steel tower design controlled by fatigue, earthquake does not control.
Note 3. Top diameter of concrete tower controlled by required base diameter of steel top tower.
Note 4. Tower designed for earthquake was not priced.

11.2.4 Cost Effects of 50-Tower Installation versus 25-Tower Installation

Table 11.9 shows the estimated change in per-tower cost associated with the reduction in project size from 50 towers to 25 towers. In assessing this sensitivity, the project duration has been kept at 28 months. The cost premiums are small and are within the range of estimating accuracy. The differences in cost result from the requirement to distribute site development costs over a smaller number of towers. Crane rental costs reduce, and if fewer cranes are needed the crane mobilization costs reduce. These cost reductions balance out the cost-increasing effects of the smaller tower basis for distributing site development costs. The detailed estimates for both the basic 50-tower scenario and the 25-tower scenario are given in Appendix C.

11.2.5 Cost Effects of Project Duration

Sample schedules that show required production rates and crane requirements are given in Appendix G. For the cost estimates developed in this study, we have assumed a 28-month project schedule to construct and outfit either the baseline 50 towers or the parametric variation of 25 towers. This results in a variable project average construction expenditure rate ranging from about $1,050,000 per month (for the $31 million project to build 25 cast-in-place concrete towers for 1.5-MW turbines in 28 months) to about $3,300,000 per month (for the $94 million project to build 50 all-cast-in-place concrete towers for 5.0-MW turbines).

Table 11.9. Relative Tower Costs: 50-Tower Project versus 25-Tower Project

Relative Tower Costs - 50 Towers vs 25 Towers - 28 Month Schedule			
Turbine/Tower Size/Construction Method	50 Tower Project Design for Wind	25 Tower Project Design for Wind	Percentage Cost Increase from 50 Tower Baseline
1.5 MW -100 m Hub Height			
Hybrid Steel Concrete			
All Precast Concrete	$1,581,707	$1,613,247	1.99%
Cast in Place Concrete	$1,188,150	$1,181,872	-0.53%
All Tubular Steel	$1,369,656	$1,451,220	5.96%
3.6 MW - 100 M Hub Height			
Hybrid Steel Concrete			
All Precast Concrete	$2,026,608	$2,007,031	-0.97%
All Cast in Place Concrete	$1,550,472	$1,567,909	1.12%
All Tubular Steel	$2,293,759	$2,331,478	1.64%
5.0 MW - 100 m Hub Height			
Hybrid Steel Concrete			
All Precast Concrete	$2,402,928	$2,262,033	-5.86%
All Cast in Place Concrete	$1,872,036	$1,890,460	0.98%
All Tubular Steel	$2,956,356	$3,061,105	3.54%

Longer schedule times result in the requirement to mobilize fewer cranes, which reduces overall cost by the mobilization of fewer cranes. This is likely more than offset by the time-dependent, increasing cost of continuing general conditions items such as site offices, site administration, and supervision.

The concepts that involve precast concrete and cast-in-place concrete tower construction require increased amounts of semi-skilled labor on site. With the larger dollar volume project sizes, this could result in a cost issue for sites far from a supply of suitable labor. The concepts that use large-diameter steel tubular towers would involve significant numbers of highly skilled welders on-site to weld the preformed tower segments together. This could also result in labor cost issues.

In summary, the requirements for and availability of different types of site labor should be considered in the development of a final project schedule.

11.3 Effects on Cost of Energy

The COE calculations for the tower construction concepts are given in Appendix I. These calculations were developed with input developed for the non-tower elements of the wind turbine installation [26].

The costs for the major, non-tower elements of the 3.6-MW turbine installation were extrapolated from the [26] values for the 3.0- and 5.0-MW turbines. To this list, we have added costs as noted from [17] and those that were developed in this study for the tower structure. The following commentary notes differences between the values used in this study for the all-steel towers and those used for the steel towers in [26].

11.3.1 Discount Rate

We have revised the COE calculation to use the NREL-specified discount rate of 11.85%. We note that the use of this higher discount rate results in increasing the overall COE by 12.24% from the values given in [26], which are based on a discount rate of 10.6%.

11.3.2 Material Costs

The tower costs [26] are based on a fabricated steel cost FOB fabricators plant of $1.50/kg. No markup has been added to this value. Based on conversations with tower steel fabricators regarding the costs for tower elements of the scale considered in this study, the baseline cost estimate for the steel towers in this study uses a fabricated plate steel cost of $1.98/kg. This is a 32% increase in the cost of fabricated steel plate over that used in [26].

Table 11.3 shows the effects of fabricated steel prices current as of March 2004 ($2.47/kg – a 64% increase over that used in [26]). Because it is hoped that the March 2004 steel prices will mitigate significantly over time, the lower price of $1.98/kg for fabricated plate steel has been used in the baseline cost estimates and in the COE calculations for this study.

11.3.3 Steel Tower Material Quantity

Based on industry input, the steel towers in this study were sized for fatigue using DEL provided by the industry partner and an m = 4. Subsequent to sizing the towers in this manner and associated with the use of the fatigue spectrum loads from the WindPACT Rotor Design Study for the design of the concrete towers, several other approaches to the fatigue design of the steel towers were also investigated (see Section 9.2). This investigation indicated that using the DEL with m = 4 resulted in the controlling fatigue stress level for the towers (see Table 9.2). This seemed appropriate for the preliminary design of the towers and will likely result in a reasonable level of conservatism appropriate at this stage of design.

Reference 26 indicates that fatigue of the towers developed in that study was checked against BS 7608 class D with an m = 3. This report also states that “The intent was to adjust all components so that margins of safety were at or very close to zero.” This is a different criterion than was used for either the steel or the concrete towers designed in this study. The concrete towers were designed with the load factors as indicated in Section 3.0 of this report. Recognizing the nature of a preliminary design effort and the lack of available service experience with the large concrete towers, the design objective was to be slightly conservative with the design of the concrete towers. Similarly, the design objective with large steel towers was to develop a design that is slightly conservative. This basic objective is different than the objective of [26], which, as we understand it, is looking at the potential cost savings from systems that have been maximally optimized through a combination of design, active control, and lessons learned from operational experience.

In the final design of steel towers of this size, there will be cost advantages to tailoring the plating thickness along the tower height in increments. This study assumed a constant plate thickness from base to mid height and linear variation of thickness from mid height to the top for the 1.5- and 3.6-MW steel towers and only a slight change in thickness from base to mid height and linear variation in thickness from mid height to the top for the 5.0-MW steel tower. Section 9.2 provides the background used for the preliminary fatigue design of the study steel towers. The reader is invited to review the methodology used.

Because of the height differences between the towers of this study and those investigated in [26], it is difficult to separate the height effects from the differences resulting from criteria. However, based on the stated approach of [26], one would expect steel towers designed per the methodology used in this study to be heavier (requiring more material) for a given tower height and turbine rating than those designed using the methodology of [26].

11.3.4 Assembly and Installation Costs

The assembly and installation costs are composed primarily of crane costs to support the erection of the towers and the turbine and its components and the on-site welding costs associated with welding the quartered tower sections together, welding the base flanges to the base tower section, and welding the horizontal joints between vertical tower sections during erection. A review of the COE costs [26] given for the Assembly and Installation item indicates that these costs do not appear to be high enough to cover the costs of the necessary cranes and welding associated with these large towers.

The Assembly and Installation costs in this study have been compared with WindPACT Area 2 [17] costs and were found to be in general agreement for the 3.6- and 5.0-MW towers. When the larger crane necessary to erect the 1.5-MW tower and turbine at 100 m versus the 86-m height assumed in the WindPACT Area 2 study is used in the crane cost determination, the study 1.5-MW crane costs compare well with the WindPACT crane cost estimates.

The reader is invited to review the detailed cost estimates provided in Appendix C that show the basis for both the crane costs included in this item and the site welding costs included.

11.3.5 Overhead and Profit Markups and Contingencies

We have assumed a project organization consistent with the value of construction involved. This organization has an overall general contractor responsible for turnkey construction of the 50-turbine installation. We have assumed that this contractor will subcontract the offsite prefabrication and construction of the towers. Thus, subcontractor markups are included in the tower costs developed as part of this study. On the overall tower and related cost amounts, we have included a 10% administrative overhead, a 10% field overhead, and a 10% profit markup resulting in an overall 30% markup. We have not included an estimating contingency in the tower cost estimates. The final organization and negotiation of the project will determine how the overhead and profit markups will be handled and what the actual values will be; but the 30% markup, absent an estimating contingency, seems reasonable. Tower costs in the COE calculations [26] do not include such a markup.

11.3.6 Combined Effect of Differences in Discount Rate, Material Costs, and Overhead Markups

The combined effect of the above differences in COE cost determination for the tower element equate to

Discount Rate Difference X Material Cost Difference X Overhead Difference =

$$X\ 1.32\ X\ 1.30 = 1.92$$

Thus, the cost estimating assumptions alone used in this study for the wind turbine towers result in a 192% increase in cost over the assumptions used in [26]. These assumptions have nothing to do with the design of the towers, but rather are inputs to the cost estimating and COE calculation process that we feel are reasonable and reflect the likely project reality.

11.3.7 Foundation Costs

In the body of this study, we have designed and estimated costs for spread footings to support the towers based on generic geotechnical conditions as described in Section 7. Although clearly the cost of the foundation is a significant part of the overall tower installation cost, it is not fruitful to further optimize the foundation costs without using site-specific foundation recommendations based on a site-specific geotechnical investigation. The constant-depth spread footings we have estimated may ultimately not be the most cost-effective solution based on local geotechnical conditions. Also, the large base diameters of these towers (5.79–9.14 m, 19–30 ft) will require extensions of current wind turbine tower foundation methods. For this reason, and because the authors of [26] have recognized in their lower foundation cost estimates the potential for lower-cost foundation solutions, for the COE calculation only, we have used the lower [26] foundation costs for the 3.0-MW, 119-m tower as applicable to the study 3.6-MW, 100-m tower and have used the 5.0-MW, 154-m foundation costs as applicable to the 5.0-MW, 100-m tower. The 1.5-MW, 84-m foundation costs [26] have been ratioed by the square of the tower heights and used as foundation costs for the 1.5-MW, 100-m tower.

11.3.8 Breakdown of COE Calculation Line items

The following outlines how the values in the COE calculation were derived.

11.3.8.1 Rotor

For the total rotor assembly cost of the 3.6-MW turbine, a linear interpolation based on power rating between [26] values for the 3.0- and 5.0-MW turbines was used. Thus, 0.6 times the difference between the cost of the rotor assembly for the 3.0- and 5.0-MW turbines was added to the [26] cost of the 3.0-MW rotor assembly to derive the cost of the 3.6-MW rotor assembly.

Blades. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Hub. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Pitch mechanism. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

11.3.8.2 Drive Train, Nacelle

For the total drive train and nacelle assembly cost of the 3.6-MW turbine, a linear interpolation based on power rating between [26] values for the 3.0- and 5.0-MW turbines was used. Thus, 0.6 times the difference between the cost of the drive train and nacelle assembly for the 3.0- and 5.0-MW turbines was added to the [26] cost of the 3.0-MW drive train and nacelle assembly to derive the cost of the 3.6-MW drive train and nacelle assembly.

Low-speed shaft. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Bearings. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Gearbox. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Mechanical brake, HS coupling. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Generator. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Variable speed electronics. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Yaw drive and bearing. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Main frame. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Electrical connections. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Hydraulic system. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

Nacelle cover. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly.

11.3.8.3 Control, Safety System

For the total control, safety system cost of the 3.6-MW turbine, a linear interpolation based on power rating between [26] values for the 3.0-MW turbine and the 5.0-MW turbine was used. Thus, 0.6 times the difference between the cost of the control and safety system for the 3.0 MW and 5.0-MW turbines was added to the [26] cost of the 3.0-MW control and safety system to derive the cost of the 3.6-MW control and safety system.

11.3.8.4 Tower

The tower cost was estimated based on designs developed in this study and includes the cost of basic steel tower structural fabrication at an off-site fabrication facility, plus the following:

- Contribution to project management and supervision
- Base flange material and fabrication
- Top flange material and fabrication
- Concrete to steel tower connection plate material and fabrication (hybrid towers only)
- Fabrication and installation of access ladders in the tower
- Prime and paint interior of tower after site welding
- Epoxy paint exterior of tower after site welding
- Exterior paint touch-up after installation is complete
- Install and remove installation scaffolding
- On-site construction work associated with site construction of the precast concrete and cast-in-place concrete alternatives.

11.3.8.5 Balance of Station

Foundations. The [26], 1.5-MW foundation costs ratioed by the square of the tower heights 1002/842 were used. The 3.0-MW, 119-m foundation cost was used for the 3.6-MW, 100-m tower. The 5.0-MW foundation cost of [26] was used for the 5.0-MW, 100-m tower.

Tower transportation. The tower transportation costs for the steel tower elements were derived from the WindPACT Technical Area 2 report [17] and have been checked to be consistent with the values given in that report. Transportation costs for the concrete elements of the concrete towers were estimated as part of this study. (COE tables [26] do not break the transportation cost down as has been done in Table 11.8.)

Blade transportation. The blade transportation costs were derived from the WindPACT Technical Area 2 report [17] and have been checked to be consistent with the values given in that report. (COE tables [26] do not break down the transportation cost.)

Hub transportation. The hub transportation costs were derived from the WindPACT Technical Area 2 report [17] and have been checked to be consistent with the values given in that report. (COE tables [26] do not break down the transportation cost.)

Nacelle transportation. The nacelle transportation costs were derived from the WindPACT Technical Area 2 report [17] and have been checked to be consistent with the values given in that report. (COE tables [26] do not break down the transportation cost.)

Roads, civil works. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly. For the 3.6-MW installation, the [26] values for this item were increased by the factor of 3.6 MW/3.0 MW = 1.20.

Assembly and installation. These costs include all costs associated with assembling the prefabricated steel tower elements on the site and the installation of the turbine nacelle, hub, and blades. These costs for the steel towers were derived from the WindPACT Technical Area 2 report [17] and have been checked to be consistent with the values given in that report. When considering the overall cost of the tower installation, the tower cost and the assembly and installation cost should be considered together. They are separated here to be consistent with the [26] approach to breaking down the COE calculation.

These assembly and installation costs include

- Crane-related costs
  - Pedestal crane (hybrid towers only)
  - Mobilization and demobilization of tube and element erection cranes
  - Rental for the tube and element erection cranes
  - Labor to assemble cranes per turbine
  - Labor to relocate cranes per turbine
  - Tube and element erection crane cribbing cost per turbine
  - Mobilization and demobilization of the turbine setting cranes
  - Rental for the turbine setting cranes per turbine
  - Labor cost to assemble the turbine setting cranes per turbine
  - Labor cost to relocate the turbine setting cranes per turbine
  - Turbine setting crane cribbing cost per turbine
  - Meals and lodging for crane crews per turbine
  - Crane fuel cost per turbine

- On-site welding costs for quartered tube sections and welding costs for horizontal tube-to-tube joints for the steel tube towers and hybrid towers.
- Jack-up of the steel tube (hybrid towers only)
- Erection of the transition section between the tower and the turbine nacelle
- Erection of the hub and nacelle

- Miscellaneous erection equipment and small cranes

The following costs are included in the tower cost and are not included in the assembly and installation costs given in the COE calculations.

Erection and structural integration of the precast concrete elements, including post-tensioning, is included in the tower cost for the precast towers.

- Placement of reinforcing and cast-in-place concrete, including post-tensioning, is included in the tower cost for the cast-in-place concrete tower.

Electrical interface/connections. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly. For the 3.6-MW installation, the [26] values for this item were increased by the factor of 3.6 MW/3.0 MW = 1.20.

Permits, engineering. For the 1.5- and 5.0-MW turbines, the cost values from [26] were used directly. For the 3.6-MW installation, the [26] values for this item were increased by the factor of 3.6 MW/3.0 MW = 1.20.

11.3.8.6 Initial Capital Cost

This is the total of the following major cost categories.

- Rotor
- Drive train, nacelle
- Control, safety system
- Tower
- Balance of Station

11.3.8.7 Net Annual Energy Production

The net annual energy production has been ratioed from the [26] values using a wind shear exponent of 0.14 to account for differences in turbine hub heights and using the ratio of the square of the rotor diameters to account for differences in rotor diameter between the 3.0-MW and 3.6-MW turbine.

For deriving the tower cost as input into the COE calculation, we have subtracted the costs included in the tower cost summarized in Section 11 for the following. These items are accounted for elsewhere in the COE calculation as outlined above.

- Access road
- Site offices
- Miscellaneous equipment move in
- Mobilization and site development
- Other equipment rental
- Foundations
- Assembly and installation
- Tower transport to the site

11.3.9 Summary

The overall tower costs developed in this study for the all-steel towers, for example, are not straightforward to compare with the tower costs in [26]. The study 1.5-MW, 100-m tower is 16 m taller than the 1.5-MW, 84-m tower of [26]. The study 3.6-MW, 100-m tower only roughly compares with the 3.0-MW, 119-m tower of [26]. The study 5.0-MW, 100-m tower is even more difficult to compare with the 5.0-MW, 154-m tower of [26].

Several differences in estimating input that have the effect of increasing the estimated tower costs over those used in [26] COE calculations have been noted above.

The fatigue-controlled design of the baseline steel towers developed for this study have been reviewed and the designs found to be appropriate in comparison with the design approach taken with the concrete towers. The crane, welding, and transportation costs have been compared with WindPACT Technical Area 2 information and found to be in close agreement for towers of this size.

There are no good baselines of large wind turbine tower installations of the size considered here that can be used to benchmark the costs developed in this report. As the industry moves forward with design and construction of large towers, it will be important to develop a cost database based on actual construction costs that can be used to validate or refine the cost estimates developed here.

11.3.10 Comparison with Reference 26 COE Values

Table 11.10 is a reproduction of Table 4-4 from the WindPACT Turbine Rotor Design Study [26] with the cost values for the all-steel towers developed in this study for the tower, the tower transportation, and the assembly and installation superimposed. In reviewing this comparison, it is important to consider the differences in tower heights, design criteria, and cost estimating inputs discussed above.

11.4 Final Design Cost and Performance Optimization Efforts

This study focused on the development of a hybrid steel/concrete tower for the 1.5-MW turbine at 100-m hub height. The design for this tower was developed in some depth, as were the construction procedures necessary to accomplish its construction. As the designs of this and the other towers progressed, and were preliminarily evaluated, a number of issues were identified that should be addressed in a more detailed final tower design. These issues include the following:

- The ratio of steel tubular tower height versus concrete base tower height must be tailored for hybrid tower designs for the 3.6- and 5.0-MW turbines. These ratios should be tailored for an optimum combination of dynamic characteristics and tower structure cost, such that overall installation costs (including turbine costs) are minimized. This tailoring is especially indicated for the 5.0-MW, 100-m hybrid steel/concrete and all-concrete towers designed for earthquake. This is advised because, as currently configured, this tower is at the high end of the desired working frequency range.

- Four high-strength, post-tensioning bars in each of the precast concrete segments (16 in the cross section) connect from the tower top to the foundation. These bars are used to provide temporary strength to the tower during erection before the tower is post-tensioned with the strand post-tensioning. Currently, for concerns regarding fatigue performance, we have elected not to consider the strength benefits of these bars in our calculations. In the final design, it should be determined whether these bars can be used for ultimate strength (reducing the quantity of strand post-tensioning materials), as the fatigue stresses in these bars is very low and may be below the endurance limit of the bars if rolled threads and special couplers are used.

Table 11.10. Cost-of-Energy Comparison of Study Steel Towers versus Reference 26 Steel Towers

COE - 100 m Hub Height - All Steel Towers Comparison with Reference 26								
Rating	kW	B/A 1.5 MW (100m)	Ref 26 - 1.5 MW (84 m)	Ref 26 - 3.0 MW (119 m) (Note 2)	3.6/3.0 factor	B/A 3.6 MW (100 m) (Note 1)	B/A 5.0 MW (100 m)	Ref 26 5.0 MW (154 m)
rotor dia		**70.5**	**70**	**99**		**108.4**	**128**	**128**
Rotor (Note 2)	$	**$247,530**	**$247,530**	**$727,931**	**1.312**	**$954,879**	**$1,484,426**	**$1,484,426**
blades (Note 2)	$	$147,791	$147,791	$437,464			$905,903	$905,903
hub (Note 2)	$	$64,191	$64,191	$213,027			$429,307	$429,307
pitch mechanism and bearings (Note 2)	$	$35,548	$35,548	$77,440			$149,216	$149,216
Drive train, nacelle (Note 2)	$	**$562,773**	**$562,773**	**$1,282,002**	**1.279**	**$1,639,679**	**$2,474,260**	**$2,474,260**
Low speed shaft (Note 2)	$	$19,857	$19,857	$56,263			$120,903	$120,903
Bearings (Note 2)	$	$12,317	$12,317	$41,436			$101,834	$101,834
gearbox (Note 2)	$	$150,880	$150,880	$357,224			$697,062	$697,062
mechanical brake, HS coupling (Note 2)	$	$2,984	$2,984	$5,968			$9,947	$9,947
generator (Note 2)	$	$97,500	$97,500	$195,000			$325,000	$325,000
variable speed electroincs (Note 2)	$	$100,500	$100,500	$201,000			$335,000	$335,000
yaw drive and bearing (Note 2)	$	$12,092	$12,092	$28,213			$109,705	$109,705
main frame (Note 2)	$	$63,992	$63,992	$192,115			$433,627	$433,627
electrical connections (Note 2)	$	$60,000	$60,000	$120,000			$200,000	$200,000
hydraulic system (Note 2)	$	$6,750	$6,750	$13,500			$22,500	$22,500
nacelle cover (Note 2)	$	$35,901	$35,901	$71,283			$118,682	$118,682
Control, safety system (Note 2)	$	**$10,200**	**$10,200**	**$10,490**	**1.008**	**$10,577**	**$10,780**	**$10,780**
Tower (Note 3)	$	**$792,123**	**$183,828**	**$551,415**		**$1,270,742**	**$1,612,628**	**$1,176,152**
Balance of Station	$	**$672,580**	**$388,411**	**$873,312**		**$1,410,765**	**$2,187,096**	**$2,458,244**
Foundations (Note 5)	$	$68,742	$48,513	$76,765		$76,765	$108,094	$108,094
Tower Transportation (Note 3)(Note 6)	$	$61,211	$32,204	$195,160		$172,552	$212,355	$992,450
Blade Transportation (Note 4)	$	$4,500	$4,500	$14,250		$19,800	$27,500	$27,500
Hub Transportation (Note 4)	$	$3,800	$3,800	$5,000		$5,900	$7,200	$7,200
Nacelle Transportation (Note 4)	$	$10,500	$10,500	$39,000		$72,000	$285,000	$285,000
Roads, civil works (Note 2)	$	$78,931	$78,931	$136,359	1.200	$163,631	$255,325	$255,325
Assembly and installation (Note 3)	$	$285,646	$50,713	$112,714		$547,240	$733,737	$224,790
Electrical interface/connections (Note 2)	$	$126,552	$126,552	$224,196	1.200	$269,035	$431,500	$431,500
Permits, engineering (Note 2)	$	$32,698	$32,698	$69,868	1.200	$83,842	$126,385	$126,385
Initial capital cost (ICC)	$	**$2,285,206**	**$1,392,742**	**$3,445,150**		**$5,286,642**	**$7,769,190**	**$7,603,862**
Initial capital cost (ICC)	$/kw	$1,523	$928	$1,148		$1,469	$1,554	$1,521
Net annual energy production	kWh	**5,002,400**	**4,816,715**	**10,371,945**	**1.158**	**12,006,000**	**16,703,000**	**18,132,994**
Rotor	¢/kWh	0.586	0.582	0.741		0.942	1.053	0.864
Drive train, nacelle	¢/kWh	1.333	1.258	1.305		1.618	1.755	1.441
Controls	¢/kWh	0.024	0.022	0.011		0.010	0.008	0.006
Tower	¢/kWh	1.876	0.415	0.561		1.254	1.144	0.685
Balance of Station	¢/kWh	1.593	0.851	0.889		1.392	1.552	1.432
Replacement Costs	¢/kWh	0.467	0.467	0.434		0.428	0.414	0.414
O and M	¢/kWh	0.800	0.800	0.800		0.800	0.800	0.800
Total COE (10.6% charge rate Ref 26)	¢/kWh	**6.680**	**4.395**	**4.741**		**6.446**	**6.726**	**5.642**
Using 11.85% fixed charge rate for Ref 26 COE calculation			4.933	5.321				6.333
Fixed Charge Rate = 11.85% (this revised fixed charge rate increases cost of energy by 12.24% over fixed charge rate of 10.6% used in Reference 26)								
This table is taken from reference 26 " WindPACT Rotor Design Study" with the addition of								
costs from this study for TOWER, and TOWER TRANSPORTATION and ASSEMBLY AND INSTALLATION.								
Note 1. Values ratioed from 3.0 MW values.								
Note 2. All cost values from reference 26								
Note 3. Values developed form this study.								
Note 4. Cost values from reference 17 - values not broken down in Reference 26.								
Note 5. Foundation cost values used from reference 26 except 1.5 MW ratioed up by square ot tower height = 1.417								
Note 6. For Ref 26 values blade, hub and nacelle transport costs from Ref 17. Remainder of Ref 26 transport cost assigned to tower.								

- We have assumed termination locations for some of the post-tensioning tendons at two levels above the foundation based on an analysis of cut-off locations for one of the tower designs. In the final design, the optimal termination locations and the number of tendons to be terminated should be determined.

- The use of the tower top connection ring as conceived for the 1.5-MW hybrid steel/concrete tower seems to extend appropriately to the 3.6-MW hybrid tower, but it becomes overly large in the current configuration of the 5.0-MW tower. Thus, a different tower-to-tower connection concept may be appropriate for the 5.0-MW hybrid steel/concrete tower.

- The tower-to-tower joint at the tower top connection ring is a location of complex force transfer. We have conceptually used a very heavy, stiff ring plate for this load transfer and feel that the concept developed is appropriate. This important joint, however, should be the subject of a more refined finite element analysis and perhaps component fatigue testing. Steel castings rather than weldments may be found to be more appropriate and more economical for the tower top connection ring.

- Both the hybrid steel/concrete and the all-precast designs involve significant labor at considerable heights above the ground. For reasons of safety and efficiency, the work platform designs and the provisions for efficient and safe transport to and from the ground for laborers and material should be carefully thought through. Similarly, safety provisions for erecting the precast pieces should be carefully developed and methods consistent with OSHA requirements incorporated. Intelligent handling of these issues will be one key to achieving the level of construction productivity assumed in the cost estimates developed here.

- In addition to the labor productivity issues mentioned above, curing the grout and closure pour concrete associated with the precast-concrete concept in cold weather may require special attention to weather-protective enclosures for use in the winter months. Heating of the enclosures or heating of the forms may be desirable to extend the ability for grout and concrete placement into the coldest periods of the winter. Performing the required high-quality field welds for the steel tubular towers would face similar cold-weather concerns.

- The decision to make the internal diameter of the 1.5-MW hybrid steel/concrete tower constant from bottom to top should be reviewed. The cost savings of reducing material by varying the internal diameter should be compared with the costs of the active lower jack-up guide system proposed for the 3.6- and 5.0-MW hybrid towers to stabilize the steel tower during the jack-up process.

- Active control of the upper tower jack-up guide system for the hybrid towers should also be explored. It will be an improvement from both safety and productivity points of view if the entire jack-up operation can be performed without having personnel on the tower during the jack-up process.

- The mobile crane costs associated with erection of the precast concrete segments for the all-precast concrete towers are significant. The costs of mobilizing, assembling, and relocating tower cranes capable of lifting the precast concrete segments should be compared against the cost of mobile cranes for this purpose.

11.5 Risk Analysis

The following qualitative risk analysis seeks to identify those aspects of the overall design and construction process that could result in changes in the costs and schedules estimated in this study. Also identified is potential design or operational risks that are associated with using different technology to accomplish objectives that have previously been handled in other ways.

11.5.1. Risks and Mitigation Measures: Hybrid Steel/Concrete and All-Precast-Concrete Towers

	Risk	Mitigation
(a.)	Costs may be higher than estimated. Operations, features, and processes may be omitted from estimate.	Use input from an experienced precast concrete fabricator/erector, develop a detailed construction erection process to guide the estimating process. (This has been done for the 1.5-MW hybrid steel/concrete tower addressed in this study.)
	Special equipment proposed may be more complex than estimated.	As part of project planning, engage equipment designers to detail the several pieces of special equipment proposed for this project. Identify problems to be resolved and any missing elements early in the project.
	Productivity may be lower than estimated.	As part of project planning, determine ways to minimize the amount of personnel and material lifting required to complete a level of precast concrete construction. Design and provide efficient methods of personnel and material vertical transport. Design and provide elevated work platforms that maximize productivity in cold and windy conditions.
	Jack-up operation used for hybrid tower may be more complex than estimated.	Before committing to this concept, engage a company that specializes in raising large loads with the strand jacking procedure to review and comment on the concept and identify missing or problematic areas of concern for resolution.
	Erection safety requirements may add significant cost.	Before committing to this concept, engage an erection safety consultant to develop an overall erection safety plan that can be reviewed with OSHA representatives.
(b.)	Fatigue of hybrid steel/concrete tower-to-tower connection and tower-to-turbine connection may be a problem.	Perform additional analysis of this connection, including a detailed FEM analysis. Consider component or scale model testing to confirm distribution of stresses and stiffness of the connection. Instrument and monitor the initial prototype installation. Revise subsequent designs as indicated by test results.

	Risk	Mitigation
		The tower-to-turbine connection is typical in concept to the connections currently used between steel tubular towers and the turbine structure and will be of less concern.
(c.)	Durability of ring-to-ring joints between precast concrete elements may be less than desired.	The particular joint design proposed should provide acceptable durability. However, before constructing hundreds of these joints in the field, it would be prudent to perform an accelerated durability test on a representative component of the joint. The test should focus on the durability of the grout and the effectiveness of the corrosion protective grout covering on the post-tensioning tendons.
(d.)	Aesthetics of towers may be a concern.	Develop computer visualization graphics of proposed tower configurations and compare with conventional tubular steel tower designs.

11.5.2. Risks and Mitigation Measures: Cast-in-Place Concrete Towers

	Risk	Mitigation
(a.)	Costs may be higher than estimated.	
	Operations, features, and processes may be omitted from estimate.	Engage contractor experienced in large-scale industrial chimney construction to prepare the basic cost estimate for the tower structure. (This has been done for this study.)
	Special equipment proposed may be more complex than estimated.	As part of project planning, engage equipment designers to detail the several pieces of special equipment proposed for this project. Identify problems and missing elements early in the project.
	Productivity may be lower than estimated.	As part of project planning, determine ways to minimize the personnel and material lifting required to complete a level of concrete construction. Design efficient methods of personnel and material vertical transport. Design elevated work platforms that maximize productivity in cold and windy conditions.

	Risk	Mitigation
(b.)	Fatigue life of tower-to-turbine connection may be a problem.	Perform additional analysis of this connection, including FEM analysis. This is less of a problem with this concept than with the hybrid concept because the transferred loads and moments are smaller.
(c.)	Durability of structure may be less than desired.	Concrete chimneys are known to be durable when properly designed and constructed. Ensure that the criteria selected for design are consistent with those found to be successful in providing durable chimney structures.
(d.)	Aesthetics of towers may be a concern.	These towers should look most like the current tubular steel towers. The large scale of any tower for the 3.6- and 5.0-MW turbines is an issue that will have to be addressed aesthetically.
(e.)	Fatigue life of external post-tensioning anchors may be a concern.	Evaluate cyclic stress levels in the post-tensioning anchors and, if necessary, encase the tendons in the tower top concrete structure for 4.6 to 6.1 m (15 to 20 ft) and grout the tendon in this area to transfer stress via bond to concrete prior to the anchor. A similar procedure can be used at the foundation.

11.5.3. Risks and Mitigation Measures: Large-Diameter Steel Tubular Towers

	Risk	Mitigation
(a.)	Costs may be higher than estimated.	
	Operations, features, and processes may be omitted from estimate.	A detailed study of site infrastructure requirements is needed to further define all of the costs associated with site assembly of the large steel tower segments, which will be shipped to the site in quarter circumferential sections.
	Special equipment proposed may be more complex than estimated.	Procedures for performing horizontal circumferential welds upon erection of tower segments using temporary strength provisions across the weld joint should be evaluated by a steel erection/welding specialist before committing to this procedure. Missing elements or concerns should be identified.

	Productivity may be lower than estimated.	As part of project planning, determine ways to minimize the personnel and material lifting required to erect the tower elements. Design efficient methods of personnel and material vertical transport. Design elevated work platforms that maximize productivity in cold and windy conditions.
	Erection safety requirements may add significant cost.	Before committing to this concept, engage an erection safety consultant to develop an overall erection safety plan that can be reviewed with OSHA representatives.
(b.)	Fatigue strength of site-performed welds may be a problem.	The requirements to achieve the necessary fatigue performance in the tower site welds should be determined in detail to ensure that the equipment and productivity rates assumed are appropriate.
(c.)	Durability of field-applied protective coatings may not be acceptable.	Determine requirements (facilities, equipment, schedule, and cost) necessary to provide a tower finish with acceptable long-term anticorrosive behavior.
(d.)	Aesthetics of towers may be a concern.	Develop computer visualization graphics of proposed tower configurations compared with conventional smaller-scale tubular steel tower designs.
(e.)	Unstiffened steel plate concept may not be viable for the large tower structures proposed.	Further investigate the buckling design requirements for shell structures of the scale of the 3.6- and 5.0-MW towers. Perform component buckling tests if necessary to confirm appropriateness of design criteria.

12.0 Conclusions and Recommendations

The results of this study indicate that for the 1.5-MW, 100-m tower size the hybrid steel/concrete, the all-cast-in-place concrete, and the tubular steel towers have reasonably comparable costs (all within 33% of each other). The cast-in-place concrete approach is estimated to be lowest cost solution. This concept represents a modest extension of current construction technology and is the recommended configuration for further development.

The cost savings associated with nacelle erection at 50 m versus 100 m are not significant enough to provide a strong cost advantage to the hybrid steel/concrete concept.

The overall cost and feasibility of site welding for the large-diameter lower sections of the tubular steel tower represent the greatest uncertainty for the tubular steel tower concept.

For the 3.6-MW, 100-m tower size, the all-cast-in-place concrete concept is 68% the estimated cost of the tubular steel concept. This concept seems to have very good potential for optimized economy in this size range and is recommended for further development for that reason.

For the 5.0-MW, 100-m tower size, the all-cast-in-place-concrete concept is 63% the estimated cost of the tubular steel concept. This concept seems to have very good potential for optimized economy in this size range and is recommended for further development for that reason.

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Appendix A – Turbine Data

Turbine Data and Design Specification

The following parameters were used in the design of the towers presented in this study. The parameters resulted from a combination of industry input and review of Reference 16 and 26. The tower hub height of 100m was set as result of industry input.

	1.5MW	**3.6MW**	**5.0MW**
Rotor Diameter:	70.5 m	108.4 m	128 m
Rotor Speed:	20.5 rpm	13.2 rpm	11.2 rpm
Blade Tip Speed:	75 m/s	75 m/s	75 m/s
Head Mass (incl. nacelle, hub and blades)	84800 kg	314912 kg	480076 kg
Hub Height:	100 m	100 m	100 m
Tower Length:	98.4 m	98 m	98 m
Working Frequency Range (1.1P~2.6P)	0.376 Hz to 0.888 Hz	0.242 Hz to 0.572 Hz	0.205 Hz to 0.485 Hz

Appendix B – Typical Design Calculations

Preliminary Tower Design Results

A complete set of design calculations for a 5.0 MW 100 m tower using a hybrid concrete steel concept, and all concrete concept, and for comparison, an all-tubular-steel concept are given in this Appendix. The flow diagrams given in Figures Appendix B-1.1, B-1.2 and B-1.3 outlines the overall design process for the different types of towers.

The design results for all of the hybrid towers are given in Table Appendix B-2. The results for the all concrete towers are given in Table Appendix B-3. Preliminary design results for comparable sized steel towers are given in Table Appendix B-4.

The 1.5 MW hybrid tower design is governed by the requirement to provide construction clearance around the steel tubular tower that is later jacked up to full height. The top dimension of the concrete tower in the 3.6 MW and 5.0 MW hybrid steel concrete towers is controlled by the necessary based diameter of the steel top tower. As a consequence all of the hybrid towers have capacity to handle seismic loads and are slightly over capacity for extreme wind loads. Separate designs for the all concrete towers were prepared for both wind and earthquake.

Design Loads

The design loads used in the design of the towers addressed in this report are given in Appendix J

Design loads used for tower design were derived from those used as input to the WindPACT Turbine Rotor Design Study (Reference 26). Design loads and the appropriate combination of loads for design were developed in collaboration with representatives of Global Energy Concepts. The appropriate design use of these load combinations for tower design was the responsibility of BERGER/ABAM. The seismic loads used for design and the direct wind loads on the tower structure itself were developed by BERGER/ABAM using References 6 and 9**.** The tower fatigue loads used were developed from Reference 26 with collaborative input from representatives of Global Energy Concepts.

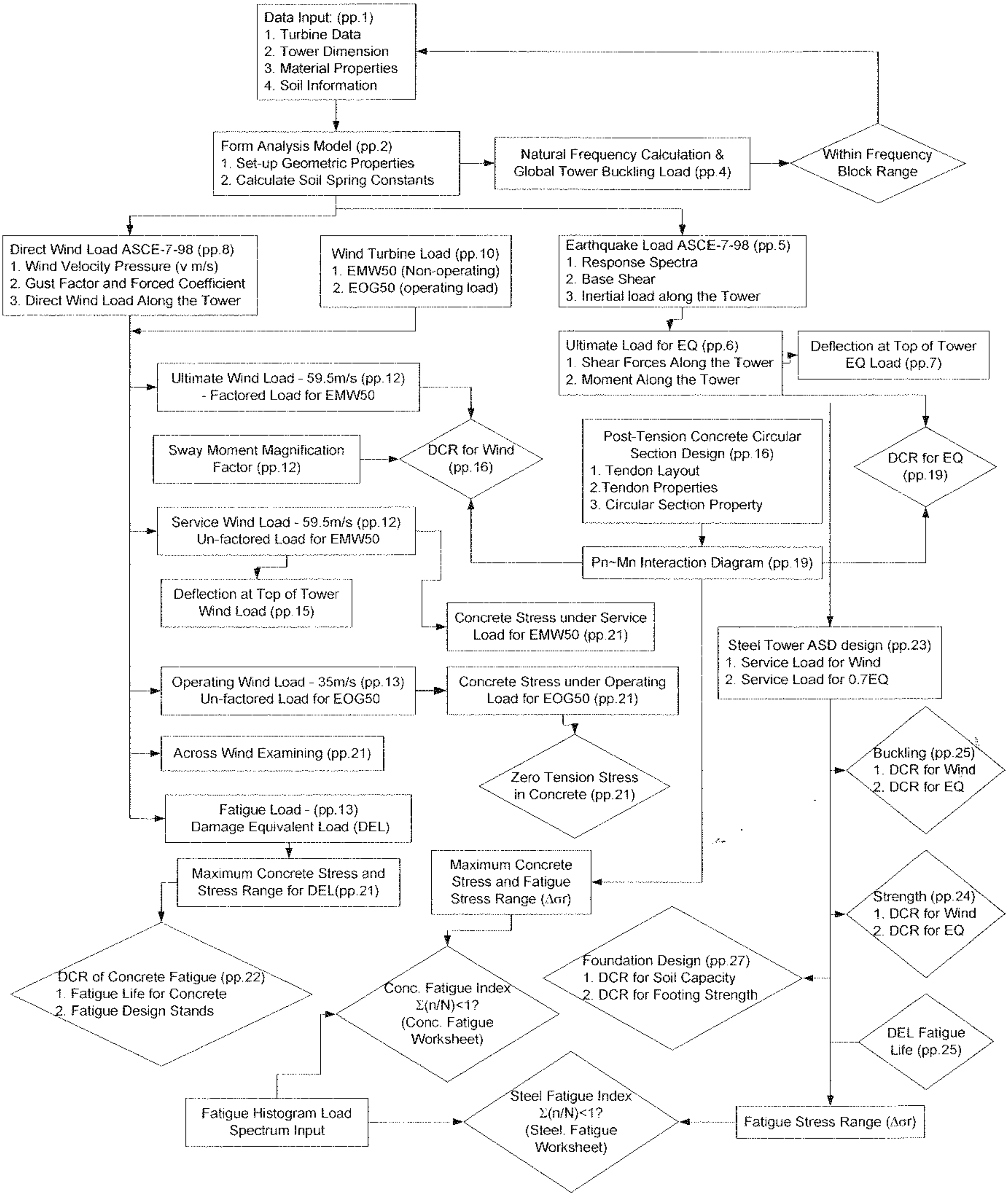
Loads for the 3.6 MW tower were scaled from the 3.0 MW loads given in Reference 26.

Design Example 5.0 MW – 100 m Hub Height Tower

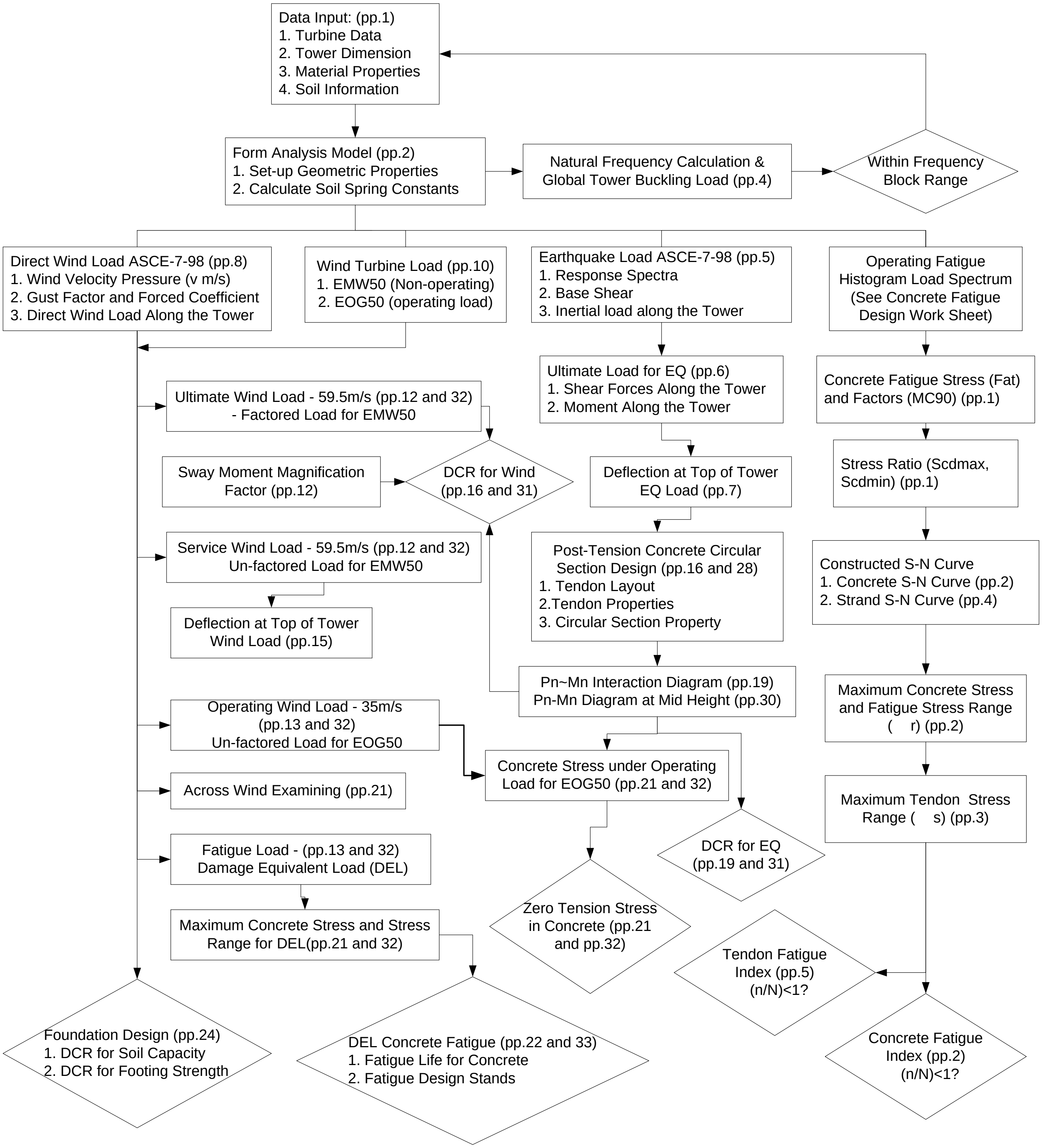
The design principles and methods used in this design example are discussed in the body of the report. While some design attention has been focused on the design details such as the steel tower to concrete tower top connection and the access opening to in the base of the concrete tower, these will require further attention in a final design effort. The tower to tower connection is particularly important as the forces being transferred are significant and the connection is subject to fatigue loads and prone to stress concentrating details.

The primary focus of the design work has been on developing the overall structural sections needed for the tower and consideration of applicable construction methods so that realistic pricing and an assessment of relative construction project risk can be developed.

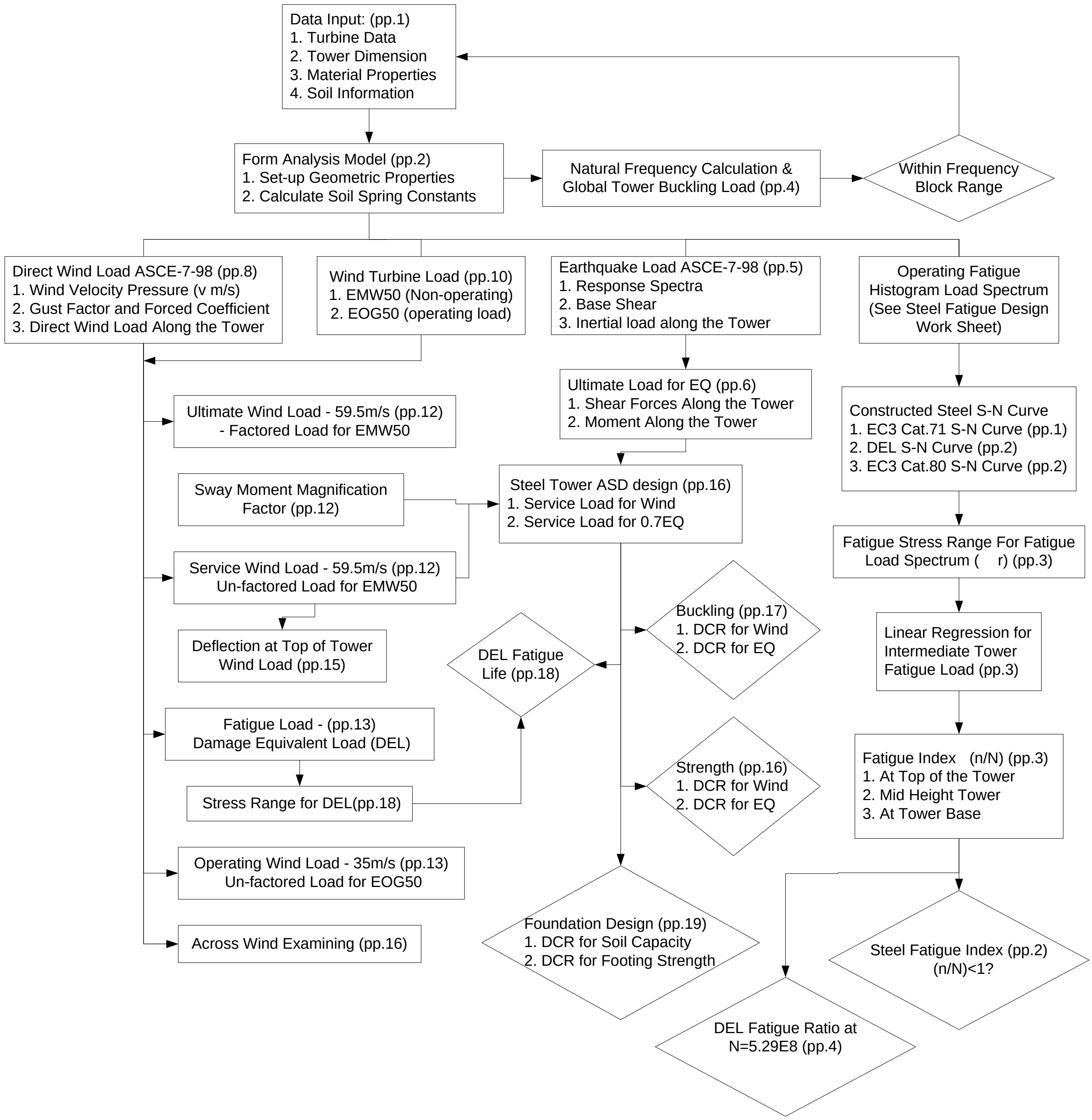
Because this is a nonsite specific study, we have not attempted to optimize the foundation system for the towers. Detailed site specific geotechnical information is needed to make such an effort fruitful.



100m Hybrid Steel/Concrete Tower Design Procedure Flow Chart
Figure Appendix B-1.1



100m All Concrete Tower Design Procedure Flow Chart
Figure Appendix B-1.2



100m All Tubular Steel Design Procedure Flow Chart
Figure Appendix B -1.3

100m Hybrid Wind Turbine Tower (fc'=7ksi fy=50ksi)

	1.5MW (Wind/EQ)		3.6MW (Wind/EQ)		5.0MW(Wind/EQ)	
Rotor Diameter	70.5 m	231.2 ft	108.4 m	355.6 ft	128 m	419.8 ft
Total Head Weight	84800 kg	187 kips	314912 kg	694 kips	480076 kg	1058 kips
Additional Weight at Transition Connection	1500 kg	3.3 kips	3600 kg	7.94 kips	5000 kg	11 kips
Concrete Tower Height	49 m	161 ft	47 m	154 ft	47 m	154 ft
Outside Diameter at Base for Concrete Tower	5.791 m	228 in	8.077 m	318 in	9.144 m	360 in
Wall Thickness at Base for Concrete Tower	0.6604 m	26 in	0.762 m	30 in	0.762 m	30 in
Outside Diameter at Top for Concrete Tower	5.258 m	207 in	7.772 m	306 in	8.687 m	342 in
Wall Thickness at Top for Concrete Tower	0.3937 m	15.5 in	0.6096 m	24 in	0.6096 m	24 in
Outside Diameter at Base for Steel Tower	3.531 m	139 in	5.639 m	222 in	6.553 m	258 in
Wall Thickness at Base for Steel Tower	0.03175 m	1.25 in	0.03175 m	1.25 in	0.03492 m	1.375 in
Outside Diameter at Top for Steel Tower	2.896 m	114 in	3.962 m	156 in	4.572 m	180 in
Wall Thickness at Top for Steel Tower	0.009525 m	0.375 in	0.01905 m	0.75 in	0.02222 m	0.875 in
Spread Foot Width and Length	16.46 m	54 ft	20.42 m	67 ft	21.34 m	70 ft
Spread Foot Depth	3.048 m	10 ft	3.658 m	12 ft	3.658 m	12 ft
Steel Tower Weight	826.5 kN	185.8 kips	1577 kN	354.5 kips	2053 kN	461.6 kips
Concrete Tower Weight	9575 kN	2153 kips	17280 kN	3884 kips	19650 kN	4417 kips
Tendon Weight	23310 kg	51390 lb	29810 kg	65730 lb	34780 kg	76680 lb
Footing Reinforcement Weight	47160 kg	104 kips	97610 kg	215.2 kips	113500 kg	250.2 kips
Defection at Top of Tower for EQ Load	1.581 m	5.186 ft	1.142 m	3.746 ft	0.9679 m	3.176 ft
Defection at Top of Tower for Wind Load	0.5394 m	1.77 ft	0.4662 m	1.53 ft	0.3583 m	1.176 ft
Max. Conc Stress for Wind for EWM50	11.91 MPa	1.727 ksi	11.3 MPa	1.639 ksi	10.65 MPa	1.545 ksi
Min. Conc Stress for Wind for EWM50	2.826 MPa	0.4099 ksi	1.435 MPa	0.2082 ksi	2.422 MPa	0.3513 ksi
Max. Conc Stress for Wind at EOG50	10.5 MPa	1.522 ksi	10.06 MPa	1.459 ksi	10.48 MPa	1.52 ksi
Min. Conc Stress for Wind at EOG50	4.237 MPa	0.6145 ksi	2.673 MPa	0.3876 ksi	2.58 MPa	0.3742 ksi
Max. Conc Stress for Fatigue Load	8.042 MPa	1.166 ksi	7.039 MPa	1.021 ksi	7.291 MPa	1.057 ksi
Min. Conc Stress for Fatigue Load	6.69 MPa	0.9704 ksi	5.69 MPa	0.8253 ksi	5.752 MPa	0.8343 ksi
Max. Tendon Stress for Fatigue Load	1107.6 MPa	160.6 ksi	1107.6 MPa	160.6 ksi	1107.6 MPa	160.6 ksi
Min. Tendon Stress for Fatigue Load	1103 Mpa	160 ksi	1103 Mpa	160 ksi	1103 Mpa	160 ksi
Number of Tendon in Concrete Tower	36		48		56	
Tower Natural Frequency (Hz) (Rayleigh-SAP)	0.4848	0.4803	0.4813	0.4793	0.4835	0.4802
Base Shear & Mom. Comparison (EQ/Wind)	2.481	2.222	2.529	1.958	3.997	2.246
Mom. DCR of Conc. at Base (Wind - EQ)	0.417	0.927	0.458	0.896	0.366	0.821
Shear DCR of Conc at Base (Wind - EQ)	0.251	0.483	0.294	0.562	0.204	0.591
Max. Stress DCR for Steel (Wind - EQ)	0.328	0.684	0.413	0.712	0.365	0.633
Max. Buckling DCR of Steel (Wind - EQ)	0.356	0.663	0.433	0.741	0.385	0.666
Soil Bearing Capacity DCR (Wind - EQ)	0.656	0.775	0.839	0.873	0.848	0.986
Footing Shear Capacity DCR (Wind - EQ)	0.288	0.348	0.339	0.381	0.334	0.402
Steel Tower Fatigue DCR	0.954		0.902		0.991	
Conc. Fatigue DEL-log(N) & Σ(n/N) @Base	76.6	6.15E-08	85.4	1.73E-08	72.6	3.55E-06
Controlling Loading Case	STL Fatigue		STL Fatigue		STL Fatigue	

Design Results – 100 M Hybrid Steel/Concrete Wind Turbine Towers
Table Appendix B-2

100m All Concrete Wind Turbine Tower (fc'=7ksi)

	1.5MW (EQ)		1.5MW (Wind)		3.6MW (EQ)		3.6MW (Wind)		5.0MW(EQ)		5.0MW(Wind)	
Rotor Diameter	70.5 m	231.2 ft	70.5 m	231.2 ft	108.4 m	355.6 ft	108.4 m	355.6 ft	128 m	419.8 ft	128 m	419.8 ft
Total Head Weight	84800 kg	187 kips	84800 kg	187 kips	314912 kg	694 kips	314912 kg	694 kips	480076 kg	1058 kips	480076 kg	1058 kips
Additional Weight at Mid Height Tower	1500 kg	3.3 kips	1500 kg	3.3 kips	3600 kg	7.94 kips	3600 kg	7.94 kips	5000 kg	11 kips	5000 kg	11 kips
Mid Height of Concrete Tower (hc)	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft
Outside Diameter at Base for Concrete Tower	6.401 m	252 in	5.791 m	228 in	7.925 m	312 in	6.706 m	264 in	9.144 m	360 in	7.62 m	300 in
Wall Thickness at Base for Concrete Tower	0.6858 m	27 in	0.6096 m	24 in	0.762 m	30 in	0.6858 m	27 in	0.8382 m	33 in	0.762 m	30 in
Outside Diameter at Mid Height of Conc Tower	4.42 m	174 in	3.962 m	156 in	5.639 m	222 in	5.182 m	204 in	6.401 m	252 in	5.639 m	222 in
Wall Thickness at Mid Height of Conc Tower	0.5334 m	21 in	0.5334 m	21 in	0.6096 m	24 in	0.6096 m	24 in	0.6858 m	27 in	0.6858 m	27 in
Outside Diameter at Top of Conc Tower	2.896 m	114 in	2.896 m	114 in	3.658 m	144 in	3.658 m	144 in	3.658 m	144 in	3.658 m	144 in
Wall Thickness at Top of Conc Tower	0.4572 m	18 in	0.4572 m	18 in	0.4572 m	18 in	0.4572 m	18 in	0.5334 m	21 in	0.4572 m	18 in
Spread Foot Width and Length	18.29 m	60 ft	16.76 m	55 ft	21.34 m	70 ft	19.2 m	63 ft	22.86 m	75 ft	20.42 m	67 ft
Spread Foot Depth	3.353 m	11 ft	3.048 m	10 ft	3.658 m	12 ft	3.658 m	12 ft	3.962 m	13 ft	3.658 m	12 ft
Concrete Tower Weight	16650 kN	3742 kips	14470 kN	3254 kips	23640 kN	5314 kips	20370 kN	4579 kips	29790 kN	6697 kips	24470 kN	5502 kips
Tendon Weight	52650 kg	116100 lb	35600 kg	78490 lb	60630 kg	133700 lb	47470 kg	104600 lb	64570 kg	142300 lb	59180 kg	130500 lb
Footing Reinforcement Weight	76570 kg	168.8 kips	64960 kg	143.2 kips	129700 kg	285.8 kips	105000 kg	231.5 kips	157600 kg	347.4 kips	131600 kg	290.2 kips
Defection at Top of Tower for EQ Load	1.251 m	4.103 ft	1.596 m	5.236 ft	1.007 m	3.304 ft	1.323 m	4.342 ft	0.8754 m	2.872 ft	1.202 m	3.944 ft
Defection at Top of Tower for Wind Load	0.2737 m	0.898 ft	0.3828 m	1.256 ft	0.3501 m	1.149 ft	0.5046 m	1.656 ft	0.2675 m	0.8776 ft	0.4148 m	1.361 ft
Max. Stress at Tower Base												
Max. Conc Stress for Wind for EWM50	12.34 MPa	1.79 ksi	12.1 MPa	1.755 ksi	12.34 MPa	1.79 ksi	15.65 MPa	2.27 ksi	10.15 MPa	1.473 ksi	14.3 MPa	2.074 ksi
Min. Conc Stress for Wind for EWM50	5.067 MPa	0.7349 ksi	2.269 MPa	0.329 ksi	2.101 MPa	0.3047 ksi	-0.5103 MPa	-0.07401 ksi	2.578 MPa	0.3739 ksi	2.036 MPa	0.2954 ksi
Max. Conc Stress for Wind at EOG50	11.15 MPa	1.617 ksi	10.5 MPa	1.523 ksi	11.07 MPa	1.605 ksi	13.64 MPa	1.978 ksi	10.03 MPa	1.454 ksi	14.1 MPa	2.046 ksi
Min. Conc Stress for Wind at EOG50	6.258 MPa	0.9077 ksi	3.864 MPa	0.5604 ksi	3.374 MPa	0.4893 ksi	1.498 MPa	0.2173 ksi	2.693 MPa	0.3906 ksi	2.215 MPa	0.3212 ksi
Max. Conc Stress for Fatigue Load	9.224 MPa	1.338 ksi	7.896 MPa	1.145 ksi	7.922 MPa	1.149 ksi	8.68 MPa	1.259 ksi	7.07 MPa	1.025 ksi	9.314 MPa	1.351 ksi
Min. Conc Stress for Fatigue Load	8.181 MPa	1.187 ksi	6.471 MPa	0.9385 ksi	6.513 MPa	0.9447 ksi	6.452 MPa	0.9358 ksi	5.635 MPa	0.8173 ksi	6.983 MPa	1.013 ksi
Max. Tendon Stress for Fatigue Load	1111.6 MPa	161.2 ksi	1111.6 MPa	161.2 ksi	1106.2 MPa	160.4 ksi	1108.3 MPa	160.8 ksi	1105 MPa	160.3 ksi	1105 MPa	160.3 ksi
Min. Tendon Stress for Fatigue Load	1094.7 Mpa	158.8 ksi	1094.7 Mpa	158.8 ksi	1102.5 Mpa	159.9 ksi	1102 Mpa	159.8 ksi	1102.7 Mpa	159.9 ksi	1102.7 Mpa	159.9 ksi
Number of Tendon at Base and Mid Section	48	32	30	24	52	40	40	32	56	42	56	34
Tower Natural Frequency (Hz) [Rayleigh-SAP]	0.4355	0.4082	0.3774	0.3557	0.4431	0.4118	0.3768	0.3419	0.4621	0.4350	0.384	0.3564
Base Shear & Moment Comprison (EQ/Wind)	3.497	3.393	3.141	3.059	3.034	2.341	2.704	2.092	5.296	2.809	4.643	2.432
Mom. DCR of Conc. Tower at Base (Wind - EQ)	0.279	0.946	0.453	1.383	0.422	0.987	0.669	1.397	0.341	0.956	0.470	1.140
Shear DCR of Conc at Base (Wind - EQ)	0.215	0.604	0.265	0.650	0.290	0.657	0.390	0.747	0.177	0.664	0.240	0.736
Soil Bearing Capacity DCR (Wind - EQ)	0.655	0.901	0.694	1.230	0.814	0.907	0.946	1.214	0.833	0.960	0.932	1.285
Footing Shear Capacity DCR (Wind - EQ)	0.300	0.416	0.326	0.463	0.398	0.475	0.390	0.465	0.362	0.455	0.409	0.517
Section Forces at Mid Height of Concrete Tower (hc)												
Shear & Moment Comprison for EQ/Wind	4.523	3.414	4.076	3.105	3.362	2.122	3.000	1.918	7.029	2.419	6.077	2.124
Mom. DCR of Conc. Tower (Wind - EQ)	0.274	0.935	0.396	1.228	0.446	0.947	0.598	1.148	0.401	0.972	0.570	1.213
Shear DCR of Conc (Wind - EQ)	0.345	0.970	0.407	0.971	0.510	1.032	0.582	1.006	0.289	1.046	0.357	1.027
Max. Conc Stress for Wind for EWM50	14.75 MPa	2.14 ksi	14.77 MPa	2.142 ksi	15.84 MPa	2.298 ksi	16.49 MPa	2.391 ksi	13.17 MPa	1.911 ksi	14.75 MPa	2.139 ksi
Min. Conc Stress for Wind for EWM50	5.713 MPa	0.8287 ksi	3.048 MPa	0.4421 ksi	2.07 MPa	0.3002 ksi	-0.3194 MPa	-0.04633 ksi	2.04 MPa	0.2959 ksi	-0.2514 MPa	-0.03646 ksi
Max. Conc Stress for Wind at EOG50	13.57 MPa	1.968 ksi	13.23 MPa	1.92 ksi	14.22 MPa	2.063 ksi	14.51 MPa	2.104 ksi	12.96 MPa	1.879 ksi	14.45 MPa	2.097 ksi
Min. Conc Stress for Wind at EOG50	6.894 MPa	0.9999 ksi	4.579 MPa	0.6642 ksi	3.683 MPa	0.5341 ksi	1.655 MPa	0.2401 ksi	2.237 MPa	0.3245 ksi	0.01887 MPa	0.002737 ksi
Max. Conc Stress for Fatigue Load	11.03 MPa	1.599 ksi	9.94 MPa	1.442 ksi	9.967 MPa	1.446 ksi	9.317 MPa	1.351 ksi	8.652 MPa	1.255 ksi	8.659 MPa	1.256 ksi
Min. Conc Stress for Fatigue Load	9.437 MPa	1.369 ksi	7.874 MPa	1.142 ksi	7.932 MPa	1.15 ksi	6.837 MPa	0.9916 ksi	6.516 MPa	0.945 ksi	5.782 MPa	0.8386 ksi
Max. Tendon Stress for Fatigue Load	1106.4 MPa	160.5 ksi	1106.4 MPa	160.5 ksi	1108.3 MPa	160.7 ksi	1111.7 MPa	161.2 ksi	1110.1 Mpa	161 ksi	1110.1 Mpa	161 ksi
Min. Tendon Stress for Fatigue Load	1102.7 Mpa	159.9 ksi	1102.7 Mpa	159.9 ksi	1101.4 Mpa	159.8 ksi	1100.3 Mpa	159.6 ksi	1096.2 Mpa	159 ksi	1096.2 Mpa	159 ksi
Conc. Fatigue (z=hc,z=0) DEL-Log(N)	42.17	85.83	38.68	73.73	39.15	74.41	34.84	42.23	44.3	79.82	32.16	37.2
Conc. Fatigue (z=hc,z=0) Σ(n/N)	2.49E-04	1.13E-09	9.89E-03	1.84E-07	5.51E-03	1.61E-07	9.80E-02	1.60E-02	4.49E-03	4.64E-07	8.87E-01	1.39E-01
Controlling Loading Case	EQ Strength		Tower Frequency		EQ Strength		Conc Fatigue		EQ Strength		Conc Fatigue & Ten. Str.	

Design Results 100m Full Height Concrete Wind Turbine Towers
Table Appendix B-3

Note that the DCR's for concrete shear in the above table are for plain concrete shear capacity and do not consider the beneficial effects of post tensioning.

100m Steel Wind Turbine Tower (50ksi)

	1.5MW		3.6MW		5.0MW	
Rotor Diameter	70.5 m	231.2 ft	108.4 m	355.6 ft	128 m	419.8 ft
Total Head Weight	84800 kg	187 kips	314912 kg	694 kips	480076 kg	1058 kips
Additional Weight at Transition Connection	1500 kg	3.3 kips	3600 kg	7.94 kips	5000 kg	11 kips
Steel Tower Mid Height	49 m	160.8 ft	49 m	160.8 ft	49 m	160.8 ft
Outside Diameter at Base for Steel Tower	5.791 m	228 in	7.62 m	300 in	8.839 m	348 in
Wall Thickness at Base for Steel Tower	0.0254 m	1 in	0.03175 m	1.25 in	0.03651 m	1.438 in
Outside Diameter at Mid Height of Steel Tower	4.267 m	168 in	5.639 m	222 in	6.706 m	264 in
Wall Thickness at Mid Height of Steel Tower	0.0254 m	1 in	0.03175 m	1.25 in	0.03492 m	1.375 in
Outside Diameter at Top of Steel Tower	2.896 m	114 in	3.962 m	156 in	4.572 m	180 in
Wall Thickness at Top of Steel Tower	0.009525 m	0.375 in	0.01905 m	0.75 in	0.02222 m	0.875 in
Spread Foot Width and Length	16.46 m	54 ft	18.29 m	60 ft	20.42 m	67 ft
Spread Foot Depth	3.048 m	10 ft	3.658 m	12 ft	3.658 m	12 ft
Steel Tower Weight	2296 kN	516.1 kips	4000 kN	899.2 kips	5282 kN	1188 kips
Footing Reinforcement Weight	23330 kg	51.44 kips	34570 kg	76.2 kips	43100 kg	95.02 kips
Defection at Top of Tower for EQ Load	1.005 m	3.296 ft	0.9011 m	2.956 ft	0.7356 m	2.413 ft
Defection at Top of Tower for Wind Load	0.9185 m	3.013 ft	0.9183 m	3.013 ft	0.6078 m	1.994 ft
Tower Natural Frequency (Hz) [Rayleigh-SAP]	0.4059	0.3669	0.3693	0.3341	0.3973	0.3605
Base Shear & Mom Comparison for EQ/Wind	0.638	0.714	0.789	0.715	1.447	0.925
Max. Stress DCR for Steel (Wind - EQ)	0.492	0.374	0.575	0.429	0.494	0.400
Max. Buckling DCR of Steel (Wind - EQ)	0.370	0.279	0.449	0.324	0.379	0.304
Soil Bearing Capacity DCR (Wind - EQ)	0.561	0.315	0.895	0.474	0.780	0.486
Footing Shear Capacity DCR (Wind - EQ)	0.243	0.172	0.235	0.160	0.267	0.207
Max. Fatigue DCR of Steel Tower	0.758		0.803		0.780	
Controlling Loading Case	STL Fatigue		STL Fatigue		STL Tower Fatigue	

Design Results 100 m Tubular Steel Wind Turbine Towers
Fy = 344 MPa (50 ksi)
Table Appendix B-4

Seismic Forces for Wind Turbine Tower

Turbine	Tower Type	Tower Weight		Base Shear		Base Moment		Weight at 49m		Shear at 49m		Moment at 49m	
Power		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	3272	736	179700	132500	1658	373	1974	444	76650	56540
(EQ)	Conc. Tower	17490	3933	4863	1093	286400	211200	6779	1524	4024	905	121900	89940
	Steel Tower	3142	706	873	196	60030	44280	1621	365	789	177	30930	22820
(Wind)	Conc. Tower	15320	3444	4259	957	255000	188100	6341	1426	3584	806	110700	81660
3.6 MW	Hybrid Tower	21980	4941	6348	1427	395200	291500	4665	1049	4590	1032	199400	147100
(EQ)	Conc. Tower	26760	6016	7438	1672	468900	345900	11460	2577	6396	1438	219000	161500
	Steel Tower	7123	1601	1980	445	145200	107100	4606	1035	1875	422	79620	58720
(Wind)	Conc. Tower	23490	5281	6530	1468	418000	308300	10980	2468	5708	1283	198100	146100
5.0 MW	Hybrid Tower	26460	5948	7675	1725	499100	368100	6761	1520	5927	1332	261000	192500
(EQ)	Conc. Tower	34550	7767	9603	2159	614400	453200	15000	3373	8310	1868	292500	215700
	Steel Tower	10040	2257	2791	627	206600	152400	6713	1509	2658	598	114300	84290
(Wind)	Conc. Tower	29230	6571	8125	1827	529300	390400	13630	3064	7134	1604	256800	189400

Ultimate Tower Design Forces for Wind Load (EWM50)

Turbine	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
Power		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	13500	3034	1319	297	80860	59640	1990	447	828	186	34900	25740
(EQ)	Conc. Tower	20990	4719	1391	313	84390	62250	8136	1829	890	200	35720	26340
	Steel Tower	3771	848	1370	308	84060	62000	1946	438	889	200	35740	26360
(Wind)	Conc. Tower	18390	4133	1356	305	83350	61480	7610	1711	880	198	35660	26300
3.6 MW	Hybrid Tower	26460	5950	2510	564	201800	148900	5688	1279	1920	432	106800	78750
(EQ)	Conc. Tower	32200	7239	2451	551	200300	147800	13840	3112	1902	428	103200	76100
	Steel Tower	8638	1942	2511	565	203200	149800	5617	1263	1940	436	103900	76660
(Wind)	Conc. Tower	28280	6357	2415	543	199900	147400	13270	2982	1902	428	103300	76180
5.0 MW	Hybrid Tower	32140	7226	1920	432	222200	163900	8505	1912	1238	278	125300	92390
(EQ)	Conc. Tower	41850	9408	1813	408	218700	161300	18400	4136	1182	266	120900	89170
	Steel Tower	12440	2796	1928	434	223500	164800	8447	1899	1258	283	122200	90130
(Wind)	Conc. Tower	35470	7973	1750	393	217700	160600	16750	3765	1174	264	120900	89180

Service Wind Load Tower Design Forces (EWM50)

Turbine	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
Power		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	871	196	55830	41180	1659	373	571	129	25130	18540
(EQ)	Conc. Tower	17490	3933	915	206	57930	42730	6780	1524	609	137	25610	18890
	Steel Tower	3142	706	902	203	57730	42580	1622	365	608	137	25630	18900
(Wind)	Conc. Tower	15320	3444	894	201	57310	42270	6341	1426	603	136	25580	18870
3.6 MW	Hybrid Tower	22050	4956	1723	387	144600	106700	4732	1064	1364	307	78030	57560
(EQ)	Conc. Tower	26830	6031	1687	379	143700	106000	11530	2592	1353	304	75470	55660
	Steel Tower	7190	1616	1724	388	145400	107300	4673	1050	1376	309	75920	56000
(Wind)	Conc. Tower	23560	5296	1665	374	143400	105800	11050	2483	1353	304	75530	55710
5.0 MW	Hybrid Tower	26750	6013	1263	284	159900	117900	7051	1585	851	191	91750	67680
(EQ)	Conc. Tower	34840	7832	1198	269	157800	116400	15290	3438	817	184	88700	65430
	Steel Tower	10330	2322	1268	285	160600	118500	7003	1574	862	194	89490	66010
(Wind)	Conc. Tower	29520	6636	1159	261	157200	116000	13920	3129	812	183	88710	65430

Wind Turbine Tower Combined Forces

Table Appendix B-5.1

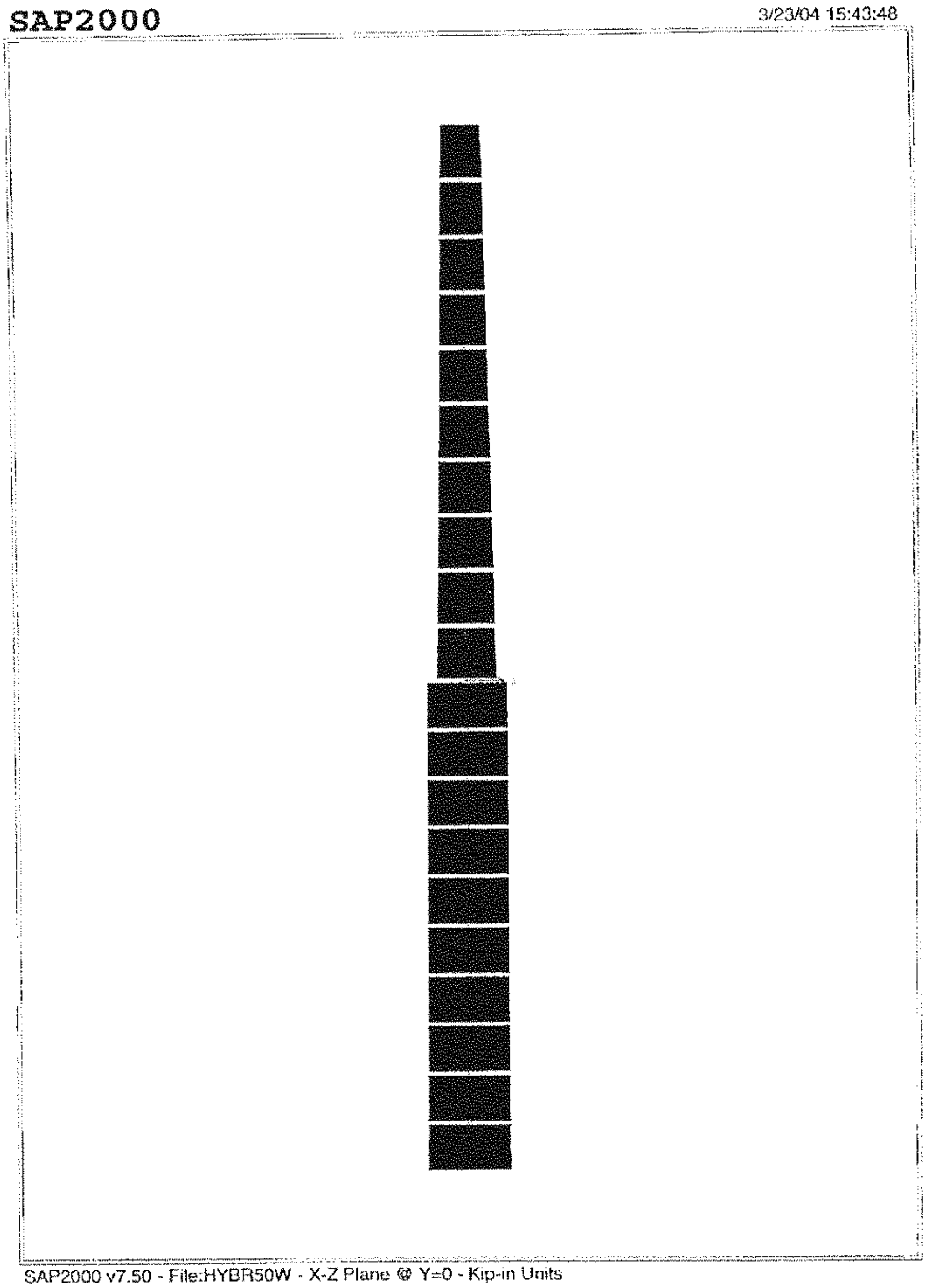
Operating Wind Load Tower Design Forces (EOG50)

Turbine Power	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	517	116	38480	28380	1659	373	454	102	18780	13850
(EQ)	Conc. Tower	17490	3933	525	118	38940	28720	6780	1524	461	104	18920	13960
	Steel Tower	3142	706	521	117	38850	28660	1622	365	461	104	18920	13950
(Wind)	Conc. Tower	15320	3444	519	117	38710	28550	6341	1426	459	103	18890	13940
3.6 MW	Hybrid Tower	22020	4950	1357	305	108300	79880	4706	1058	1275	287	59770	44080
(EQ)	Conc. Tower	26800	6025	1348	303	108000	79630	11500	2586	1272	286	57760	42610
	Steel Tower	7164	1611	1353	304	108300	79890	4647	1045	1276	287	57890	42700
(Wind)	Conc. Tower	23530	5290	1341	301	107800	79480	11020	2478	1271	286	57760	42600
5.0 MW	Hybrid Tower	26630	5987	1241	279	153500	113200	6932	1558	1150	259	88270	65110
(EQ)	Conc. Tower	34720	7805	1226	276	152800	112700	15170	3411	1142	257	85410	63000
	Steel Tower	10210	2295	1238	278	153600	113300	6884	1548	1151	259	85680	63190
(Wind)	Conc. Tower	29400	6609	1215	273	152400	112400	13800	3103	1139	256	85380	62980

Fatigue Wind Load Tower Design Forces

Turbine Power	Tower Type	Base Axial Force		Base Shear		Base Moment		Axial Force at 49m		Shear at 49m		Moment at 49m	
		kN	kips	kN	kips	kNm	kips-ft	kN	kips	kN	kips	kNm	kips-ft
1.5 MW	Hybrid Tower	11250	2529	57	13	8311	6130	1658	373	57	13	4510	3327
(EQ)	Conc. Tower	17490	3933	57	13	8311	6130	6779	1524	57	13	4510	3327
	Steel Tower	3142	706	57	13	8311	6130	1621	365	57	13	4510	3327
(Wind)	Conc. Tower	15320	3444	57	13	8311	6130	6341	1426	57	13	4510	3327
3.6 MW	Hybrid Tower	21980	4941	143	32	19770	14580	4665	1049	143	32	11500	8481
(EQ)	Conc. Tower	26760	6016	143	32	19770	14580	11460	2577	143	32	11150	8222
	Steel Tower	7123	1601	143	32	19770	14580	4606	1035	143	32	11150	8222
(Wind)	Conc. Tower	23490	5281	143	32	19770	14580	10980	2468	143	32	11150	8222
5.0 MW	Hybrid Tower	26460	5948	197	44	29890	22050	6761	1520	197	44	17540	12940
(EQ)	Conc. Tower	34550	7767	197	44	29890	22050	15000	3373	197	44	17020	12550
	Steel Tower	10040	2257	197	44	29890	22050	6713	1509	197	44	17020	12550
(Wind)	Conc. Tower	29230	6571	197	44	29890	22050	13630	3064	197	44	17020	12550

Unfactored Wind Turbine Tower Combined Forces
Table Appendix B-5.2



5.0 MW Hybrid Tower Model and Dynamics Properties

Tower Freq.	Mode-1		Mode-2		Mode-3	
Hybr50	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)
Spring Base	0.4802	2.0825	1.8989	0.5266	3.9108	0.2557
Fixed Base	0.5584	1.7908	2.8943	0.3455	8.0973	0.1235

Revised Wind Load --- 100m Hybrid Tower for 5.0MW (EQ Load Design)

Units Conversion:

$kips := 1000 \cdot lbf$ $\quad ksi := \frac{kips}{in^2}$ $\quad psf := \frac{lbf}{ft^2}$ $\quad kN := 1000 \cdot newton$ $\quad MPa := 10^6 \cdot Pa$

1.5MW Turbine Data

Totoal Turbine Weight:	$HeadWeight := 480076 \cdot kgf$	$HeadWeight = 1058 kips$
Additional Weight at Top of Concrete Tower:	$Wcc := 5000 \cdot kgf$	$Wcc = 11.02 kips$

Tower Dimension:

Totoal Tower Height:	$h := 100 \cdot m$	$h = 328 ft$
Concrete Tower Height:	$hc := 47 \cdot m$	$hc = 154 ft$
Outside Diameter at Base of Concrete Tower	$Dcb = 9.144 m$	$Dcb = 360 in$
Wall Thickness at Base of Concrete Tower	$Tcb = 0.762 m$	$Tcb = 30 in$
Outside Diameter at Top of Concrete Tower	$Dct = 8.687 m$	$Dct = 342 in$
Wall Thickness at Top of Concrete Tower	$Tct = 0.6096 m$	$Tct = 24 in$
Outside Diameter at Base of Steel Tower	$Dsb = 6.553 m$	$Dsb = 258 in$
Wall Thickness at Base of Steel Tower	$Tsb = 0.0349 m$	$Tsb = 1.375 in$
Outside Diameter at Top of Steel Tower	$Dst = 4.572 m$	$Dst = 180 in$
Wall Thickness at Top of Steel Tower	$Tst = 0.0222 m$	$Tst = 0.875 in$

Tower Material Properties:

Steel Tower Density :	$\rho s = 76.97 \frac{kN}{m^3}$	$\rho s = 490 \frac{lbf}{ft^3}$
Steel Elastic Modulus :	$Es = 196501 MPa$	$Es = 28500 ksi$
Steel Yeilding Stress :	$fy = 344.7 MPa$	$fy = 50 ksi$
Concrete Tower Density :	$\rho c = 23.563 \frac{kN}{m^3}$	$\rho c = 150 \frac{lbf}{ft^3}$
Concrete Compression Strength :	$fc = 48.3 MPa$	$fc = 7 ksi$
Concrete Elastic Modulus :	$Ec = 34972 MPa$	$Ec = 5072 ksi$

Tower Foundation:

Footing Concrete Strength:	$fcft = 27.6 MPa$	$fcft = 4 ksi$	
Concrete Elastic Modulus :	$Ecft = 26436 MPa$	$Ecft = 3834 ksi$	
Footing Length and Width:	$B = 21.336 m$	$B = 70 ft$	$L := B$
Footing Depth:	$D = 3.658 m$	$D = 12 ft$	

Soil Information:

Soil Tower Density :	$\rho so = 18.85 \frac{kN}{m^3}$	$\rho so = 120 \frac{lbf}{ft^3}$
Soil Bearing Capacity	$cso = 0.287 MPa$	$cso = 6000 psf$
Soil Shear Modulus	$Gso = 20.684 MPa$	$Gso = 3000 psi$
Soil Poission Ratio	$\mu so := 0.35$	
Soil Bearing Capacity Safety Factor for EQ:	$\gamma soq := 2$	

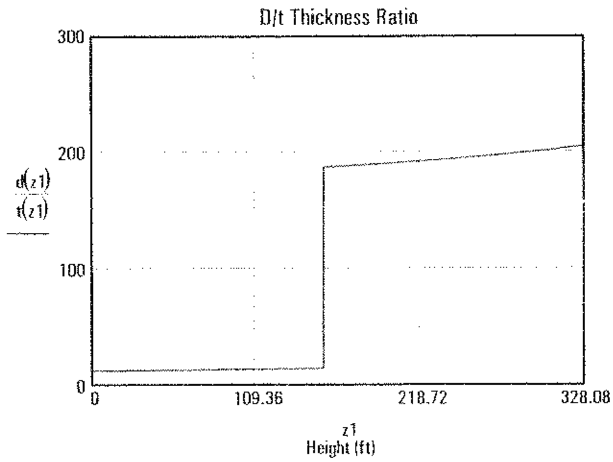
Tower Configuration Along the Height (z):

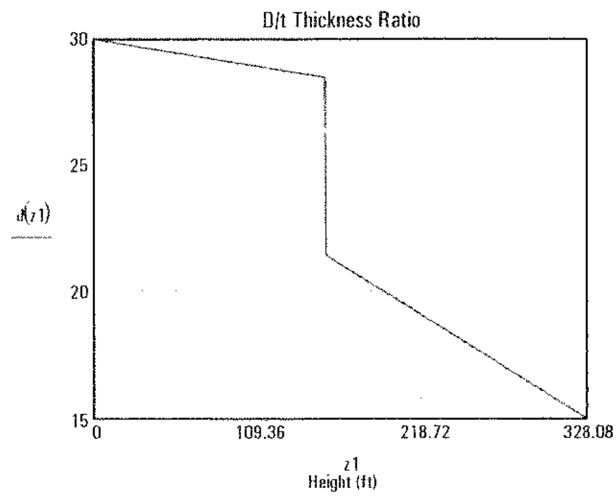
Ground Elevation: $z0 := 0 \cdot m$

Tower Diameter:
$$d(z) := \begin{cases} \left(\frac{Dct - Dcb}{hc} \cdot z + Dcb \right) & \text{if } z \le hc \\ \left[\frac{Dst - Dsb}{h - hc} \cdot (z - hc) + Dsb \right] & \text{otherwise} \end{cases}$$

Tower Wall Thickness:
$$t(z) := \begin{cases} \left(\frac{Tct - Tcb}{hc} \cdot z + Tcb \right) & \text{if } z \le hc \\ \left[\frac{Tst - Tsb}{h - hc} \cdot (z - hc) + Tsb \right] & \text{otherwise} \end{cases}$$

Tower Riadus:
$$R(z) := \frac{d(z) - t(z)}{2}$$





Tower Cross Section Area:
$$Ac(z) := \frac{\pi}{4} \cdot \left[d(z)^2 - (d(z) - 2 \cdot t(z))^2 \right]$$

Section Moment of Inertia:
$$I(z) := \frac{\pi}{64} \cdot \left[d(z)^4 - (d(z) - 2\, t(z))^4 \right]$$

Section Modulus:
$$S(z) := \frac{2 I(z)}{d(z)}$$

Elastic Modulus:
$$E(z) := \begin{cases} Ec & \text{if } z \le hc \\ Es & \text{otherwise} \end{cases}$$

Tower Weight Distribution:
$$wt(z) := \begin{cases} Ac(z) \cdot \rho c & \text{if } z \le hc \\ Ac(z) \cdot \rho s & \text{otherwise} \end{cases} \qquad Wz(z) := \int_z^h wt(x)\, dx$$

Steel Tower Weight: $Wz(hc) = 2053\,kN$ $\qquad Wz(hc) = 462\,kips$

Tower Weight: $Wz(z0) = 21702\,kN$ $\qquad Wz(z0) = 4879\,kips$

Total Weight: $W := Wz(z0) + HeadWeight + Wcc$ $\qquad W = 2698033\,kgf$

$W = 26459\,kN$ $\qquad W = 5948\,kips$

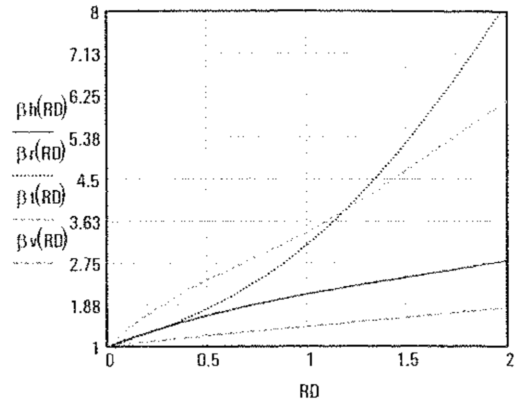
Soil Spring Constants: Ref. to Highway Bridge Design Manual:

Translation Equivalent Radius $R0 := \sqrt{\frac{B \cdot L}{\pi}}$ $R0 = 39.493\,ft$ $R0 = 39.493\,ft$

Rotation X Equivalent Radius $R1 := \sqrt[4]{\frac{B \cdot L \cdot (B^2 + L^2)}{6 \cdot \pi}}$

Rotation X Equivalent Radius $R2 := \sqrt[4]{\frac{(B)^3 \cdot L}{3 \cdot \pi}}$

Rotation X Equivalent Radius $R3 := \sqrt[4]{\frac{(L)^3 \cdot B}{3 \cdot \pi}}$



Embedment Factor $\frac{D}{R1} = 0.3$

Shape Factor (see Ref.) $\alpha x := 1.02$ $\alpha y := 1.02$ $\alpha v := 1.03$ $\alpha r := 1.05$

$\beta h\left(\frac{D}{R1}\right) = 1.42$ $\beta r\left(\frac{D}{R1}\right) = 1.43$ $\beta v\left(\frac{D}{R1}\right) = 1.15$ $\beta t\left(\frac{D}{R1}\right) = 1.94$

Vertical Spring Constant: $Kv := \alpha v \cdot \beta v\left(\frac{D}{R1}\right) \cdot \frac{4 \cdot Gso \cdot R0}{1 - \mu so}$ $Kv = 1807762 \frac{kN}{m}$ $Kv = 10323 \frac{kips}{in}$

Horizontal Spring Constant: $Kh := \alpha x \cdot \beta h\left(\frac{D}{R1}\right) \cdot \frac{8 \cdot Gso \cdot R0}{2 - \mu so}$ $Kh = 1748559 \frac{kN}{m}$ $Kh = 9985 \frac{kips}{in}$

Torsional Spring Constant: $Kt := \alpha r \cdot \beta t\left(\frac{D}{R1}\right) \cdot \frac{16 \cdot Gso \cdot R3^3}{3}$ $Kt = 405755712\,kN \cdot m$ $Kt = 3591319044\,kips \cdot in$

Rocking Spring Constant: $Kr := \alpha r \cdot \beta r\left(\frac{D}{R1}\right) \cdot \frac{8 \cdot Gso \cdot R1^3}{3 \cdot (1 - \mu so)}$ $Kr = 230514563\,kN \cdot m$ $Kr = 2040270326\,kips \cdot in$

Natural Frequency of Tower

Rayleigh Energy Method

Defomation Shape Function
(Fix - Free End)

$$x(a1, a2, z) := \begin{cases} a1 - a1 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) & \text{if } z \le hc \\ a2 - a2 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + h - 2 \cdot hc}{h - hc}\right) + \frac{a1\pi}{2hc} \cdot (z - hc) + a1 & \text{if } hc < z \le h \end{cases}$$

First Order Differential Equation

$$y1(a1, a2, z) := \begin{cases} \frac{-1}{2} \cdot a1 \cdot \cos\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) \cdot \frac{\pi}{hc} & \text{if } z \le hc \\ \frac{-1}{2} \cdot a2 \cdot \cos\left[\frac{\pi}{2} \cdot \frac{(z + h - 2 \cdot hc)}{(h - hc)}\right] \cdot \frac{\pi}{(h - hc)} + \frac{a1}{2} \cdot \frac{\pi}{hc} & \text{if } hc < z \le h \end{cases}$$

Second Order Differential Equation

$$y2(a1, a2, z) := \begin{cases} \frac{1}{4} \cdot a1 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) \cdot \frac{\pi^2}{hc^2} & \text{if } z \le hc \\ \frac{1}{4} \cdot a2 \cdot \sin\left[\frac{1}{2} \cdot \pi \cdot \frac{(z + h - 2 \cdot hc)}{(h - hc)}\right] \cdot \frac{\pi^2}{(h - hc)^2} & \text{if } hc < z \le h \end{cases}$$

Strain Energy of Tower $Umax(a1,a2) := \frac{1}{2}\int_0^h E(z)\cdot I(z)\cdot y2(a1,a2,z)^2\,dz$

Kenitic Energy of Tower $Tmax(a1,a2) := \frac{1}{2}\left(\int_0^h \frac{wt(z)}{g}\cdot x(a1,a2,z)^2\,dz + \frac{HeadWeight}{g}\cdot x(a1,a2,h)^2 + \frac{Wcc}{g}\cdot x(a1,a2,hc)^2\right)$

Rayleigh Quotient $Freq(a1,a2) := \frac{1}{2\cdot\pi}\sqrt{\frac{Umax(a1,a2)}{Tmax(a1,a2)}}$

Minimum Energy Principle $i := 1..10$ $hi := 0.01\cdot in$ $j := 1..10$ $hj := 0.1\cdot in$ $Fq_{i,j} := Freq(i\cdot hi, j\cdot hj)$

Tower Frequency (fixed base) $Freq := \min(Fq)$ $Freq = 0.58\,Hz$

Deformation Shape for Base Rotation $x1(p,z) := \frac{p\cdot h}{Kr}\cdot z$ $U1max(p) := \frac{(p\cdot h)^2}{2\cdot Kr}$

$T1max(p) := \frac{1}{2}\left(\int_0^h \frac{wt(z)}{g}\cdot x1(p,z)^2\,dz + \frac{HeadWeight}{g}\cdot x1(p,h)^2 + \frac{Wcc}{g}\cdot x1(p,hc)^2\right)$

Freqency for Base Rotation $Fr1(p) := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{U1max(p)}{T1max(p)}}$ $Fr1(10\cdot kips) = 0.897\,Hz$

Freqency for Base Translation $Fr2 := \frac{1}{2\cdot\pi}\sqrt{\frac{Kh\cdot g}{W}}$ $Fr2 = 4.052\,Hz$

Natural Freqency of Tower $Fq := \sqrt{\frac{Fr1(100\cdot kips)^2\cdot Fr2^2\cdot Freq^2}{Fr1(100\cdot kips)^2\cdot Freq^2 + Fr2^2\cdot Freq^2 + Fr1(100\cdot kips)^2\cdot Fr2^2}}$ $Fq = 0.483\,Hz$

Global Buckling Load (Rayleigh's Method):

External Work: $\lambda max(a1,a2) := \frac{1}{2}\int_0^h y1(a1,a2,z)^2\,dz$

Self-Weight Work: $Wmax(a1,a2) := \frac{1}{2}\left(HeadWeight\cdot\int_0^h y1(a1,a2,z)^2\,dz + Wcc\int_0^{hc} y1(a1,a2,z)^2\,dz + \int_0^h wt(z)\,z\cdot y1(a1,a2,z)^2\,dz\right)$

Global Buckling Load:
Based on Minimum Energy Method
$Pcr(a1,a2) := \frac{Umax(a1,a2) - Wmax(a1,a2)}{\lambda max(a1,a2)}$ $pcr_{i,j} := Pcr(i\cdot hi, j\cdot hj)$

$Pcr(z) := \min(pcr) + Wz(z) + HeadWeight + if(z < hc, Wcc, 0\cdot kips)$

Buckling Load at Top : $Pcr(z0) = 415793\,kN$ $Pcr(z0) = 93476\,kips$ $Pe := \min(pcr)$

Total Global Buckling Load: $Pe = 389334\,kN$ $Pe = 87528\,kips$

Earthquake Load: ASCE 7-98

Seismic Soil Data (Table and Figure 9.4.1) :

Site Class Factor: Soil Class "D" $Fa := 1$ $Fv := 1.5$

Design Acceleration for Short Period: $Sds := 1.5 \cdot \frac{2}{3} \cdot Fa$ $Sds = 1$

Design Acceleration for One Second: $Sd1 := 0.6 \cdot \frac{2}{3} \cdot Fv$ $Sd1 = 0.6$

$Ts := \frac{Sd1}{Sds} \cdot sec$ $T0 := 0.2 \cdot Ts$

Design Response Spectra

$$Sa(T) := \begin{cases} \frac{Sd1}{T} & \text{if } T > Ts \\ Sds \cdot \left(0.4 + 0.6 \cdot \frac{T}{T0}\right) & \text{if } T < T0 \\ Sds & \text{otherwise} \end{cases}$$

Building Period (sec):

$\beta := 0.75$ $Ct := 0.02$

0.035 for Steel MF
0.03 for EBF
0.018 for Concrete MF
0.020 for all others

$Ta := Ct \left(\frac{h}{ft}\right)^{\beta} \cdot sec$ $Ta = 1.542 sec$

$T := 1.4 \cdot Ta$ $T = 2.158 sec$

Base Shear Factor:

Reduction Factor $Rq := 1$ $T := \min\left(T, \frac{1}{Fq}\right)$ $T = 2.068 sec$

Importance Factor of Occupancy $Iq := 1$

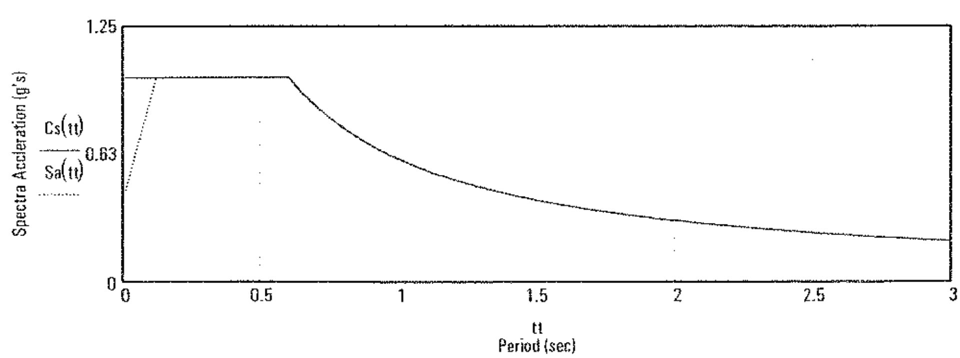
Seismic Response Coefficient $Cs(T) := \frac{Sd1 \cdot Iq}{Rq \cdot T} \cdot sec$ $Csup := \frac{Sds \cdot Iq}{Rq}$ $Csup = 1$ *Upperbound*

$Cslo := 0.044 \cdot Sds \cdot Iq$ $Cslo = 0.044$ *Lowerbound*

$$Cs(T) := \begin{cases} Csup & \text{if } Cs(T) \ge Csup \\ Cslo & \text{if } Cs(T) < Cslo \\ Cs(T) & \text{otherwise} \end{cases}$$

$Cs(T) = 0.29$

$tt := 0.01, 0.02 .. 3$



ASCE 7 Design Response Spectra

Tower Shear Force and Moment :

Base Shear: $V := Cs(T) \cdot W \cdot Rq$ $V = 7674.9\,kN$ $V = 1725.4\,kips$

Distributed Forces Along the Tower:

$$k(T) := \begin{cases} 1 & \text{if } T < 0.5 \cdot sec \\ 2 & \text{if } T > 2.5 \cdot sec \\ \left(0.5 \cdot \frac{T}{sec} + 0.75\right) & \text{otherwise} \end{cases}$$

$k0 := k(T)$ $k(T) = 1.784$

Mode Shape Factor

Force Distribution along Tower:

$$wtz := \int_0^h wt(z) \cdot z^{k0}\,dz \qquad F(z) := \frac{wt(z) \cdot z^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

Concentrated Load at Height of h:

$$Fh := \frac{HeadWeight \cdot h^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

$Fh = 1073.8\,kips$

Concentrated Load at Height of hc:

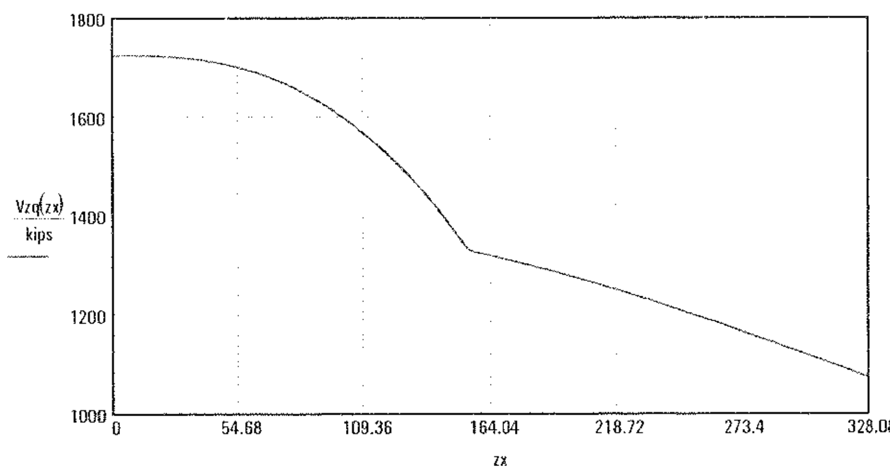
$$Fhc := \frac{Wcc \cdot hc^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

$Fhc = 2.9\,kips$

Shear Force along the Tower:

$$Vzq(z) := \int_z^h F(x)\,dx + Fh + if(z \le hc, Fhc, 0 \cdot kips)$$

$zx := 0 \cdot m, 1 \cdot m .. h$



Shear Force:

$Vzq(z0) = 7674.9\,kN$ $Vzq(z0) = 1725.4\,kips$

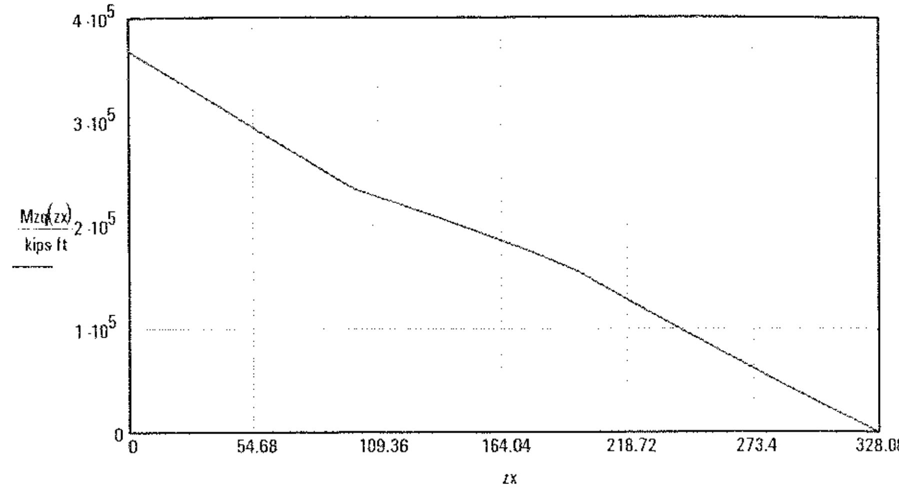
$Vzq(hc) = 5927.1\,kN$ $Vzq(hc) = 1332.5\,kips$

Over Turning Moment along the Tower:

$$\tau(z) := \begin{cases} 1 & \text{if } z > 60 \cdot m \\ \left[\frac{z - 30 \cdot m}{60 \cdot m - 30 \cdot m} \cdot (1 - 0.8) + 0.8\right] & \text{if } 30 \cdot m \le z \le 60 \cdot m \\ 0.8 & \text{if } z < 30 \cdot m \end{cases}$$

Overturning Moment Reduction Factor

$$Mzq(z) := \tau(z) \cdot \left[\int_z^h F(x) \cdot (x - z)\,dx + Fh \cdot (h - z) + if[z \le hc, Fhc \cdot (hc - z), 0 \cdot kips \cdot ft]\right]$$



Over Turning Moment:

$Mzq(z0) = 499082\,kN\cdot m$ $\quad Mzq(z0) = 368112\,kips\cdot ft$

$Mzq(hc) = 260994\,kN\cdot m$ $\quad Mzq(hc) = 192503\,kips\cdot ft$

Deflection at Top of Tower

$$\Delta q(z) := \int_{z0}^{z} \frac{Mzq(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vzq(z0)}{Kh} + \frac{Mzq(z0)}{Kr}\cdot z$$

$QDisT := \Delta q(h)$ $\quad QDisT = 0.968\,m$ $\quad QDisT = 3.176\,ft$ $\quad \frac{h}{QDisT} = 103$

$QDisM := \Delta q(hc)$ $\quad QDisM = 0.186\,m$ $\quad QDisM = 0.61\,ft$ $\quad \frac{hc}{QDisM} = 253$

Moment Magnification Factor

at Base: $\delta sqb := \dfrac{1}{1 - \dfrac{1.2W}{Pcr(z0)}}$ $\quad \delta sqb = 1.083$

at Height of hc: $\delta sqt := \dfrac{1}{1 - \dfrac{1.2(Wz(hc) + HeadWeight)}{Pcr(z0)}}$ $\quad \delta sqt = 1.02$

P-Δ Effect

Moment of Tower due to Gravity Load for P-Δ effect :

$$Mqg(z) := \left(QDisT - \Delta q(z)\right)\cdot HeadWeight + \int_{z}^{h} wt(y)\cdot\left(\Delta q(y) - \Delta q(z)\right)dy + Wcc\cdot if\left(z < hc, QDisM - \Delta q(z), 0\cdot m\right)$$

Approx. Method of Moment at Base for P-Δ effect :

$$Mqgb := \Delta q(h)\cdot HeadWeight + Wcc\cdot\Delta q(hc) + Wz(hc)\cdot\Delta q\left(\frac{h+hc}{2}\right) + (Wz(z0) - Wz(hc))\cdot\Delta q\left(\frac{hc}{2}\right)$$

$\delta qb := \dfrac{Mqgb}{Mzq(z0)} + 1$ $\quad \delta qb = 1.014$

Wind Load: ASCE 7-98 Design Wind Category : D

Wind Speed at Hub: $v\_EWM50 := 59.5 \cdot \frac{m}{sec}$ Nonoperating Load (EWM50)

$v\_EOG50 := 35 \cdot \frac{m}{sec}$ Operating Load (EOG50)

Design Wind Speed: $v1 := v\_EWM50 \cdot \left(\frac{33 \cdot ft}{h}\right)^{0.1}$ $v1 = 47.3 \frac{m}{sec}$ $v1 = 105.8\,mph$

$v2 := v\_EOG50 \cdot \left(\frac{33 \cdot ft}{h}\right)^{0.2}$ $v2 = 22.1 \frac{m}{sec}$ $v2 = 49.5\,mph$

Importance factor: $Im := 1$

Parameters for Speed-up Over Hill and Escarpment: (Figure 6-2 of ASCE-7-98)

for flat area $\gamma := 4$ $\mu := 1.5$ $x := 0 \cdot ft$ $Lh := 100000 \cdot m$ $H := 1 \cdot m$

Topographic Factor, Kzt for Exposure D: $K1 := 1.55 \cdot \frac{H}{Lh}$ $K1 = 0$

$K2 := 1 - \frac{|x|}{\mu \cdot Lh}$ $K2 = 1$

$K3(z) := e^{-\gamma \cdot \frac{z}{Lh}}$

$Kzt(z) := (1 + K1 \cdot K2 \cdot K3(z))^2$

Terrain Expoure Constants for Exposure D: (Table 6-4 of ASCE-7-98)

$\alpha 1 := 11.5$ $zg := 700 \cdot ft$ $c := 0.15$ $b := 0.8$ $\alpha := \frac{1}{9}$ $\varepsilon := \frac{1}{8}$ $l := 650 \cdot ft$

Basic Velocity Pressure:

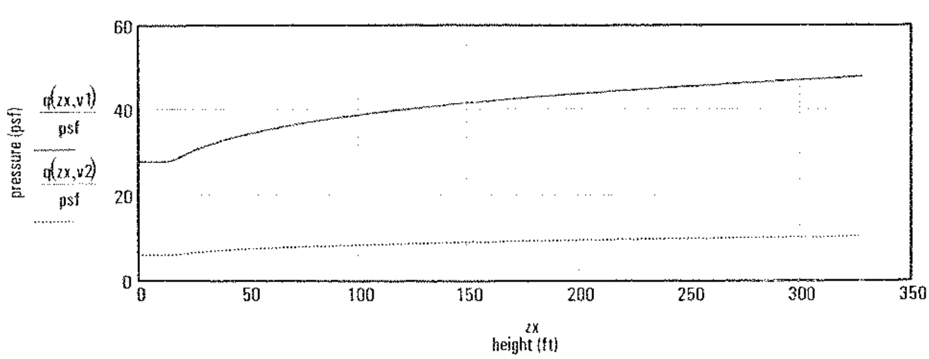
Velocity Pressure Coefficient:

$$K(z) := \begin{cases} \left[2.01 \cdot \left(\frac{15 \cdot ft}{zg}\right)^{\frac{2}{\alpha 1}}\right] & \text{if } z < 15 \cdot ft \\ \left[2.01 \cdot \left(\frac{z}{zg}\right)^{\frac{2}{\alpha 1}}\right] & \text{otherwise} \end{cases}$$

Direcitionality Factor for Round: $Kd := 0.95$

Velocity Pressure: $Vw(v) := \frac{v}{mph}$ $0.00256 \cdot Vw(v1)^2 \cdot psf = 28.6\,psf$ $0.00256 \cdot Vw(v2)^2 \cdot psf = 6.3\,psf$

$q(z,v) := 0.00256 \cdot K(z) \cdot Kzt(z) \cdot Kd \cdot Vw(v)^2 \cdot Im \cdot psf$



Velocity Pressure at 100m High:

$q(h,v1) = 2296\,Pa$ $\quad q(h,v2) = 502\,Pa$

$q(h,v1) = 47.9\,psf$ $\quad q(h,v2) = 10\,psf$

$q(hc,v1) = 2013\,Pa$ $\quad q(hc,v2) = 440\,Pa$

$q(hc,v1) = 42\,psf$ $\quad q(hc,v2) = 9\,psf$

Damping Ratio: $\beta d := 0.02$

Gust Factor Calculation:

Intensity of turbulence: $Ig(z) := c\cdot\left(\frac{33\cdot ft}{z}\right)^{\frac{1}{6}}$ $\quad Lg(z) := l\cdot\left(\frac{z}{33\cdot ft}\right)^{\varepsilon}$

Peak Factor for Background: $gQ := 3.4$ $\quad gv := 3.4$

Peak Factor for Resonant: $gR := \sqrt{2\cdot\ln(3600\cdot sec\cdot Fq)} + \frac{0.577}{\sqrt{2\cdot\ln(3600\cdot sec\cdot Fq)}}$ $\quad gR = 4.012$

Mean hourly velocity: $Vw(z,v) := b\cdot\left(\frac{z}{33\cdot ft}\right)^{\alpha}\cdot v\cdot\left(\frac{88}{60}\right)$

Reduced Frequency $N1(z,v) := \frac{Fq\cdot Lg(z)}{Vw(z,v)}$

Resonant response factor $\eta h(z,v) := \frac{4.6\cdot Fq\cdot h}{Vw(z,v)}$ $\quad \eta B(z,v) := \frac{4.6\cdot Fq\cdot d(hc)}{Vw(z,v)}$ $\quad \eta L(z,v) := \frac{15.4\cdot Fq\cdot d(hc)}{Vw(z,v)}$

$$Rh(z,v) := \frac{1}{\eta h(z,v)} - \frac{1}{2(\eta h(z,v))^2}\cdot\left(1 - e^{-2\cdot\eta h(z,v)}\right)$$

$$Rn(z,v) := \frac{7.47\cdot N1(z,v)}{(1 + 10.3\cdot N1(z,v))^{\frac{5}{3}}}$$

$$RB(z,v) := \frac{1}{\eta B(z,v)} - \frac{1}{2(\eta B(z,v))^2}\cdot\left(1 - e^{-2\cdot\eta B(z,v)}\right)$$

$$RG(z,v) := \sqrt{\frac{1}{\beta d}\cdot Rh(z,v)\cdot RB(z,v)\cdot Rn(z,v)\cdot(0.53 + 0.47\cdot RB(z,v))}$$

$$Q(z) := \sqrt{\frac{1}{1 + 0.63\cdot\left(\frac{d(hc) + h}{Lg(z)}\right)^{0.63}}}$$

Gust Effect factor $G(z) := 0.925\cdot\frac{(1 + 1.7\cdot gQ\cdot Ig(z)\cdot Q(z))}{1 + 1.7\cdot gv\cdot Ig(z)}$ $\quad G(h) = 0.876$

for Flexible Structure < 1 Hz $Gf(z,v) := 0.925\cdot\frac{\left(1 + 1.7\cdot Ig(z)\cdot\sqrt{gQ^2\cdot Q(z)^2 + gR^2\cdot RG(z,v)^2}\right)}{1 + 1.7\cdot gv\cdot Ig(z)}$

$Gf(h,v1) = 1.083$ $\quad Gf(h,v2) = 0.94$

Direct Wind Load on Tower:

Forced Coefficient: $d(hc)\cdot\sqrt{\frac{q(hc,v1)}{psf}} = 184.809\,ft$ $\quad > 2.5$

Table 6-10 of ASCE-7-98

$$Cf(x) := \begin{cases} \left[\frac{0.6-0.5}{7-1}\cdot(x-1)+0.5\right] & \text{if } 1 \le x < 7 \\ \left[\frac{0.7-0.6}{25-7}\cdot(x-7)+0.6\right] & \text{if } 7 \le x \le 25 \\ 0.7 & \text{if } x > 25 \end{cases}$$

For Smooth Surface

$$Cf\left(\frac{h}{d(hc)}\right) = 0.625 \qquad \frac{h}{d(hc)} = 11.5$$

Distributed Forces Along the Tower: $Fw(z,v) := q(z,v)\cdot Gf(z,v)\cdot Cf\left(\frac{h}{d(z)}\right)\cdot d(z)$

Shear Force along the Tower: $Vzw(z,v) := \int_z^h Fw(x,v)\,dx$

Vzw(z0, v1) = 941 kN	Vzw(z0, v1) = 211.6 kips
Vzw(hc, v1) = 456 kN	Vzw(hc, v1) = 102.5 kips
Vzw(z0, v2) = 177 kN	Vzw(z0, v2) = 39.9 kips
Vzw(hc, v2) = 86 kN	Vzw(hc, v2) = 19.4 kips

Moment along the Tower: $Mzw(z,v) := \int_z^h Fw(x,v)\cdot(x-z)\,dx$

Mzw(z0, v1) = 45321.4 kN·m	Mzw(z0, v1) = 33428 kips·ft
Mzw(hc, v1) = 11739 kN·m	Mzw(hc, v1) = 8658 kips·ft
Mzw(z0, v2) = 8564.5 kN·m	Mzw(z0, v2) = 6317 kips·ft
Mzw(hc, v2) = 2223 kN·m	Mzw(hc, v2) = 1640 kips·ft

Wind Turbine Load (WindPact Load):

Coordinate Direction: x:= downwind y:= lateral z:= vertical

Wind Turbine Load (No Safety Factor) : Non-operating Load (EMW50) — Operating Load (EOG50)

Maximum Wind Load at Top (yaw bearing -100m):

	Non-operating Load (EMW50)		Operating Load (EOG50)	
Maximum Horizontal Thrust:	FxT1 := 199·kN	FxT1 = 45 kips	FxT2 := 1057·kN	FxT2 = 238 kips
	FyT1 := 543·kN	FyT1 = 122 kips	FyT2 := 128·kN	FyT2 = 29 kips
	FzT1 := 4998·kN	FzT1 = 1124 kips	FzT2 := 4879·kN	FzT2 = 1097 kips
Maximum Horizontal Moment:	MxT1 := 21820·kN·m	MxT1 = 16094 kips·ft	MxT2 := 5822·kN·m	MxT2 = 4294 kips·ft
	MyT1 := 18440·kN·m	MyT1 = 13601 kips·ft	MyT2 := 18440·kN·m	MyT2 = 13601 kips·ft
	MzT1 := 5834·kN·m	MzT1 = 4303 kips·ft	MzT2 := 3714·kN·m	MzT2 = 2739 kips·ft

Maximum Wind Load at Base (0m):

MxB1 := 133961·kN·m	MxB1 = 98807 kips·ft	MxB2 := 54370·kN·m	MxB2 = 40102 kips·ft
MyB1 := 41916·kN·m	MyB1 = 30916 kips·ft	MyB2 := 135000·kN·m	MyB2 = 99573 kips·ft
MzB1 := 5603·kN·m	MzB1 = 4133 kips·ft	MzB2 := 3966·kN·m	MzB2 = 2925 kips·ft

Fatigue Thrust Range:	ΔFxT := 197·kN	ΔFxT = 44 kips	ΔMzT := 3483·kN·m	ΔMzT = 2569 kips·ft
Fatigue Applied Moment Range:	ΔMxT := 722·kN·m	ΔMxT = 533 kips·ft	ΔMyT := 3616·kN·m	ΔMyT = 2667 kips·ft
	ΔMxB := 14151·kN·m	ΔMxB = 10437 kips·ft	ΔMyB := 29894·kN·m	ΔMyB = 22049 kips·ft

Turbine offset in Vertical Direction: offset := 0·m offset = 0 ft

Turbine Wind Load on Tower:

Moment (Linear Interpolation):

$$Mxwt1(z) := \frac{MxT1 - MxB1}{h} \cdot z + MxB1 \qquad Mxwt2(z) := \frac{MxT2 - MxB2}{h} \cdot z + MxB2$$

$$Mywt1(z) := \frac{MyT1 - MyB1}{h} \cdot z + MyB1 \qquad Mywt2(z) := \frac{MyT2 - MyB2}{h} \cdot z + MyB2$$

$$Mwt1(z) := \sqrt{Mxwt1(z)^2 + Mywt1(z)^2} \qquad Mwt2(z) := \sqrt{Mxwt2(z)^2 + Mywt2(z)^2}$$

$$Mzwt1(z) := \frac{MzT1 - MzB1}{h} \cdot z + MzB1 \qquad Mzwt2(z) := \frac{MzT2 - MzB2}{h} \cdot z + MzB2$$

$$\Delta Mxwt(z) := \frac{\Delta MxT - \Delta MxB}{h} \cdot z + \Delta MxB \qquad \Delta Mywt(z) := \frac{\Delta MyT - \Delta MyB}{h} \cdot z + \Delta MyB$$

$$\Delta Mwt(z) := \max(\Delta Mxwt(z), \Delta Mywt(z))$$

Moment (Thrust from Wind Turbine):

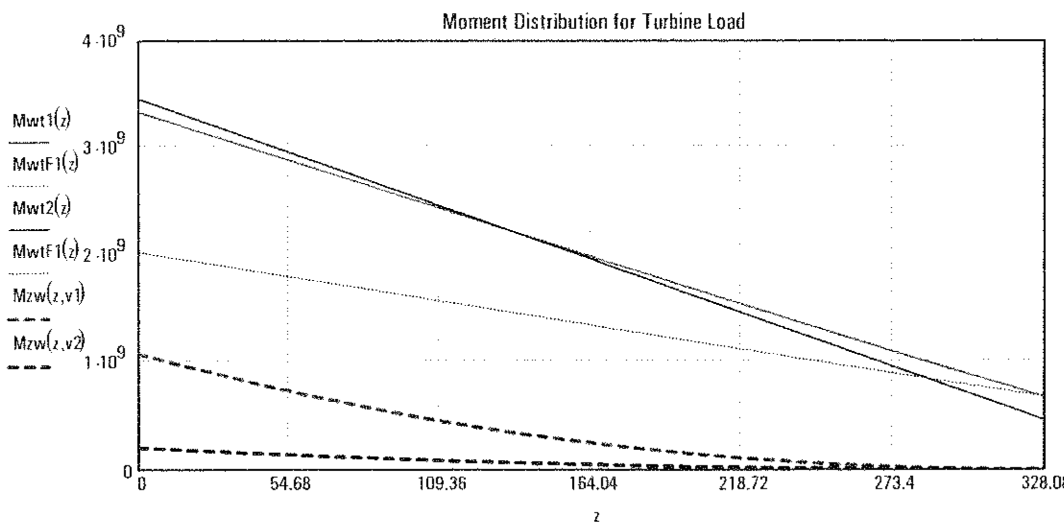
$$MxwtF1(z) := MxT1 + FyT1 \cdot (h + offset - z) \qquad MxwtF2(z) := MxT2 + FyT2 \cdot (h + offset - z)$$

$$MywtF1(z) := MyT1 + FxT1 \cdot (h + offset - z) \qquad MywtF2(z) := MyT2 + FxT2 \cdot (h + offset - z)$$

$$MwtF1(z) := \sqrt{MxwtF1(z)^2 + MywtF1(z)^2} \qquad MwtF2(z) := \sqrt{MxwtF2(z)^2 + MywtF2(z)^2}$$

$$\Delta MxwtF(z) := \Delta MxT \qquad \Delta MywtF(z) := \Delta MyT + \Delta FxT \cdot (h + offset - z)$$

$$\Delta MwtF(z) := \Delta MywtF(z)$$



$$\frac{MwtF1(z0)}{Mwt1(z0)} = 0.607 \qquad \frac{MwtF2(z0)}{Mwt2(z0)} = 0.863 \qquad \frac{\Delta MwtF(z0)}{\Delta Mwt(z0)} = 0.78$$

Wind Load Combination:

Load Factor for Ultimate Load:

$\gamma DL := 1.2$ *Dead Load*

$\gamma WL := 1.6$ *Wind Load*

$\gamma SF := 1.35$ Partial Safety Factor (Wind Energy Hand Book p213):

Ultimate Load (ASCE7-98 Load Combination)

$PuT := (FzT1 - HeadWeight)\cdot\gamma SF + \gamma DL\cdot HeadWeight$

$PuD(xz) := \gamma DL\cdot(Wz(xz) + if(xz < hc, Wcc, 0\cdot kips))$

$VuT := \sqrt{FxT1^2 + FyT1^2}\cdot\gamma SF$

$VuD(xz) := \gamma WL\cdot Vzw(xz, v1)$

$MuTx(xz) := \gamma SF\cdot Mxwt1(xz)$

$MuTy(xz) := \gamma SF\cdot Mywt1(xz)$

$MuT(xz) := \sqrt{MuTx(xz)^2 + MuTy(xz)^2}$

$MuD(xz) := \gamma WL\cdot Mzw(xz, v1)$

$Pu(xz) := PuT + PuD(xz)$

$Vu(xz) := \sqrt{(FxT1\cdot\gamma SF + VuD(xz))^2 + (FyT1\cdot\gamma SF)^2}$

$Mu(xz) := \sqrt{(MuTy(xz) + MuD(xz))^2 + MuTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PuT = 6041 kN	PuD(xz) = 26101 kN	Pu(xz) = 32142 kN
VuT = 781 kN	VuD(xz) = 1506 kN	Vu(xz) = 1920 kN
MuT(xz) = 189494 kN·m	MuD(xz) = 72514 kN·m	Mu(xz) = 222200 kN·m
Pu(xz) = 7226 kips	PuD(xz) = 5868 kips	Pu(xz) = 7226 kips
VuT = 176 kips	VuD(xz) = 339 kips	Vu(xz) = 432 kips
MuT(xz) = 139766 ft kips	MuD(xz) = 53485 ft kips	Mu(xz) = 163890 ft kips

$xz := hc$

at base of steel tower

PuT = 6041 kN	PuD(xz) = 2464 kN	Pu(xz) = 8505 kN
VuT = 781 kN	VuD(xz) = 730 kN	Vu(xz) = 1238 kN
MuT(xz) = 117349 kN·m	MuD(xz) = 18782 kN·m	Mu(xz) = 125259 kN·m
Pu(xz) = 1912 kips	PuD(xz) = 554 kips	Pu(xz) = 1912 kips
VuT = 176 kips	VuD(xz) = 164 kips	Vu(xz) = 278 kips
MuT(xz) = 86554 ft kips	MuD(xz) = 13853 ft kips	Mu(xz) = 92388 ft kips

Service Load (Unfactored Wind Load)

$PsT := FzT1$

$v1 = 47.29\frac{m}{sec}$

$PsD(xz) := Wz(xz) + if(xz < hc, Wcc, 0\cdot kips)$

$VsT := \sqrt{FxT1^2 + FyT1^2}$

$VsD(xz) := Vzw(xz, v1)$

$MsTx(xz) := Mxwt1(xz)$

$MsTy(xz) := Mywt1(xz)$

$MsT(xz) := \sqrt{MsTx(xz)^2 + MsTy(xz)^2}$

$MsD(xz) := Mzw(xz, v1)$

$Ps(xz) := PsT + PsD(xz)$

$Vs(xz) := \sqrt{(FxT1 + VsD(xz))^2 + (FyT1)^2}$

$Ms(xz) := \sqrt{(MsTy(xz) + MsD(xz))^2 + MsTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PsT = 4998 kN	PsD(xz) = 21751 kN	Ps(xz) = 26749 kN
VsT = 578 kN	VsD(xz) = 941 kN	Vs(xz) = 1263 kN
MsT(xz) = 140366 kN·m	MsD(xz) = 45321 kN·m	Ms(xz) = 159862 kN·m

Ps(xz) = 6013kips	PsD(xz) = 4890kips	Ps(xz) = 6013kips
VsT = 130kips	VsD(xz) = 212kips	Vs(xz) = 284kips
MsT(xz) = 103531ftkips	MsD(xz) = 33428ftkips	Ms(xz) = 117911ftkips

xz := hc

at base of steel tower

PsT = 4998kN	PsD(xz) = 2053kN	Ps(xz) = 7051kN
VsT = 578kN	VsD(xz) = 456kN	Vs(xz) = 851kN
MsT(xz) = 86926kN·m	MsD(xz) = 11739kN·m	Ms(xz) = 91754kN·m
Ps(xz) = 1585kips	PsD(xz) = 462kips	Ps(xz) = 1585kips
VsT = 130kips	VsD(xz) = 103kips	Vs(xz) = 191kips
MsT(xz) = 64114ftkips	MsD(xz) = 8658ftkips	Ms(xz) = 67676ftkips

Operation Load at 35m/sec

$v2 = 22.109\frac{m}{sec}$

PoT := FzT2

PoD(xz) := Wz(xz) + if(xz < hc, Wcc, 0·kips)

$VoT := \sqrt{FxT2^2 + FyT2^2}$

VoD(xz) := Vzw(xz, v2)

MoTx(xz) := Mxwt2(xz)

MoTy(xz) := Mywt2(xz)

$MoT(xz) := \sqrt{MoTx(xz)^2 + MoTy(xz)^2}$

MoD(xz) := Mzw(xz, v2)

Po(xz) := PoT + PoD(xz)

$Vo(xz) := \sqrt{(FxT2 + VoD(xz))^2 + (FyT2)^2}$

$Mo(xz) := \sqrt{(MoTy(xz) + MoD(xz))^2 + MoTx(xz)^2}$

xz := 0·m

at base of concrete tower

PoT = 4879kN	PoD(xz) = 21751kN	Po(xz) = 26630kN
VoT = 1065kN	VoD(xz) = 177kN	Vo(xz) = 1241kN
MoT(xz) = 145537kN·m	MoD(xz) = 8565kN·m	Mo(xz) = 153515kN·m
Po(xz) = 5987kips	PoD(xz) = 4890kips	Po(xz) = 5987kips
VoT = 239kips	VoD(xz) = 40kips	Vo(xz) = 279kips
MoT(xz) = 107345ftkips	MoD(xz) = 6317ftkips	Mo(xz) = 113229ftkips

xz := hc

at base of steel tower

PoT = 4879kN	PoD(xz) = 2053kN	Po(xz) = 6932kN
VoT = 1065kN	VoD(xz) = 86kN	Vo(xz) = 1150kN
MoT(xz) = 86199kN·m	MoD(xz) = 2223kN·m	Mo(xz) = 88272kN·m
Po(xz) = 1558kips	PoD(xz) = 462kips	Po(xz) = 1558kips
VoT = 239kips	VoD(xz) = 19kips	Vo(xz) = 259kips
MoT(xz) = 63579ftkips	MoD(xz) = 1640ftkips	Mo(xz) = 65107ftkips

Fatigue Load - Damage Equvalent Load

Fatigue Safety Factor: $\gamma f := 1$

Pf(xz) := Wz(xz) + HeadWeight + if(xz < hc, Wcc, 0·kips)

$Vf(xz) := \Delta FxT \cdot \gamma f$

$Mf(xz) := \Delta Mwt(xz) \cdot \gamma f$

xz := 0·m

at base of concrete tower

Pf(xz) = 26459kN	Pf(xz) = 5948kips
Vf(xz) = 197kN	Vf(xz) = 44kips
Mf(xz) = 29894kN·m	Mf(xz) = 22049ftkips

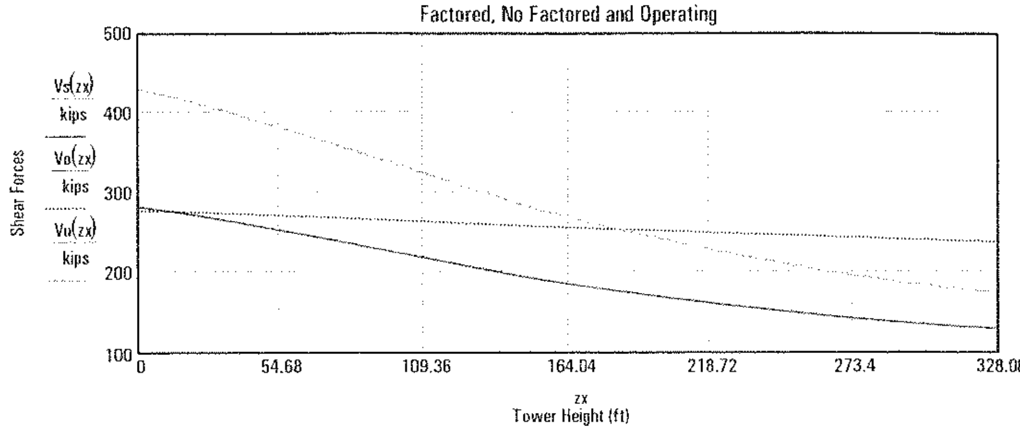
xz := hc

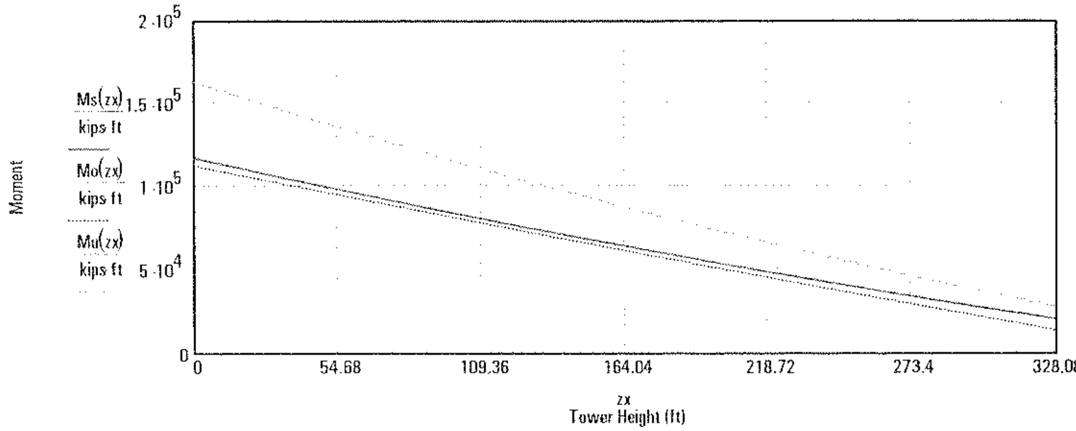
at base of steel tower

Pf(xz) = 6761kN	Pf(xz) = 1520kips
Vf(xz) = 197kN	Vf(xz) = 44kips
Mf(xz) = 17543kN·m	Mf(xz) = 12940ftkips

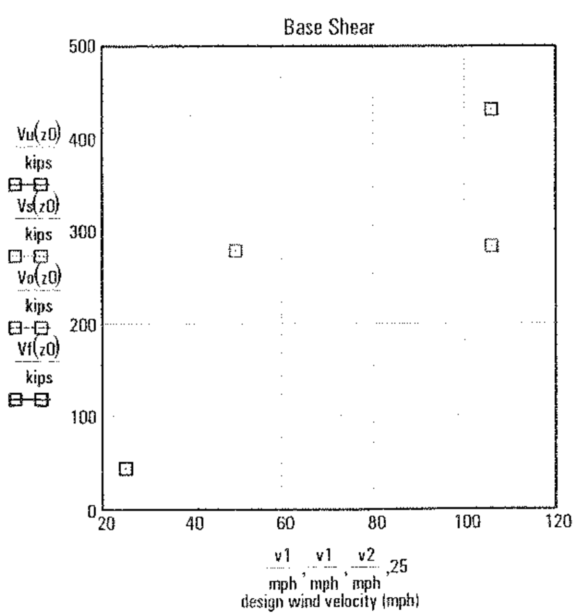
Ratio of Ultimate Load for Seismic/Wind

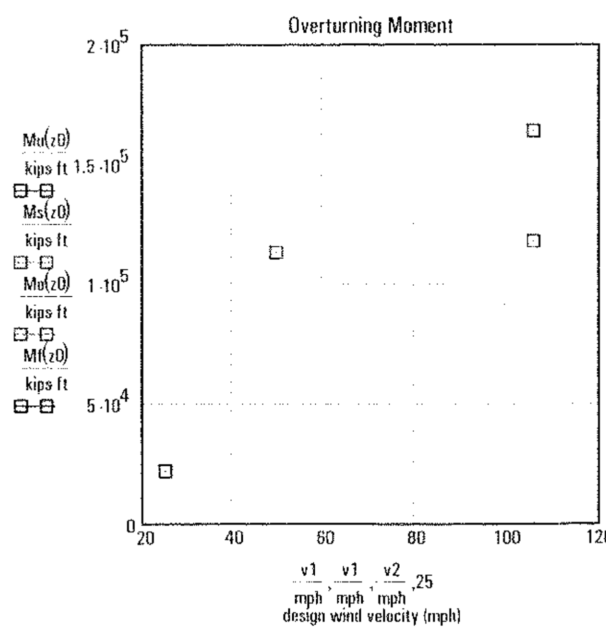
$$\frac{Vzq(z0)}{Vu(z0)} = 3.997 \qquad \frac{Mzq(z0)}{Mu(z0)} = 2.246$$





Design Wind Load Comparison Diagram





Deflection for Wind Load at Top of Tower

Wind Speed for 60m/sec (133mph)

$$\Delta ws(z) := \int_0^z \frac{Ms(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vs(z0)}{Kh} + \frac{Ms(z0)}{Kr}\cdot z$$

$WDisT := \Delta ws(h)$ $\quad WDisT = 0.358m$ $\quad WDisT = 1.176ft$ $\quad \frac{h}{WDisT} = 279$

$WDisM := \Delta ws(hc)$ $\quad WDisM = 0.06m$ $\quad WDisM = 0.197ft$ $\quad \frac{hc}{WDisM} = 782$

Moment Magnification Factor

at Base: $\delta swb := \dfrac{1}{1-\dfrac{Pu(z0)}{Pcr(z0)}}$ $\quad \delta swb = 1.084$

at Height of hc: $\delta swt := \dfrac{1}{1-\dfrac{Pu(hc)}{Pcr(z0)}}$ $\quad \delta swt = 1.021$

P-Δ Effect

Moment of Tower due to Gravity Load for P-Δ effect :

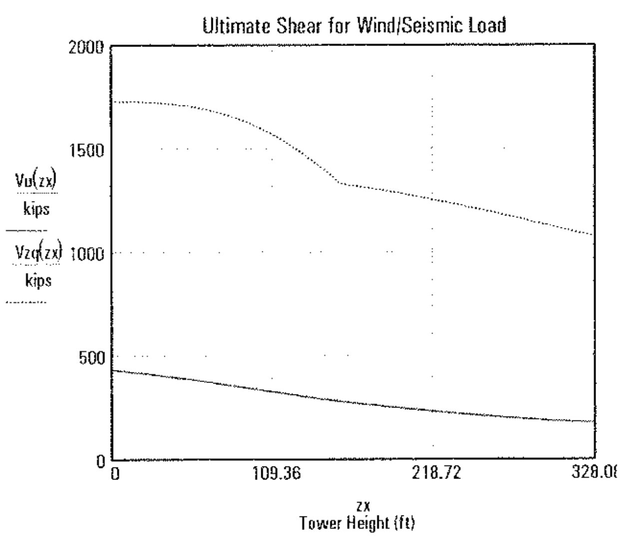
$$Mwg(z) := (WDisT - \Delta ws(z))\cdot HeadWeight + \int_z^h wt(y)\cdot(\Delta ws(y) - \Delta ws(z))\,dy + Wcc\cdot if[z < hc, (WDisM - \Delta ws(z)), 0\cdot m]$$

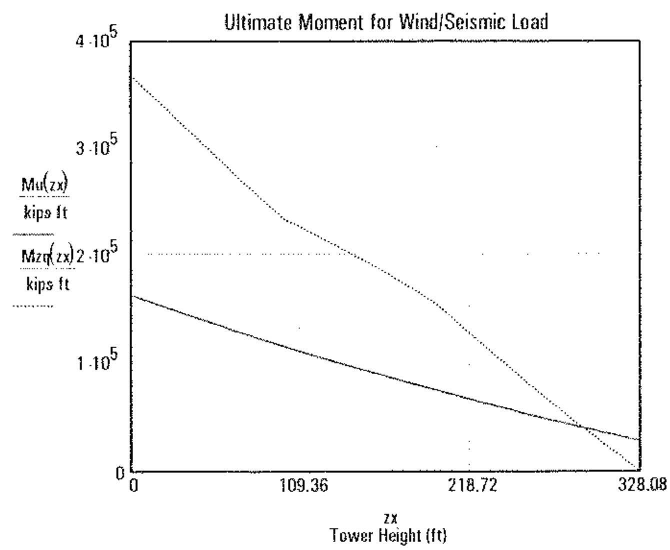
Approx. Method of Moment at Base for P-Δ effect :

$$Mwgb := \Delta ws(h)\cdot HeadWeight + Wcc\cdot\Delta ws(hc) + Wz(hc)\cdot\Delta ws\left(\frac{h+hc}{2}\right) + (Wz(z0) - Wz(hc))\cdot\Delta ws\left(\frac{hc}{2}\right)$$

$\delta wb := \dfrac{Mwgb}{Ms(z0)} + 1$ $\quad \delta wb = 1.015$

Ultimate Design Forces for Wind/Earthquake Load





Governing Loading Case Conclusion:

BASE SHEAR: if(Vu(z0) > Vzq(z0), "Wind Load Control", "Earthquake Load Control") = "Earthquake Load Control"

OVERTURNING MOMENT: if(Mu(z0) > Mzq(z0), "Wind Load Control", "Earthquake Load Control") = "Earthquake Load Control"

Post-Tension Concrete Circular Section Design (PT-CCSD)

Section Geometric Data: $z := z0$ Section at Base

Outside Radius: $R1 := \frac{d(z)}{2}$ $R1 = 4.572\,m$ $R1 = 180\,in$

Inside Radius: $R2 := \frac{d(z)}{2} - t(z)$ $R2 = 3.81\,m$ $R2 = 150\,in$

Tendon Cordinates:

Number of Tendon: $NT1 := 56$ $NT2 := NT1$ $NT := NT1 + NT2$

Clear Distance: $Cr1 := 15 \cdot in$ $Cr2 := 15 \cdot in$

$Cr1 = 0.381\,m$ $Cr2 = 0.381\,m$

Tendom Area: $i := 1..NT$ $i1 := 1..NT1$ $i2 := NT1 + 1..NT$

Area of Tendon (16.8cm2) $At_i := 1.302 \cdot in^2$ 12-5/8 Dia. Low-Relaxation (7 wire strand)

Tendom Distribution:

$$tx_{i1} := (R1 - Cr1) \cdot \sin\left(\frac{2 \cdot \pi}{NT1} \cdot i1\right) \qquad ty_{i1} := (R1 - Cr1) \cdot \cos\left(\frac{2 \cdot \pi}{NT1} \cdot i1\right)$$

$$tx_{i2} := (R2 + Cr2) \cdot \sin\left(\frac{2 \cdot \pi}{NT2} \cdot i2\right) \qquad ty_{i2} := (R2 + Cr2) \cdot \cos\left(\frac{2 \cdot \pi}{NT2} \cdot i2\right)$$

Section Geometric Properties:

Section Circular Function:

$$f1(x) := \sqrt{R1^2 - x^2} \qquad g1(x) := -\left(\sqrt{R1^2 - x^2}\right)$$

$$f2(x) := \sqrt{R2^2 - x^2} \qquad g2(x) := -\left(\sqrt{R2^2 - x^2}\right)$$

Section Layout and Properties:

$$Area1 := \int_{-R1}^{R1} (f1(x) - g1(x))\,dx$$

$$Area2 := \int_{-R2}^{R2} (f2(x) - g2(x))\,dx$$

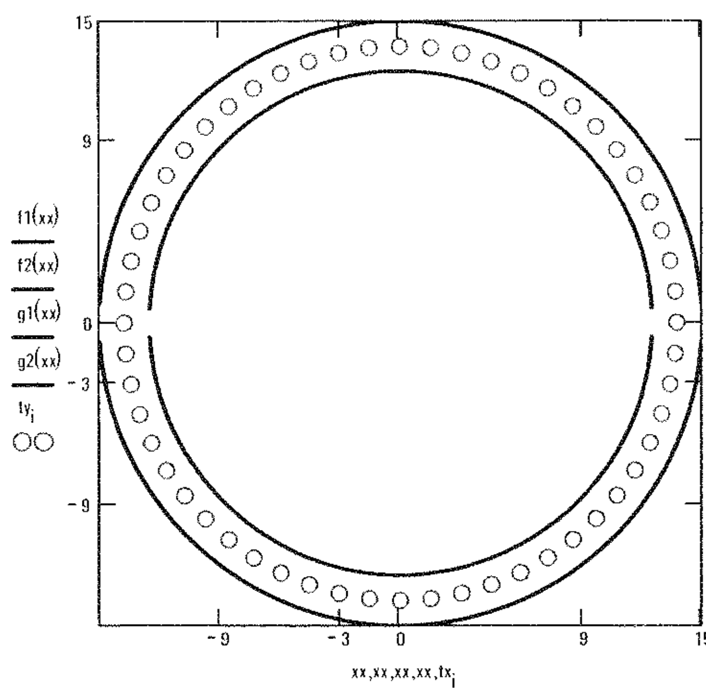
$$Area := Area1 - Area2$$

$$J := \frac{\pi}{2} \cdot \left(R1^4 - R2^4\right)$$

$$rxx := \sqrt{\frac{I(z)}{Ac(z)}}$$

$rxx = 2.976\,m$ $rxx = 117\,in$

$Eps_i := Es$



Steel Tendon Ratio:

$$\rho t := \frac{\sum_{i=1}^{NT} At_i}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]} \qquad \rho t = 0.00471$$

Post-Tension Tendon Properties:

Tendon Ultimate Strength: $fsu = 1862 MPa$ $fsu = 270 ksi$ Low-Relaxation (7 wire strand)

Effective strand stress after loss: $fse0 = 1103 MPa$ $fse0 = 160 ksi$ $fse_i := fse0$

Strand strain (stress-strain curve): $eps := 0.0086$

Stress loss: $0.75 \cdot fsu - fse0 = 293 MPa$ $0.75 \cdot fsu - fse0 = 42.5 ksi$

Ultimate concrete strain: $ecu := 0.003$

Nominal Strength of Tendon For unbonded strain (assume 50% ratio for flexure):

$$fps := fse0 + 10 \cdot ksi + \frac{fc}{100 \cdot \rho t \cdot 0.5} \qquad fps = 1377 MPa \qquad fps = 200 ksi$$

Nominal stress of strand: From strand stress-strain relation curve

$$fps(e) := \begin{cases} Es \cdot e & \text{if } e < eps \\ 270 \cdot ksi - \dfrac{0.04 \cdot ksi}{e - 0.007} & \text{otherwise} \end{cases}$$

Section Property Calculating as function of depth (a):

$$xx1(a) := if\left(R1 < |a|, 0 \cdot in, \sqrt{R1^2 - a^2}\right) \qquad xx2(a) := if\left(R2 < |a|, 0 \cdot in, \sqrt{R2^2 - a^2}\right)$$

$$Areay11(a) := \int_{-xx1(a)}^{xx1(a)} (f1(x) - a)\, dx \qquad Areay1(a) := \begin{cases} (Areay11(|a|)) & \text{if } a \ge 0 \cdot in \\ (Area1 - Areay11(|a|)) & \text{otherwise} \end{cases}$$

$$Areay22(a) := \int_{-xx2(a)}^{xx2(a)} (f2(x) - a)\, dx \qquad Areay2(a) := \begin{cases} (Areay22(|a|)) & \text{if } a \ge 0in \\ (Area2 - Areay22(|a|)) & \text{otherwise} \end{cases}$$

Area at Depth of a: $Areay(a) := Areay1(a) - Areay2(a)$

$$SAy1(a) := \int_{-xx1(a)}^{xx1(a)} \int_{a}^{f1(x)} y\, dy\, dx \qquad SAy2(a) := \int_{-xx2(a)}^{xx2(a)} \int_{a}^{f2(x)} y\, dy\, dx$$

Neutral Axis at Depth of a: $YN(a) := \dfrac{SAy1(a) - SAy2(a)}{Areay(a)}$ $YN(z) = 2.68 m$ $YN(z) = 105 in$

Tendon and Concrete Stress for Prestressed Tendon:

Tendon Force and Strain: $Pe := \sum_{i=1}^{NT} fse_i \cdot At_i$ $Pe = 103782.9 kN$ $Pe = 23331.8 kips$

$$epe := \frac{Pe}{\sum_{i=1}^{NT} At_i \cdot Eps_i} \qquad epe = 0.00561$$

Concrete Strain by Tendon Forces:

$$ece := \frac{Pe}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right] Ec} \qquad ece = 0.0001486$$

Elastic Shorten Loss after Direct Transfer:

$$\frac{0.75\cdot fsu\cdot\left(\sum_{i=1}^{NT} At_i\right)\cdot Es}{\left[Area-\left(\sum_{i=1}^{NT} At_i\right)\right]\cdot Ec} = 37MPa \qquad \frac{0.75\cdot fsu\cdot\left(\sum_{i=1}^{NT} At_i\right)\cdot Es}{\left[Area-\left(\sum_{i=1}^{NT} At_i\right)\right]\cdot Ec} = 5.36ksi$$

Beta Factor for Concrete Compression Depth:

$$\beta 1 := 0.85 - 0.05\cdot\left(\frac{fc}{ksi}-4\right) \qquad \beta 1 = 0.7$$

Total Concrete Deformation after Prestressed: $depy := eps - epe - ece$ $\quad depy = 0.002837$

Calculating Pn~Mn interaction diagram

Strain Compababilty Relation: $dy := \max(ty) + R1$

$$cby := \frac{dy\cdot\frac{ecu}{depy}}{\left(1+\frac{ecu}{depy}\right)}$$

Cb at for fps (balance point): $cb := cby$ $\quad cby = 4.504m$ $\quad cby = 177.3in$

Concrete Compression Depth: $a := R1 - cby\cdot\beta 1$ $\quad a = 1.42m$ $\quad a = 55.886in$

Concrete Compression Forces: $Cn(cb) := 0.85\cdot fc\cdot Areay(R1 - \beta 1\cdot cb)$ $\quad Cn(cb) = 321021kN$

$Cn(cb) = 72170kips$

Tendon Forces in Tention:

$$Tsn(cb) := \left|\begin{array}{l} s \leftarrow 0 \\ \text{for } i \in 1..NT \\ \quad \left|\begin{array}{l} eey_i \leftarrow ece + epe + ecu\cdot\left(\frac{R1 - ty_i}{cb} - 1\right) \\ s \leftarrow s + fps(eey_i)\cdot At_i \end{array}\right. \\ s \end{array}\right.$$

$Tsn(cb) = 107371.4kN$

$Tsn(cb) = 24138.6kips$

Pn~Mn Interaction Relation:

$Pn(cb) := Cn(cb) - Tsn(cb)$

$Pn(cb) = 213650kN$ $\quad Pn(cb) = 48031kips$

$$Mn(cb) := \left|\begin{array}{l} s \leftarrow 0 \\ \text{for } i \in 1..NT \\ \quad \left|\begin{array}{l} eey_i \leftarrow ece + epe + ecu\cdot\left(\frac{R1 - ty_i}{cb} - 1\right) \\ s \leftarrow s - fps(eey_i)\cdot At_i\cdot ty_i \end{array}\right. \\ s \leftarrow s + Cn(cb)\cdot YN(R1 - \beta 1\cdot cb) \end{array}\right.$$

$$\frac{Mn(cb)}{Pn(cb)} = 210.875in$$

$Mn(cb) = 1144357kN\cdot m$ $\quad Mn(cb) = 844053kips\cdot ft$

Pure Compression Condition

$$Pn0 := 0.85\cdot fc\cdot Area - \sum_{i=1}^{NT} fse_i\cdot At_i \qquad Pn0 = 719368kN \qquad Pn0 = 161724kips$$

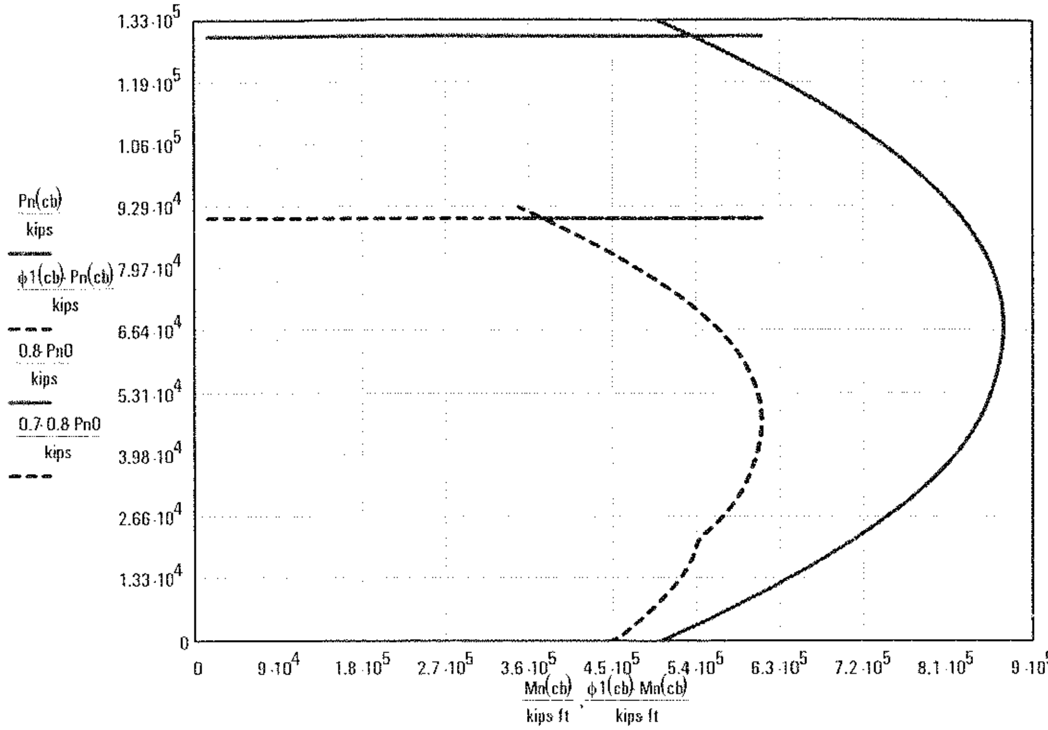
Strength Reduction Factor:

$$\phi(cb) := \frac{0.9\cdot 0.1\cdot fc\cdot Area}{0.1\cdot fc\cdot Area + 0.2\cdot \text{if}(Pn(cb) > 0\cdot kips, Pn(cb), 0\cdot kips)}$$

$$\phi 1(cb) := \left|\begin{array}{l} 0.7 \text{ if } \phi(cb) < 0.7 \\ (\phi(cb)) \text{ otherwise} \end{array}\right.$$

$cb := 5\cdot in, 10\cdot in..450\cdot in$

Pn~Mn Interaction Diagram:



Demand and Capacity Ratio:

DCR for Wind $cb := 73.7\cdot in$ $\frac{Pu(z)}{\phi1(cb)\cdot Pn(cb)} = 1.003$ $DCRw := \frac{Mu(z)}{\phi1(cb)\cdot Mn(cb)}$ $DCRw = 0.333$

$Pn(cb) = 38448\,kN$ $Mn(cb) = 801344\,kN\cdot m$ $\phi1(cb)\cdot Pn(cb) = 32057\,kN$ $\phi1(cb)\cdot Mn(cb) = 668155\,kN\cdot m$

$Pn(cb) = 8644\,kips$ $Mn(cb) = 591054\,kips\cdot ft$ $\phi1(cb)\cdot Pn(cb) = 7207\,kips$ $\phi1(cb)\cdot Mn(cb) = 492817\,kips\cdot ft$

DCR for Seismic $cb := 73.5\cdot in$ $\frac{\gamma DL\cdot W}{\phi1(cb)\cdot Pn(cb)} = 1.001$ $DCRq := \frac{Mzq(z)}{\phi1(cb)\cdot Mn(cb)}$ $DCRq = 0.748$

$Pn(cb) = 38021\,kN$ $Mn(cb) = 800057\,kN\cdot m$ $\phi1(cb)\cdot Pn(cb) = 31728\,kN$ $\phi1(cb)\cdot Mn(cb) = 667628\,kN\cdot m$

$Pn(cb) = 8548\,kips$ $Mn(cb) = 590105\,kips\cdot ft$ $\phi1(cb)\cdot Pn(cb) = 7133\,kips$ $\phi1(cb)\cdot Mn(cb) = 492428\,kips\cdot ft$

Modified DCR Ratio: $DCRw := DCRw\cdot\delta swb\cdot\delta wb$ $DCRw = 0.366$

$DCRq := DCRq\cdot\delta sqb\cdot\delta qb$ $DCRq = 0.821$

Calculate Tendon Stresses $eey_i := ece + epe + ecu\cdot\left(\frac{R1 - ty_i}{cb} - 1\right)$

Maximum Tendon Stress: $Te_i := \left| \begin{array}{l} \left[eey_i \leftarrow ece + epe + ecu\cdot\left(\frac{R1 - ty_i}{cb} - 1\right)\right] \\ fps(eey_i) \end{array}\right.$ $max(Te) = 1834\,MPa$

$max(Te) = 266\,ksi$

Post-Tension Concrete Section for Service Load (Ref. to ACI 318, Chapter 18)

Concrete Yield stress: $0.45fc = 21.7\,MPa$ $0.45fc = 3.15\,ksi$

Concrete Ultimate stress: $0.6fc = 29\,MPa$ $0.6\cdot fc = 4.2\,ksi$

Concrete Cracking stress: $\frac{6}{1000}\cdot\sqrt{\frac{fc\cdot 1000}{ksi}}\cdot ksi = 3.46\,MPa$ $\frac{6}{1000}\cdot\sqrt{\frac{fc\cdot 1000}{ksi}}\cdot ksi = 0.502\,ksi$

Stiffness Ratio: $n := \frac{Es}{Ec}$ $n = 5.619$

Section Moment of Inertia: $Ix := I(z) + (n-1)\cdot\sum_{i=1}^{NT} At_i\cdot(ty_i)^2$ $\frac{Ix}{I(z)} = 1.021$

Stress under Service Load Condition :

Tendon Stress: $fs_i := \frac{Ms(z)\cdot ty_i}{Ix}n + fse_i$ $fsmax := max(fs)$ $fsmax = 1123.9\,MPa$ $fsmax = 163\,ksi$

$fsmin := min(fs)$ $fsmin = 1082.4\,MPa$ $fsmin = 157\,ksi$

Concrete Stress: $fcc := \frac{Ms(z)}{S(z)}$ $fcc = 4.114\,MPa$ $fcc = 0.597\,ksi$ Bending Stress

$fg := \frac{Ps(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $fg = 1.34\,MPa$ $fg = 0.194\,ksi$ Axial Stress

$fcmax := ece\cdot Ec + fcc + fg$ $fcmax = 10.65\,MPa$ $fcmax = 1.545\,ksi$ Max Stress in Compression

$fcmin := ece\cdot Ec - fcc + fg$ $fcmin = 2.422\,MPa$ $fcmin = 0.351\,ksi$ Max Stress in Tension:

$ecmax := \frac{fcmax}{Ec}$ $ecmax = 0.0003$ Max Strain in Compression:

Concrete Shear Stress:

Shear Strength: $\tau c(z) := 2\cdot\left(1 + \frac{Pu(z)}{2000\cdot psi\cdot Ac(z)}\right)\cdot\sqrt{\frac{fc\cdot 1000}{ksi}}\cdot psi$

$\tau c(z) = 1.29\,MPa$ $\tau c(z) = 0.187\,ksi$

Torsion Moment: $Ts := Mzwt1(z)$ $Ts = 5603\,kN\cdot m$ $Ts = 4133\,kips\cdot ft$

$Qs := \frac{Area}{2}\cdot\left(\frac{4}{3\cdot\pi}\cdot\frac{R1^3 - R2^3}{R1^2 - R2^2}\right)$ $\frac{Vs(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)} = 0.018\,ksi$

Shear Stress in Concrete $\tau cc := \frac{Ts\cdot R1}{J} + \frac{Vu(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)}$ $\tau cc = 0.262\,MPa$ $\tau cc = 0.038\,ksi$

DCR for Shear Strength (Wind): $DCRvw := \frac{\tau cc}{\tau c(z)}$ $DCRvw = 0.204$

DCR for Shear Strength (EQ): $DCRvq := \frac{Vzq(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)\cdot\tau c(z)}$ $DCRvq = 0.591$

Stress under Operating Load Condition :

Tendon Stress: $fo_i := \frac{Mo(z) \cdot ty_i}{Ix} \cdot n + fse_i$ $fomax := max(fo)$ $fomax = 1123.1\,MPa$ $fomax = 162.9\,ksi$

$fomin := min(fo)$ $fomin = 1083.2\,MPa$ $fomin = 157.1\,ksi$

Concrete Stress: $foc := \frac{Mo(z)}{S(z)}$ $foc = 3.95\,MPa$ $foc = 0.573\,ksi$ Bending Stress

$fog := \frac{Po(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $fog = 1.33\,MPa$ $fog = 0.193\,ksi$ Axial Stress

$focmax := ece \cdot Ec + foc + fog$ $focmax = 10.48\,MPa$ $focmax = 1.52\,ksi$ Max Stress in Compression

$focmin := ece \cdot Ec - foc + fog$ $focmin = 2.58\,MPa$ $focmin = 0.374\,ksi$ Max Stress in Tension:

Stress under Fatigue Load Condition:

Tendon Stress: $ff_i := \frac{Mf(z) \cdot ty_i}{Ix} \cdot n + fse_i$ $ffsmax := max(ff)$ $ffsmax = 1107\,MPa$ $ffsmax = 160.6\,ksi$

$ffsmin := min(ff)$ $ffsmin = 1099.3\,MPa$ $ffsmin = 159.4\,ksi$

Concrete Stress: $ffc := \frac{Mf(z)}{S(z)}$ $ffc = 0.769\,MPa$ $ffc = 0.112\,ksi$ Bending Stress

$ffg := \frac{Pf(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $ffg = 1.32\,MPa$ $fg = 0.194\,ksi$ Axial Stress

$ece \cdot Ec + ffg = 6.521\,MPa$ $S(z) = 38.862\,m^3$

$ffcmax := ece \cdot Ec + ffc + ffg$ $ffcmax = 7.29\,MPa$ $ffcmax = 1.057\,ksi$ Max Stress in Compression

$ffcmin := ece \cdot Ec - ffc + ffg$ $ffcmin = 5.752\,MPa$ $ffcmin = 0.834\,ksi$ Max Stress in Tension:

Across Wind Load (ACI 307-98 Chimney Design- 4.2.3.1)

Only First Mode is Examined

Wind Speed at Cristical Height: $zcr := \frac{5}{6} \cdot h$

Hourly Mean Design Speed (ASCE-7): $Vw(zcr, v1) = 157\,mph$ $Vw(zcr, v2) = 73\,mph$

Hourly Mean Design Speed (ACI-307): $Vw(z, v) := 1.47 \cdot v \cdot \left(\frac{z}{33 \cdot ft}\right)^{0.154} \cdot 0.65$

$Vw(zcr, v1) = 140\,mph$ $Vw(zcr, v2) = 65\,mph$

Mean Outside Diameter: $du := d\left(\frac{2}{3} \cdot h\right)$ $du = 5.8\,m$ $du = 19.1\,ft$

Strouhal Number: $St := 0.25 \cdot \left(0.333 + 0.206 \cdot \ln\left(\frac{h}{du}\right)\right)$ $St = 0.23$

Critical Speed at zcr: $Vcr := \frac{Fq \cdot du}{St}$ $Vcr = 12.244\,\frac{m}{sec}$ $Vcr = 27.389\,mph$

Conclusion: $DCRa(v) := \frac{Vcr}{Vw(zcr, v)}$ Across wind need not be considered if DCRa <0.5 or >1.3

$DCRa(v1) = 0.196$ $DCRa(v2) = 0.419$

Prestressed Concrete Fatigue Design (Model Code 90)

Operating frequency of 20RPM for 30 years: $nf := 5.29 \cdot 10^8$

Concrete Strength: $fck := fc$ $fck = 7\,ksi$

Concrete Reference Strength: $fck0 := 10 \cdot MPa$ $fck0 = 1.45\,ksi$

Concrete Material Factor: $\gamma c := 1.5$

$ffcmax := ffcmax$ $ffcmax = 1.057\,ksi$

Model Factor: $\gamma sd := 1.1$

$ffcmin := ffcmin$ $ffcmin = 0.834\,ksi$

Age of Concrete at Begin Fatigue Loading: $Day := 60$

Concrete High Strength Factor: $s := 0.2$

Advancing Hydratication Factor: $\beta cc := \exp\left(s \cdot \sqrt{1 - \frac{28}{Day}}\right)$ $\beta cc = 1.157$

Concrete Fatigue Stress: $fat := 0.85 \cdot \beta cc \cdot fck \cdot \left(1 - \frac{fck}{25 \cdot fck0}\right) \cdot \frac{1}{\gamma c}$

$fat = 25.54\,MPa$ $fat = 3.704\,ksi$

Fatigue Parameter: $\alpha f := 0.5$ *Absolute stress ratio within 300mm; 1 for constant compression*

$\eta c := \frac{1}{1.5 - 0.5 \cdot \alpha f}$ *1 for reinforcement and nearly constant amplitude; 0.5 for others*

$\eta c := 1$

Concrete Fatigue Design Life: *Simplified Method for Checking:*

$\gamma sd \cdot ffcmax \cdot \eta c = 1.163\,ksi$ $0.45 \cdot fat = 1.667\,ksi$

Detail calculation required for concrete compression

Fatigue Stress Ratio:

$Scdmin := \frac{ffcmin \cdot \gamma sd}{fat} \cdot \eta c$ $Scdmin = 0.248$

$Scdmax := \frac{ffcmax \cdot \gamma sd}{fat} \cdot \eta c$ $Scdmax = 0.314$

$\Delta Scd := Scdmax - Scdmin$ $\Delta Scd = 0.066$

Set M1 = logN1; M2 = logN2 and M3 = logN3

$M1 := \left(12 + 16 \cdot Scdmin + 8 \cdot Scdmin^2\right) \cdot (1 - Scdmax)$ $M1 = 11.3$

$M2 := 0.2 \cdot M1 \cdot (M1 - 1)$ *0 < Scdmin <0.8* $M2 = 23.2$

$M3 := \frac{M2}{\Delta Scd} \cdot \left(0.3 - \frac{3}{8} \cdot Scdmin\right)$ $M3 = 72.6$

$$0.3 - \frac{3}{8}\cdot Scdmin = 0.207$$

$$M := \begin{cases} M1 & \text{if } M1 \le 6 \\ M2 & \text{if } \left(M1 > 6 \wedge \Delta Scd \ge 0.3 - \frac{3}{8}\cdot Scdmin\right) \\ M3 & \text{if } \left(M1 > 6 \wedge \Delta Scd < 0.3 - \frac{3}{8}\cdot Scdmin\right) \end{cases}$$

Fatigue Design Life: $M = 72.59$ $\quad N := 10^{M}$ $\quad \frac{nf}{N} = 0$

Steel Tendon Fatigue Stress:

Area ratio of prestress tendon with reinforcement rebar: $Aps := 30$

Diameter ratio of prestress tendon with reinforcement rebar: $Dps := 5$

For smooth strands: $\zeta := 0.2$

$$\eta s := \frac{1 + Aps}{1 + Aps\cdot\sqrt{Dps\cdot\zeta}} \qquad \eta s = 1$$

$\gamma s := 1.15$

$\Delta\sigma Rsk := 95\cdot MPa$ $\qquad \Delta\sigma Rsk = 13.779\,ksi$

$\Delta\sigma RskN := 160\cdot MPa$ $\qquad \Delta\sigma RskN = 23.206\,ksi$

$k1 := 5$ $\qquad k2 := 9$

Max and Min tendon stress:

$\Delta\sigma s := ffsmax - ffsmin$

$\Delta\sigma s = 1.125\,ksi$ $\qquad \Delta\sigma s = 7.758\,MPa$

$\gamma sd\cdot\Delta\sigma s = 1.238\,ksi$

$$\frac{\Delta\sigma Rsk}{\gamma s} = 11.981\,ksi$$

Steel Tower Design Analysis (ASD-Method)

Elevation of Base of Steel Tube: $z := hc\cdot 1.00001$ $\qquad \gamma os := 1.33$ $\qquad$ 33% Overstress Factor

Applied Stress for Wind:

Axial Stress:	$fa(z) := \frac{Ps(z)}{Ac(z)}$	$fa(z) = 9.86\,MPa$	$fa(z) = 1.43\,ksi$
Bendind Stress:	$fb(z) := \frac{Ms(z)}{S(z)}$	$fb(z) = 79.15\,MPa$	$fb(z) = 11.48\,ksi$
Shear Stress:	$fv(z) := \frac{Vs(z)}{\pi\cdot R(z)\cdot t(z)}$	$fv(z) = 2.38\,MPa$	$fv(z) = 0.35\,ksi$
Shear Stress for Torsion:	$fvt(z) := \frac{Ts\cdot d(z)}{4\cdot I(z)}$	$fvt(z) = 2.42\,MPa$	$fvt(z) = 0.35\,ksi$

Max Normal Stress: $fa(z) + fb(z) = 89\,MPa$ $\quad fa(z) + fb(z) = 12.91\,ksi$

Max Shear Stress: $fv(z) + fvt(z) = 4.8\,MPa$ $\quad fv(z) + fvt(z) = 0.696\,ksi$

Combined Stress: $\sigma w(z) := \sqrt{(fa(z) + fb(z))^2 + 3\cdot(fv(z) + fvt(z))^2}$

$\sigma w(z) = 89.4\,MPa$ $\quad \sigma w(z) = 13\,ksi$

Applied Stress for Earthquake:

Axial Stress: $faq(z) := \frac{Wz(z) + HeadWeight + Wcc}{Ac(z)}$ $\quad faq(z) = 9.52\,MPa$ $\quad faq(z) = 1.38\,ksi$

Bendind Stress: $fbq(z) := \frac{0.7\,Mzq(z)}{S(z)}$ $\quad fbq(z) = 157.6\,MPa$ $\quad fbq(z) = 22.86\,ksi$

Shear Stress: $fvq(z) := \frac{0.7\,Vzq(z)}{\pi\cdot R(z)\cdot t(z)}$ $\quad fvq(z) = 11.58\,MPa$ $\quad fvq(z) = 1.68\,ksi$

Max Normal Stress: $faq(z) + fbq(z) = 167.1\,MPa$ $\quad faq(z) + fbq(z) = 24.2\,ksi$

Combined Stress: $\sigma q(z) := \sqrt{(faq(z) + fbq(z))^2 + 3\cdot(fvq(z))^2}$

$\sigma q(z) = 168.3\,MPa$ $\quad \sigma q(z) = 24.4\,ksi$

Allowable Stress:

Allowable Bending Stress: $Fb := 0.6\cdot fy$ $\quad Fb = 206.8\,MPa$ $\quad Fb = 30\,ksi$

Allowable Shear Stress: $Fv := 0.4\cdot fy$ $\quad Fv = 137.9\,MPa$ $\quad Fv = 20\,ksi$

Allowable Compression Stress: $k := 2$ $\quad r(z) := \sqrt{\frac{I(z)}{Ac(z)}}$

$kLr := \frac{k\cdot(h - hc)}{r(hc)}$ $\quad kLr = 37$ $\quad Cc := \sqrt{\frac{2\cdot\pi^2\cdot Es}{fy}}$

$$Fa := \begin{cases} \dfrac{\left(1 - \dfrac{kLr^2}{2\cdot Cc^2}\right)\cdot fy}{\dfrac{5}{3} + \dfrac{3\cdot kLr}{8\cdot Cc} - \dfrac{kLr^3}{8\cdot Cc^3}} & \text{if } kLr \le Cc \\ \dfrac{12\cdot\pi^2\cdot Es}{23\cdot kLr^2} & \text{otherwise} \end{cases}$$

$r(z) = 2.305\,m$

$r(z) = 90.7\,in$

$Cc = 106.1$

$Fa = 180.6\,MPa$

$Fa = 26.2\,ksi$

Unity Check for Wind Load: $\frac{fa(z)}{Fa} = 0.055$ $\quad \frac{fv(z) + fvt(z)}{Fv} = 0.035$

Combine Stress Ratio for fa/Fa <0.15 $\quad DCRsw(z) := \left(\frac{fa(z)}{Fa} + \frac{fb(z)}{Fb}\right)\frac{1}{\gamma os}$ $\quad DCRsw(z) = 0.329$

Unity Check for Earthquake Load: $\frac{faq(z)}{Fa} = 0.053$ $\quad \frac{fvq(z)}{Fv} = 0.084$

Combine Stress Ratio for fa/Fa <0.15 $\quad DCRsq(z) := \left(\frac{faq(z)}{Fa} + \frac{fbq(z)}{Fb}\right)\frac{1}{\gamma os}$ $\quad DCRsq(z) = 0.61$

Buckling Stress (wind energy hand book):

Elastic Tube Buckling Stress: $\sigma cr(z) := 0.605\cdot Es\cdot\frac{t(z)}{R(z)}$ $\quad \sigma cr(z) = 1274\,MPa$ $\quad \sigma cr(z) = 185\,ksi$

Reduction Coefficient for Axial

$$\alpha0(z) := \begin{cases} \dfrac{0.83}{\sqrt{1 + 0.01 \cdot \dfrac{R(z)}{t(z)}}} & \text{if } \dfrac{R(z)}{t(z)} < 212 \\ \dfrac{0.7}{\sqrt{0.1 + 0.01 \cdot \dfrac{R(z)}{t(z)}}} & \text{if } \dfrac{R(z)}{t(z)} \geq 212 \end{cases}$$

$\alpha0(z) = 0.597$

Reduction Coefficient for Bending $\alpha B(z) := 0.1887 + 0.8113 \cdot \alpha0(z)$ $\alpha B(z) = 0.673$

Combined Buckling Stress

$$\sigma u(z) := \begin{cases} fy \cdot \left[1 - 0.4123 \cdot \left(\dfrac{fy}{\alpha B(z) \cdot \sigma cr(z)}\right)^{0.6}\right] & \text{if } \alpha B(z) \cdot \sigma cr(z) > \dfrac{fy}{2} \\ 0.75 \cdot \alpha B(z) \cdot \sigma cr(z) & \text{if } \alpha B(z) \cdot \sigma cr(z) \leq \dfrac{fy}{2} \end{cases}$$

$\sigma u(z) = 262.5\,MPa$ $\sigma u(z) = 38.1\,ksi$ $\dfrac{\sigma u(z)}{fy} = 0.761$

Combined Buckling Stress Ratio $\dfrac{\sigma w(z)}{\sigma u(z)} = 0.341$ $\dfrac{\sigma q(z)}{\sigma u(z)} = 0.641$

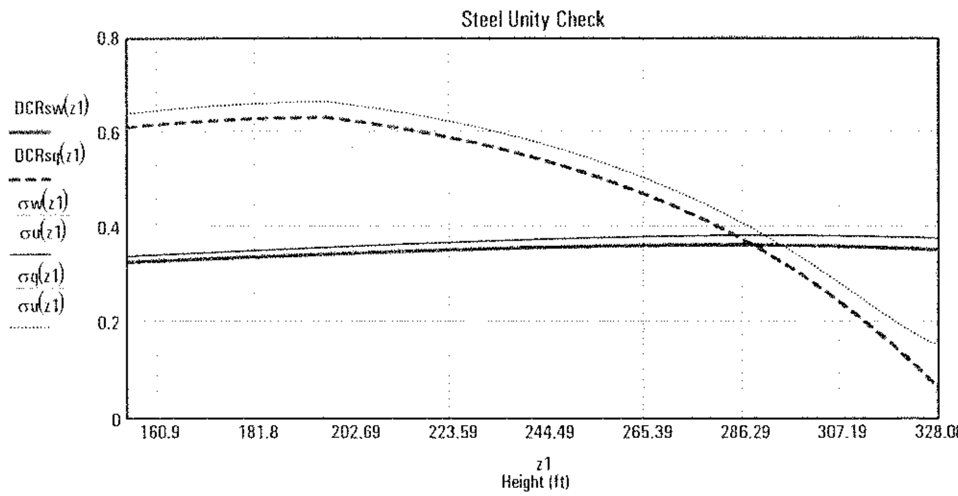
Buckling Unity Check Diagrahm:

DCRswmax = 0.365

DCRsqmax = 0.633

DCRbwmax = 0.384

DCRbqmax = 0.666



Steel Tower Fatigue Design:

Design Cycle: $N1 := nf$ $\Delta\sigma y := 301 \cdot MPa$ $\gamma ss := 1.265$

Initial Cycle without Degradation: $N0 := 10000$ Slope Rate: $n := 4$

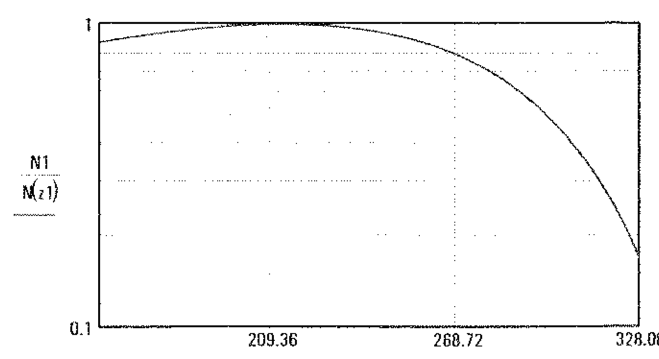
Yielding Moment: $Mfs(z) := \Delta\sigma y \cdot S(z)$ $Mfs(z0) = 8627623.4\,kips \cdot ft$ $Mfs(z0) = 11697231.4\,kN \cdot m$

Extrapolated Yielding Moment: $Mss(z) := Mfs(z) \cdot \sqrt[n]{N0}$ $\sqrt[n]{N0} = 10$

Number of Cycle at Applied Moment: $N(z) := \left(\dfrac{Mf(z) \cdot \gamma ss}{Mss(z)}\right)^{-n}$

$N(z) = 6.1115 \times 10^{8}$

DCRfat = 0.991



Moment Magnification Factors
P-Δ factors

$\delta swb = 1.084$ $\delta sqb = 1.083$
$\delta wb = 1.015$ $\delta qb = 1.014$

Concrete Spread Footing Design

Footing Area: $Af := B \cdot L$ $Af = 455.2m^2$ $Af = 4900ft^2$

Footing Weight: $Wft := Af \cdot D \cdot \rho c$ $Wft = 39232kN$ $Wft = 8820kips$

Footing Section Modulus: $Sft := \frac{1}{6} \cdot B \cdot L^2$

Service Load for Wind:

soil pressure under wind load: $Pft := Ps(z0) + \rho c \cdot D \cdot Af$ $Pft = 65981kN$ $Pft = 14833kips$

Eccentricity: $eft := \frac{Ms(z0)}{Pft}$ $eft = 2.423m$ $eft = 7.949ft$

Soil Pressure: $pmax := \frac{Pft}{Af} + \frac{Ms(z0)}{Sft}$ $pmax = 0.244MPa$ $pmax = 5090psf$

$pmin := \frac{Pft}{Af} - \frac{Ms(z0)}{Sft}$ $pmin = 0.046MPa$ $pmin = 965psf$

$$ptmax := \begin{cases} pmax & \text{if } pmin > 0 \\ \dfrac{2 \cdot Pft}{3 \cdot B \cdot \left(\frac{L}{2} - eft\right)} & \text{otherwise} \end{cases}$$

$ptmax = 0.244MPa$ $ptmax = 5090psf$

DCR for Soil Pressure: $DCRsoilw := \frac{ptmax}{cso}$ $DCRsoilw = 0.848$ $\frac{eft}{L} = 0.114$

Depth of Footing for Shear Capacity:
(One way action):

$$p := \frac{pmax - pmin}{L} \cdot \left(\frac{L}{2} + \frac{d(z0)}{2} + D\right) + pmin$$

Shear Force due to Soil Pressure:

$$Vpft := \frac{p + pmax}{2} \cdot \left[\frac{L}{2} - \left(\frac{d(z0)}{2} + D\right)\right] \cdot B \cdot \gamma WL$$

$Vpft = 19346kN$ $Vpft = 4349kips$

Shear Capacity of Concrete Footing: $Vcft := 0.85 \cdot 2 \cdot \sqrt{\frac{fcft}{ksi} \cdot 1000} \cdot psi \cdot B \cdot D$ $Vcft = 57849kN$ $Vcft = 13005kips$

DCR for Shear Capacity: $DCRvftw := \frac{Vpft}{Vcft}$ $DCRvftw = 0.334$

Bending Moment at Face of Footing:

$$Mpft := \left[p \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B + \frac{pmax - p}{3} \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B\right] \cdot \gamma WL$$

$Mpft = 290062kN \cdot m$ $Mpft = 213943kips \cdot ft$

Bending Reinforcement Ratio Required:

$$\rho ft := \frac{0.85 \cdot fcft}{60 \cdot ksi} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot Mpft}{0.85 \cdot fcft \cdot B \cdot D^2 \cdot 0.7}}\right)$$

$\rho ft = 0.00363$

$Asft := max(\rho ft, 0.0018) \cdot B \cdot D$ $Asft = 2829.1cm^2$ $Asft = 438.5in^2$

The Reinforcement Weight: $2Asft \cdot L \cdot \rho s = 94756kgf$ $2Asft \cdot L \cdot \rho s = 209kips$

Ultimate Load forEQ:

soil pressure under EQ load: $Pftq := Pu(z0) + \rho c \cdot D \cdot Af \cdot \gamma DL$ $\quad Pftq = 79221\,kN$ $\quad Pftq = 17810\,kips$

Eccentricity: $eftq := \frac{Mzq(z0)}{Pftq}$ $\quad eftq = 6.3\,m$ $\quad eftq = 20.669\,ft$

Soil Pressure: $pmaxq := \frac{Pftq}{Af} + \frac{Mzq(z0)}{Sft}$ $\quad pmaxq = 0.482\,MPa$ $\quad pmaxq = 10074\,psf$

$pminq := \frac{Pftq}{Af} - \frac{Mzq(z0)}{Sft}$ $\quad pminq = -0.134\,MPa$ $\quad pminq = -2805\,psf$

$$ptmaxq := \begin{cases} pmaxq & \text{if } pminq > 0 \\ \dfrac{2 \cdot Pftq}{3 \cdot B \cdot \left(\dfrac{L}{2} - eftq\right)} & \text{otherwise} \end{cases}$$

$ptmaxq = 0.567\,MPa$ $\quad ptmaxq = 11836\,psf$

DCR for Soil Pressure: $DCRsoilq := \frac{ptmaxq}{cso \cdot \gamma soq}$ $\quad DCRsoilq = 0.986$ $\quad \frac{eftq}{L} = 0.295$

Govern Design: if(DCRsoilq > DCRsoilw, "Seismic Load Control", "Wind Load Control") = "Seismic Load Control"

Depth of Footing for Shear Capacity:
(One way action):

$$pq := \frac{pmaxq - pminq}{L} \cdot \left(\frac{L}{2} + \frac{d(z0)}{2} + D\right) + pminq$$

Shear Force due to Soil Pressure:

$$Vpftq := \frac{pq + pmaxq}{2} \cdot \left[\frac{L}{2} - \left(\frac{d(z0)}{2} + D\right)\right] \cdot B$$

$Vpftq = 23261\,kN$ $\quad Vpftq = 5229\,kips$

DCR for Shear Capacity: $DCRvftq := \frac{Vpftq}{Vcft}$ $\quad DCRvftq = 0.402$

Bending Moment at Face of Footing:

$$Mpftq := pq \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B + \frac{pmaxq - pq}{3} \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B$$

$Mpftq = 345179\,kN \cdot m$ $\quad Mpftq = 254597\,kips \cdot ft$

Bending Reinforcement Ratio Required:

$$\rho ftq := \frac{0.85 \cdot fcft}{60 \cdot ksi} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot Mpftq}{0.85 \cdot fcft \cdot B \cdot D^2 \cdot 0.7}}\right)$$

$\rho ftq = 0.00434$

$Asftq := \max(\rho ftq, 0.0018) \cdot B \cdot D$ $\quad Asftq = 3388.9\,cm^2$ $\quad Asftq = 525.3\,in^2$

The Reinforcement Weight: $2Asftq \cdot L \cdot \rho s = 113503\,kgf$ $\quad 2Asftq \cdot L \cdot \rho s = 250\,kips$

Results Summary:

Tower Information:

Total Structure Weight:	W = 26459kN	W = 5948kips
Steel Tower Weight:	Wz(hc) = 2053kN	Wz(hc) = 462kips
Concrete Tower Weight:	Wz(z0) − Wz(hc) = 19648kN	Wz(z0) − Wz(hc) = 4417kips
Number of Tendon:	NT1 = 56	
Tendon Weight:	$8.88 \cdot \frac{lbf}{ft} \cdot NT1 \cdot hc = 34781\,kgf$	$8.88 \cdot \frac{lbf}{ft} \cdot NT1 \cdot hc = 76680\,lbf$

Natural Frequency:

	Fq = 0.483Hz	$\frac{1}{Fq} = 2.068\,sec$

Tower Forces for Earthquake Load:

Shear Force at Base:	Vzq(z0) = 7675kN	Vzq(z0) = 1725kips
Shear Force at hc:	Vzq(hc) = 5927kN	Vzq(hc) = 1332kips
Overturning Moment at Base:	Mzq(z0) = 499082kN·m	Mzq(z0) = 368112ftkips
Overturning Moment at hc:	Mzq(hc) = 260994kN·m	Mzq(hc) = 192503ftkips
Deflection at Top:	QDisT = 0.968m	QDisT = 3.176ft

Tower Forces for Wind Load:

Ultimate Wind Load:

xz := 0·m	Pu(xz) = 32142kN	Pu(xz) = 7226kips
at base of concrete tower	Vu(xz) = 1920kN	Vu(xz) = 432kips
	Mu(xz) = 222200kN·m	Mu(xz) = 163890ftkips
xz := hc	Pu(xz) = 8505kN	Pu(xz) = 1912kips
at base of steel tower	Vu(xz) = 1238kN	Vu(xz) = 278kips
	Mu(xz) = 125259kN·m	Mu(xz) = 92388ftkips

Service Wind Load:

xz := 0·m	Ps(xz) = 26749kN	Ps(xz) = 6013kips
at base of concrete tower	Vs(xz) = 1263kN	Vs(xz) = 284kips
	Ms(xz) = 159862kN·m	Ms(xz) = 117911ftkips
xz := hc	Ps(xz) = 7051kN	Ps(xz) = 1585kips
at base of steel tower	Vs(xz) = 851kN	Vs(xz) = 191kips
	Ms(xz) = 91754kN·m	Ms(xz) = 67676ftkips

Operating Wind Load:

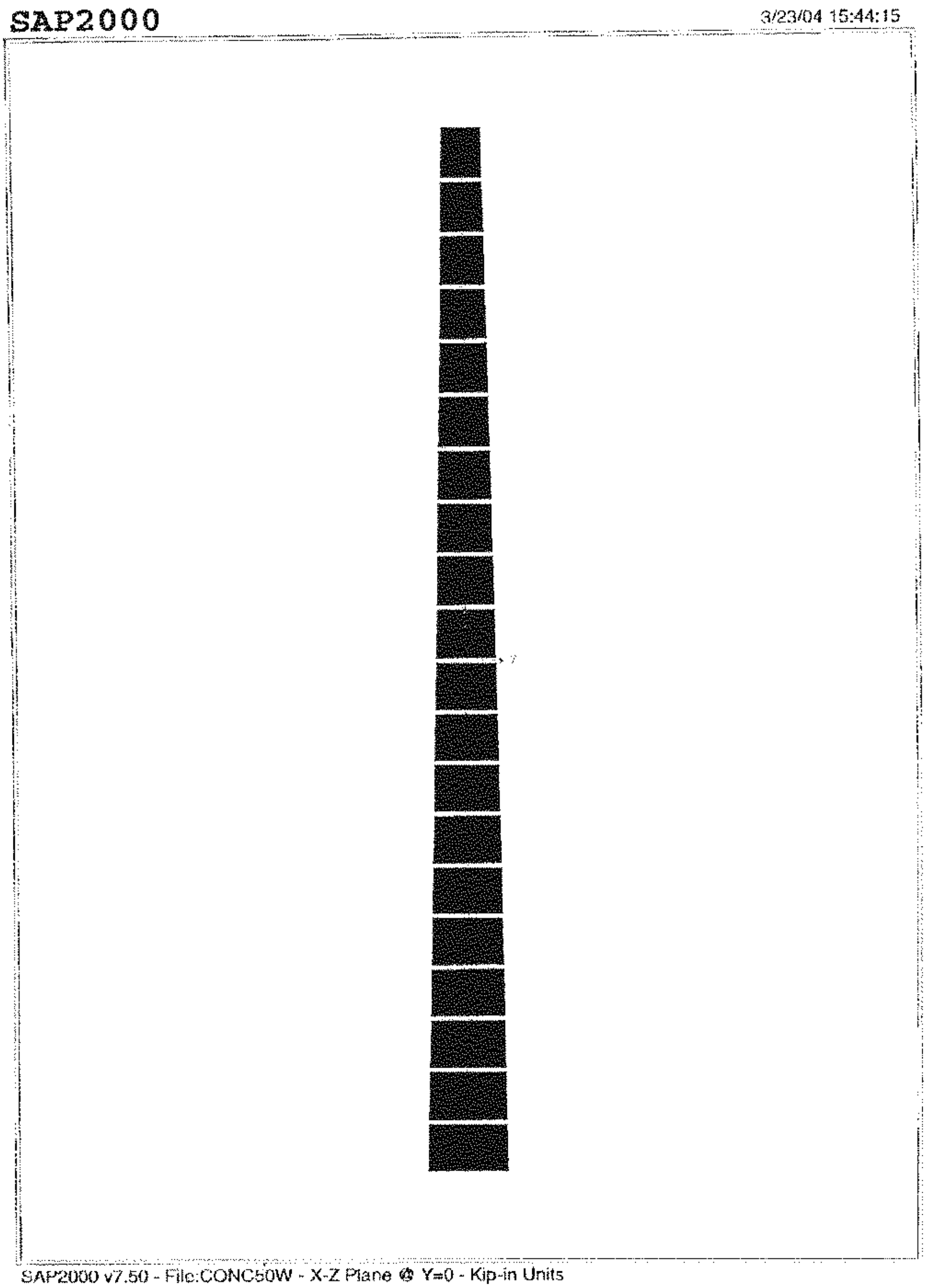
xz := 0·m	Po(xz) = 26630kN	Po(xz) = 5987kips
at base of concrete tower	Vo(xz) = 1241kN	Vo(xz) = 279kips
	Mo(xz) = 153515kN·m	Mo(xz) = 113229ftkips
xz := hc	Po(xz) = 6932kN	Po(xz) = 1558kips
at base of steel tower	Vo(xz) = 1150kN	Vo(xz) = 259kips
	Mo(xz) = 88272kN·m	Mo(xz) = 65107ftkips

Fatigue Load:

xz := 0·m	Pf(xz) = 26459kN	Pf(xz) = 5948kips
at base of concrete tower	Vf(xz) = 197kN	Vf(xz) = 44kips
	Mf(xz) = 29894kN·m	Mf(xz) = 22049ftkips
xz := hc	Pf(xz) = 6761kN	Pf(xz) = 1520kips
at base of steel tower	Vf(xz) = 197kN	Vf(xz) = 44kips
	Mf(xz) = 17543kN·m	Mf(xz) = 12940ftkips

Deflection at Top:	WDisT = 0.358m	WDisT = 1.176ft

Ratio of Ultimate Load for EQ/Wind	$\frac{Vzq(z0)}{Vu(z0)} = 3.997$	$\frac{Mzq(z0)}{Mu(z0)} = 2.246$
Moment Magnification Factors	$\delta swb = 1.084$	$\delta sqb = 1.083$
P-Δ factors	$\delta wb = 1.015$	$\delta qb = 1.014$
Demand and Capacity Ratio at Base:	$z := z0$	
<u>DCR for Wind</u>	$DCRw = 0.366$	<u>Modified DCR for Wind</u>
	$cb := 73.7 \cdot in$	$\frac{Pu(z)}{\phi1(cb) \cdot Pn(cb)} = 1.003$
	$DCRw := \frac{Mu(z)}{\phi1(cb) \cdot Mn(cb)}$	$DCRw = 0.333$
	$\phi1(cb) \cdot Pn(cb) = 32057 kN$	$\phi1(cb) \cdot Pn(cb) = 7207 kips$
	$\phi1(cb) \cdot Mn(cb) = 668155 kN \cdot m$	$\phi1(cb) \cdot Mn(cb) = 492817 kips \cdot ft$
	$DCRvw = 0.204$	DCR for Shear Strength:
<u>DCR for Seismic</u>	$DCRq = 0.821$	<u>Modified DCR for EQ</u>
	$cb := 73.5 \cdot in$	$\frac{\gamma DL \cdot W}{\phi1(cb) \cdot Pn(cb)} = 1.001$
	$DCRq := \frac{Mzq(z)}{\phi1(cb) \cdot Mn(cb)}$	$DCRq = 0.748$
	$\phi1(cb) \cdot Pn(cb) = 31728 kN$	$\phi1(cb) \cdot Pn(cb) = 7133 kips$
	$\phi1(cb) \cdot Mn(cb) = 667628 kN \cdot m$	$\phi1(cb) \cdot Mn(cb) = 492428 kips \cdot ft$
	$DCRvq = 0.591$	DCR for Shear Strength:
Tower Stress for Service Wind Load:		
Tendon Stress:	$fsmax = 1123.9 MPa$	$fsmax = 163 ksi$
Concrete Stress:	$fsmin = 1082.4 MPa$	$fsmin = 157 ksi$
	$fcmax = 10.65 MPa$	$fcmax = 1.545 ksi$
	$fcmin = 2.422 MPa$	$fcmin = 0.351 ksi$
Tower Stress for Operating Wind Load:	$fomax = 1123.1 MPa$	$fomax = 162.9 ksi$
Tendon Stress:	$fomin = 1083.2 MPa$	$fomin = 157.1 ksi$
Concrete Stress:	$focmax = 10.48 MPa$	$focmax = 1.52 ksi$
	$focmin = 2.58 MPa$	$focmin = 0.374 ksi$
Tower Stress for Fatigue Load:	$ffsmax = 1107 MPa$	$ffsmax = 160.6 ksi$
Tendon Stress:	$ffsmin = 1099.3 MPa$	$ffsmin = 159.4 ksi$
	$ffcmax = 7.29 MPa$	$ffcmax = 1.057 ksi$
Concrete Stress:	$ffcmin = 5.752 MPa$	$ffcmin = 0.834 ksi$
Across Wind <0.5Vcr:	$DCRa(v1) = 0.196$	$DCRa(v2) = 0.419$
Steel Tower Stress Check:		
Maximum Stress for Wind Load:	$\sigma w(hc \cdot 1.0001) = 89.4 MPa$	$\sigma w(hc \cdot 1.0001) = 13 ksi$
	$DCRswmax = 0.365$	$DCRbwmax = 0.384$
Maximum Stress for EQ Load:	$\sigma q(hc \cdot 1.0001) = 168.3 MPa$	$\sigma q(hc \cdot 1.0001) = 24.4 ksi$
	$DCRsqmax = 0.633$	$DCRbqmax = 0.666$
Fatigue Ratio:	$DCRfat = 0.991$	$M = 72.6$
DCR for Soil Bearing Capacity:	$DCRsoilw = 0.848$	$DCRsoilq = 0.986$
DCR for Footing Shear Capacity:	$DCRvftw = 0.334$	$DCRvftq = 0.402$
Footing Reinforcement Weight:	$2Asftq \cdot L \cdot \rho s = 113503 kgf$	$2Asftq \cdot L \cdot \rho s = 250 kips$



5.0 MW Full Concrete Tower Model and Dynamics Properties

Tower Freq.	Mode-1		Mode-2		Mode-3	
Conc50w	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)
Spring Base	0.3564	2.8058	1.6742	0.5973	3.6203	0.2762
Fixed Base	0.4125	2.4241	2.0094	0.4977	5.4059	0.1850
Conc50EQ	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)
Spring Base	0.4350	2.2991	1.8708	0.5345	3.5531	0.2814
Fixed Base	0.5184	1.9288	2.3394	0.4275	6.0783	0.1645

Revised Wind Load --- 100m Concrete Tower for 5.0MW (Wind Load Design)

Units Conversion:

$kips := 1000 \cdot lbf$ $\quad ksi := \frac{kips}{in^2}$ $\quad psf := \frac{lbf}{ft^2}$ $\quad kN := 1000 \cdot newton$ $\quad MPa := 10^6 \cdot Pa$

1.5MW Turbine Data

Totoal Turbine Weight:	$HeadWeight := 480076 \cdot kgf$	$HeadWeight = 1058 kips$
Additional Weight at Mid of Concrete Tower:	$Wcc := 5000 \cdot kgf$	$Wcc = 11.02 kips$

Tower Dimension:

Totoal Tower Height:	$h := 100 \cdot m$	$h = 328 ft$
Concrete Tower Height:	$hc := 49 \cdot m$	$hc = 161 ft$
Outside Diameter at Base of Concrete Tower	$Dcb = 7.62 m$	$Dcb = 300 in$
Wall Thickness at Base of Concrete Tower	$Tcb = 0.762 m$	$Tcb = 30 in$
Outside Diameter at Top of Concrete Tower	$Dct = 5.639 m$	$Dct = 222 in$
Wall Thickness at Top of Concrete Tower	$Tct = 0.6858 m$	$Tct = 27 in$
Outside Diameter at Base of Upper Tower	$Dsb = 5.639 m$	$Dsb = 222 in$
Wall Thickness at Base of Upper Tower	$Tsb = 0.6858 m$	$Tsb = 27 in$
Outside Diameter at Top of Upper Tower	$Dst = 3.658 m$	$Dst = 144 in$
Wall Thickness at Top of Upper Tower	$Tst = 0.4572 m$	$Tst = 18 in$

Tower Material Properties:

Concrete Tower Density :	$\rho c = 23.563 \frac{kN}{m^3}$	$\rho c = 150 \frac{lbf}{ft^3}$
Concrete Compression Strength :	$fc = 7 ksi$	$fc = 7 ksi$
	$Es = 196501 MPa$ $Es = 28500 ksi$	$Ec := 33 \cdot \left(\frac{\rho c \cdot ft^3}{lbf}\right)^{1.5} \cdot \frac{\sqrt{\frac{fc}{ksi} \cdot 1000}}{1000} \cdot ksi$
Concrete Elastic Modulus :	$Ec = 34972 MPa$	$Ec = 5072 ksi$

Tower Foundation:

Footing Concrete Strength:	$fcft = 27.6 MPa$	$fcft = 4 ksi$	
Concrete Elastic Modulus :	$Ecft = 26436 MPa$	$Ecft = 3834 ksi$	
Footing Length and Width:	$B = 20.422 m$	$B = 67 ft$	$L := B$
Footing Depth:	$D = 3.658 m$	$D = 12 ft$	

Soil Information:

Soil Tower Density :	$\rho so = 18.85 \frac{kN}{m^3}$	$\rho so = 120 \frac{lbf}{ft^3}$
Allowable Soil Bearing Capacity	$cso = 0.287 MPa$	$cso = 6000 psf$
Soil Shear Modulus	$Gso = 20.684 MPa$	$Gso = 3000 psi$
Soil Poission Ratio	$\mu so := 0.35$	
Soil Bearing Capacity Safety Factor for EQ:	$\gamma soq := 2$	

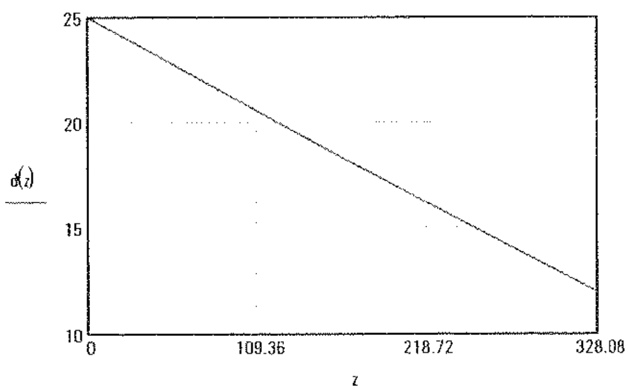
Tower Configuration Along the Height (z):

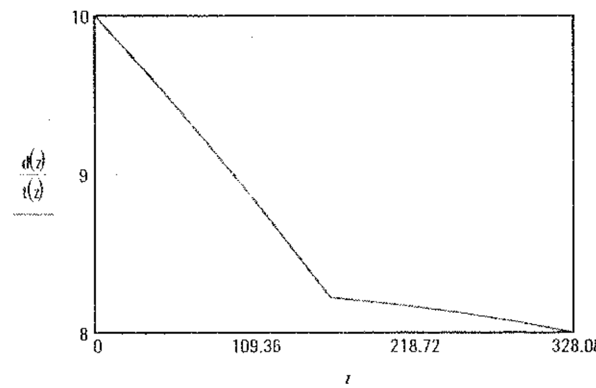
Ground Elevation: $z0 := 0 \cdot m$

Tower Diameter:
$$d(z) := \begin{cases} \left(\dfrac{Dct - Dcb}{hc} \cdot z + Dcb\right) & \text{if } z \le hc \\ \left[\dfrac{Dst - Dsb}{h - hc} \cdot (z - hc) + Dsb\right] & \text{otherwise} \end{cases}$$

Tower Wall Thickness:
$$t(z) := \begin{cases} \left(\dfrac{Tct - Tcb}{hc} \cdot z + Tcb\right) & \text{if } z \le hc \\ \left[\dfrac{Tst - Tsb}{h - hc} \cdot (z - hc) + Tsb\right] & \text{otherwise} \end{cases}$$

Tower Riadus: $R(z) := \dfrac{d(z) - t(z)}{2}$





Tower Cross Section Area: $Ac(z) := \dfrac{\pi}{4} \cdot \left[d(z)^2 - (d(z) - 2 \cdot t(z))^2 \right]$

Section Moment of Inertia: $I(z) := \dfrac{\pi}{64} \left[d(z)^4 - (d(z) - 2 t(z))^4 \right]$

Section Modulus: $S(z) := \dfrac{2 I(z)}{d(z)}$

Elastic Modulus: $E(z) := Ec$

Tower Weight Distribution: $wt(z) := Ac(z) \cdot \rho c$ $\qquad Wz(z) := \int_z^h wt(x)\, dx$

Upper Tower Weight: $Wz(hc) = 8922\,kN$ $\qquad Wz(hc) = 2006\,kips$

Tower Weight: $Wz(z0) = 24472\,kN$ $\qquad Wz(z0) = 5502\,kips$

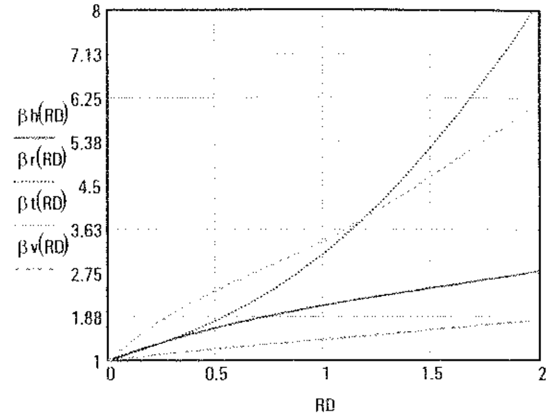
Total Weight: $W := Wz(z0) + HeadWeight + Wcc$ $\qquad W = 2980500\,kgf$

$W = 29229\,kN$ $\qquad W = 6571\,kips$

Soil Spring Constants: Ref. to Highway Bridge Design Manual:

Translation Equivalent Radius $R0 := \sqrt{\frac{B \cdot L}{\pi}}$ $R0 = 37.801\,ft$ $R0 = 37.801\,ft$

Rotation X Equivalent Radius $R1 := \sqrt[4]{\frac{B \cdot L \cdot (B^2 + L^2)}{6 \cdot \pi}}$



Rotation X Equivalent Radius $R2 := \sqrt[4]{\frac{(B)^3 \cdot L}{3 \cdot \pi}}$

Rotation X Equivalent Radius $R3 := \sqrt[4]{\frac{(L)^3 \cdot B}{3 \cdot \pi}}$

Embedment Factor $\frac{D}{R1} = 0.314$

Shape Factor (see Ref.) $\alpha x := 1.02$ $\alpha y := 1.02$ $\alpha v := 1.03$ $\alpha r := 1.05$

$\beta h\left(\frac{D}{R1}\right) = 1.44$ $\beta r\left(\frac{D}{R1}\right) = 1.46$ $\beta v\left(\frac{D}{R1}\right) = 1.15$ $\beta t\left(\frac{D}{R1}\right) = 1.97$

Vertical Spring Constant: $Kv := \alpha v \cdot \beta v\left(\frac{D}{R1}\right) \cdot \frac{4 \cdot Gso \cdot R0}{1 - \mu so}$ $Kv = 1739277\frac{kN}{m}$ $Kv = 9932\frac{kips}{in}$

Horizontal Spring Constant: $Kh := \alpha x \cdot \beta h\left(\frac{D}{R1}\right) \cdot \frac{8 \cdot Gso \cdot R0}{2 - \mu so}$ $Kh = 1693210\frac{kN}{m}$ $Kh = 9669\frac{kips}{in}$

Torsional Spring Constant: $Kt := \alpha r \cdot \beta t\left(\frac{D}{R1}\right) \cdot \frac{16 \cdot Gso \cdot R3^3}{3}$ $Kt = 362056825\,kN \cdot m$ $Kt = 3204542865\,kips \cdot in$

Rocking Spring Constant: $Kr := \alpha r \cdot \beta r\left(\frac{D}{R1}\right) \cdot \frac{8 \cdot Gso \cdot R1^3}{3 \cdot (1 - \mu so)}$ $Kr = 205289298\,kN \cdot m$ $Kr = 1817003047\,kips \cdot in$

Natural Frequency of Tower

Rayleigh Energy Method

Defomation Shape Function
(Fix - Free End)

$$x(a1, a2, z) := \begin{cases} a1 - a1 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) & \text{if } z \le hc \\ a2 - a2 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + h - 2 \cdot hc}{h - hc}\right) + \frac{a1\pi}{2hc} \cdot (z - hc) + a1 & \text{if } hc < z \le h \end{cases}$$

First Order Differential Equation

$$y1(a1, a2, z) := \begin{cases} \frac{-1}{2} \cdot a1 \cdot \cos\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) \cdot \frac{\pi}{hc} & \text{if } z \le hc \\ \frac{-1}{2} \cdot a2 \cdot \cos\left[\frac{\pi}{2} \cdot \frac{(z + h - 2 \cdot hc)}{(h - hc)}\right] \cdot \frac{\pi}{(h - hc)} + \frac{a1}{2} \cdot \frac{\pi}{hc} & \text{if } hc < z \le h \end{cases}$$

Second Order Differential Equation

$$y2(a1, a2, z) := \begin{cases} \frac{1}{4} \cdot a1 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) \cdot \frac{\pi^2}{hc^2} & \text{if } z \le hc \\ \frac{1}{4} \cdot a2 \cdot \sin\left[\frac{1}{2} \cdot \pi \cdot \frac{(z + h - 2 \cdot hc)}{(h - hc)}\right] \cdot \frac{\pi^2}{(h - hc)^2} & \text{if } hc < z \le h \end{cases}$$

Strain Energy of Tower $Umax(a1,a2) := \frac{1}{2}\int_0^h E(z)\cdot I(z)\cdot y2(a1,a2,z)^2\,dz$

Kenitic Energy of Tower $Tmax(a1,a2) := \frac{1}{2}\left(\int_0^h \frac{wt(z)}{g}\cdot x(a1,a2,z)^2\,dz + \frac{HeadWeight}{g}\cdot x(a1,a2,h)^2 + \frac{Wcc}{g}\cdot x(a1,a2,hc)^2\right)$

Rayleigh Quotient $Freq(a1,a2) := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{Umax(a1,a2)}{Tmax(a1,a2)}}$

Minimum Energy Principle $i := 1..10$ $hi := 0.01\cdot in$ $j := 1..10$ $hj := 0.2\cdot in$ $Fq_{i,j} := Freq(i\cdot hi, j\cdot hj)$

Tower Frequency (fixed base) $Freq := \min(Fq)$ $Freq = 0.464\,Hz$

Deformation Shape for Base Rotation $x1(p,z) := \frac{p\cdot h}{Kr}\cdot z$ $U1max(p) := \frac{(p\cdot h)^2}{2\cdot Kr}$

$$T1max(p) := \frac{1}{2}\left(\int_0^h \frac{wt(z)}{g}\cdot x1(p,z)^2\,dz + \frac{HeadWeight}{g}\cdot x1(p,h)^2 + \frac{Wcc}{g}\cdot x1(p,hc)^2\right)$$

Freqency for Base Rotation $Fr1(p) := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{U1max(p)}{T1max(p)}}$ $Fr1(10\cdot kips) = 0.696\,Hz$

Freqency for Base Translation $Fr2 := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{Kh\cdot g}{W}}$ $Fr2 = 3.793\,Hz$

Natural Freqency of Tower $Fq := \sqrt{\frac{Fr1(100\cdot kips)^2\cdot Fr2^2\cdot Freq^2}{Fr1(100\cdot kips)^2\cdot Freq^2 + Fr2^2\cdot Freq^2 + Fr1(100\cdot kips)^2\cdot Fr2^2}}$ $Fq = 0.384\,Hz$

Global Buckling Load (Rayleigh's Method):

External Work: $\lambda max(a1,a2) := \frac{1}{2}\int_0^h y1(a1,a2,z)^2\,dz$

Self-Weight Work: $Wmax(a1,a2) := \frac{1}{2}\left(HeadWeight\cdot\int_0^h y1(a1,a2,z)^2\,dz + Wcc\cdot\int_0^{hc} y1(a1,a2,z)^2\,dz + \int_0^h wt(z)\cdot z\cdot y1(a1,a2,z)^2\,dz\right)$

Global Buckling Load:
Based on Minimum Energy Method
$Pcr(a1,a2) := \frac{Umax(a1,a2) - Wmax(a1,a2)}{\lambda max(a1,a2)}$ $pcr_{i,j} := Pcr(i\cdot hi, j\cdot hj)$

$$Pcr(z) := \min(pcr) + Wz(z) + HeadWeight + if(z < hc, Wcc, 0\cdot kips)$$

Buckling Load at Top : $Pcr(z0) = 471751\,kN$ $Pcr(z0) = 106056\,kips$ $Pe := \min(pcr)$

Total Global Buckling Load: $Pe = 442522\,kN$ $Pe = 99485\,kips$

Earthquake Load: ASCE 7-98

Seismic Soil Data (Table and Figure 9.4.1) :

Site Class Factor: Soil Class "D" $Fa := 1$ $Fv := 1.5$

Design Acceleration for Short Period: $Sds := 1.5 \cdot \frac{2}{3} \cdot Fa$ $Sds = 1$

Design Acceleration for One Second: $Sd1 := 0.6 \cdot \frac{2}{3} \cdot Fv$ $Sd1 = 0.6$

$Ts := \frac{Sd1}{Sds} \cdot sec$ $T0 := 0.2 \cdot Ts$

Design Response Spectra

$$Sa(T) := \begin{cases} \frac{Sd1}{T} & \text{if } T > Ts \\ Sds \cdot \left(0.4 + 0.6 \cdot \frac{T}{T0}\right) & \text{if } T < T0 \\ Sds & \text{otherwise} \end{cases}$$

Building Period (sec):

$\beta := 0.75$ $Ct := 0.02$

0.035 for Steel MF
0.03 for EBF
0.018 for Concrete MF
0.020 for all others

$Ta := Ct \cdot \left(\frac{h}{ft}\right)^{\beta} \cdot sec$ $Ta = 1.542sec$

$T := 1.4 \cdot Ta$ $T = 2.158sec$

Base Shear Factor:

Reduction Factor $Rq := 1$ $T := \min\left(T, \frac{1}{Fq}\right)$ $T = 2.158sec$

Importance Factor of Occupancy $Iq := 1$

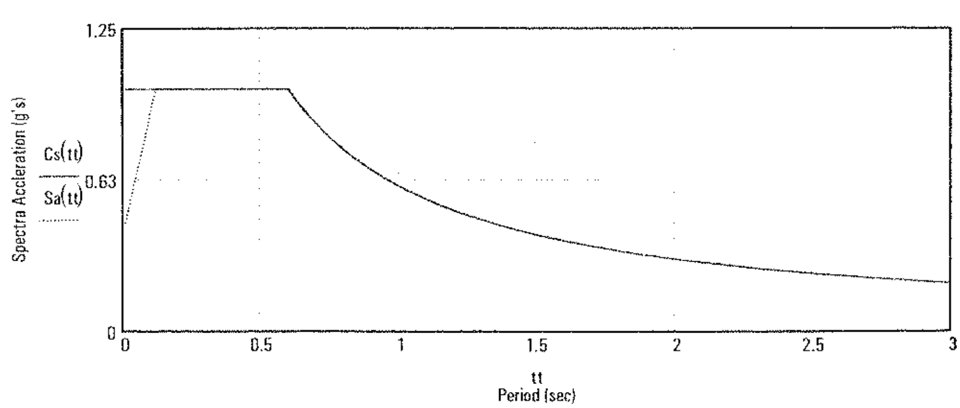
Seismic Response Coefficient $Cs(T) := \frac{Sd1 \cdot Iq}{Rq \cdot T} \cdot sec$ $Csup := \frac{Sds \cdot Iq}{Rq}$ $Csup = 1$ *Upperbound*

$Cslo := 0.044 \cdot Sds \cdot Iq$ $Cslo = 0.044$ *Lowerbound*

$$Cs(T) := \begin{cases} Csup & \text{if } Cs(T) \geq Csup \\ Cslo & \text{if } Cs(T) < Cslo \\ Cs(T) & \text{otherwise} \end{cases}$$

$Cs(T) = 0.278$

$tt := 0.01, 0.02 .. 3$



ASCE 7 Design Response Spectra

Tower Shear Force and Moment :

Base Shear: $V := Cs(T) \cdot W \cdot Rq$ $V = 8124.8\,kN$ $V = 1826.6\,kips$

Distributed Forces Along the Tower:

$$k(T) := \begin{cases} 1 & \text{if } T < 0.5 \cdot sec \\ 2 & \text{if } T > 2.5 \cdot sec \\ \left(0.5 \cdot \frac{T}{sec} + 0.75\right) & \text{otherwise} \end{cases}$$

$0 := k(T)$ $k(T) = 1.829$

Mode Shape Factor

Force Distribution along Tower:

$$wtz := \int_0^h wt(z) \cdot z^{k0}\,dz \qquad F(z) := \frac{wt(z) \cdot z^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

Concentrated Load at Height of h:

$$Fh := \frac{HeadWeight \cdot h^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

$Fh = 783.2\,kips$

Concentrated Load at Height of hc:

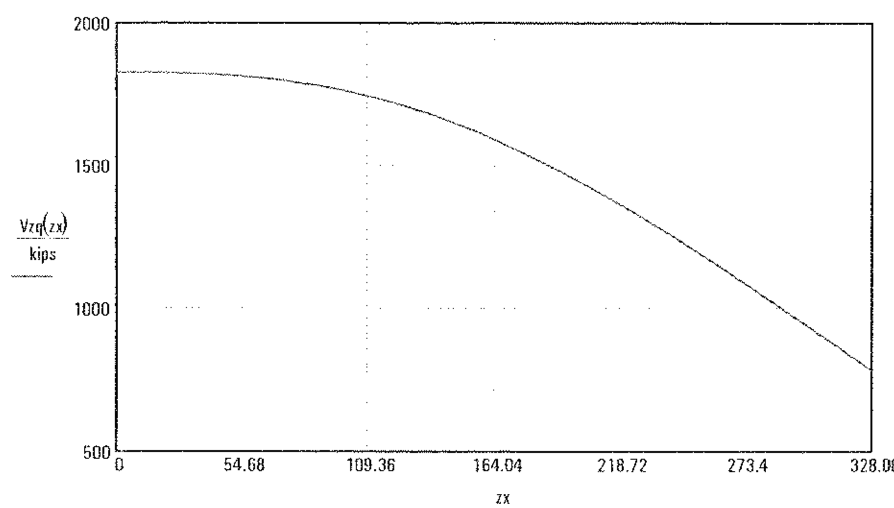
$$Fhc := \frac{Wcc \cdot hc^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

$Fhc = 2.2\,kips$

Shear Force along the Tower:

$$Vzq(z) := \int_z^h F(x)\,dx + Fh + if(z \le hc, Fhc, 0 \cdot kips)$$

$zx := 0 \cdot m, 1 \cdot m .. h$



Shear Force:

$Vzq(z0) = 8124.8\,kN$ $Vzq(z0) = 1826.6\,kips$

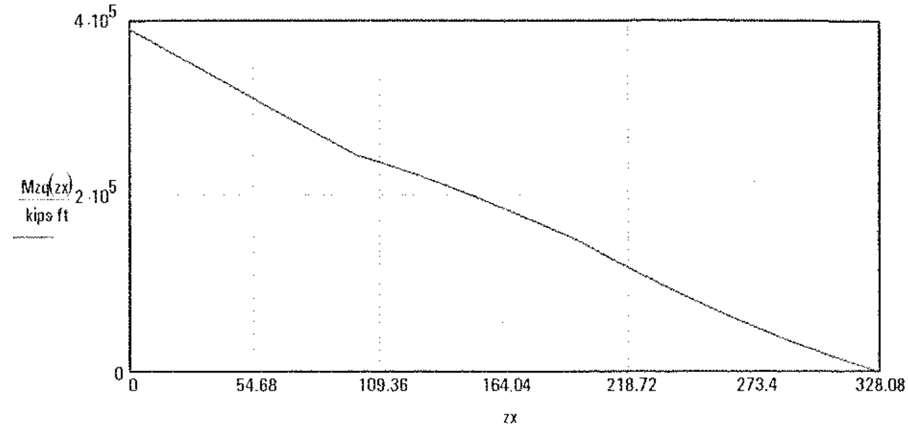
$Vzq(hc) = 7133.7\,kN$ $Vzq(hc) = 1603.8\,kips$

Over Turning Moment along the Tower:

$$\tau(z) := \begin{cases} 1 & \text{if } z > 60 \cdot m \\ \left[\frac{z - 30 \cdot m}{60 \cdot m - 30 \cdot m} \cdot (1 - 0.8) + 0.8\right] & \text{if } 30 \cdot m \le z \le 60 \cdot m \\ 0.8 & \text{if } z < 30 \cdot m \end{cases}$$

Overturning Moment Reduction Factor

$$Mzq(z) := \tau(z)\cdot\left[\int_z^h F(x)\cdot(x-z)\,dx + Fh\cdot(h-z) + \text{if}(z \le hc, Fhc\cdot(hc-z), 0\cdot kips\cdot ft)\right]$$



Over Turning Moment:

$Mzq(z0) = 529295\,kN\cdot m$ $\quad Mzq(z0) = 390396\,kips\cdot ft$

$Mzq(hc) = 256764\,kN\cdot m$ $\quad Mzq(hc) = 189383\,kips\cdot ft$

Deflection at Top of Tower

$$\Delta q(z) := \int_{z0}^{z} \frac{Mzq(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vzq(z0)}{Kh} + \frac{Mzq(z0)}{Kr}\cdot z$$

$QDisT := \Delta q(h)$ $\quad QDisT = 1.202\,m$ $\quad QDisT = 3.944\,ft$ $\quad \frac{h}{QDisT} = 83$

$QDisM := \Delta q(hc)$ $\quad QDisM = 0.337\,m$ $\quad QDisM = 1.107\,ft$ $\quad \frac{hc}{QDisM} = 145$

Moment Magnification Factor

at Base: $\delta sqb := \dfrac{1}{1 - \dfrac{1.2W}{Pcr(z0)}}$ $\quad \delta sqb = 1.08$

at Height of hc: $\delta sqt := \dfrac{1}{1 - \dfrac{1.2(Wz(hc) + HeadWeight + Wcc)}{Pcr(z0)}}$ $\quad \delta sqt = 1.036$

P-Δ Effect

Moment of Tower due to Gravity Load for P-Δ effect :

$$Mqg(z) := \left(QDisT - \Delta q(z)\right)\cdot HeadWeight + \int_z^h wt(y)\cdot\left(\Delta q(y) - \Delta q(z)\right)dy + Wcc\cdot\text{if}\left(z < hc, QDisM - \Delta q(z), 0\cdot m\right)$$

Approx. Method of Moment at Base and at hc for P-Δ effect:

$$Mqgb := \Delta q(h)\cdot HeadWeight + Wcc\cdot\Delta q(hc) + Wz(hc)\cdot\Delta q\left(\frac{h+hc}{2}\right) + (Wz(z0) - Wz(hc))\cdot\Delta q\left(\frac{hc}{2}\right)$$

$$Mqgt := \left(\Delta q(h) - \Delta q(hc)\right)\cdot HeadWeight + Wz(hc)\cdot\Delta q\left(\frac{h+hc}{2}\right)$$

$\delta qb := \dfrac{Mqgb}{Mzq(z0)} + 1$ $\quad \delta qb = 1.026$ $\quad \delta qt := \dfrac{Mqgt}{Mzq(hc)} + 1$ $\quad \delta qt = 1.04$

Wind Load: ASCE 7-98 Design Wind Category : D

Wind Speed at Hub: $v\_EWM50 := 59.5 \cdot \frac{m}{sec}$ Nonoperating Load (EWM50)

$v\_EOG50 := 35 \cdot \frac{m}{sec}$ Operating Load (EOG50)

Design Wind Speed: $v1 := v\_EWM50 \cdot \left(\frac{33 \cdot ft}{h}\right)^{0.1}$ $v1 = 47.3 \frac{m}{sec}$ $v1 = 105.8\,mph$

$v2 := v\_EOG50 \cdot \left(\frac{33 \cdot ft}{h}\right)^{0.2}$ $v2 = 22.1 \frac{m}{sec}$ $v2 = 49.5\,mph$

Importance factor: $Im := 1$

Parameters for Speed-up Over Hill and Escarpment: (Figure 6-2 of ASCE-7-98)

for flat area $\gamma := 4$ $\mu := 1.5$ $x := 0 \cdot ft$ $Lh := 100000 \cdot m$ $H := 1 \cdot m$

Topographic Factor, Kzt for Exposure D: $K1 := 1.55 \cdot \frac{H}{Lh}$ $K1 = 1.55 \times 10^{-5}$

$K2 := 1 - \frac{|x|}{\mu \cdot Lh}$ $K2 = 1$

$K3(z) := e^{-\gamma \cdot \frac{z}{Lh}}$

$Kzt(z) := (1 + K1 \cdot K2 \cdot K3(z))^2$

Terrain Expoure Constants for Exposure D: (Table 6-4 of ASCE-7-98)

$\alpha 1 := 11.5$ $zg := 700 \cdot ft$ $c := 0.15$ $b := 0.8$ $\alpha := \frac{1}{9}$ $\varepsilon := \frac{1}{8}$ $l := 650 \cdot ft$

Basic Velocity Pressure:

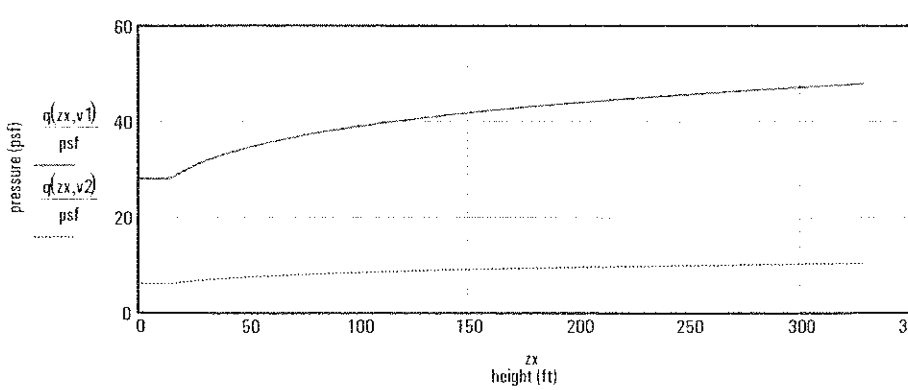
Velocity Pressure Coefficient:

$$K(z) := \begin{cases} 2.01 \cdot \left(\frac{15 \cdot ft}{zg}\right)^{\frac{2}{\alpha 1}} & \text{if } z < 15 \cdot ft \\ 2.01 \cdot \left(\frac{z}{zg}\right)^{\frac{2}{\alpha 1}} & \text{otherwise} \end{cases}$$

Direcitionality Factor for Round: $Kd := 0.95$

Velocity Pressure: $Vw(v) := \frac{v}{mph}$ $0.00256 \cdot Vw(v1)^2 \cdot psf = 28.6\,psf$ $0.00256 \cdot Vw(v2)^2 \cdot psf = 6.3\,psf$

$q(z,v) := 0.00256 \cdot K(z) \cdot Kzt(z) \cdot Kd \cdot Vw(v)^2 \cdot Im \cdot psf$



Velocity Pressure at 100m High:

$q(h,v1) = 2296\,Pa$ $\quad q(h,v2) = 502\,Pa$

$q(h,v1) = 47.9\,psf$ $\quad q(h,v2) = 10\,psf$

$q(hc,v1) = 2028\,Pa$ $\quad q(hc,v2) = 443\,Pa$

$q(hc,v1) = 42.4\,psf$ $\quad q(hc,v2) = 9\,psf$

Damping Ratio: $\beta d := 0.02$

Gust Factor Calculation:

Intensity of turbulence:

$$Ig(z) := c\cdot\left(\frac{33\cdot ft}{z}\right)^{\frac{1}{6}} \qquad Lg(z) := l\cdot\left(\frac{z}{33\cdot ft}\right)^{\varepsilon}$$

Peak Factor for Resonant: $gQ := 3.4$ $\quad gv := 3.4$

$$gR := \sqrt{2\cdot \ln(3600\cdot sec\cdot Fq)} + \frac{0.577}{\sqrt{2\cdot \ln(3600\cdot sec\cdot Fq)}} \qquad gR = 3.955$$

Mean hourly velocity:

$$Vw(z,v) := b\cdot\left(\frac{z}{33\cdot ft}\right)^{\alpha}\cdot v\cdot\left(\frac{88}{60}\right)$$

Reduced Frequency

$$N1(z,v) := \frac{Fq\cdot Lg(z)}{Vw(z,v)}$$

Resonant response factor

$$\eta h(z,v) := \frac{4.6\cdot Fq\cdot h}{Vw(z,v)} \qquad \eta B(z,v) := \frac{4.6\cdot Fq\cdot d(hc)}{Vw(z,v)} \qquad \eta L(z,v) := \frac{15.4\cdot Fq\cdot d(hc)}{Vw(z,v)}$$

$$Rh(z,v) := \frac{1}{\eta h(z,v)} - \frac{1}{2(\eta h(z,v))^2}\cdot\left(1 - e^{-2\cdot\eta h(z,v)}\right)$$

$$Rn(z,v) := \frac{7.47\cdot N1(z,v)}{(1 + 10.3\cdot N1(z,v))^{\frac{5}{3}}}$$

$$RB(z,v) := \frac{1}{\eta B(z,v)} - \frac{1}{2(\eta B(z,v))^2}\cdot\left(1 - e^{-2\cdot\eta B(z,v)}\right)$$

$$RG(z,v) := \sqrt{\frac{1}{\beta d}\cdot Rh(z,v)\cdot RB(z,v)\cdot Rn(z,v)\cdot(0.53 + 0.47\cdot RB(z,v))}$$

$$Q(z) := \sqrt{\frac{1}{1 + 0.63\cdot\left(\frac{d(hc) + h}{Lg(z)}\right)^{0.63}}}$$

Gust Effect factor

$$G(z) := 0.925\cdot\frac{(1 + 1.7\cdot gQ\cdot Ig(z)\cdot Q(z))}{1 + 1.7\cdot gv\cdot Ig(z)} \qquad G(h) = 0.877$$

for Flexible Structure < 1 Hz

$$Gf(z,v) := 0.925\cdot\frac{\left(1 + 1.7\cdot Ig(z)\cdot\sqrt{gQ^2\cdot Q(z)^2 + gR^2\cdot RG(z,v)^2}\right)}{1 + 1.7\cdot gv\cdot Ig(z)}$$

$Gf(h,v1) = 1.159$ $\quad Gf(h,v2) = 0.981$

Direct Wind Load on Tower:

Forced Coefficient:
Table 6-10 of ASCE-7-98

$$d(hc)\cdot\sqrt{\frac{q(hc,v1)}{psf}} = 120.399\,ft \qquad > 2.5$$

$$Cf(x) := \begin{cases} \left[\frac{0.6-0.5}{7-1}\cdot(x-1)+0.5\right] & \text{if } 1 \le x < 7 \\ \left[\frac{0.7-0.6}{25-7}\cdot(x-7)+0.6\right] & \text{if } 7 \le x \le 25 \\ 0.7 & \text{if } x > 25 \end{cases}$$

For Smooth Surface

$$Cf\left(\frac{h}{d(hc)}\right) = 0.66 \qquad \frac{h}{d(hc)} = 17.7$$

Distributed Forces Along the Tower: $Fw(z,v) := q(z,v)\cdot Gf(z,v)\cdot Cf\left(\frac{h}{d(z)}\right)\cdot d(z)$

Shear Force along the Tower: $Vzw(z,v) := \int_z^h Fw(x,v)\,dx$

$Vzw(z0,v1) = 825\,kN$	$Vzw(z0,v1) = 185.5\,kips$
$Vzw(hc,v1) = 405\,kN$	$Vzw(hc,v1) = 91.1\,kips$
$Vzw(z0,v2) = 151\,kN$	$Vzw(z0,v2) = 34\,kips$
$Vzw(hc,v2) = 75\,kN$	$Vzw(hc,v2) = 16.8\,kips$

Moment along the Tower: $Mzw(z,v) := \int_z^h Fw(x,v)\cdot(x-z)\,dx$

$Mzw(z0,v1) = 40354.3\,kN\cdot m$	$Mzw(z0,v1) = 29764\,kips\cdot ft$
$Mzw(hc,v1) = 9919\,kN\cdot m$	$Mzw(hc,v1) = 7316\,kips\cdot ft$
$Mzw(z0,v2) = 7424.9\,kN\cdot m$	$Mzw(z0,v2) = 5476\,kips\cdot ft$
$Mzw(hc,v2) = 1831\,kN\cdot m$	$Mzw(hc,v2) = 1350\,kips\cdot ft$

Wind Turbine Load (WindPact Load):

Coordinate Direction: x:= downwind y:= lateral z:= vertical

Wind Turbine Load (No Safety Factor) : Non-operating Load (EMW50) Operating Load (EOG50)

Maximum Wind Load at Top (yaw bearing -100m):

	Non-operating Load (EMW50)		Operating Load (EOG50)	
Maximum Horizontal Thrust:	$FxT1 := 199\cdot kN$	$FxT1 = 45\,kips$	$FxT2 := 1057\cdot kN$	$FxT2 = 238\,kips$
	$FyT1 := 543\cdot kN$	$FyT1 = 122\,kips$	$FyT2 := 128\cdot kN$	$FyT2 = 29\,kips$
	$FzT1 := 4998\cdot kN$	$FzT1 = 1124\,kips$	$FzT2 := 4879\cdot kN$	$FzT2 = 1097\,kips$
Maximum Horizontal Moment:	$MxT1 := 21820\cdot kN\cdot m$	$MxT1 = 16094\,kips\cdot ft$	$MxT2 := 5822\cdot kN\cdot m$	$MxT2 = 4294\,kips\cdot ft$
	$MyT1 := 18440\cdot kN\cdot m$	$MyT1 = 13601\,kips\cdot ft$	$MyT2 := 18440\cdot kN\cdot m$	$MyT2 = 13601\,kips\cdot ft$
	$MzT1 := 5834\cdot kN\cdot m$	$MzT1 = 4303\,kips\cdot ft$	$MzT2 := 3714\cdot kN\cdot m$	$MzT2 = 2739\,kips\cdot ft$
Maximum Wind Load at Base (0m):				
	$MxB1 := 133961\cdot kN\cdot m$	$MxB1 = 98807\,kips\cdot ft$	$MxB2 := 54370\cdot kN\cdot m$	$MxB2 = 40102\,kips\cdot ft$
	$MyB1 := 41916\cdot kN\cdot m$	$MyB1 = 30916\,kips\cdot ft$	$MyB2 := 135000\cdot kN\cdot m$	$MyB2 = 99573\,kips\cdot ft$
	$MzB1 := 5603\cdot kN\cdot m$	$MzB1 = 4133\,kips\cdot ft$	$MzB2 := 3966\cdot kN\cdot m$	$MzB2 = 2925\,kips\cdot ft$
Fatigue Thrust Range:	$\Delta FxT := 197\cdot kN$	$\Delta FxT = 44\,kips$	$\Delta MzT := 3483\cdot kN\cdot m$	$\Delta MzT = 2569\,kips\cdot ft$
Fatigue Applied Moment Range:	$\Delta MxT := 722\cdot kN\cdot m$	$\Delta MxT = 533\,kips\cdot ft$	$\Delta MyT := 3616\cdot kN\cdot m$	$\Delta MyT = 2667\,kips\cdot ft$
	$\Delta MxB := 14151\cdot kN\cdot m$	$\Delta MxB = 10437\,kips\cdot ft$	$\Delta MyB := 29894\cdot kN\cdot m$	$\Delta MyB = 22049\,kips\cdot ft$
Turbine offset in Vertical Direction:	$offset := 0\cdot m$	$offset = 0\,ft$		

Turbine Wind Load on Tower:

Moment (Linear Interpolation):

$$Mxwt1(z) := \frac{MxT1 - MxB1}{h} \cdot z + MxB1 \qquad Mxwt2(z) := \frac{MxT2 - MxB2}{h} \cdot z + MxB2$$

$$Mywt1(z) := \frac{MyT1 - MyB1}{h} \cdot z + MyB1 \qquad Mywt2(z) := \frac{MyT2 - MyB2}{h} \cdot z + MyB2$$

$$Mwt1(z) := \sqrt{Mxwt1(z)^2 + Mywt1(z)^2} \qquad Mwt2(z) := \sqrt{Mxwt2(z)^2 + Mywt2(z)^2}$$

$$Mzwt1(z) := \frac{MzT1 - MzB1}{h} \cdot z + MzB1 \qquad Mzwt2(z) := \frac{MzT2 - MzB2}{h} \cdot z + MzB2$$

$$\Delta Mxwt(z) := \frac{\Delta MxT - \Delta MxB}{h} \cdot z + \Delta MxB \qquad \Delta Mywt(z) := \frac{\Delta MyT - \Delta MyB}{h} \cdot z + \Delta MyB$$

$$\Delta Mwt(z) := \max(\Delta Mxwt(z), \Delta Mywt(z))$$

Moment (Thrust from Wind Turbine):

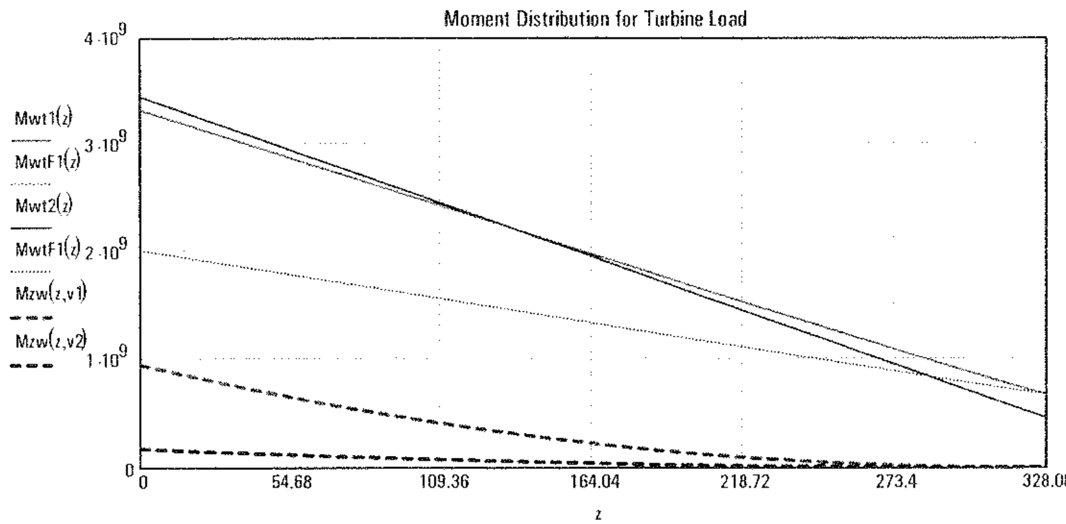
$$MxwtF1(z) := MxT1 + FyT1 \cdot (h + offset - z) \qquad MxwtF2(z) := MxT2 + FyT2 \cdot (h + offset - z)$$

$$MywtF1(z) := MyT1 + FxT1 \cdot (h + offset - z) \qquad MywtF2(z) := MyT2 + FxT2 \cdot (h + offset - z)$$

$$MwtF1(z) := \sqrt{MxwtF1(z)^2 + MywtF1(z)^2} \qquad MwtF2(z) := \sqrt{MxwtF2(z)^2 + MywtF2(z)^2}$$

$$\Delta MxwtF(z) := \Delta MxT \qquad \Delta MywtF(z) := \Delta MyT + \Delta FxT \cdot (h + offset - z)$$

$$\Delta MwtF(z) := \Delta MywtF(z)$$



$$\frac{MwtF1(z0)}{Mwt1(z0)} = 0.607 \qquad \frac{MwtF2(z0)}{Mwt2(z0)} = 0.863 \qquad \frac{\Delta MwtF(z0)}{\Delta Mwt(z0)} = 0.78$$

Wind Load Combination:

Load Factor for Ultimate Load:

$\gamma DL := 1.2$ *Dead Load*

$\gamma WL := 1.6$ *Wind Load*

$\gamma SF := 1.35$ Partial Safety Factor (Wind Energy Hand Book p213):

Ultimate Load (ASCE7-98 Load Combination)

$PuT := (FzT1 - HeadWeight)\cdot\gamma SF + \gamma DL\cdot HeadWeight$

$PuD(xz) := \gamma DL\cdot(Wz(xz) + if(xz < hc, Wcc, 0\cdot kips))$

$VuT := \sqrt{FxT1^2 + FyT1^2}\cdot\gamma SF$

$VuD(xz) := \gamma WL\cdot Vzw(xz, v1)$

$MuTx(xz) := \gamma SF\cdot Mxwt1(xz)$

$MuTy(xz) := \gamma SF\cdot Mywt1(xz)$

$MuT(xz) := \sqrt{MuTx(xz)^2 + MuTy(xz)^2}$

$MuD(xz) := \gamma WL\cdot Mzw(xz, v1)$

$Pu(xz) := PuT + PuD(xz)$

$Vu(xz) := \sqrt{(FxT1\cdot\gamma SF + VuD(xz))^2 + (FyT1\cdot\gamma SF)^2}$

$Mu(xz) := \sqrt{(MuTy(xz) + MuD(xz))^2 + MuTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PuT = 6041 kN	PuD(xz) = 29425 kN	Pu(xz) = 35466 kN
VuT = 781 kN	VuD(xz) = 1320 kN	Vu(xz) = 1750 kN
MuT(xz) = 189494 kN·m	MuD(xz) = 64567 kN·m	Mu(xz) = 217679 kN·m
Pu(xz) = 7973 kips	PuD(xz) = 6615 kips	Pu(xz) = 7973 kips
VuT = 176 kips	VuD(xz) = 297 kips	Vu(xz) = 393 kips
MuT(xz) = 139766 ft kips	MuD(xz) = 47623 ft kips	Mu(xz) = 160555 ft kips

$xz := hc$

at base of steel tower

PuT = 6041 kN	PuD(xz) = 10706 kN	Pu(xz) = 16747 kN
VuT = 781 kN	VuD(xz) = 648 kN	Vu(xz) = 1174 kN
MuT(xz) = 114295 kN·m	MuD(xz) = 15871 kN·m	Mu(xz) = 120907 kN·m
Pu(xz) = 3765 kips	PuD(xz) = 2407 kips	Pu(xz) = 3765 kips
VuT = 176 kips	VuD(xz) = 146 kips	Vu(xz) = 264 kips
MuT(xz) = 84302 ft kips	MuD(xz) = 11706 ft kips	Mu(xz) = 89178 ft kips

Service Load (Unfactored Wind Load)

$v1 = 47.29\frac{m}{sec}$

$PsT := FzT1$

$PsD(xz) := Wz(xz) + if(xz < hc, Wcc, 0\cdot kips)$

$VsT := \sqrt{FxT1^2 + FyT1^2}$

$VsD(xz) := Vzw(xz, v1)$

$MsTx(xz) := Mxwt1(xz)$

$MsTy(xz) := Mywt1(xz)$

$MsT(xz) := \sqrt{MsTx(xz)^2 + MsTy(xz)^2}$

$MsD(xz) := Mzw(xz, v1)$

$Ps(xz) := PsT + PsD(xz)$

$Vs(xz) := \sqrt{(FxT1 + VsD(xz))^2 + (FyT1)^2}$

$Ms(xz) := \sqrt{(MsTy(xz) + MsD(xz))^2 + MsTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PsT = 4998 kN	PsD(xz) = 24521 kN	Ps(xz) = 29519 kN
VsT = 578 kN	VsD(xz) = 825 kN	Vs(xz) = 1159 kN
MsT(xz) = 140366 kN·m	MsD(xz) = 40354 kN·m	Ms(xz) = 157207 kN·m

$Ps(xz) = 6636\,kips$ $\quad$ $PsD(xz) = 5513\,kips$ $\quad$ $Ps(xz) = 6636\,kips$

$VsT = 130\,kips$ $\quad$ $VsD(xz) = 185\,kips$ $\quad$ $Vs(xz) = 261\,kips$

$MsT(xz) = 103531\,ft\,kips$ $\quad$ $MsD(xz) = 29764\,ft\,kips$ $\quad$ $Ms(xz) = 115952\,ft\,kips$

$xz := hc$

at base of steel tower

$PsT = 4998\,kN$ $\quad$ $PsD(xz) = 8922\,kN$ $\quad$ $Ps(xz) = 13920\,kN$

$VsT = 578\,kN$ $\quad$ $VsD(xz) = 405\,kN$ $\quad$ $Vs(xz) = 812\,kN$

$MsT(xz) = 84663\,kN\cdot m$ $\quad$ $MsD(xz) = 9919\,kN\cdot m$ $\quad$ $Ms(xz) = 88710\,kN\cdot m$

$Ps(xz) = 3129\,kips$ $\quad$ $PsD(xz) = 2006\,kips$ $\quad$ $Ps(xz) = 3129\,kips$

$VsT = 130\,kips$ $\quad$ $VsD(xz) = 91\,kips$ $\quad$ $Vs(xz) = 183\,kips$

$MsT(xz) = 62446\,ft\,kips$ $\quad$ $MsD(xz) = 7316\,ft\,kips$ $\quad$ $Ms(xz) = 65431\,ft\,kips$

Operation Load at 35m/sec

$PoT := FzT2$

$v2 = 22.109\frac{m}{sec}$

$PoD(xz) := Wz(xz) + if(xz < hc, Wcc, 0\cdot kips)$

$VoT := \sqrt{FxT2^2 + FyT2^2}$

$VoD(xz) := Vzw(xz, v2)$

$MoTx(xz) := Mxwt2(xz)$

$MoTy(xz) := Mywt2(xz)$

$MoT(xz) := \sqrt{MoTx(xz)^2 + MoTy(xz)^2}$

$MoD(xz) := Mzw(xz, v2)$

$Po(xz) := PoT + PoD(xz)$

$Vo(xz) := \sqrt{(FxT2 + VoD(xz))^2 + (FyT2)^2}$

$Mo(xz) := \sqrt{(MoTy(xz) + MoD(xz))^2 + MoTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

$PoT = 4879\,kN$ $\quad$ $PoD(xz) = 24521\,kN$ $\quad$ $Po(xz) = 29400\,kN$

$VoT = 1065\,kN$ $\quad$ $VoD(xz) = 151\,kN$ $\quad$ $Vo(xz) = 1215\,kN$

$MoT(xz) = 145537\,kN\cdot m$ $\quad$ $MoD(xz) = 7425\,kN\cdot m$ $\quad$ $Mo(xz) = 152450\,kN\cdot m$

$Po(xz) = 6609\,kips$ $\quad$ $PoD(xz) = 5513\,kips$ $\quad$ $Po(xz) = 6609\,kips$

$VoT = 239\,kips$ $\quad$ $VoD(xz) = 34\,kips$ $\quad$ $Vo(xz) = 273\,kips$

$MoT(xz) = 107345\,ft\,kips$ $\quad$ $MoD(xz) = 5476\,ft\,kips$ $\quad$ $Mo(xz) = 112444\,ft\,kips$

$xz := hc$

at base of steel tower

$PoT = 4879\,kN$ $\quad$ $PoD(xz) = 8922\,kN$ $\quad$ $Po(xz) = 13801\,kN$

$VoT = 1065\,kN$ $\quad$ $VoD(xz) = 75\,kN$ $\quad$ $Vo(xz) = 1139\,kN$

$MoT(xz) = 83674\,kN\cdot m$ $\quad$ $MoD(xz) = 1831\,kN\cdot m$ $\quad$ $Mo(xz) = 85381\,kN\cdot m$

$Po(xz) = 3103\,kips$ $\quad$ $PoD(xz) = 2006\,kips$ $\quad$ $Po(xz) = 3103\,kips$

$VoT = 239\,kips$ $\quad$ $VoD(xz) = 17\,kips$ $\quad$ $Vo(xz) = 256\,kips$

$MoT(xz) = 61716\,ft\,kips$ $\quad$ $MoD(xz) = 1350\,ft\,kips$ $\quad$ $Mo(xz) = 62975\,ft\,kips$

Fatigue Load - Damage Equivalent Load

Fatigue Safety Factor: $\gamma f := 1$

$Pf(xz) := Wz(xz) + HeadWeight + if(xz < hc, Wcc, 0\cdot kips)$

$Vf(xz) := \Delta FxT\cdot\gamma f$

$Mf(xz) := \Delta Mwt(xz)\cdot\gamma f$

$xz := 0\cdot m$

at base of concrete tower

$Pf(xz) = 29229\,kN$ $\quad$ $Pf(xz) = 6571\,kips$

$Vf(xz) = 197\,kN$ $\quad$ $Vf(xz) = 44\,kips$

$Mf(xz) = 29894\,kN\cdot m$ $\quad$ $Mf(xz) = 22049\,ft\,kips$

$xz := hc$

at base of steel tower

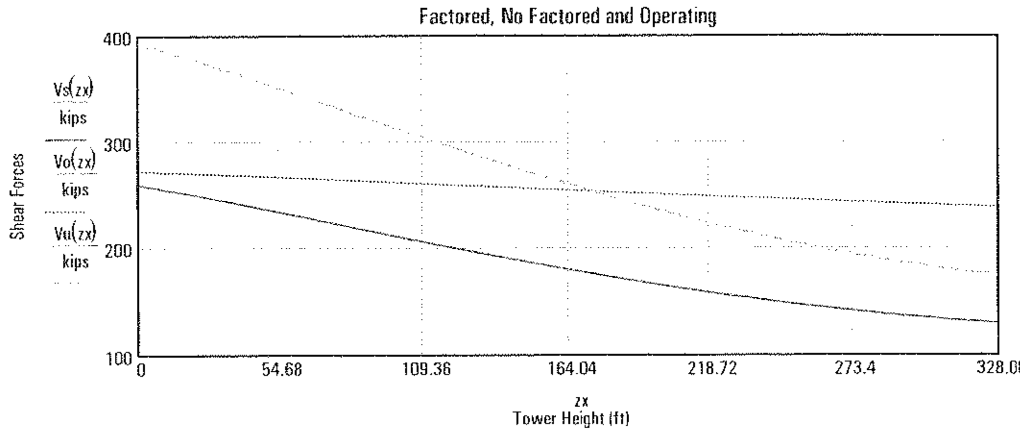
$Pf(xz) = 13630\,kN$ $\quad$ $Pf(xz) = 3064\,kips$

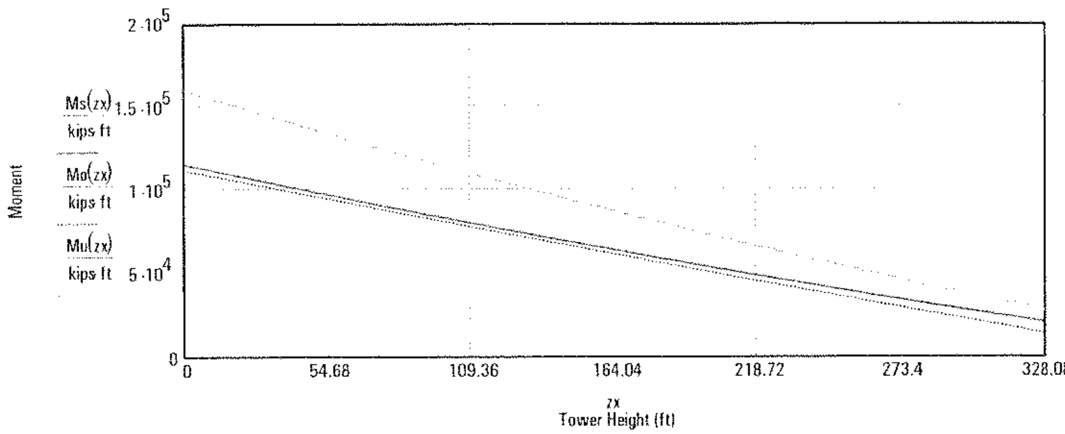
$Vf(xz) = 197\,kN$ $\quad$ $Vf(xz) = 44\,kips$

$Mf(xz) = 17018\,kN\cdot m$ $\quad$ $Mf(xz) = 12552\,ft\,kips$

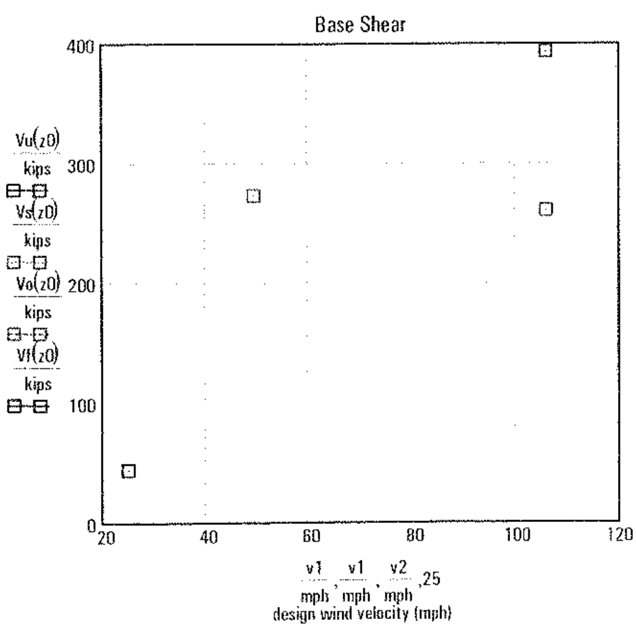
Ratio of Ultimate Load for Seismic/Wind

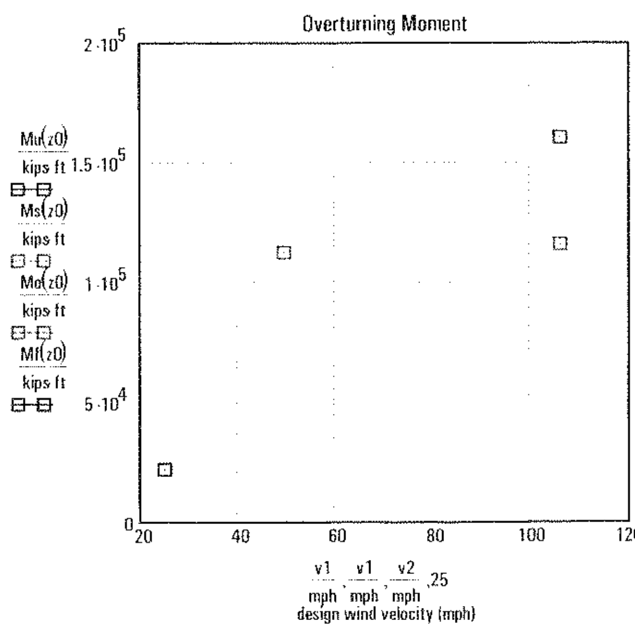
$$\frac{Vzq(z0)}{Vu(z0)} = 4.643 \qquad \frac{Mzq(z0)}{Mu(z0)} = 2.432$$





Design Wind Load Comparison Diagram





Deflection for Wind Load at Top of Tower

Wind Speed for 59.5m/sec (133mph)

$$\Delta ws(z) := \int_0^z \frac{Ms(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vs(z0)}{Kh} + \frac{Ms(z0)}{Kr}\cdot z$$

$WDisT := \Delta ws(h)$ $\quad WDisT = 0.415\,m$ $\quad WDisT = 1.361\,ft$ $\quad \frac{h}{WDisT} = 241$

$WDisM := \Delta ws(hc)$ $\quad WDisM = 0.103\,m$ $\quad WDisM = 0.34\,ft$ $\quad \frac{hc}{WDisM} = 473$

$$\Delta wo(z) := \int_0^z \frac{Mo(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vo(z0)}{Kh} + \frac{Mo(z0)}{Kr}\cdot z$$

$\Delta wo(h) = 1.3\,ft$ $\quad \Delta wo(h) = 0.396\,m$

Moment Magnification Factor

at Base: $\delta swb := \dfrac{1}{1-\dfrac{Pu(z0)}{Pcr(z0)}}$ $\quad \delta swb = 1.081$

at Height of hc: $\delta swt := \dfrac{1}{1-\dfrac{Pu(hc)}{Pcr(z0)}}$ $\quad \delta swt = 1.037$

P-Δ Effect

Moment of Tower due to Gravity Load for P-Δ effect :

$$Mwg(z) := (WDisT - \Delta ws(z))\cdot HeadWeight + \int_z^h wt(y)\cdot(\Delta ws(y) - \Delta ws(z))\,dy + Wcc\cdot if[z < hc, (WDisM - \Delta ws(z)), 0\cdot m]$$

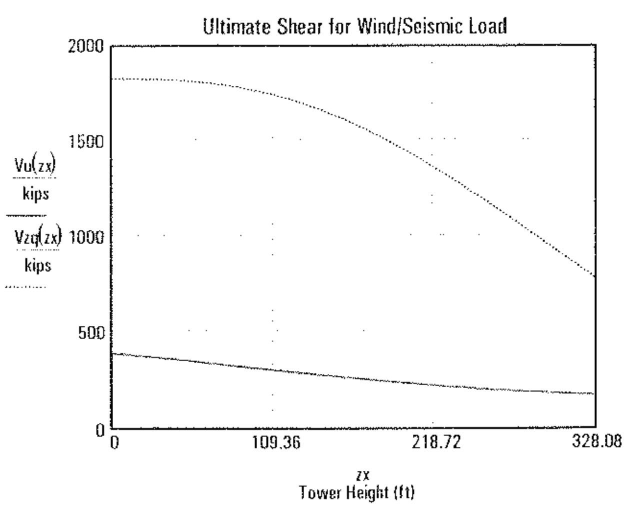
Approx. Method of Moment at Base for P-Δ effect :

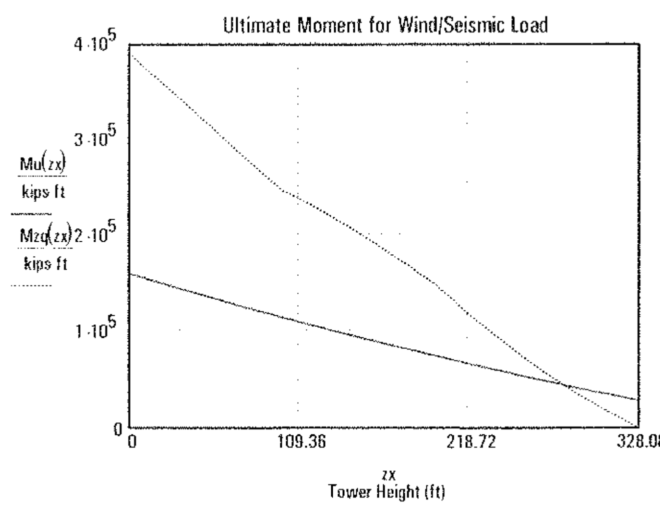
$$Mwgb := \Delta ws(h)\cdot HeadWeight + Wcc\cdot\Delta ws(hc) + Wz(hc)\cdot\Delta ws\left(\frac{h+hc}{2}\right) + (Wz(z0) - Wz(hc))\cdot\Delta ws\left(\frac{hc}{2}\right)$$

$$Mwgt := (\Delta ws(h) - \Delta ws(hc))\cdot HeadWeight + Wz(hc)\cdot\Delta ws\left(\frac{h+hc}{2}\right)$$

$\delta wb := \dfrac{Mwgb}{Ms(z0)} + 1$ $\quad \delta wb = 1.029$ $\quad \delta wt := \dfrac{Mwgt}{Ms(hc)} + 1$ $\quad \delta wt = 1.039$

Ultimate Design Forces for Wind/Earthquake Load





Governing Loading Case Conclusion:

BASE SHEAR: if(Vu(z0) > Vzq(z0), "Wind Load Control", "Earthquake Load Control") = "Earthquake Load Control"

OVERTURNING MOMENT: if(Mu(z0) > Mzq(z0), "Wind Load Control", "Earthquake Load Control") = "Earthquake Load Control"

Post-Tension Concrete Circular Section Design (PT-CCSD)

Section Geometric Data: $z := z0$ Section at Base

Outside Radius: $R1 := \frac{d(z)}{2}$ $R1 = 3.81\,m$ $R1 = 150\,in$

Inside Radius: $R2 := \frac{d(z)}{2} - t(z)$ $R2 = 3.048\,m$ $R2 = 120\,in$

Tendon Cordinates:

Number of Tendon: $NT1 := 56$ $NT2 := 56$ $NT := NT1 + NT2$

Clear Distance: $Cr1 := 15\cdot in$ $Cr2 := 15\cdot in$

$Cr1 = 0.381\,m$ $Cr2 = 0.381\,m$

Tendom Area: $i := 1..NT$ $i1 := 1..NT1$ $i2 := NT1 + 1..NT$

Area of Tendon (16.8cm2) $At_i := 1.302\cdot in^2$ 12-5/8 Dia. Low-Relaxation (7 wire strand)

Tendom Distribution: $tx_{i1} := (R1 - Cr1)\cdot \sin\left(\frac{2\cdot\pi}{NT1}\cdot i1\right)$ $ty_{i1} := (R1 - Cr1)\cdot \cos\left(\frac{2\cdot\pi}{NT1}\cdot i1\right)$

$tx_{i2} := (R2 + Cr2)\cdot \sin\left(\frac{2\cdot\pi}{NT2}\cdot i2\right)$ $ty_{i2} := (R2 + Cr2)\cdot \cos\left(\frac{2\cdot\pi}{NT2}\cdot i2\right)$

Section Geometric Properties: $f1(x) := \sqrt{R1^2 - x^2}$ $g1(x) := -\left(\sqrt{R1^2 - x^2}\right)$

Section Circular Function: $f2(x) := \sqrt{R2^2 - x^2}$ $g2(x) := -\left(\sqrt{R2^2 - x^2}\right)$

Section Layout and Properties:

$$Area1 := \int_{-R1}^{R1} (f1(x) - g1(x))\,dx$$

$$Area2 := \int_{-R2}^{R2} (f2(x) - g2(x))\,dx$$

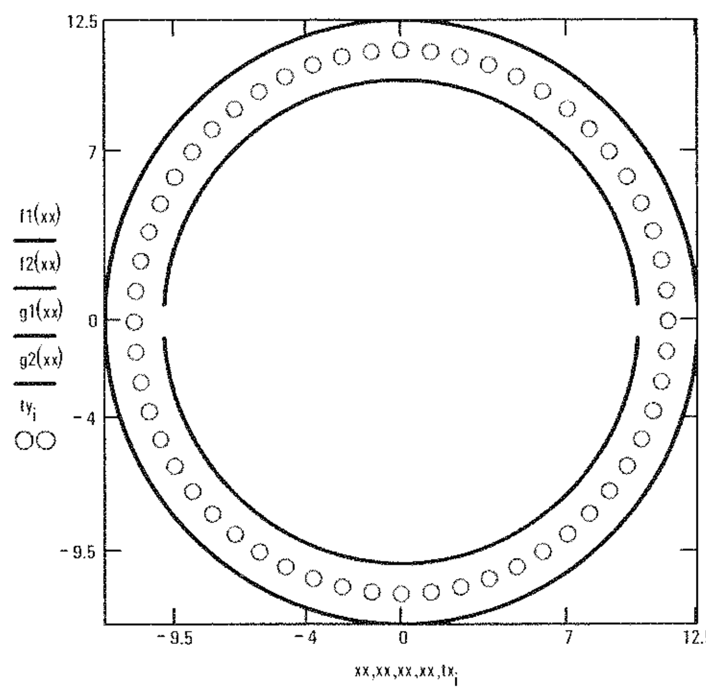
$$Area := Area1 - Area2$$

$$J := \frac{\pi}{2}\cdot\left(R1^4 - R2^4\right)$$

$$rxx := \sqrt{\frac{I(z)}{Ac(z)}}$$

$rxx = 2.44\,m$ $rxx = 96\,in$

$Eps_i := Es$



Steel Tendon Ratio:

$$\rho t := \frac{\sum_{i=1}^{NT} At_i}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$$

$\rho t = 0.00576$

Post-Tension Tendon Properties:

Tendon Ultimate Strength:	$fsu = 1862MPa$	$fsu = 270ksi$	Low-Relaxation (7 wire strand)
Effective strand stress after loss:	$fse0 = 1103MPa$	$fse0 = 160ksi$	$fse_i := fse0$
Strand strain (stress-strain curve):	$eps := 0.0086$		
Stress loss:	$0.75 \cdot fsu - fse0 = 293MPa$	$0.75 \cdot fsu - fse0 = 42.5ksi$	
Ultimate concrete strain:	$ecu := 0.003$		

Nominal Strength of Tendon For unbonded strain (assume 50% ratio for flexure):

$$fps := fse0 + 10 \cdot ksi + \frac{fc}{100 \cdot \rho t \cdot 0.5} \qquad fps = 1340MPa \qquad fps = 194ksi$$

Nominal stress of strand:
From strand stress-strain relation curve

$$fps(e) := \begin{cases} Es \cdot e & \text{if } e < eps \\ 270 \cdot ksi - \dfrac{0.04 \cdot ksi}{e - 0.007} & \text{otherwise} \end{cases}$$

Section Property Calculating as function of depth (a):

$$xx1(a) := if\left(R1 < |a|, 0 \cdot in, \sqrt{R1^2 - a^2}\right) \qquad xx2(a) := if\left(R2 < |a|, 0 \cdot in, \sqrt{R2^2 - a^2}\right)$$

$$Areay11(a) := \int_{-xx1(a)}^{xx1(a)} (f1(x) - a)\,dx \qquad Areay1(a) := \begin{cases} (Areay11(|a|)) & \text{if } a \ge 0in \\ (Area1 - Areay11(|a|)) & \text{otherwise} \end{cases}$$

$$Areay22(a) := \int_{-xx2(a)}^{xx2(a)} (f2(x) - a)\,dx \qquad Areay2(a) := \begin{cases} (Areay22(|a|)) & \text{if } a \ge 0 \cdot in \\ (Area2 - Areay22(|a|)) & \text{otherwise} \end{cases}$$

Area at Depth of a: $Areay(a) := Areay1(a) - Areay2(a)$

$$SAy1(a) := \int_{-xx1(a)}^{xx1(a)} \int_{a}^{f1(x)} y\,dy\,dx \qquad SAy2(a) := \int_{-xx2(a)}^{xx2(a)} \int_{a}^{f2(x)} y\,dy\,dx$$

Neutral Axis at Depth of a: $YN(a) := \dfrac{SAy1(a) - SAy2(a)}{Areay(a)}$ $\qquad YN(z) = 2.19m \qquad YN(z) = 86in$

Tendon and Concrete Stress for Prestressed Tendon:

Tendon Force and Strain:

$$Pe := \sum_{i=1}^{NT} fse_i \cdot At_i \qquad Pe = 103782.9kN \qquad Pe = 23331.8kips$$

$$epe := \frac{Pe}{\sum_{i=1}^{NT} At_i \cdot Eps_i} \qquad epe = 0.00561$$

Concrete Strain by Tendon Forces:

$$ece := \frac{Pe}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right] Ec} \qquad ece = 0.0001818$$

Elastic Shorten Loss after Direct Transfer:

$$\frac{0.75\cdot fsu\cdot\left(\sum_{i=1}^{NT} At_i\right)\cdot Es}{\left[Area-\left(\sum_{i=1}^{NT} At_i\right)\right]\cdot Ec} = 45.2\,MPa \qquad \frac{0.75\cdot fsu\cdot\left(\sum_{i=1}^{NT} At_i\right)\cdot Es}{\left[Area-\left(\sum_{i=1}^{NT} At_i\right)\right]\cdot Ec} = 6.56\,ksi$$

Beta Factor for Concrete Compression Depth:

$$\beta 1 := 0.85 - 0.05\cdot\left(\frac{fc}{ksi}-4\right) \qquad \beta 1 = 0.7$$

Total Concrete Deformation after Prestressed: $depy := eps - epe - ece$ $\quad depy = 0.002804$

Calculating Pn~Mn interaction diagram

Strain Compabability Relation: $dy := \max(ty) + R1$ $\quad cby := \dfrac{dy\cdot\dfrac{ecu}{depy}}{\left(1+\dfrac{ecu}{depy}\right)}$

Cb at for fps (balance point): $cb := cby$ $\quad cby = 3.742\,m$ $\quad cby = 147.3\,in$

Concrete Compression Depth: $a := R1 - cby\cdot\beta 1$ $\quad a = 1.191\,m$ $\quad a = 46.884\,in$

Concrete Compression Forces: $Cn(cb) := 0.85\cdot fc\cdot Areay(R1 - \beta 1\cdot cb)$ $\quad Cn(cb) = 260685\,kN$

Tendon Forces in Tention:

$$Tsn(cb) := \left|\begin{array}{l} s \leftarrow 0 \\ \text{for } i \in 1..NT \\ \quad \left|\begin{array}{l} eey_i \leftarrow ece + epe + ecu\cdot\left(\dfrac{R1 - ty_i}{cb} - 1\right) \\ s \leftarrow s + fps(eey_i)\cdot At_i \end{array}\right. \\ s \end{array}\right.$$

$Cn(cb) = 58606\,kips$

$Tsn(cb) = 108156.1\,kN$

$Tsn(cb) = 24315\,kips$

Pn~Mn Interaction Relation: $Pn(cb) := Cn(cb) - Tsn(cb)$

$Pn(cb) = 152529\,kN$ $\quad Pn(cb) = 34291\,kips$

$$Mn(cb) := \left|\begin{array}{l} s \leftarrow 0 \\ \text{for } i \in 1..NT \\ \quad \left|\begin{array}{l} eey_i \leftarrow ece + epe + ecu\cdot\left(\dfrac{R1 - ty_i}{cb} - 1\right) \\ s \leftarrow s - fps(eey_i)\cdot At_i\cdot ty_i \end{array}\right. \\ s \leftarrow s + Cn(cb)\cdot YN(R1 - \beta 1\cdot cb) \end{array}\right.$$

$$\frac{Mn(cb)}{Pn(cb)} = 201.198\,in$$

$Mn(cb) = 779486\,kN\cdot m$ $\quad Mn(cb) = 574932\,kips\cdot ft$

Pure Compression Condition: $Pn0 := 0.85\cdot fc\cdot Area - \sum_{i=1}^{NT} fse_i\cdot At_i$ $\quad Pn0 = 569704\,kN$ $\quad Pn0 = 128077\,kips$

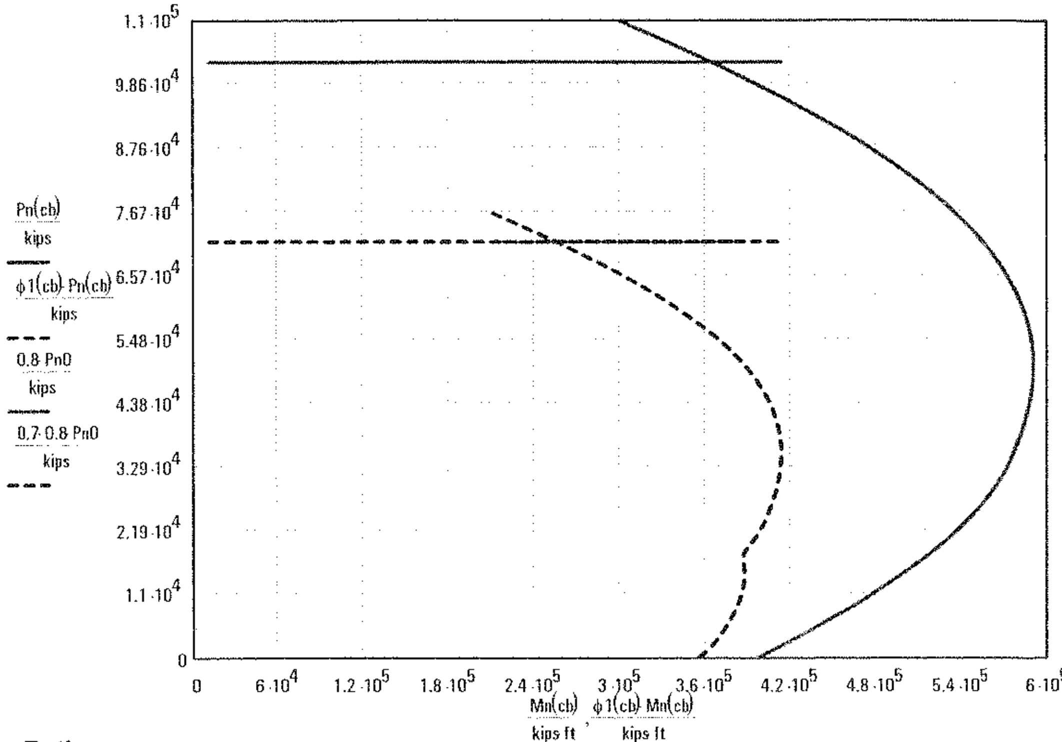
Strength Reduction Factor:

$$\phi(cb) := \frac{0.9\cdot 0.1\cdot fc\cdot Area}{0.1\cdot fc\cdot Area + 0.2\cdot \text{if}(Pn(cb) > 0\cdot kips, Pn(cb), 0\cdot kips)}$$

$$\phi 1(cb) := \left|\begin{array}{l} 0.7 \text{ if } \phi(cb) < 0.7 \\ (\phi(cb)) \text{ otherwise} \end{array}\right.$$

$cb := 5\cdot in, 10\cdot in..380\cdot in$

Pn~Mn Interaction Diagram:



Demand and Capacity Ratio:

DCR for Wind

$cb := 82.5 \cdot in$ $\qquad \frac{Pu(z)}{\phi 1(cb) \cdot Pn(cb)} = 1.001$ $\qquad DCRw := \frac{Mu(z)}{\phi 1(cb) \cdot Mn(cb)}$ $\qquad DCRw = 0.423$

$Pn(cb) = 43734 kN$ $\qquad Mn(cb) = 635522 kN \cdot m$ $\qquad \phi 1(cb) \cdot Pn(cb) = 35447 kN$ $\qquad \phi 1(cb) \cdot Mn(cb) = 515107 kN \cdot m$

$Pn(cb) = 9832 kips$ $\qquad Mn(cb) = 468747 kips \cdot ft$ $\qquad \phi 1(cb) \cdot Pn(cb) = 7969 kips$ $\qquad \phi 1(cb) \cdot Mn(cb) = 379931 kips \cdot ft$

DCR for Seismic

$cb := 82.2 \cdot in$ $\qquad \frac{\gamma DL \cdot W}{\phi 1(cb) \cdot Pn(cb)} = 1.001$ $\qquad DCRq := \frac{Mzq(z)}{\phi 1(cb) \cdot Mn(cb)}$ $\qquad DCRq = 1.028$

$Pn(cb) = 43160 kN$ $\qquad Mn(cb) = 634363 kN \cdot m$ $\qquad \phi 1(cb) \cdot Pn(cb) = 35028 kN$ $\qquad \phi 1(cb) \cdot Mn(cb) = 514839 kN \cdot m$

$Pn(cb) = 9703 kips$ $\qquad Mn(cb) = 467892 kips \cdot ft$ $\qquad \phi 1(cb) \cdot Pn(cb) = 7875 kips$ $\qquad \phi 1(cb) \cdot Mn(cb) = 379734 kips \cdot ft$

Modified DCR Ratio:

$DCRw := DCRw \cdot \delta swb \cdot \delta wb$ $\qquad DCRw = 0.47$

$DCRq := DCRq \cdot \delta sqb \cdot \delta qb$ $\qquad DCRq = 1.14$

Calculate Tendon Stresses

$$eey_i := ece + epe + ecu \cdot \left(\frac{R1 - ty_i}{cb} - 1 \right)$$

Maximum Tendon Stress:

$$Te_i := \left| \begin{array}{l} \left[eey_i \leftarrow ece + epe + ecu \cdot \left(\frac{R1 - ty_i}{cb} - 1 \right) \right] \\ fps(eey_i) \end{array} \right.$$

$max(Te) = 1817 MPa$

$max(Te) = 264 ksi$

Post-Tension Concrete Section for Service Load (Ref. to ACI 318, Chapter 18)

Concrete Yield stress:	$0.45fc = 21.7\,MPa$	$0.45fc = 3.15\,ksi$
Concrete Ultimate stress:	$0.6fc = 29MPa$	$0.6\cdot fc = 4.2\,ksi$
Concrete Cracking stress:	$\frac{6}{1000}\cdot\sqrt{\frac{fc\cdot 1000}{ksi}}\cdot ksi = 3.46\,MPa$	$\frac{6}{1000}\cdot\sqrt{\frac{fc\cdot 1000}{ksi}}\cdot ksi = 0.502\,ksi$
Stiffness Ratio:	$n := \frac{Es}{Ec}$	$n = 5.619$
Section Moment of Inertia:	$Ix := I(z) + (n-1)\cdot\sum_{i=1}^{NT} At_i\cdot(ty_i)^2$	$\frac{Ix}{I(z)} = 1.026$

Stress under Service Load Condition:

Tendon Stress: $fs_i := \frac{Ms(z)\cdot ty_i}{Ix}n + fse_i$

$fsmax := max(fs)$ $fsmax = 1133.4\,MPa$ $fsmax = 164.4\,ksi$

$fsmin := min(fs)$ $fsmin = 1073MPa$ $fsmin = 155.6\,ksi$

Concrete Stress: $fcc := \frac{Ms(z)}{S(z)}$ $fcc = 6.13\,MPa$ $fcc = 0.889ksi$ Bending Stress

$$fg := \frac{Ps(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$$

$fg = 1.81\,MPa$ $fg = 0.262ksi$ Axial Stress

$fcmax := ece\cdot Ec + fcc + fg$ $fcmax = 14.3\,MPa$ $fcmax = 2.074ksi$ Max Stress in Compression

$fcmin := ece\cdot Ec - fcc + fg$ $fcmin = 2.036MPa$ $fcmin = 0.295ksi$ Max Stress in Tension:

$ecmax := \frac{fcmax}{Ec}$ $ecmax = 0.00041$ Max Strain in Compression:

Concrete Shear Strength:

$$\tau c(z) := 2\cdot\left(1 + \frac{Pu(z)}{2000\cdot psi\cdot Ac(z)}\right)\sqrt{\frac{fc\cdot 1000}{ksi}}\,psi$$

Shear Strength:

$\tau c(z) = 1.33\,MPa$ $\tau c(z) = 0.194ksi$

Torsion Moment: $Ts := Mzwt1(z)$ $Ts = 5603kN\cdot m$ $Ts = 4133kips\cdot ft$

$$Qs := \frac{Area}{2}\cdot\left(\frac{4}{3\cdot\pi}\cdot\frac{R1^3 - R2^3}{R1^2 - R2^2}\right)$$

$\frac{Vs(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)} = 0.02\,ksi$

Shear Stress in Concrete $\tau cc := \frac{Ts\cdot R1}{J} + \frac{Vu(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)}$ $\tau cc = 0.321\,MPa$ $\tau cc = 0.047\,ksi$

DCR for Shear Strength (Wind): $DCRvw := \frac{\tau cc}{\tau c(z)}$ $DCRvw = 0.24$

DCR for Shear Strength (EQ): $DCRvq := \frac{Vzq(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)\cdot\tau c(z)}$ $DCRvq = 0.736$

Stress under Operating Load Condition:

Tendon Stress: $fo_i := \frac{Mo(z) \cdot ty_i}{Ix} \cdot n + fse_i$ $fomax := max(fo)$ $fomax = 1132.5\,MPa$ $fomax = 164.2\,ksi$

$fomin := min(fo)$ $fomin = 1073.9\,MPa$ $fomin = 155.8\,ksi$

Concrete Stress: $foc := \frac{Mo(z)}{S(z)}$ $foc = 5.945\,MPa$ $foc = 0.862\,ksi$ Bending Stress

$fog := \frac{Po(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $fog = 1.8\,MPa$ $fog = 0.261\,ksi$ Axial Stress

$focmax := ece \cdot Ec + foc + fog$ $focmax = 14.1\,MPa$ $focmax = 2.046\,ksi$ Max Stress in Compression

$focmin := ece \cdot Ec - foc + fog$ $focmin = 2.215\,MPa$ $focmin = 0.321\,ksi$ Max Stress in Tension:

Stress under Fatigue Load Condition:

$Ix = 100.264\,m^4$ $max(ty) = 3.429\,m$ $min(ty) = -3.429\,m$

Tendon Stress: $ff_i := \frac{Mf(z) \cdot ty_i}{Ix} \cdot n + fse_i$ $ffsmax := max(ff)$ $ffsmax = 1108.9\,MPa$ $ffsmax = 160.8\,ksi$

$ffsmin := min(ff)$ $ffsmin = 1097.4\,MPa$ $ffsmin = 159.2\,ksi$

Concrete Stress: $ffc := \frac{Mf(z)}{S(z)}$ $ffc = 1.166\,MPa$ $ffc = 0.169\,ksi$ Bending Stress

$ffg := \frac{Pf(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $ffg = 1.79\,MPa$ $ffg = 0.26\,ksi$ Axial Stress

$ece \cdot Ec + ffg = 8.149\,MPa$ $ece \cdot Ec + ffg = 1.182\,ksi$ $S(z) = 25.645\,m^3$

$ffcmax := ece \cdot Ec + ffc + ffg$ $ffcmax = 9.31\,MPa$ $ffcmax = 1.351\,ksi$ Max Stress in Compression

$ffcmin := ece \cdot Ec - ffc + ffg$ $ffcmin = 6.983\,MPa$ $ffcmin = 1.013\,ksi$ Max Stress in Tension:

Across Wind Load (ACI 307-98 Chimney Design- 4.2.3.1)

Only First Mode is Examined

Wind Speed at Cristical Height: $zcr := \frac{5}{6} \cdot h$

Hourly Mean Design Speed (ASCE-7): $Vw(zcr, v1) = 157\,mph$ $Vw(zcr, v2) = 73\,mph$

Hourly Mean Design Speed (ACI-307): $Vw(z, v) := 1.47 \cdot v \cdot \left(\frac{z}{33 \cdot ft}\right)^{0.154} \cdot 0.65$

$Vw(zcr, v1) = 140\,mph$ $Vw(zcr, v2) = 65\,mph$

Mean Outside Diameter: $du := d\left(\frac{2}{3} \cdot h\right)$ $du = 5\,m$ $du = 16.2\,ft$

Strouhal Number: $St := 0.25 \cdot \left(0.333 + 0.206 \cdot ln\left(\frac{h}{du}\right)\right)$ $St = 0.238$

Critical Speed at zcr: $Vcr := \frac{Fq \cdot du}{St}$ $Vcr = 7.989\frac{m}{sec}$ $Vcr = 17.872\,mph$

Conclusion: $DCRa(v) := \frac{Vcr}{Vw(zcr, v)}$ Across wind need not be considered if DCRa <0.5 or >1.3

$DCRa(v1) = 0.128$ $DCRa(v2) = 0.273$

Prestressed Concrete Fatigue Design (Model Code 90)

Operating frequency of 20RPM for 30 years: $nf := 5.29\cdot 10^8$

Concrete Strength: $fck := fc$ $\quad fck = 7\,ksi$

Concrete Reference Strength: $fck0 := 10\,MPa$ $\quad fck0 = 1.45\,ksi$

Concrete Material Factor: $\gamma c := 1.5$

Model Factor: $\gamma sd := 1.1$

$ffcmax := ffcmax$ $\quad ffcmax = 1.351\,ksi$

Age of Concrete at Begin Fatigue Loading: $Day := 60$

$ffcmin := ffcmin$ $\quad ffcmin = 1.013\,ksi$

Concrete High Strength Factor: $s := 0.2$

Advancing Hydratication Factor: $\beta cc := \exp\left(s\cdot\sqrt{1-\frac{28}{Day}}\right)$ $\quad \beta cc = 1.157$

Concrete Fatigue Stress:

$$fat := 0.85\cdot\beta cc\cdot fck\cdot\left(1-\frac{fck}{25\cdot fck0}\right)\frac{1}{\gamma c}$$

$fat = 25.54\,MPa$ $\quad fat = 3.704\,ksi$

Fatigue Parameter: $\alpha f := 0.5$ *Absolute stress ratio within 300mm;1 for constant compression*

$$\eta c := \frac{1}{1.5-0.5\cdot\alpha f}$$

1 for reinforcement and nearly constant amplitude; 0.5 for others

$\eta c := 1$

Concrete Fatigue Design Life:

Simplified Method for Checking:

$\gamma sd\cdot ffcmax\cdot\eta c = 1.486\,ksi$ $\quad 0.45\cdot fat = 1.667\,ksi$

Detail calculation required for concrete compression

Fatigue Stress Ratio:

$$Scdmin := \frac{ffcmin\cdot\gamma sd}{fat}\cdot\eta c \qquad Scdmin = 0.301$$

$$Scdmax := \frac{ffcmax\cdot\gamma sd}{fat}\cdot\eta c \qquad Scdmax = 0.401$$

$$\Delta Scd := Scdmax - Scdmin \qquad \Delta Scd = 0.1$$

Set M1 = logN1; M2 = logN2 and M3 = logN3

$$M1 := \left(12 + 16\cdot Scdmin + 8\cdot Scdmin^2\right)\cdot(1 - Scdmax) \qquad M1 = 10.5$$

$$M2 := 0.2\cdot M1\cdot(M1 - 1) \qquad M2 = 20$$

0 < Scdmin <0.8

$$M3 := \frac{M2}{\Delta Scd}\cdot\left(0.3 - \frac{3}{8}\cdot Scdmin\right) \qquad M3 = 37.2$$

$$0.3 - \frac{3}{8}\cdot Scdmin = 0.187$$

$$M := \begin{cases} M1 & \text{if } M1 \le 6 \\ M2 & \text{if } \left(M1 > 6 \wedge \Delta Scd \ge 0.3 - \frac{3}{8} \cdot Scdmin\right) \\ M3 & \text{if } \left(M1 > 6 \wedge \Delta Scd < 0.3 - \frac{3}{8} \cdot Scdmin\right) \end{cases}$$

Fatigue Design Life: $M = 37.204$ $N := 10^M$ $\frac{nf}{N} = 0$

Steel Tendon Fatigue Stress:

Area ratio of prestress tendon with reinforcement rebar: $Aps := 30$

Diameter ratio of prestress tendon with reinforcement rebar: $Dps := 5$

For smooth strands: $\zeta := 0.2$

$$\eta s := \frac{1 + Aps}{1 + Aps \cdot \sqrt{Dps \cdot \zeta}} \qquad \eta s = 1$$

$\gamma s := 1.15$

$\Delta\sigma Rsk := 95 \cdot MPa$ $\Delta\sigma Rsk = 13.779\,ksi$

$\Delta\sigma RskN := 160 \cdot MPa$ $\Delta\sigma RskN = 23.206\,ksi$

$k1 := 5$ $k2 := 9$

Max and Min tendon stress: $\Delta\sigma s := ffsmax - ffsmin$

$\Delta\sigma s = 1.666\,ksi$ $\Delta\sigma s = 11.489\,MPa$

$\gamma sd \cdot \Delta\sigma s = 1.833\,ksi$

$$\frac{\Delta\sigma Rsk}{\gamma s} = 11.981\,ksi$$

Concrete Spread Footing Design

Footing Area: $Af := B \cdot L$ $\quad Af = 417\,m^2 \quad Af = 4489\,ft^2$

Footing Weight: $Wft := Af \cdot D \cdot \rho c$ $\quad Wft = 35942\,kN \quad Wft = 8080\,kips$

Footing Section Modulus: $Sft := \frac{1}{6} \cdot B \cdot L^2$

Service Load for Wind:

soil pressure under wind load: $Pft := Ps(z0) + \rho c \cdot D \cdot Af$ $\quad Pft = 65460\,kN \quad Pft = 14716\,kips$

Eccentricity: $eft := \frac{Ms(z0)}{Pft}$ $\quad eft = 2.402\,m \quad eft = 7.879\,ft$

Soil Pressure: $pmax := \frac{Pft}{Af} + \frac{Ms(z0)}{Sft}$ $\quad pmax = 0.268\,MPa \quad pmax = 5591\,psf$

$pmin := \frac{Pft}{Af} - \frac{Ms(z0)}{Sft}$ $\quad pmin = 0.046\,MPa \quad pmin = 965\,psf$

$$ptmax := \begin{cases} pmax & \text{if } pmin > 0 \\ \dfrac{2 \cdot Pft}{3 \cdot B \cdot \left(\dfrac{L}{2} - eft\right)} & \text{otherwise} \end{cases}$$

$ptmax = 0.268\,MPa \quad ptmax = 5591\,psf$

DCR for Soil Pressure: $DCRsoilw := \frac{ptmax}{cso}$ $\quad DCRsoilw = 0.932 \quad \frac{eft}{L} = 0.118$

Depth of Footing for Shear Capacity:
(One way action):

$$p := \frac{pmax - pmin}{L} \cdot \left(\frac{L}{2} + \frac{d(z0)}{2} + D\right) + pmin$$

Shear Force due to Soil Pressure:

$$Vpft := \frac{p + pmax}{2} \cdot \left[\frac{L}{2} - \left(\frac{d(z0)}{2} + D\right)\right] \cdot B \cdot \gamma WL$$

$Vpft = 22663\,kN \quad Vpft = 5095\,kips$

Shear Capacity of Concrete Footing: $Vcft := 0.85 \cdot 2 \cdot \sqrt{\frac{fcft}{ksi} \cdot 1000} \cdot psi \cdot B \cdot D$ $\quad Vcft = 55370\,kN \quad Vcft = 12448\,kips$

DCR for Shear Capacity: $DCRvftw := \frac{Vpft}{Vcft}$ $\quad DCRvftw = 0.409$

Bending Moment at Face of Footing:

$$Mpft := \left[p \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B + \frac{pmax - p}{3} \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B\right] \cdot \gamma WL$$

$Mpft = 331833\,kN \cdot m \quad Mpft = 244753\,kips \cdot ft$

Bending Reinforcement Ratio Required:

$$\rho ft := \frac{0.85 \cdot fcft}{60\,ksi} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot Mpft}{0.85 \cdot fcft \cdot B \cdot D^2 \cdot 0.7}}\right)$$

$\rho ft = 0.00436$

$Asft := \max(\rho ft, 0.0018) \cdot B \cdot D$ $\quad Asft = 3258.5\,cm^2 \quad Asft = 505.1\,in^2$

The Reinforcement Weight: $2Asft \cdot L \cdot \rho s = 104457\,kgf \quad 2Asft \cdot L \cdot \rho s = 230\,kips$

Ultimate Load forEQ:

soil pressure under EQ load: $Pftq := Pu(z0) + \rho c \cdot D \cdot Af \cdot \gamma DL$ $Pftq = 78596\,kN$ $Pftq = 17669\,kips$

Eccentricity: $eftq := \frac{Mzq(z0)}{Pftq}$ $eftq = 6.734\,m$ $eftq = 22.094\,ft$

Soil Pressure: $pmaxq := \frac{Pftq}{Af} + \frac{Mzq(z0)}{Sft}$ $pmaxq = 0.561\,MPa$ $pmaxq = 11724\,psf$

$pminq := \frac{Pftq}{Af} - \frac{Mzq(z0)}{Sft}$ $pminq = -0.184\,MPa$ $pminq = -3852\,psf$

$$ptmaxq := \begin{cases} pmaxq & \text{if } pminq > 0 \\ \dfrac{2 \cdot Pftq}{3 \cdot B \cdot \left(\frac{L}{2} - eftq\right)} & \text{otherwise} \end{cases}$$

$ptmaxq = 0.738\,MPa$ $ptmaxq = 15415\,psf$

DCR for Soil Pressure: $DCRsoilq := \frac{ptmaxq}{cso \cdot \gamma soq}$ $DCRsoilq = 1.285$ $\frac{eftq}{L} = 0.33$

Govern Design: if(DCRsoilq > DCRsoilw, "Seismic Load Control" , "Wind Load Control") = "Seismic Load Control"

Depth of Footing for Shear Capacity:
(One way action):

$$pq := \frac{pmaxq - pminq}{L} \cdot \left(\frac{L}{2} + \frac{d(z0)}{2} + D\right) + pminq$$

Shear Force due to Soil Pressure:

$$Vpftq := \frac{pq + pmaxq}{2} \left[\frac{L}{2} - \left(\frac{d(z0)}{2} + D\right)\right] \cdot B$$

$Vpftq = 28641\,kN$ $Vpftq = 6439\,kips$

DCR for Shear Capacity: $DCRvftq := \frac{Vpftq}{Vcft}$ $DCRvftq = 0.517$

Bending Moment at Face of Footing:

$$Mpftq := pq \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B + \frac{pmaxq - pq}{3} \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B$$

$Mpftq = 413791\,kN \cdot m$ $Mpftq = 305203\,kips \cdot ft$

Bending Reinforcement Ratio Required:

$$\rho ftq := \frac{0.85 \cdot fcft}{60\,ksi} \left(1 - \sqrt{1 - \frac{2 \cdot Mpftq}{0.85 \cdot fcft \cdot B \cdot D^2 \cdot 0.7}}\right)$$

$\rho ftq = 0.0055$

$Asftq := \max(\rho ftq, 0.0018) \cdot B \cdot D$ $Asftq = 4106\,cm^2$ $Asftq = 636.4\,in^2$

The Reinforcement Weight: $2 Asftq \cdot L \cdot \rho s = 131627\,kgf$ $2 Asftq \cdot L \cdot \rho s = 290\,kips$

Results Summary:

Tower Information:

Total Structure Weight:	W = 29229 kN	W = 6571 kips
Concrete Tower Weight:	Wz(z0) = 24472 kN	Wz(z0) = 5502 kips
Number of Tendon:	NT1 = 56	NT2 := 34
Tendon Weight:	$8.88 \cdot \frac{lbf}{ft} \cdot [NT1 \cdot hc + NT2 \cdot (h - hc)] = 59175\,kgf$	$8.88 \cdot \frac{lbf}{ft} \cdot [NT1 \cdot hc + NT2 \cdot (h - hc)] = 130461\,lbf$
Natural Frequency:	Fq = 0.384 Hz	$\frac{1}{Fq} = 2.604\,sec$

Tower Forces for Earthquake Load:

Shear Force at Base:	Vzq(z0) = 8125 kN	Vzq(z0) = 1827 kips
Shear Force at hc:	Vzq(hc) = 7134 kN	Vzq(hc) = 1604 kips
Overturning Moment at Base:	Mzq(z0) = 529295 kN·m	Mzq(z0) = 390396 ft kips
Overturning Moment at hc:	Mzq(hc) = 256764 kN·m	Mzq(hc) = 189383 ft kips
Deflection at Top:	QDisT = 1.202 m	QDisT = 3.944 ft

Tower Forces for Wind Load:

Ultimate Wind Load:

xz := 0·m *at base of concrete tower*	Pu(xz) = 35466 kN Vu(xz) = 1750 kN Mu(xz) = 217679 kN·m	Pu(xz) = 7973 kips Vu(xz) = 393 kips Mu(xz) = 160555 ft kips
xz := hc *at base of steel tower*	Pu(xz) = 16747 kN Vu(xz) = 1174 kN Mu(xz) = 120907 kN·m	Pu(xz) = 3765 kips Vu(xz) = 264 kips Mu(xz) = 89178 ft kips

Service Wind Load:

xz := 0·m *at base of concrete tower*	Ps(xz) = 29519 kN Vs(xz) = 1159 kN Ms(xz) = 157207 kN·m	Ps(xz) = 6636 kips Vs(xz) = 261 kips Ms(xz) = 115952 ft kips
xz := hc *at base of steel tower*	Ps(xz) = 13920 kN Vs(xz) = 812 kN Ms(xz) = 88710 kN·m	Ps(xz) = 3129 kips Vs(xz) = 183 kips Ms(xz) = 65431 ft kips

Operating Wind Load:

xz := 0·m *at base of concrete tower*	Po(xz) = 29400 kN Vo(xz) = 1215 kN Mo(xz) = 152450 kN·m	Po(xz) = 6609 kips Vo(xz) = 273 kips Mo(xz) = 112444 ft kips
xz := hc *at base of steel tower*	Po(xz) = 13801 kN Vo(xz) = 1139 kN Mo(xz) = 85381 kN·m	Po(xz) = 3103 kips Vo(xz) = 256 kips Mo(xz) = 62975 ft kips

Fatigue Load:

xz := 0·m *at base of concrete tower*	Pf(xz) = 29229 kN Vf(xz) = 197 kN Mf(xz) = 29894 kN·m	Pf(xz) = 6571 kips Vf(xz) = 44 kips Mf(xz) = 22049 ft kips
xz := hc *at base of steel tower*	Pf(xz) = 13630 kN Vf(xz) = 197 kN Mf(xz) = 17018 kN·m	Pf(xz) = 3064 kips Vf(xz) = 44 kips Mf(xz) = 12552 ft kips
Deflection at Top:	WDisT = 0.415 m	WDisT = 1.361 ft

Ratio of Ultimate Load for EQ/Wind	$\frac{Vzq(z0)}{Vu(z0)} = 4.643$	$\frac{Mzq(z0)}{Mu(z0)} = 2.432$
Moment Magnification Factors	$\delta swb = 1.081$	$\delta sqb = 1.08$
P-Δ factors	$\delta wb = 1.029$	$\delta qb = 1.026$

Demand and Capacity Ratio at Base:

$z := z0$

DCR for Wind

$DCRw = 0.47$

$cb := 82.5 \cdot in$

$DCRw := \frac{Mu(z)}{\phi 1(cb) \cdot Mn(cb)}$

$\phi 1(cb) \cdot Pn(cb) = 35447\,kN$

$\phi 1(cb) \cdot Mn(cb) = 515107\,kN \cdot m$

$DCRvw = 0.24$

Modified DCR for Wind

$\frac{Pu(z)}{\phi 1(cb) \cdot Pn(cb)} = 1.001$

$DCRw = 0.423$

$\phi 1(cb) \cdot Pn(cb) = 7969\,kips$

$\phi 1(cb) \cdot Mn(cb) = 379931\,kips \cdot ft$

DCR for Shear Forces:

DCR for Seismic

$DCRq = 1.14$

$cb := 82.2 \cdot in$

$DCRq := \frac{Mzq(z)}{\phi 1(cb) \cdot Mn(cb)}$

$\phi 1(cb) \cdot Pn(cb) = 35028\,kN$

$\phi 1(cb) \cdot Mn(cb) = 514839\,kN \cdot m$

$DCRvq = 0.736$

Modified DCR for EQ

$\frac{\gamma DL \cdot W}{\phi 1(cb) \cdot Pn(cb)} = 1.001$

$DCRq = 1.028$

$\phi 1(cb) \cdot Pn(cb) = 7875\,kips$

$\phi 1(cb) \cdot Mn(cb) = 379734\,kips \cdot ft$

DCR for Shear Forces:

Tower Stress for Service Wind Load:	$fsmax = 1133.4\,MPa$	$fsmax = 164.4\,ksi$
Tendon Stress:	$fsmin = 1073\,MPa$	$fsmin = 155.6\,ksi$
Concrete Stress:	$fcmax = 14.3\,MPa$	$fcmax = 2.074\,ksi$
	$fcmin = 2.036\,MPa$	$fcmin = 0.295\,ksi$
Tower Stress for Operating Wind Load:		
	$fomax = 1132.5\,MPa$	$fomax = 164.2\,ksi$
Tendon Stress:	$fomin = 1073.9\,MPa$	$fomin = 155.8\,ksi$
Concrete Stress:	$focmax = 14.1\,MPa$	$focmax = 2.046\,ksi$
	$focmin = 2.215\,MPa$	$focmin = 0.321\,ksi$
Tower Stress for Fatigue Load:	$ffsmax = 1108.9\,MPa$	$ffsmax = 160.8\,ksi$
Tendon Stress:	$ffsmin = 1097.4\,MPa$	$ffsmin = 159.2\,ksi$
Concrete Stress:	$ffcmax = 9.31\,MPa$	$ffcmax = 1.351\,ksi$
	$ffcmin = 6.983\,MPa$	$ffcmin = 1.013\,ksi$
Across Wind <0.5Vcr:	$DCRa(v1) = 0.128$	$DCRa(v2) = 0.273$
Concrete Fatigue Design Life:	$\frac{nf}{N} = 0$	$M = 37$
DCR for Soil Bearing Capacity:	$DCRsoilw = 0.932$	$DCRsoilq = 1.285$
DCR for Footing Shear Capacity:	$DCRvftw = 0.409$	$DCRvftq = 0.517$
Footing Reinforcement Weight:	$2Asftq \cdot L \cdot \rho s = 131627\,kgf$	$2Asftq \cdot L \cdot \rho s = 290\,kips$

Post-Tension Concrete Circular Section Design (PT-CCSD)

Section Geometric Data: $z := hc$ Section at Base

Outside Radius: $R1 := \frac{d(z)}{2}$ $R1 = 2.819\,m$ $R1 = 111\,in$

Inside Radius: $R2 := \frac{d(z)}{2} - t(z)$ $R2 = 2.134\,m$ $R2 = 84\,in$

Tendon Cordinates:

Number of Tendon: $NT1 := NT2$ $NT2 = 34$ $NT := NT1 + NT2$

Clear Distance: $Cr1 := 13\cdot in$ $Cr2 := 14\cdot in$

$Cr1 = 0.33\,m$ $Cr2 = 0.356\,m$

Tendom Area: $i := 1..NT$ $i1 := 1..NT1$ $i2 := NT1 + 1..NT$

Area of Tendon (16.8cm2) $At_i := 1.302\cdot in^2$ 12-5/8 Dia. Low-Relaxation (7 wire strand)

Tendom Distribution:

$tx_{i1} := (R1 - Cr1)\cdot \sin\left(\frac{2\cdot\pi}{NT1}\cdot i1\right)$ $ty_{i1} := (R1 - Cr1)\cdot \cos\left(\frac{2\cdot\pi}{NT1}\cdot i1\right)$

$tx_{i2} := (R2 + Cr2)\cdot \sin\left(\frac{2\cdot\pi}{NT2}\cdot i2\right)$ $ty_{i2} := (R2 + Cr2)\cdot \cos\left(\frac{2\cdot\pi}{NT2}\cdot i2\right)$

Section Geometric Properties:

Section Circular Function:

$f1(x) := \sqrt{R1^2 - x^2}$ $g1(x) := -\left(\sqrt{R1^2 - x^2}\right)$

$f2(x) := \sqrt{R2^2 - x^2}$ $g2(x) := -\left(\sqrt{R2^2 - x^2}\right)$

Section Layout and Properties:

$Area1 := \int_{-R1}^{R1} (f1(x) - g1(x))\,dx$

$Area2 := \int_{-R2}^{R2} (f2(x) - g2(x))\,dx$

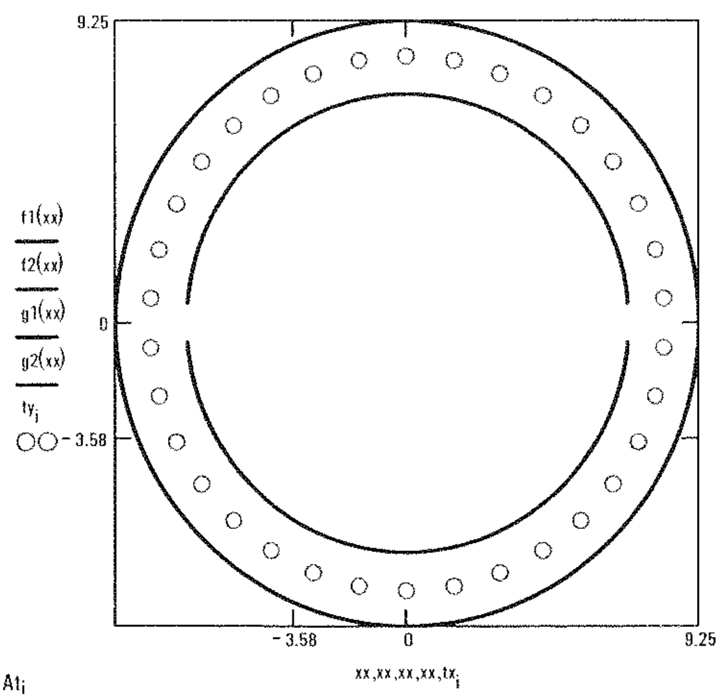
$Area := Area1 - Area2$

$J := \frac{\pi}{2}\cdot\left(R1^4 - R2^4\right)$

$rxx := \sqrt{\frac{I(z)}{Ac(z)}}$

$rxx = 1.768\,m$ $rxx = 70\,in$

$Eps_i := Es$



Steel Tendon Ratio: $\rho t := \frac{\sum_{i=1}^{NT} At_i}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $\rho t = 0.00538$ $ty1_i := ty_i$

Section Property Calculating as function of depth (a):

$$xx1(a) := \mathrm{if}\left(R1 < |a|, 0\cdot in, \sqrt{R1^2 - a^2}\right) \qquad xx2(a) := \mathrm{if}\left(R2 < |a|, 0\cdot in, \sqrt{R2^2 - a^2}\right)$$

$$Areay11(a) := \int_{-xx1(a)}^{xx1(a)} (f1(x) - a)\,dx \qquad Areay1(a) := \begin{cases} (Areay11(|a|)) & \text{if } a \ge 0\cdot in \\ (Area1 - Areay11(|a|)) & \text{otherwise} \end{cases}$$

$$Areay22(a) := \int_{-xx2(a)}^{xx2(a)} (f2(x) - a)\,dx \qquad Areay2(a) := \begin{cases} (Areay22(|a|)) & \text{if } a \ge 0\cdot in \\ (Area2 - Areay22(|a|)) & \text{otherwise} \end{cases}$$

Area at Depth of a: $Areay(a) := Areay1(a) - Areay2(a)$

$$SAy1(a) := \int_{-xx1(a)}^{xx1(a)} \int_{a}^{f1(x)} y\,dy\,dx \qquad SAy2(a) := \int_{-xx2(a)}^{xx2(a)} \int_{a}^{f2(x)} y\,dy\,dx$$

Neutral Axis at Depth of a: $YN(a) := \dfrac{SAy1(a) - SAy2(a)}{Areay(a)}$ $\quad YN(z) = 0\,m \quad YN(z) = 0\,in$

Tendon and Concrete Stress for Prestressed Tendon:

Tendon Force and Strain: $Pe := \sum_{i=1}^{NT} fse_i \cdot At_i$ $\quad Pe = 63011.1\,kN \quad Pe = 14165.8\,kips$

$$epe := \frac{Pe}{\sum_{i=1}^{NT} At_i \cdot Eps_i} \qquad epe = 0.00561$$

Concrete Strain by Tendon Forces:

$$ece := \frac{Pe}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right] Ec} \qquad ece = 0.0001698$$

Elastic Shorten Loss after Direct Transfer:

$$\frac{0.75\cdot fsu\cdot\left(\sum_{i=1}^{NT} At_i\right)\cdot Es}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]\cdot Ec} = 42.2\,MPa \qquad \frac{0.75\cdot fsu\cdot\left(\sum_{i=1}^{NT} At_i\right)\cdot Es}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]\cdot Ec} = 6.12\,ksi$$

Beta Factor for Concrete Compression Depth:

$$\beta 1 := 0.85 - 0.05\cdot\left(\frac{fc}{ksi} - 4\right) \qquad \beta 1 = 0.7$$

Total Concrete Deformation after Prestressed: $depy := eps - epe - ece$ $\quad depy = 0.002816$

Calculating Pn~Mn interaction diagram

Strain Compababilty Relation: $dy := \max(ty1) + R1$ $\quad cby := \dfrac{dy\cdot\dfrac{ecu}{depy}}{\left(1 + \dfrac{ecu}{depy}\right)}$

Cb at for fps (balance point): $cb := cby$ $\quad cby = 2.738\,m \quad cby = 107.8\,in$

Concrete Compression Depth: $a := R1 - cby\cdot\beta 1$ $\quad a = 0.903\,m \quad a = 35.538\,in$

Concrete Compression Forces: $Cn(cb) := 0.85\cdot fc\cdot Areay(R1 - \beta 1\cdot cb)$ $\quad Cn(cb) = 166867\,kN$

Tendon Forces in Tention:

$$Tsn(cb) := \begin{vmatrix} s \leftarrow 0 \\ \text{for } i \in 1..NT \\ \quad \begin{vmatrix} eey_i \leftarrow ece + epe + ecu\left(\dfrac{R1 - ty1_i}{cb} - 1\right) \\ s \leftarrow s + fps(eey_i) \cdot At_i \end{vmatrix} \\ s \end{vmatrix}$$

$Cn(cb) = 37514\,kips$

$Tsn(cb) = 65914\,kN$

$Tsn(cb) = 14818.4\,kips$

Pn~Mn Interaction Relation:

$Pn(cb) := Cn(cb) - Tsn(cb)$

$Pn(cb) = 100953\,kN$ $\qquad Pn(cb) = 22696\,kips$

$$Mn(cb) := \begin{vmatrix} s \leftarrow 0 \\ \text{for } i \in 1..NT \\ \quad \begin{vmatrix} eey_i \leftarrow ece + epe + ecu\left(\dfrac{R1 - ty1_i}{cb} - 1\right) \\ s \leftarrow s - fps(eey_i) \cdot At_i \cdot ty_i \end{vmatrix} \\ s \leftarrow s + Cn(cb) \cdot YN(R1 - \beta 1 \cdot cb) \end{vmatrix}$$

$\dfrac{Mn(cb)}{Pn(cb)} = 141.03\,in$

$Mn(cb) = 361629\,kN \cdot m$ $\qquad Mn(cb) = 266729\,kips \cdot ft$

Pure Compression Condition

$$Pn0 := 0.85 \cdot fc \cdot Area - \sum_{i=1}^{NT} fse_i \cdot At_i \qquad Pn0 = 374755\,kN \qquad Pn0 = 84250\,kips$$

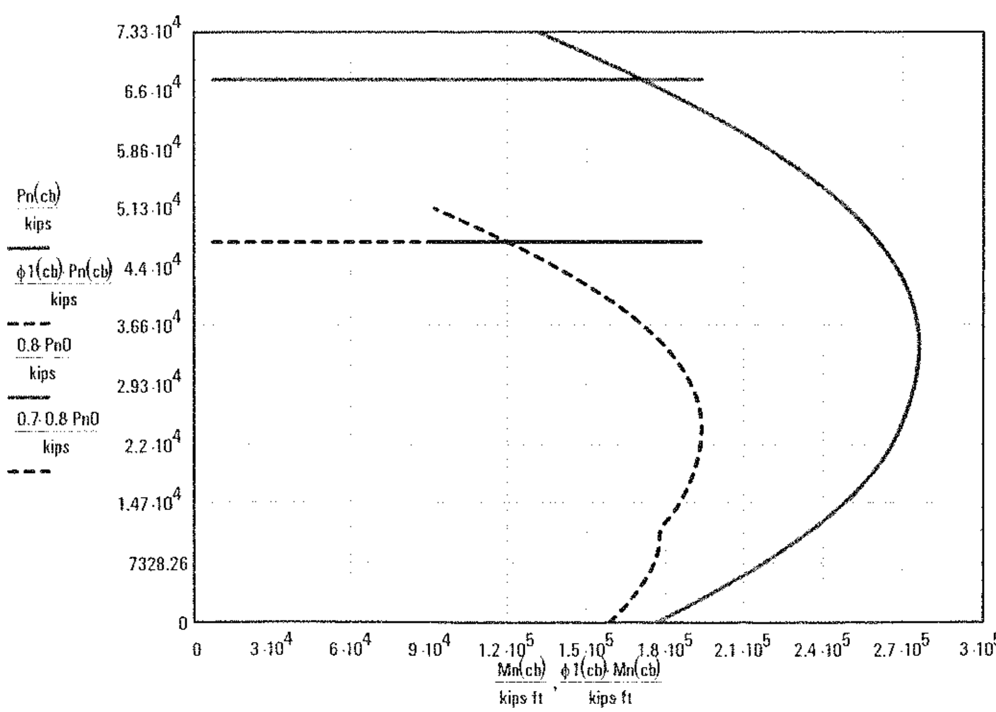
Strength Reduction Factor:

$$\phi(cb) := \frac{0.9 \cdot 0.1 \cdot fc \cdot Area}{0.1 \cdot fc \cdot Area + 0.2 \cdot if(Pn(cb) > 0 \cdot kips, Pn(cb), 0 \cdot kips)}$$

$$\phi 1(cb) := \begin{vmatrix} 0.7 \text{ if } \phi(cb) < 0.7 \\ (\phi(cb)) \text{ otherwise} \end{vmatrix}$$

$cb := 5 \cdot in, 10 \cdot in .. 280 \cdot in$

Pn~Mn Interaction Diagram:



Demand and Capacity Ratio:

DCR for Wind

$cb := 55.3 \cdot in$ $\qquad \dfrac{Pu(z)}{\phi1(cb) \cdot Pn(cb)} = 1.002$ $\qquad DCRw := \dfrac{Mu(z)}{\phi1(cb) \cdot Mn(cb)}$ $\qquad DCRw = 0.529$

$Pn(cb) = 20022kN$ $\quad Mn(cb) = 273618 kN \cdot m$ $\quad \phi1(cb) \cdot Pn(cb) = 16720kN$ $\quad \phi1(cb) \cdot Mn(cb) = 228490 kN \cdot m$

$Pn(cb) = 4501 kips$ $\quad Mn(cb) = 201815 kips \cdot ft$ $\quad \phi1(cb) \cdot Pn(cb) = 3759 kips$ $\quad \phi1(cb) \cdot Mn(cb) = 168529 kips \cdot ft$

DCR for Seismic

$cb := 55. \cdot in$ $\qquad \dfrac{\gamma DL \cdot (Wz(z) + HeadWeight)}{\phi1(cb) \cdot Pn(cb)} = 1.004$ $\qquad DCRq := \dfrac{Mzq(z)}{\phi1(cb) \cdot Mn(cb)}$ $\qquad DCRq = 1.125$

$Pn(cb) = 19460kN$ $\quad Mn(cb) = 272701 kN \cdot m$ $\quad \phi1(cb) \cdot Pn(cb) = 16284kN$ $\quad \phi1(cb) \cdot Mn(cb) = 228186 kN \cdot m$

$Pn(cb) = 4375kips$ $\quad Mn(cb) = 201138 kips \cdot ft$ $\quad \phi1(cb) \cdot Pn(cb) = 3661 kips$ $\quad \phi1(cb) \cdot Mn(cb) = 168305 kips \cdot ft$

Modified DCR Ratio:

$DCRw := DCRw \cdot \delta swt \cdot \delta wt$ $\qquad DCRw = 0.57$

$DCRq := DCRq \cdot \delta sqt \cdot \delta qt$ $\qquad DCRq = 1.213$

Calculate Tendon Stresses

$$eey_i := ece + epe + ecu \cdot \left(\frac{R1 - ty1_i}{cb} - 1\right)$$

Maximum Tendon Stress:

$$Te1_i := \left| \begin{array}{l} \left[eey_i \leftarrow ece + epe + ecu \cdot \left(\dfrac{R1 - ty1_i}{cb} - 1\right)\right] \\ fps(eey_i) \end{array} \right.$$

$max(Te1) = 1823MPa$

$max(Te1) = 264 ksi$

Post-Tension Concrete Section for Service Load (Ref. to ACI 318, Chapter 18)

Concrete Yield stress: $\quad 0.45fc = 21.7 MPa$ $\qquad 0.45fc = 3.15 ksi$

Concrete Ultimate stress: $\quad 0.6fc = 29MPa$ $\qquad 0.6 \cdot fc = 4.2 ksi$

Concrete Cracking stress: $\quad \dfrac{6}{1000} \cdot \sqrt{\dfrac{fc \cdot 1000}{ksi}} \cdot ksi = 3.46 MPa$ $\qquad \dfrac{6}{1000} \cdot \sqrt{\dfrac{fc \cdot 1000}{ksi}} \cdot ksi = 0.502 ksi$

Stiffness Ratio: $\quad n := \dfrac{Es}{Ec}$ $\qquad n = 5.619$

Section Moment of Inertia: $\quad Ix := I(z) + (n-1) \cdot \sum_{i=1}^{NT} At_i \cdot (ty1_i)^2$ $\qquad \dfrac{Ix}{I(z)} = 1.025$

Stress under Service Load Condition:

Tendon Stress: $\quad fs1_i := \dfrac{Ms(z) \cdot ty1_i}{Ix} n + fse_i$

$fsmax := max(fs1)$ $\quad fsmax = 1139.5 MPa$ $\quad fsmax = 165.3 ksi$

$fsmin := min(fs1)$ $\quad fsmin = 1066.8 MPa$ $\quad fsmin = 154.7 ksi$

Concrete Stress: $\quad fcc := \dfrac{Ms(z)}{S(z)}$ $\quad fcc = 7.499MPa$ $\quad fcc = 1.088 ksi$ $\quad$ Bending Stress

$$fg := \frac{Ps(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$$

$fg = 1.31 MPa$ $\quad fg = 0.19 ksi$ $\quad$ Axial Stress

$fcmax := ece \cdot Ec + fcc + fg$ $\quad fcmax = 14.75 MPa$ $\quad fcmax = 2.139 ksi$ $\quad$ Max Stress in Compression

$fcmin := ece \cdot Ec - fcc + fg$ $\quad fcmin = -0.251 MPa$ $\quad fcmin = -0.036 ksi$ $\quad$ Max Stress in Tension:

$ecmax := \frac{fcmax}{Ec}$ $ecmax = 0.00042$ Max Strain in Compression:

Concrete Shear Stress:

Ultimate Shear Stress: $\tau c(z) := 2\cdot\left(1 + \frac{Pu(z)}{2000 \cdot psi \cdot Ac(z)}\right)\sqrt{\frac{fc \cdot 1000}{ksi}} \cdot psi$

$\tau c(z) = 1.29\,MPa$ $\tau c(z) = 0.186\,ksi$

Torsion Moment: $Ts := Mzwt1(z)$ $Ts = 5716\,kN\cdot m$ $Ts = 4216\,kips\cdot ft$

$Qs := \frac{Area}{2}\cdot\left(\frac{4}{3\cdot\pi}\cdot\frac{R1^3 - R2^3}{R1^2 - R2^2}\right)$ $\frac{Vs(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)} = 0.022\,ksi$

Shear Strength in Concrete $\tau cc := \frac{Ts\cdot R1}{J} + \frac{Vu(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)}$ $\tau cc = 0.459\,MPa$ $\tau cc = 0.067\,ksi$

DCR for Shear Strength (Wind): $DCRvw := \frac{\tau cc}{\tau c(z)}$ $DCRvw = 0.357$

DCR for Shear Strength (EQ): $DCRvq := \frac{Vzq(z)\cdot Qs}{I(z)\cdot 2\cdot(R1 - R2)\cdot\tau c(z)}$ $DCRvq = 1.027$

Stress under Operating Load Condition:

Tendon Stress: $fo1_i := \frac{Mo(z)\cdot ty1_i}{Ix}\cdot n + fse_i$

$fomax := max(fo1)$ $fomax = 1138.1\,MPa$ $fomax = 165.1\,ksi$

$fomin := min(fo1)$ $fomin = 1068.2\,MPa$ $fomin = 154.9\,ksi$

Concrete Stress: $foc := \frac{Mo(z)}{S(z)}$ $foc = 7.218\,MPa$ $foc = 1.047\,ksi$ Bending Stress

$fog := \frac{Po(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $fog = 1.3\,MPa$ $fog = 0.189\,ksi$ Axial Stress

$focmax := ece\cdot Ec + foc + fog$ $focmax = 14.45\,MPa$ $focmax = 2.097\,ksi$ Max Stress in Compression

$focmin := ece\cdot Ec - foc + fog$ $focmin = 0.019\,MPa$ $focmin = 0.003\,ksi$ Max Stress in Tension:

Stress under Fatigue Load Condition:

$Ix = 34.168\,m^4$ $max(ty1) = 2.489\,m$ $min(ty1) = -2.489\,m$

Tendon Stress: $ff1_i := \frac{Mf(z)\cdot ty1_i}{Ix}\cdot n + fse_i$

$ffsmax := max(ff1)$ $ffsmax = 1110.1\,MPa$ $ffsmax = 161\,ksi$

$ffsmin := min(ff1)$ $ffsmin = 1096.2\,MPa$ $ffsmin = 159\,ksi$

Concrete Stress: $ffc := \frac{Mf(z)}{S(z)}$ $ffc = 1.439\,MPa$ $ffc = 0.209\,ksi$ Bending Stress

$ffg := \frac{Pf(z)}{\left[Area - \left(\sum_{i=1}^{NT} At_i\right)\right]}$ $ffg = 1.28\,MPa$ $ffg = 0.186\,ksi$ Axial Stress

$ece\cdot Ec + ffg = 7.221\,MPa$ $S(z) = 11.829\,m^3$

$ffcmax := ece\cdot Ec + ffc + ffg$ $ffcmax = 8.66\,MPa$ $ffcmax = 1.256\,ksi$ Max Stress in Compression

$ffcmin := ece\cdot Ec - ffc + ffg$ $ffcmin = 5.782\,MPa$ $ffcmin = 0.839\,ksi$ Max Stress in Tension:

Concrete Fatigue Stress:

$ffcmax := ffcmax \quad ffcmax = 1.256\,ksi$

$ffcmin := ffcmin \quad ffcmin = 0.839\,ksi$

Concrete Fatigue Design:

Simplified Method for Checking: $fat = 25.54\,MPa$

$\gamma sd \cdot ffcmax \cdot \eta c = 1.382\,ksi \qquad 0.45 \cdot fat = 1.667\,ksi$

Detail calculation required for concrete compression

Fatigue Stress Ratio:

$$Scdmin := \frac{ffcmin \cdot \gamma sd}{fat} \cdot \eta c \qquad Scdmin = 0.249$$

$$Scdmax := \frac{ffcmax \cdot \gamma sd}{fat} \cdot \eta c \qquad Scdmax = 0.373$$

$$\Delta Scd := Scdmax - Scdmin \qquad \Delta Scd = 0.124$$

Set M1 = logN1; M2 = logN2 and M3 = logN3

$$M1 := \left(12 + 16 \cdot Scdmin + 8 \cdot Scdmin^2\right) \cdot (1 - Scdmax) \qquad M1 = 10.3$$

$$M2 := 0.2 \cdot M1 \cdot (M1 - 1) \qquad \underline{0 < Scdmin < 0.8} \qquad M2 = 19.3$$

$$M3 := \frac{M2}{\Delta Scd} \cdot \left(0.3 - \frac{3}{8} \cdot Scdmin\right) \qquad M3 = 32.2$$

$$0.3 - \frac{3}{8} \cdot Scdmin = 0.207$$

$$M := \begin{cases} M1 & \text{if } M1 \le 6 \\ M2 & \text{if } \left(M1 > 6 \wedge \Delta Scd \ge 0.3 - \frac{3}{8} \cdot Scdmin\right) \\ M3 & \text{if } \left(M1 > 6 \wedge \Delta Scd < 0.3 - \frac{3}{8} \cdot Scdmin\right) \end{cases}$$

Fatigue Design Life:

$$M = 32.164 \qquad N := 10^M \qquad \frac{nf}{N} = 0$$

Max and Min tendon stress:

$\Delta\sigma s := ffsmax - ffsmin$

$\Delta\sigma s = 2.021\,ksi \qquad \Delta\sigma s = 13.932\,MPa$

$\gamma sd \cdot \Delta\sigma s = 2.223\,ksi$

$$\frac{\Delta\sigma Rsk}{\gamma s} = 11.981\,ksi$$

Results Summary 2 (Section at hc):

Ratio of Ultimate Load for EQ/Wind $\frac{Vzq(hc)}{Vu(hc)} = 6.077$ $\frac{Mzq(hc)}{Mu(hc)} = 2.124$

Moment Magnification Factors $\delta swt = 1.037$ $\delta sqt = 1.036$

Moment Magnification for P-Δ effect $\delta wt = 1.039$ $\delta qt = 1.04$

Demand and Capacity Ratio at Base: $z := hc$

DCR for Wind

$DCRw = 0.57$

$cb := 55.3 \cdot in$

$$DCRw := \frac{Mu(z)}{\phi 1(cb) \cdot Mn(cb)}$$

$\phi 1(cb) \cdot Pn(cb) = 16720 kN$

$\phi 1(cb) \cdot Mn(cb) = 228490 kN \cdot m$

$DCRvw = 0.357$

Modified DCR for Wind

$$\frac{Pu(z)}{\phi 1(cb) \cdot Pn(cb)} = 1.002$$

$DCRw = 0.529$

$\phi 1(cb) \cdot Pn(cb) = 3759 kips$

$\phi 1(cb) \cdot Mn(cb) = 168529 kips \cdot ft$

DCR for Shear Forces:

DCR for Seismic

$DCRq = 1.213$

$cb := 55 \cdot in$

$$DCRq := \frac{Mzq(z)}{\phi 1(cb) \cdot Mn(cb)}$$

$\phi 1(cb) \cdot Pn(cb) = 16284 kN$

$\phi 1(cb) \cdot Mn(cb) = 228186 kN \cdot m$

$DCRvq = 1.027$

Modified DCR for EQ

$$\frac{\gamma DL \cdot (Wz(z) + HeadWeight)}{\phi 1(cb) \cdot Pn(cb)} = 1.004$$

$DCRq = 1.125$

$\phi 1(cb) \cdot Pn(cb) = 3661 kips$

$\phi 1(cb) \cdot Mn(cb) = 168305 kips \cdot ft$

DCR for Shear Forces:

Tower Stress for Service Wind Load:

Tendon Stress:

$fsmax = 1139.5 MPa$ $fsmax = 165.3 ksi$

$fsmin = 1066.8 MPa$ $fsmin = 154.7 ksi$

Concrete Stress:

$fcmax = 14.75 MPa$ $fcmax = 2.139 ksi$

$fcmin = -0.251 MPa$ $fcmin = -0.036 ksi$

Tower Stress for Operating Wind Load:

Tendon Stress:

$fomax = 1138.1 MPa$ $fomax = 165.1 ksi$

$fomin = 1068.2 MPa$ $fomin = 154.9 ksi$

Concrete Stress:

$focmax = 14.45 MPa$ $focmax = 2.097 ksi$

$focmin = 0.019 MPa$ $focmin = 2.737 \times 10^{-3} ksi$

Tower Stress for Fatigue Load:

Tendon Stress:

$ffsmax = 1110.1 MPa$ $ffsmax = 161 ksi$

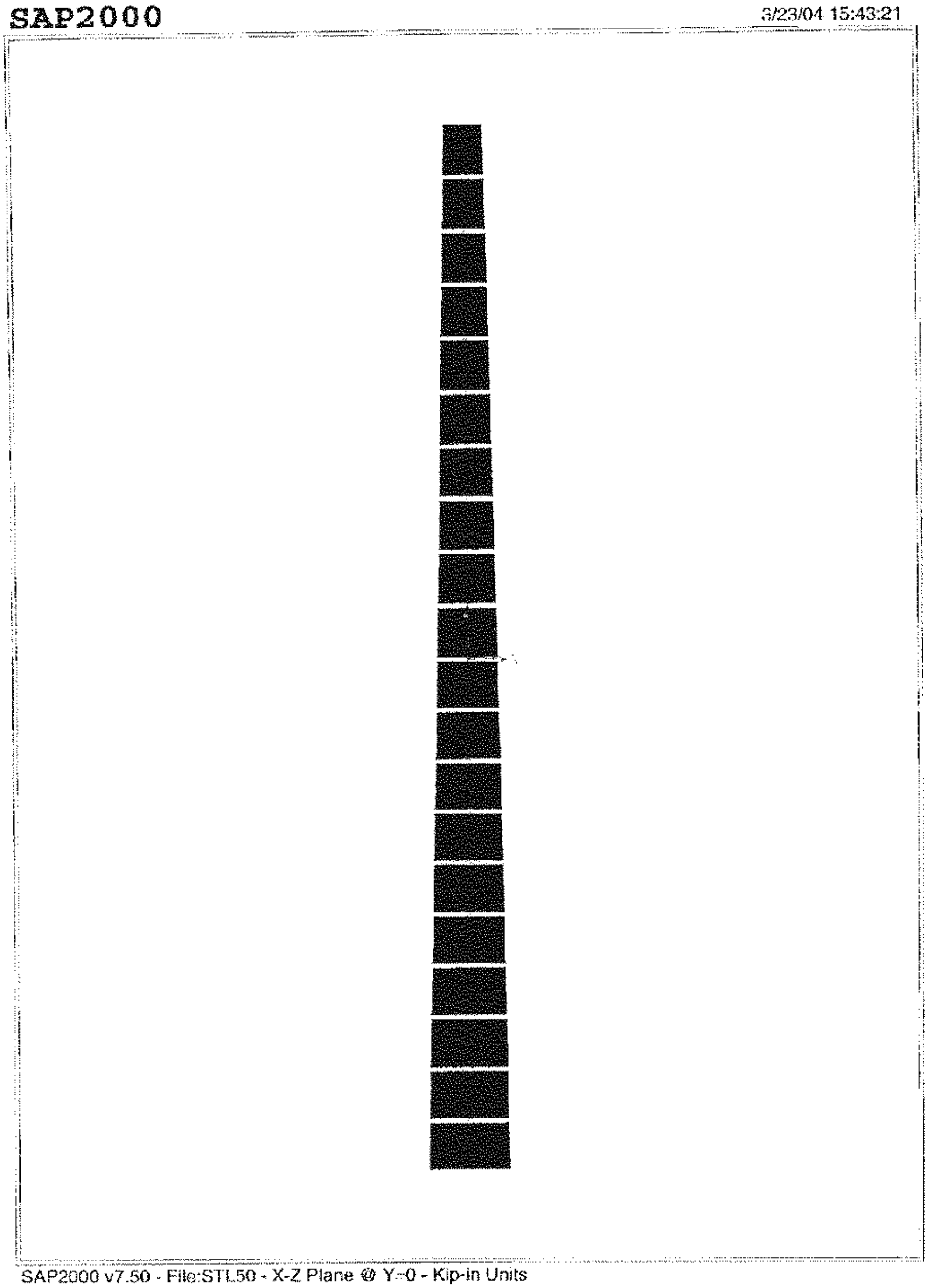
$ffsmin = 1096.2 MPa$ $ffsmin = 159 ksi$

Concrete Stress:

$ffcmax = 8.66 MPa$ $ffcmax = 1.256 ksi$

$ffcmin = 5.782 MPa$ $ffcmin = 0.839 ksi$

Fatigue Life (logN): $M = 32$



5.0 MW Full Steel Tower Model and Dynamics Properties

Tower Freq.	Mode-1		Mode-2		Mode-3	
STL50	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)	Freq.(Hz)	Period (sec)
Spring Base	0.3605	2.7742	2.7021	0.3701	5.0398	0.1984
Fixed Base	0.3913	2.5553	3.0617	0.3266	7.2953	0.1371

Revised Wind Load --- 100m Steel Tower for 5.0MW (Wind Load Design)

Units Conversion:

$kips := 1000 \cdot lbf$ $ksi := \frac{kips}{in^2}$ $psf := \frac{lbf}{ft^2}$ $kN := 1000 \cdot newton$ $MPa := 10^6 \cdot Pa$

1.5MW Turbine Data

Totoal Turbine Weight:	$HeadWeight := 480076 \cdot kgf$	$HeadWeight = 1058 kips$
Additional Weight at Top of Mid Height Tower:	$Wcc := 5000 \cdot kgf$	$Wcc = 11.02 kips$

Tower Dimension:

Totoal Tower Height:	$h := 100 \cdot m$	$h = 328 ft$
Lower Steel Tower Height:	$hc := 49 \cdot m$	$hc = 161 ft$
Outside Diameter at Base of Lower Steel Tower	$Dcb = 8.839 m$	$Dcb = 348 in$
Wall Thickness at Base of Lower Steel Tower	$Tcb = 0.0365 m$	$Tcb = 1.438 in$
Outside Diameter at Top of Lower Steel Tower	$Dct = 6.706 m$	$Dct = 264 in$
Wall Thickness at Top of Lower Steel Tower	$Tct = 0.0349 m$	$Tct = 1.375 in$
Outside Diameter at Base of Upper Steel Tower	$Dsb = 6.706 m$	$Dsb = 264 in$
Wall Thickness at Base of Upper Steel Tower	$Tsb = 0.0349 m$	$Tsb = 1.375 in$
Outside Diameter at Top of Upper Steel Tower	$Dst = 4.572 m$	$Dst = 180 in$
Wall Thickness at Top of Upper Steel Tower	$Tst = 0.0222 m$	$Tst = 0.875 in$

Tower Material Properties:

Steel Tower Density :	$\rho s = 76.97 \frac{kN}{m^3}$	$\rho s = 490 \frac{lbf}{ft^3}$
Steel Elastic Modulus :	$Es = 196501 MPa$	$Es = 28500 ksi$
Steel Yeilding Stress :	$fy = 344.7 MPa$	$fy = 50 ksi$
Concrete Tower Density :	$\rho c = 23.563 \frac{kN}{m^3}$	$\rho c = 150 \frac{lbf}{ft^3}$
Concrete Compression Strength :	$fc = 5 ksi$	$fc = 5 ksi$
Concrete Elastic Modulus :	$Ec = 29557 MPa$	$Ec = 4287 ksi$

Tower Foundation:

Footing Concrete Strength:	$fcft = 27.6 MPa$	$fcft = 4 ksi$	
Concrete Elastic Modulus :	$Ecft = 26436 MPa$	$Ecft = 3834 ksi$	
Footing Length and Width:	$B = 20.422 m$	$B = 67 ft$	$L := B$
Footing Depth:	$D = 3.658 m$	$D = 12 ft$	

Soil Information:

Soil Tower Density :	$\rho so = 18.85 \frac{kN}{m^3}$	$\rho so = 120 \frac{lbf}{ft^3}$
Soil Bearing Capacity	$cso = 0.287 MPa$	$cso = 6000 psf$
Soil Shear Modulus	$Gso = 20.684 MPa$	$Gso = 3000 psi$
Soil Poission Ratio	$\mu so := 0.35$	
Soil Bearing Capacity Safety Factor for EQ:	$\gamma soq := 2$	

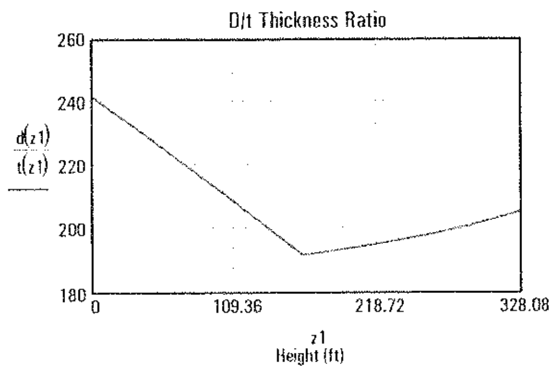
Tower Configuration Along the Height (z):

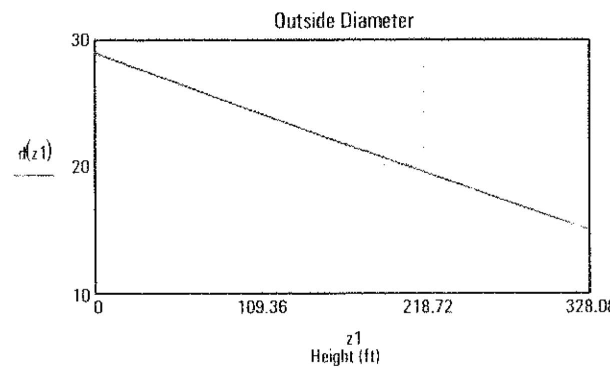
Ground Elevation: $z0 := 0 \cdot m$

Tower Diameter:
$$d(z) := \begin{cases} \left(\frac{Dct - Dcb}{hc} \cdot z + Dcb\right) & \text{if } z \le hc \\ \left[\frac{Dst - Dsb}{h - hc} \cdot (z - hc) + Dsb\right] & \text{otherwise} \end{cases}$$

Tower Wall Thickness:
$$t(z) := \begin{cases} \left(\frac{Tct - Tcb}{hc} \cdot z + Tcb\right) & \text{if } z \le hc \\ \left[\frac{Tst - Tsb}{h - hc} \cdot (z - hc) + Tsb\right] & \text{otherwise} \end{cases}$$

Tower Riadus: $R(z) := \frac{d(z) - t(z)}{2}$





Tower Cross Section Area: $Ac(z) := \frac{\pi}{4} \cdot \left[d(z)^2 - (d(z) - 2 \cdot t(z))^2 \right]$

Section Moment of Inertia: $I(z) := \frac{\pi}{64} \cdot \left[d(z)^4 - (d(z) - 2\, t(z))^4 \right]$

Section Modulus: $S(z) := \frac{2\, I(z)}{d(z)}$

Elastic Modulus: $E(z) := Es$

Tower Weight Distribution: $wt(z) := Ac(z) \cdot \rho s$ $\qquad Wz(z) := \int_z^h wt(x)\, dx$

Steel Tower Weight: $Wz(hc) = 2005 kN$ $\qquad Wz(hc) = 451\, kips$

Tower Weight: $Wz(z0) = 5282 kN$ $\qquad Wz(z0) = 1188 kips$

Total Weight: $W := Wz(z0) + HeadWeight + Wcc$ $\qquad W = 1023731\, kgf$

$W = 10039 kN$ $\qquad W = 2257 kips$

Soil Spring Constants:

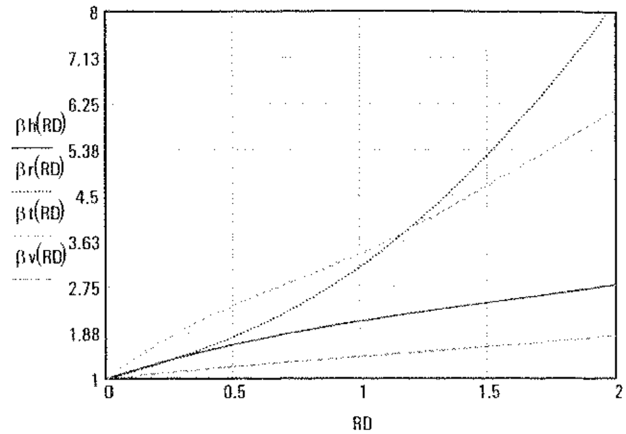
Ref. to Highway Bridge Design Manual:

Translation Equivalent Radius $R0 := \sqrt{\frac{B \cdot L}{\pi}}$ $R0 = 37.801\,ft$ $R0 = 11.522\,m$

Rotation X Equivalent Radius $R1 := \sqrt[4]{\frac{B \cdot L \cdot (B^2 + L^2)}{6 \cdot \pi}}$

Rotation X Equivalent Radius $R2 := \sqrt[4]{\frac{(B)^3 \cdot L}{3 \cdot \pi}}$

Rotation X Equivalent Radius $R3 := \sqrt[4]{\frac{(L)^3 \cdot B}{3 \cdot \pi}}$



Embedment Factor $\frac{D}{R1} = 0.314$

Shape Factor (see Ref.) $\alpha x := 1.02$ $\alpha y := 1.02$ $\alpha v := 1.03$ $\alpha r := 1.05$

$\beta h\left(\frac{D}{R1}\right) = 1.44$ $\beta r\left(\frac{D}{R1}\right) = 1.46$ $\beta v\left(\frac{D}{R1}\right) = 1.15$ $\beta t\left(\frac{D}{R1}\right) = 1.97$

Vertical Spring Constant: $Kv := \alpha v \cdot \beta v\left(\frac{D}{R1}\right) \cdot \frac{4 \cdot Gso \cdot R0}{1 - \mu so}$ $Kv = 1739277 \frac{kN}{m}$ $Kv = 9932 \frac{kips}{in}$

Horizontal Spring Constant: $Kh := \alpha x \cdot \beta h\left(\frac{D}{R1}\right) \cdot \frac{8 \cdot Gso \cdot R0}{2 - \mu so}$ $Kh = 1693210 \frac{kN}{m}$ $Kh = 9669 \frac{kips}{in}$

Torsional Spring Constant: $Kt := \alpha r \cdot \beta t\left(\frac{D}{R1}\right) \cdot \frac{16 \cdot Gso \cdot R3^3}{3}$ $Kt = 362056825\,kN \cdot m$ $Kt = 3204542865\,kips \cdot in$

Rocking Spring Constant: $Kr := \alpha r \cdot \beta r\left(\frac{D}{R1}\right) \cdot \frac{8 \cdot Gso \cdot R1^3}{3 \cdot (1 - \mu so)}$ $Kr = 205289298\,kN \cdot m$ $Kr = 1817003047\,kips \cdot in$

Natural Frequency of Tower

Rayleigh Energy Method

Defomation Shape Function
(Fix - Free End)

$$x(a1, a2, z) := \begin{cases} a1 - a1 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) & \text{if } z \le hc \\ a2 - a2 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + h - 2 \cdot hc}{h - hc}\right) + \frac{a1 \pi}{2hc} \cdot (z - hc) + a1 & \text{if } hc < z \le h \end{cases}$$

First Order Differential Equation

$$y1(a1, a2, z) := \begin{cases} \frac{-1}{2} \cdot a1 \cdot \cos\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) \cdot \frac{\pi}{hc} & \text{if } z \le hc \\ \frac{-1}{2} \cdot a2 \cdot \cos\left[\frac{\pi}{2} \cdot \frac{(z + h - 2 \cdot hc)}{(h - hc)}\right] \cdot \frac{\pi}{(h - hc)} + \frac{a1}{2} \cdot \frac{\pi}{hc} & \text{if } hc < z \le h \end{cases}$$

Second Order Differential Equation

$$y2(a1, a2, z) := \begin{cases} \frac{1}{4} \cdot a1 \cdot \sin\left(\frac{\pi}{2} \cdot \frac{z + hc}{hc}\right) \cdot \frac{\pi^2}{hc^2} & \text{if } z \le hc \\ \frac{1}{4} \cdot a2 \cdot \sin\left[\frac{1}{2} \cdot \pi \cdot \frac{(z + h - 2 \cdot hc)}{(h - hc)}\right] \cdot \frac{\pi^2}{(h - hc)^2} & \text{if } hc < z \le h \end{cases}$$

Strain Energy of Tower $$Umax(a1,a2) := \frac{1}{2}\cdot\int_0^h E(z)\cdot I(z)\cdot y2(a1,a2,z)^2\,dz$$

Kenitic Energy of Tower $$Tmax(a1,a2) := \frac{1}{2}\cdot\left(\int_0^h \frac{wt(z)}{g}\cdot x(a1,a2,z)^2\,dz + \frac{HeadWeight}{g}\cdot x(a1,a2,h)^2 + \frac{Wcc}{g}\cdot x(a1,a2,hc)^2\right)$$

Rayleigh Quotient $$Freq(a1,a2) := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{Umax(a1,a2)}{Tmax(a1,a2)}}$$

Minimum Energy Principle $i := 1..10$ $\quad hi := 0.01\cdot in$ $\quad j := 1..10$ $\quad hj := 0.2\cdot in$ $\quad Fq_{i,j} := Freq(i\cdot hi, j\cdot hj)$

Tower Frequency (fixed base) $Freq := min(Fq)$ $\quad Freq = 0.441\,Hz$

Deformation Shape for Base Rotation $$x1(p,z) := \frac{p\cdot h}{Kr}\cdot z \qquad U1max(p) := \frac{(p\cdot h)^2}{2\cdot Kr}$$

$$T1max(p) := \frac{1}{2}\cdot\left(\int_0^h \frac{wt(z)}{g}\cdot x1(p,z)^2\,dz + \frac{HeadWeight}{g}\cdot x1(p,h)^2 + \frac{Wcc}{g}\cdot x1(p,hc)^2\right)$$

Freqency for Base Rotation $$Fr1(p) := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{U1max(p)}{T1max(p)}}$$ $Fr1(10\cdot kips) = 0.921\,Hz$

Freqency for Base Translation $$Fr2 := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{Kh\cdot g}{W}}$$ $Fr2 = 6.473\,Hz$

Natural Freqency of Tower $$Fq := \sqrt{\frac{Fr1(100\cdot kips)^2\cdot Fr2^2\cdot Freq^2}{Fr1(100\cdot kips)^2\cdot Freq^2 + Fr2^2\cdot Freq^2 + Fr1(100\cdot kips)^2\cdot Fr2^2}}$$ $Fq = 0.397\,Hz$

Global Buckling Load (Rayleigh's Method):

External Work: $$\lambda max(a1,a2) := \frac{1}{2}\cdot\int_0^h y1(a1,a2,z)^2\,dz$$

Self-Weight Work: $$Wmax(a1,a2) := \frac{1}{2}\left(HeadWeight\cdot\int_0^h y1(a1,a2,z)^2\,dz + Wcc\cdot\int_0^{hc} y1(a1,a2,z)^2\,dz + \int_0^h wt(z)\,z\cdot y1(a1,a2,z)^2\,dz\right)$$

Global Buckling Load:
Based on Minimum Energy Method $$Pcr(a1,a2) := \frac{Umax(a1,a2) - Wmax(a1,a2)}{\lambda max(a1,a2)} \qquad pcr_{i,j} := Pcr(i\cdot hi, j\cdot hj)$$

$$Pcr(z) := min(pcr) + Wz(z) + HeadWeight + if(z < hc, Wcc, 0\cdot kips)$$

Buckling Load at Top : $Pcr(z0) = 299488\,kN$ $\quad Pcr(z0) = 67329\,kips$ $\quad Pe := min(pcr)$

Total Global Buckling Load: $Pe = 289448\,kN$ $\quad Pe = 65072\,kips$

Earthquake Load: ASCE 7-98

Seismic Soil Data (Table and Figure 9.4.1) :

Site Class Factor: Soil Class "D" $Fa := 1$ $Fv := 1.5$

Design Acceleration for Short Period: $Sds := 1.5 \cdot \frac{2}{3} \cdot Fa$ $Sds = 1$

Design Acceleration for One Second: $Sd1 := 0.6 \cdot \frac{2}{3} \cdot Fv$ $Sd1 = 0.6$

$Ts := \frac{Sd1}{Sds} \cdot sec$ $T0 := 0.2 \cdot Ts$

Design Response Spectra

$$Sa(T) := \begin{cases} \frac{Sd1}{T} & \text{if } T > Ts \\ Sds \cdot \left(0.4 + 0.6 \cdot \frac{T}{T0}\right) & \text{if } T < T0 \\ Sds & \text{otherwise} \end{cases}$$

Building Period (sec):

$\beta := 0.75$ $Ct := 0.02$

0.035 for Steel MF
0.03 for EBF
0.018 for Concrete MF
0.020 for all others

$Ta := Ct \cdot \left(\frac{h}{ft}\right)^{\beta} \cdot sec$ $Ta = 1.542 sec$

$T := 1.4 \cdot Ta$ $T = 2.158 sec$

Base Shear Factor:

Reduction Factor $Rq := 1$ $T := \min\left(T, \frac{1}{Fq}\right)$ $T = 2.158 sec$

Importance Factor of Occupancy $Iq := 1$

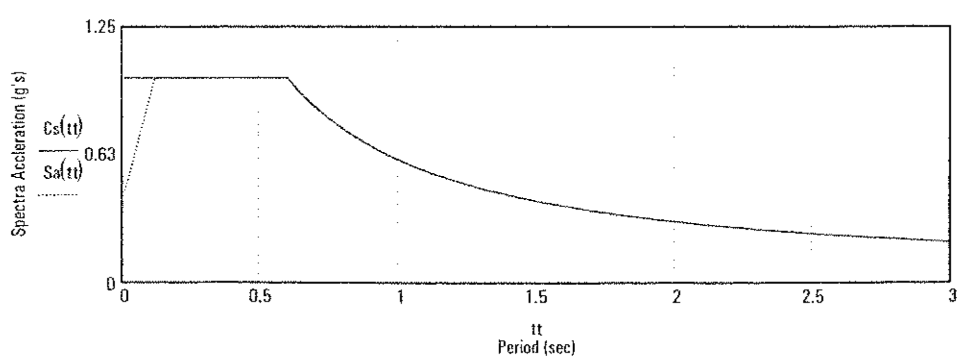
Seismic Response Coefficient $Cs(T) := \frac{Sd1 \cdot Iq}{Rq \cdot T} \cdot sec$ $Csup := \frac{Sds \cdot Iq}{Rq}$ $Csup = 1$ *Upperbound*

$Cslo := 0.044 \cdot Sds \cdot Iq$ $Cslo = 0.044$ *Lowerbound*

$$Cs(T) := \begin{cases} Csup & \text{if } Cs(T) \geq Csup \\ Cslo & \text{if } Cs(T) < Cslo \\ Cs(T) & \text{otherwise} \end{cases}$$

$Cs(T) = 0.278$

$tt := 0.01, 0.02 .. 3$



ASCE 7 Design Response Spectra

Tower Shear Force and Moment :

Base Shear: $V := Cs(T) \cdot W \cdot Rq$ $V = 2790.7\,kN$ $V = 627.4\,kips$

Distributed Forces Along the Tower:

$$k(T) := \begin{cases} 1 & \text{if } T < 0.5 \cdot sec \\ 2 & \text{if } T > 2.5 \cdot sec \\ \left(0.5 \cdot \frac{T}{sec} + 0.75\right) & \text{otherwise} \end{cases}$$

$k0 := k(T)$ $k(T) = 1.829$

Mode Shape Factor

Force Distribution along Tower:

$$wtz := \int_0^h wt(z) \cdot z^{k0}\, dz \qquad F(z) := \frac{wt(z) \cdot z^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V$$

Concentrated Load at Height of h:

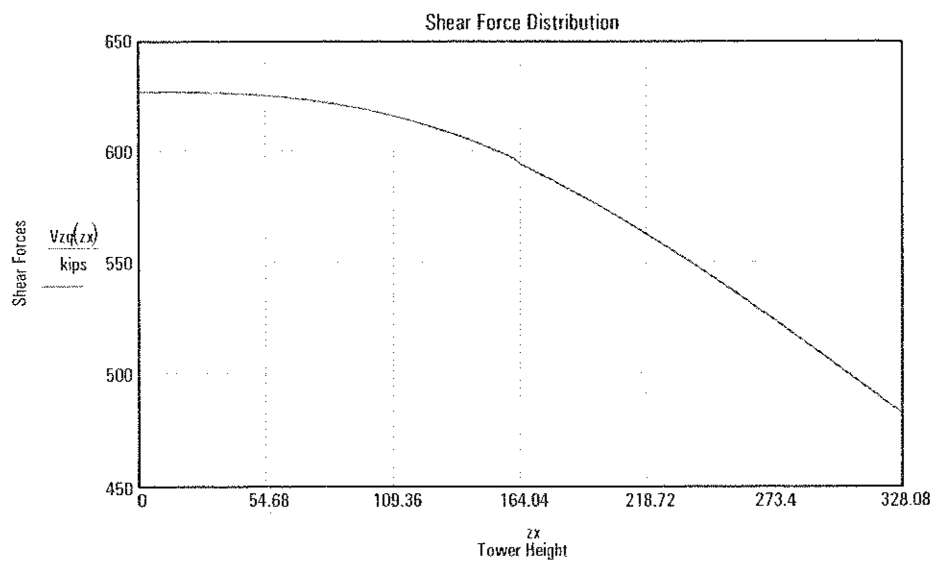
$$Fh := \frac{HeadWeight \cdot h^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V \qquad Fh = 482.8\,kips$$

Concentrated Load at Height of hc:

$$Fhc := \frac{Wcc \cdot hc^{k0}}{wtz + HeadWeight \cdot h^{k0} + Wcc \cdot hc^{k0}} \cdot V \qquad Fhc = 1.4\,kips$$

Shear Force along the Tower:

$$Vzq(z) := \int_z^h F(x)\, dx + Fh + if(z \le hc, Fhc, 0 \cdot kips) \qquad zx := 0 \cdot m, 1 \cdot m .. h$$



Shear Force:

$Vzq(z0) = 2790.7\,kN$ $Vzq(z0) = 627.4\,kips$

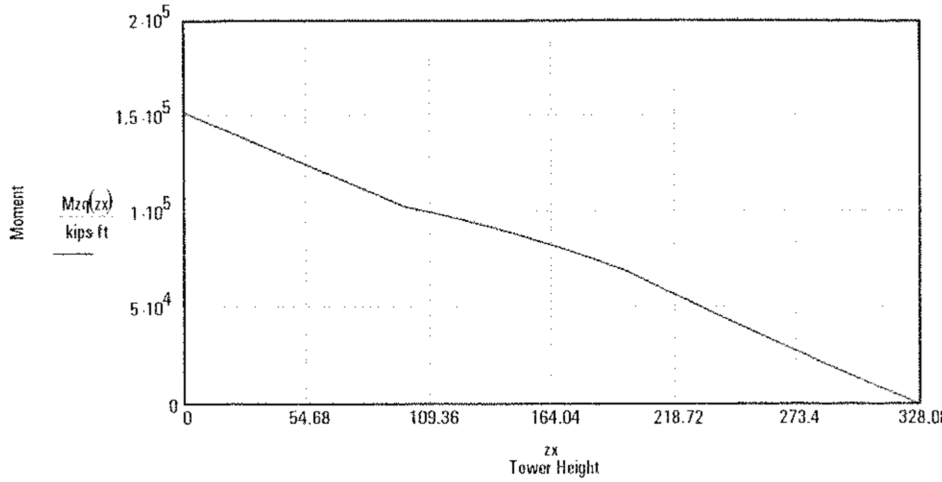
$Vzq(hc) = 2658.3\,kN$ $Vzq(hc) = 597.6\,kips$

Over Turning Moment along the Tower:

$$\tau(z) := \begin{cases} 1 & \text{if } z > 60 \cdot m \\ \left[\frac{z - 30 \cdot m}{60 \cdot m - 30 \cdot m} \cdot (1 - 0.8) + 0.8\right] & \text{if } 30 \cdot m \le z \le 60 \cdot m \\ 0.8 & \text{if } z < 30 \cdot m \end{cases}$$

Overturning Moment Reduction Factor

$$Mzq(z) := \tau(z)\cdot\left[\int_z^h F(x)\cdot(x-z)\,dx + Fh\cdot(h-z) + \text{if}(z \le hc, Fhc\cdot(hc-z), 0\cdot kips\cdot ft)\right]$$



Over Turning Moment:

$Mzq(z0) = 206628\,kN\cdot m$ $\quad Mzq(z0) = 152404\,kips\cdot ft$

$Mzq(hc) = 114280\,kN\cdot m$ $\quad Mzq(hc) = 84291\,kips\cdot ft$

Deflection at Top of Tower

$$\Delta q(z) := \int_{z0}^{z} \frac{Mzq(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vzq(z0)}{Kh} + \frac{Mzq(z0)}{Kr}\cdot z$$

$QDisT := \Delta q(h)$ $\quad QDisT = 0.736\,m$ $\quad QDisT = 2.413\,ft$ $\quad \frac{h}{QDisT} = 136$

$QDisM := \Delta q(hc)$ $\quad QDisM = 0.19\,m$ $\quad QDisM = 0.624\,ft$ $\quad \frac{hc}{QDisM} = 257$

Moment Magnification Factor

at Base: $\delta sqb := \dfrac{1}{1 - \dfrac{1.2W}{Pcr(z0)}}$ $\quad \delta sqb = 1.042$

at Height of hc: $\delta sqt := \dfrac{1}{1 - \dfrac{1.2(Wz(hc) + HeadWeight)}{Pcr(z0)}}$ $\quad \delta sqt = 1.028$

P-Δ Effect

Moment of Tower due to Gravity Load for P-Δ effect :

$$Mqg(z) := (QDisT - \Delta q(z))\cdot HeadWeight + \int_z^h wt(y)\cdot(\Delta q(y) - \Delta q(z))\,dy + Wcc\cdot \text{if}(z < hc, QDisM - \Delta q(z), 0\cdot m)$$

Approx. Method of Moment at Base for P-Δ effect :

$$Mqgb := \Delta q(h)\cdot HeadWeight + Wcc\cdot\Delta q(hc) + Wz(hc)\cdot\Delta q\left(\frac{h+hc}{2}\right) + (Wz(z0) - Wz(hc))\cdot\Delta q\left(\frac{hc}{2}\right)$$

$\delta qb := \dfrac{Mqgb}{Mzq(z0)} + 1$ $\quad \delta qb = 1.022$

Wind Load: ASCE 7-98 Design Wind Category : D

Wind Speed at Hub: $v\_EWM50 := 59.5 \cdot \frac{m}{sec}$ Nonoperating Load (EWM50)

$v\_EOG50 := 35 \cdot \frac{m}{sec}$ Operating Load (EOG50)

Design Wind Speed: $v1 := v\_EWM50 \cdot \left(\frac{33 \cdot ft}{h}\right)^{0.1}$ $v1 = 47.3 \frac{m}{sec}$ $v1 = 105.8\,mph$

$v2 := v\_EOG50 \cdot \left(\frac{33 \cdot ft}{h}\right)^{0.2}$ $v2 = 22.1 \frac{m}{sec}$ $v2 = 49.5\,mph$

Importance factor: $Im := 1$

Parameters for Speed-up Over Hill and Escarpment: (Figure 6-2 of ASCE-7-98)

for flat area $\gamma := 4$ $\mu := 1.5$ $x := 0 \cdot ft$ $Lh := 100000 \cdot m$ $H := 1 \cdot m$

Topographic Factor, Kzt for Exposure D: $K1 := 1.55 \cdot \frac{H}{Lh}$ $K1 = 1.55 \times 10^{-5}$

$K2 := 1 - \frac{|x|}{\mu \cdot Lh}$ $K2 = 1$

$K3(z) := e^{-\gamma \cdot \frac{z}{Lh}}$

$Kzt(z) := (1 + K1 \cdot K2 \cdot K3(z))^2$

Terrain Expoure Constants for Exposure D: (Table 6-4 of ASCE-7-98)

$\alpha1 := 11.5$ $zg := 700 \cdot ft$ $c := 0.15$ $b := 0.8$ $\alpha := \frac{1}{9}$ $\varepsilon := \frac{1}{8}$ $l := 650 \cdot ft$

Basic Velocity Pressure:

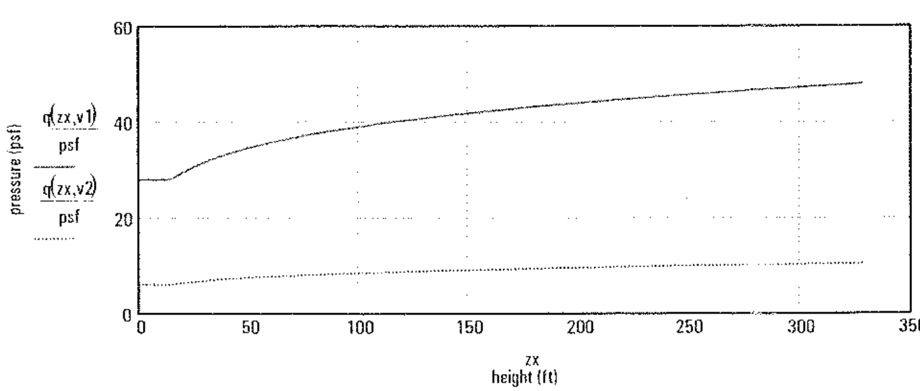
Velocity Pressure Coefficient:

$$K(z) := \begin{cases} \left[2.01 \cdot \left(\frac{15 \cdot ft}{zg}\right)^{\frac{2}{\alpha1}}\right] & \text{if } z < 15 \cdot ft \\ \left[2.01 \cdot \left(\frac{z}{zg}\right)^{\frac{2}{\alpha1}}\right] & \text{otherwise} \end{cases}$$

Direcitionality Factor for Round: $Kd := 0.95$

Velocity Pressure: $Vw(v) := \frac{v}{mph}$ $0.00256 \cdot Vw(v1)^2 \cdot psf = 28.6\,psf$ $0.00256 \cdot Vw(v2)^2 \cdot psf = 6.3\,psf$

$q(z,v) := 0.00256 \cdot K(z) \cdot Kzt(z) \cdot Kd \cdot Vw(v)^2 \cdot Im \cdot psf$



Velocity Pressure at 100m High:

$q(h, v1) = 2296\,Pa$ $q(h, v2) = 502\,Pa$

$q(h, v1) = 47.9\,psf$ $q(h, v2) = 10\,psf$

$q(hc, v1) = 2028\,Pa$ $q(hc, v2) = 443\,Pa$

$q(hc, v1) = 42.4\,psf$ $q(hc, v2) = 9\,psf$

Damping Ratio: $\beta d := 0.02$

Gust Factor Calculation:

Intensity of turbulence: $Ig(z) := c \cdot \left(\frac{33 \cdot ft}{z}\right)^{\frac{1}{6}}$ $Lg(z) := l \cdot \left(\frac{z}{33 \cdot ft}\right)^{\varepsilon}$

Peak Factor for Resonant: $gQ := 3.4$ $gv := 3.4$

$$gR := \sqrt{2 \cdot \ln(3600 \cdot sec \cdot Fq)} + \frac{0.577}{\sqrt{2 \cdot \ln(3600 \cdot sec \cdot Fq)}} \qquad gR = 3.963$$

Mean hourly velocity: $Vw(z, v) := b \cdot \left(\frac{z}{33 \cdot ft}\right)^{\alpha} \cdot v \cdot \left(\frac{88}{60}\right)$

Reduced Frequency $N1(z, v) := \frac{Fq \cdot Lg(z)}{Vw(z, v)}$

Resonant response factor $\eta h(z, v) := \frac{4.6 \cdot Fq \cdot h}{Vw(z, v)}$ $\eta B(z, v) := \frac{4.6 \cdot Fq \cdot d(hc)}{Vw(z, v)}$ $\eta L(z, v) := \frac{15.4 \cdot Fq \cdot d(hc)}{Vw(z, v)}$

$$Rh(z, v) := \frac{1}{\eta h(z, v)} - \frac{1}{2(\eta h(z, v))^2} \cdot \left(1 - e^{-2 \cdot \eta h(z, v)}\right)$$

$$Rn(z, v) := \frac{7.47 \cdot N1(z, v)}{(1 + 10.3 \cdot N1(z, v))^{\frac{5}{3}}}$$

$$RB(z, v) := \frac{1}{\eta B(z, v)} - \frac{1}{2(\eta B(z, v))^2} \cdot \left(1 - e^{-2 \cdot \eta B(z, v)}\right)$$

$$RG(z, v) := \sqrt{\frac{1}{\beta d} \cdot Rh(z, v) \cdot RB(z, v) \cdot Rn(z, v) \cdot (0.53 + 0.47 \cdot RB(z, v))}$$

$$Q(z) := \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{d(hc) + h}{Lg(z)}\right)^{0.63}}}$$

Gust Effect factor $G(z) := 0.925 \cdot \frac{(1 + 1.7 \cdot gQ \cdot Ig(z) \cdot Q(z))}{1 + 1.7 \cdot gv \cdot Ig(z)}$ $G(h) = 0.876$

for Flexible Structure < 1 Hz $Gf(z, v) := 0.925 \cdot \frac{\left(1 + 1.7 \cdot Ig(z) \cdot \sqrt{gQ^2 \cdot Q(z)^2 + gR^2 \cdot RG(z, v)^2}\right)}{1 + 1.7 \cdot gv \cdot Ig(z)}$

$Gf(h, v1) = 1.144$ $Gf(h, v2) = 0.972$

Direct Wind Load on Tower:

Forced Coefficient:
Table 6-10 of ASCE-7-98

$d(hc) \cdot \sqrt{\frac{q(hc, v1)}{psf}} = 143.177\,ft$ $d(hc) \cdot \sqrt{\frac{q(hc, v2)}{psf}} = 66.939\,ft$ > 2.5ft

$$Cf(x) := \begin{cases} \left[\frac{0.6-0.5}{7-1}\cdot(x-1)+0.5\right] & \text{if } 1 \le x < 7 \\ \left[\frac{0.7-0.6}{25-7}\cdot(x-7)+0.6\right] & \text{if } 7 \le x \le 25 \\ 0.7 & \text{if } x > 25 \end{cases}$$

For Smooth Surface

$Cf\left(\frac{h}{d(hc)}\right) = 0.644$ $\qquad \frac{h}{d(hc)} = 14.9$

Distributed Forces Along the Tower: $Fw(z,v) := q(z,v)\cdot Gf(z,v)\cdot Cf\left(\frac{h}{d(z)}\right)\cdot d(z)$

Shear Force along the Tower: $Vzw(z,v) := \int_z^h Fw(x,v)\,dx$

$Vzw(z0,v1) = 947\,kN$	$Vzw(z0,v1) = 212.9\,kips$
$Vzw(hc,v1) = 471\,kN$	$Vzw(hc,v1) = 105.8\,kips$
$Vzw(z0,v2) = 174\,kN$	$Vzw(z0,v2) = 39.2\,kips$
$Vzw(hc,v2) = 87\,kN$	$Vzw(hc,v2) = 19.6\,kips$

Moment along the Tower: $Mzw(z,v) := \int_z^h Fw(x,v)\cdot(x-z)\,dx$

$Mzw(z0,v1) = 46712\,kN\cdot m$	$Mzw(z0,v1) = 34454\,kips\cdot ft$
$Mzw(hc,v1) = 11604\,kN\cdot m$	$Mzw(hc,v1) = 8559\,kips\cdot ft$
$Mzw(z0,v2) = 8625.6\,kN\cdot m$	$Mzw(z0,v2) = 6362\,kips\cdot ft$
$Mzw(hc,v2) = 2149\,kN\cdot m$	$Mzw(hc,v2) = 1585\,kips\cdot ft$

Wind Turbine Load (WindPact Load):

Coordinate Direction: x:= downwind y:= lateral z:= vertical

Wind Turbine Load (No Safety Factor) :	Non-operating Load (EMW50)		Operating Load (EOG50)	
Maximum Wind Load at Top (yaw bearing -100m):				
Maximum Horizontal Thrust:	$FxT1 := 199\cdot kN$	$FxT1 = 45\,kips$	$FxT2 := 1057\cdot kN$	$FxT2 = 238\,kips$
	$FyT1 := 543\cdot kN$	$FyT1 = 122\,kips$	$FyT2 := 128\cdot kN$	$FyT2 = 29\,kips$
	$FzT1 := 4998\cdot kN$	$FzT1 = 1124\,kips$	$FzT2 := 4879\cdot kN$	$FzT2 = 1097\,kips$
Maximum Horizontal Moment:	$MxT1 := 21820\cdot kN\cdot m$	$MxT1 = 16094\,kips\cdot ft$	$MxT2 := 5822\cdot kN\cdot m$	$MxT2 = 4294\,kips\cdot ft$
	$MyT1 := 18440\cdot kN\cdot m$	$MyT1 = 13601\,kips\cdot ft$	$MyT2 := 18440\cdot kN\cdot m$	$MyT2 = 13601\,kips\cdot ft$
	$MzT1 := 5834\cdot kN\cdot m$	$MzT1 = 4303\,kips\cdot ft$	$MzT2 := 3714\cdot kN\cdot m$	$MzT2 = 2739\,kips\cdot ft$
Maximum Wind Load at Base (0m):				
	$MxB1 := 133961\cdot kN\cdot m$	$MxB1 = 98807\,kips\cdot ft$	$MxB2 := 54370\cdot kN\cdot m$	$MxB2 = 40102\,kips\cdot ft$
	$MyB1 := 41916\cdot kN\cdot m$	$MyB1 = 30916\,kips\cdot ft$	$MyB2 := 135000\cdot kN\cdot m$	$MyB2 = 99573\,kips\cdot ft$
	$MzB1 := 5603\cdot kN\cdot m$	$MzB1 = 4133\,kips\cdot ft$	$MzB2 := 3966\cdot kN\cdot m$	$MzB2 = 2925\,kips\cdot ft$
Fatigue Thrust Range:	$\Delta FxT := 197\cdot kN$	$\Delta FxT = 44\,kips$	$\Delta MzT := 3483\cdot kN\cdot m$	$\Delta MzT = 2569\,kips\cdot ft$
Fatigue Applied Moment Range:	$\Delta MxT := 722\cdot kN\cdot m$	$\Delta MxT = 533\,kips\cdot ft$	$\Delta MyT := 3616\cdot kN\cdot m$	$\Delta MyT = 2667\,kips\cdot ft$
	$\Delta MxB := 14151\cdot kN\cdot m$	$\Delta MxB = 10437\,kips\cdot ft$	$\Delta MyB := 29894\cdot kN\cdot m$	$\Delta MyB = 22049\,kips\cdot ft$
Turbine offset in Vertical Direction:	$offset := 0\cdot m$	$offset = 0\,ft$		

Turbine Wind Load on Tower:

Moment (Linear Interpolation):

$$Mxwt1(z) := \frac{MxT1 - MxB1}{h} \cdot z + MxB1 \qquad Mxwt2(z) := \frac{MxT2 - MxB2}{h} \cdot z + MxB2$$

$$Mywt1(z) := \frac{MyT1 - MyB1}{h} \cdot z + MyB1 \qquad Mywt2(z) := \frac{MyT2 - MyB2}{h} \cdot z + MyB2$$

$$Mwt1(z) := \sqrt{Mxwt1(z)^2 + Mywt1(z)^2} \qquad Mwt2(z) := \sqrt{Mxwt2(z)^2 + Mywt2(z)^2}$$

$$Mzwt1(z) := \frac{MzT1 - MzB1}{h} \cdot z + MzB1 \qquad Mzwt2(z) := \frac{MzT2 - MzB2}{h} \cdot z + MzB2$$

$$\Delta Mxwt(z) := \frac{\Delta MxT - \Delta MxB}{h} \cdot z + \Delta MxB \qquad \Delta Mywt(z) := \frac{\Delta MyT - \Delta MyB}{h} \cdot z + \Delta MyB$$

$$\Delta Mwt(z) := \max(\Delta Mxwt(z), \Delta Mywt(z))$$

Moment (Thrust from Wind Turbine):

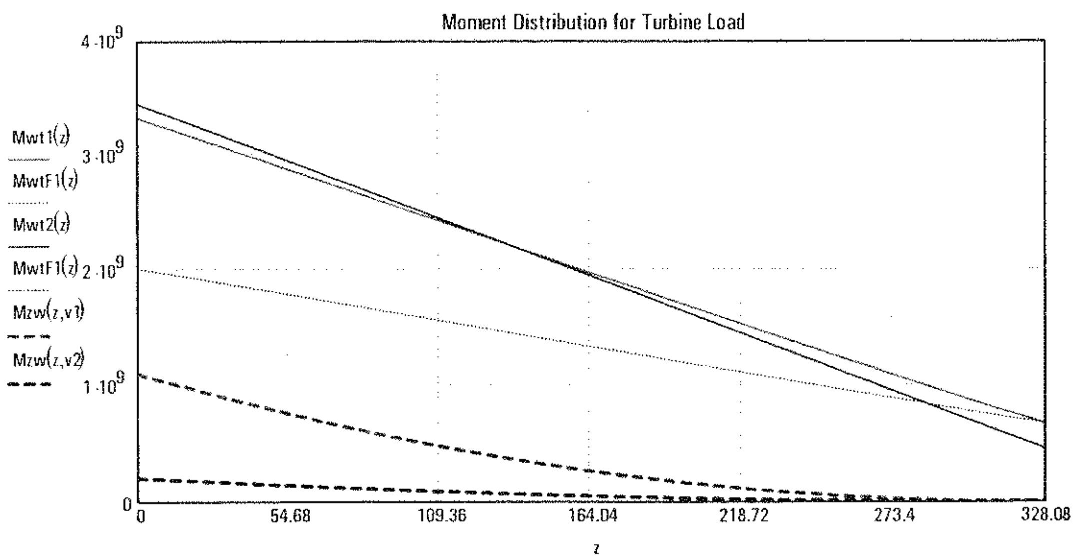
$$MxwtF1(z) := MxT1 + FyT1 \cdot (h + offset - z) \qquad MxwtF2(z) := MxT2 + FyT2 \cdot (h + offset - z)$$

$$MywtF1(z) := MyT1 + FxT1 \cdot (h + offset - z) \qquad MywtF2(z) := MyT2 + FxT2 \cdot (h + offset - z)$$

$$MwtF1(z) := \sqrt{MxwtF1(z)^2 + MywtF1(z)^2} \qquad MwtF2(z) := \sqrt{MxwtF2(z)^2 + MywtF2(z)^2}$$

$$\Delta MxwtF(z) := \Delta MxT \qquad \Delta MywtF(z) := \Delta MyT + \Delta FxT \cdot (h + offset - z)$$

$$\Delta MwtF(z) := \Delta MywtF(z)$$



$$\frac{MwtF1(z0)}{Mwt1(z0)} = 0.607 \qquad \frac{MwtF2(z0)}{Mwt2(z0)} = 0.863 \qquad \frac{\Delta MwtF(z0)}{\Delta Mwt(z0)} = 0.78$$

Wind Load Combination:

Load Factor for Ultimate Load:

$\gamma DL := 1.2$ *Dead Load*

$\gamma WL := 1.6$ *Wind Load*

$\gamma SF := 1.35$ Partial Safety Factor (Wind Energy Hand Book p213):

Ultimate Load (ASCE7-98 Load Combination)

$PuT := (FzT1 - HeadWeight)\cdot\gamma SF + \gamma DL\cdot HeadWeight$

$PuD(xz) := \gamma DL\cdot(Wz(xz) + if(xz < hc, Wcc, 0\cdot kips))$

$VuT := \sqrt{FxT1^2 + FyT1^2}\cdot\gamma SF$

$VuD(xz) := \gamma WL\cdot Vzw(xz, v1)$

$MuTx(xz) := \gamma SF\cdot Mxwt1(xz)$

$MuTy(xz) := \gamma SF\cdot Mywt1(xz)$

$MuT(xz) := \sqrt{MuTx(xz)^2 + MuTy(xz)^2}$

$MuD(xz) := \gamma WL\cdot Mzw(xz, v1)$

$Pu(xz) := PuT + PuD(xz)$

$Vu(xz) := \sqrt{(FxT1\cdot\gamma SF + VuD(xz))^2 + (FyT1\cdot\gamma SF)^2}$

$Mu(xz) := \sqrt{(MuTy(xz) + MuD(xz))^2 + MuTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PuT = 6041 kN	PuD(xz) = 6398 kN	Pu(xz) = 12439 kN
VuT = 781 kN	VuD(xz) = 1515 kN	Vu(xz) = 1928 kN
MuT(xz) = 189494 kN·m	MuD(xz) = 74739 kN·m	Mu(xz) = 223500 kN·m
Pu(xz) = 2796 kips	PuD(xz) = 1438 kips	Pu(xz) = 2796 kips
VuT = 176 kips	VuD(xz) = 341 kips	Vu(xz) = 434 kips
MuT(xz) = 139766 ft kips	MuD(xz) = 55126 ft kips	Mu(xz) = 164849 ft kips

$xz := hc$

at base of steel tower

PuT = 6041 kN	PuD(xz) = 2406 kN	Pu(xz) = 8447 kN
VuT = 781 kN	VuD(xz) = 753 kN	Vu(xz) = 1258 kN
MuT(xz) = 114295 kN·m	MuD(xz) = 18567 kN·m	Mu(xz) = 122199 kN·m
Pu(xz) = 1899 kips	PuD(xz) = 541 kips	Pu(xz) = 1899 kips
VuT = 176 kips	VuD(xz) = 169 kips	Vu(xz) = 283 kips
MuT(xz) = 84302 ft kips	MuD(xz) = 13694 ft kips	Mu(xz) = 90132 ft kips

Service Load (Unfactored Wind Load)

$PsT := FzT1$

$v1 = 47.29\frac{m}{sec}$

$PsD(xz) := Wz(xz) + if(xz < hc, Wcc, 0\cdot kips)$

$VsT := \sqrt{FxT1^2 + FyT1^2}$

$VsD(xz) := Vzw(xz, v1)$

$MsTx(xz) := Mxwt1(xz)$

$MsTy(xz) := Mywt1(xz)$

$MsT(xz) := \sqrt{MsTx(xz)^2 + MsTy(xz)^2}$

$MsD(xz) := Mzw(xz, v1)$

$Ps(xz) := PsT + PsD(xz)$

$Vs(xz) := \sqrt{(FxT1 + VsD(xz))^2 + (FyT1)^2}$

$Ms(xz) := \sqrt{(MsTy(xz) + MsD(xz))^2 + MsTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PsT = 4998 kN	PsD(xz) = 5331 kN	Ps(xz) = 10329 kN
VsT = 578 kN	VsD(xz) = 947 kN	Vs(xz) = 1268 kN
MsT(xz) = 140366 kN·m	MsD(xz) = 46712 kN·m	Ms(xz) = 160625 kN·m

Ps(xz) = 2322kips	PsD(xz) = 1199kips	Ps(xz) = 2322kips
VsT = 130kips	VsD(xz) = 213kips	Vs(xz) = 285kips
MsT(xz) = 103531ftkips	MsD(xz) = 34454ftkips	Ms(xz) = 118474ftkips

$xz := hc$

at base of steel tower

PsT = 4998kN	PsD(xz) = 2005kN	Ps(xz) = 7003kN
VsT = 578kN	VsD(xz) = 471kN	Vs(xz) = 862kN
MsT(xz) = 84663kN·m	MsD(xz) = 11604kN·m	Ms(xz) = 89489kN·m
Ps(xz) = 1574kips	PsD(xz) = 451kips	Ps(xz) = 1574kips
VsT = 130kips	VsD(xz) = 106kips	Vs(xz) = 194kips
MsT(xz) = 62446ftkips	MsD(xz) = 8559ftkips	Ms(xz) = 66005ftkips

Operation Load at 35m/sec

$v2 = 22.109\frac{m}{sec}$

$PoT := FzT2$

$PoD(xz) := Wz(xz) + if(xz < hc, Wcc, 0\cdot kips)$

$VoT := \sqrt{FxT2^2 + FyT2^2}$

$VoD(xz) := Vzw(xz, v2)$

$MoTx(xz) := Mxwt2(xz)$

$MoTy(xz) := Mywt2(xz)$

$MoT(xz) := \sqrt{MoTx(xz)^2 + MoTy(xz)^2}$

$MoD(xz) := Mzw(xz, v2)$

$Po(xz) := PoT + PoD(xz)$

$Vo(xz) := \sqrt{(FxT2 + VoD(xz))^2 + (FyT2)^2}$

$Mo(xz) := \sqrt{(MoTy(xz) + MoD(xz))^2 + MoTx(xz)^2}$

$xz := 0\cdot m$

at base of concrete tower

PoT = 4879kN	PoD(xz) = 5331kN	Po(xz) = 10210kN
VoT = 1065kN	VoD(xz) = 174kN	Vo(xz) = 1238kN
MoT(xz) = 145537kN·m	MoD(xz) = 8626kN·m	Mo(xz) = 153572kN·m
Po(xz) = 2295kips	PoD(xz) = 1199kips	Po(xz) = 2295kips
VoT = 239kips	VoD(xz) = 39kips	Vo(xz) = 278kips
MoT(xz) = 107345ftkips	MoD(xz) = 6362ftkips	Mo(xz) = 113272ftkips

$xz := hc$

at base of steel tower

PoT = 4879kN	PoD(xz) = 2005kN	Po(xz) = 6884kN
VoT = 1065kN	VoD(xz) = 87kN	Vo(xz) = 1151kN
MoT(xz) = 83674kN·m	MoD(xz) = 2149kN·m	Mo(xz) = 85678kN·m
Po(xz) = 1548kips	PoD(xz) = 451kips	Po(xz) = 1548kips
VoT = 239kips	VoD(xz) = 20kips	Vo(xz) = 259kips
MoT(xz) = 61716ftkips	MoD(xz) = 1585ftkips	Mo(xz) = 63194ftkips

Fatigue Load - Damage Equivalent Load

Fatigue Safety Factor: $\gamma f := 1$

$Pf(xz) := Wz(xz) + HeadWeight + if(xz < hc, Wcc, 0\cdot kips)$

$Vf(xz) := \Delta FxT\cdot\gamma f$

$Mf(xz) := \Delta Mwt(xz)\cdot\gamma f$

$xz := 0\cdot m$

at base of concrete tower

Pf(xz) = 10039kN	Pf(xz) = 2257kips
Vf(xz) = 197kN	Vf(xz) = 44kips
Mf(xz) = 29894kN·m	Mf(xz) = 22049ftkips

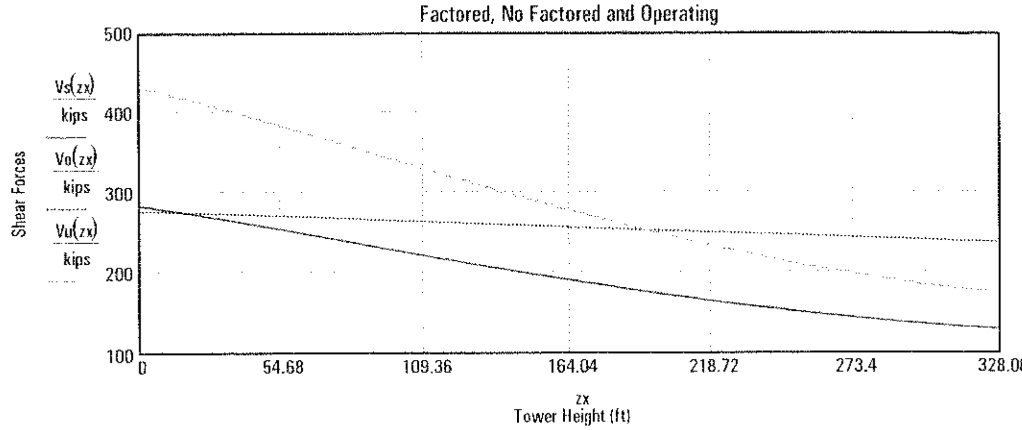
$xz := hc$

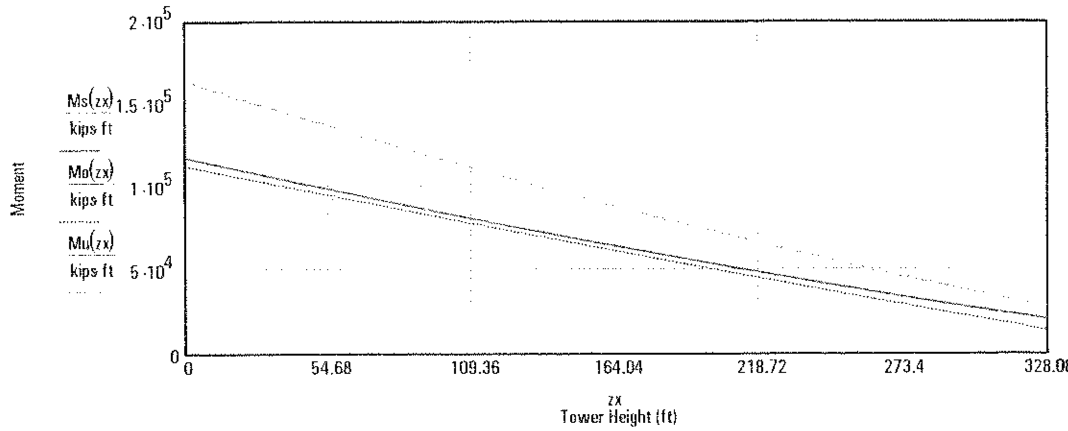
at base of steel tower

Pf(xz) = 6713kN	Pf(xz) = 1509kips
Vf(xz) = 197kN	Vf(xz) = 44kips
Mf(xz) = 17018kN·m	Mf(xz) = 12552ftkips

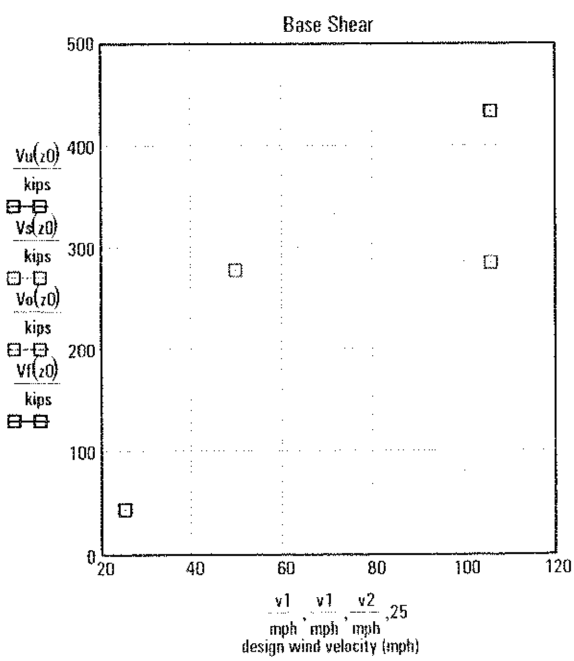
Ratio of Ultimate Load for Seismic/Wind

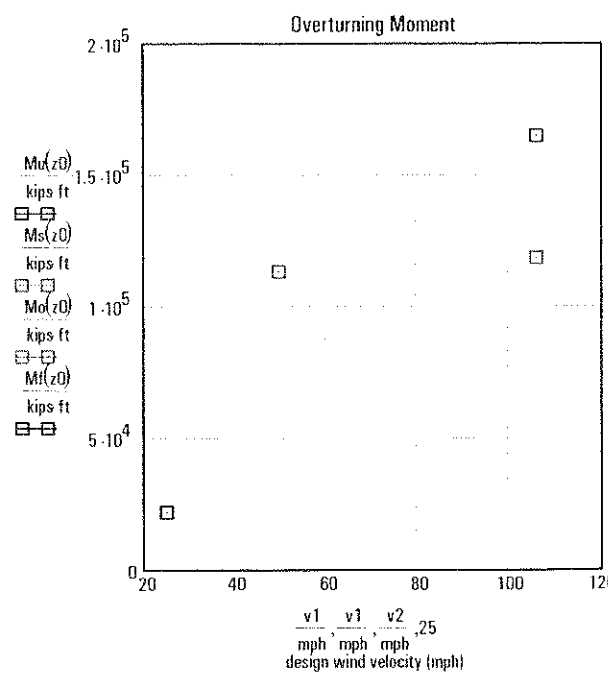
$$\frac{Vzq(z0)}{Vu(z0)} = 1.447 \qquad \frac{Mzq(z0)}{Mu(z0)} = 0.925$$





Design Wind Load Comparison Diagram





Deflection for Wind Load at Top of Tower

Wind Speed for 60m/sec (133mph)

$$\Delta ws(z) := \int_0^z \frac{Ms(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vs(z0)}{Kh} + \frac{Ms(z0)}{Kr}\cdot z$$

$WDisT := \Delta ws(h)$ $\quad WDisT = 0.608\,m$ $\quad WDisT = 1.994\,ft$ $\quad \frac{h}{WDisT} = 165$

$WDisM := \Delta ws(hc)$ $\quad WDisM = 0.15\,m$ $\quad WDisM = 0.492\,ft$ $\quad \frac{hc}{WDisM} = 327$

$$\Delta wo(z) := \int_0^z \frac{Mo(x)}{E(x)\cdot I(x)}\cdot(z-x)\,dx + \frac{Vo(z0)}{Kh} + \frac{Mo(z0)}{Kr}\cdot z$$

$\Delta wo(h) = 1.891\,ft$ $\quad \Delta wo(h) = 0.576\,m$

Moment Magnification Factor

at Base: $\delta swb := \dfrac{1}{1 - \dfrac{Pu(z0)}{Pcr(z0)}}$ $\quad \delta swb = 1.043$

at Height of hc: $\delta swt := \dfrac{1}{1 - \dfrac{Pu(hc)}{Pcr(z0)}}$ $\quad \delta swt = 1.029$

P-Δ Effect

Moment of Tower due to Gravity Load for P-Δ effect :

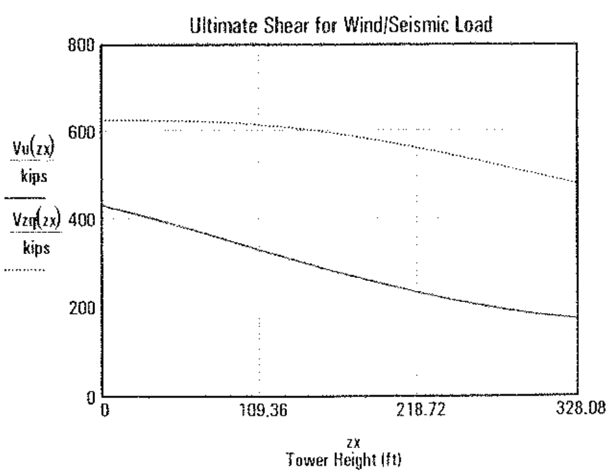
$$Mwg(z) := (WDisT - \Delta ws(z))\cdot HeadWeight + \int_z^h wt(y)\cdot(\Delta ws(y) - \Delta ws(z))\,dy + Wcc\cdot if[z < hc, (WDisM - \Delta ws(z)), 0\cdot m]$$

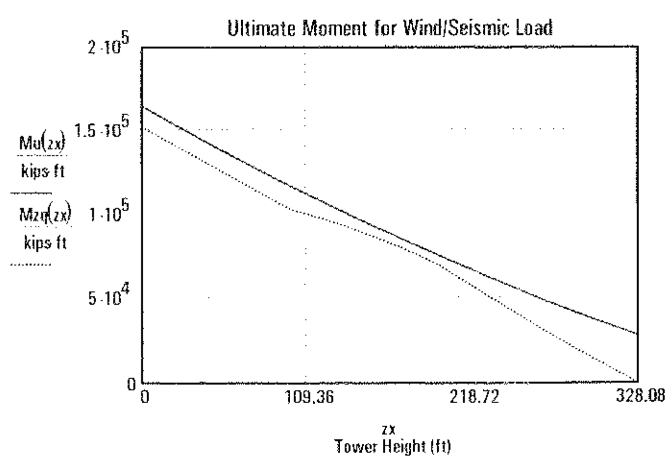
Approx. Method of Moment at Base for P-Δ effect :

$$Mwgb := \Delta ws(h)\cdot HeadWeight + Wcc\cdot\Delta ws(hc) + Wz(hc)\cdot\Delta ws\left(\frac{h+hc}{2}\right) + (Wz(z0) - Wz(hc))\cdot\Delta ws\left(\frac{hc}{2}\right)$$

$\delta wb := \dfrac{Mwgb}{Ms(z0)} + 1$ $\quad \delta wb = 1.023$

Ultimate Design Forces for Wind/Earthquake Load





Across Wind Load: Only First Mode is Examined

Wind Speed at Cristical Height: $zcr := \frac{5}{6} \cdot h$

Hourly Mean Design Speed (ASCE-7): $Vw(zcr, v1) = 70 \frac{m}{sec}$ $Vw(zcr, v1) = 157\,mph$

$Vw(zcr, v2) = 33 \frac{m}{sec}$ $Vw(zcr, v2) = 73\,mph$

Mean Outside Diameter: $du := d\left(\frac{2}{3} \cdot h\right)$ $du = 6\,m$ $du = 19.6\,ft$

Strouhal Number: $St := 0.25 \cdot \left(0.333 + 0.206 \cdot \ln\left(\frac{h}{du}\right)\right)$ $St = 0.228$

Critical Speed at zcr: $Vcr := \frac{Fq \cdot du}{St}$ $Vcr = 10.376 \frac{m}{sec}$ $Vcr = 23.211\,mph$

Conclusion: $DCRa(v) := \frac{Vcr}{Vw(zcr, v)}$ Across wind need not be considered if DCRa <0.5 or >1.3

$DCRa(v1) = 0.148$ $DCRa(v2) = 0.316$

Steel Tower Design Analysis (ASD-Method)

$z := z0$

Applied Stress for Wind:

Axial Stress: $fa(z) := \frac{Ps(z)}{Ac(z)}$ $fa(z) = 10.23\,MPa$ $fa(z) = 1.48\,ksi$

Bendind Stress: $fb(z) := \frac{Ms(z)}{S(z)}$ $fb(z) = 72.6\,MPa$ $fb(z) = 10.53\,ksi$

Shear Stress: $fv(z) := \frac{Vs(z)}{\pi \cdot R(z) \cdot t(z)}$ $fv(z) = 2.51\,MPa$ $fv(z) = 0.36\,ksi$

Shear Stress for Torsion: $fvt(z) := \frac{Mzwt1(z) \cdot d(z)}{4 \cdot I(z)}$ $fvt(z) = 1.27\,MPa$ $fvt(z) = 0.18\,ksi$

Max Normal Stress: $fa(z) + fb(z) = 82.8\,MPa$ $fa(z) + fb(z) = 12\,ksi$

Max Shear Stress: $fv(z) + fvt(z) = 3.8\,MPa$ $fv(z) + fvt(z) = 0.548\,ksi$

Combined Stress: $\sigma w(z) := \sqrt{(fa(z) + fb(z))^2 + 3 \cdot (fv(z) + fvt(z))^2}$

$\sigma w(z) = 83.1\,MPa$ $\sigma w(z) = 12\,ksi$

Applied Stress for Earthquake:

Axial Stress: $faq(z) := \frac{Wz(z) + HeadWeight + Wcc}{Ac(z)}$ $faq(z) = 9.94\,MPa$ $faq(z) = 1.44\,ksi$

Bendind Stress: $fbq(z) := \frac{0.7\,Mzq(z)}{S(z)}$ $fbq(z) = 65.36\,MPa$ $fbq(z) = 9.48\,ksi$

Shear Stress: $fvq(z) := \frac{0.7\,Vzq(z)}{\pi \cdot R(z) \cdot t(z)}$ $fvq(z) = 3.87\,MPa$ $fvq(z) = 0.56\,ksi$

Max Normal Stress: $faq(z) + fbq(z) = 75.3\,MPa$ $\quad faq(z) + fbq(z) = 10.9\,ksi$

Combined Stress: $\sigma q(z) := \sqrt{(faq(z) + fbq(z))^2 + 3 \cdot (fv(z))^2}$ $\quad \sigma q(z) = 75.4\,MPa$ $\quad \sigma q(z) = 10.9\,ksi$

Allowable Stress:

Allowable Bending Stress: $Fb := 0.6 \cdot fy$ $\quad Fb = 206.8\,MPa$ $\quad Fb = 30\,ksi$

Allowable Shear Stress: $Fv := 0.4 \cdot fy$ $\quad Fv = 137.9\,MPa$ $\quad Fv = 20\,ksi$

Allowable Compression Stress: $k := 2$ $\quad r(z) := \sqrt{\frac{I(z)}{Ac(z)}}$

$kLr := \frac{k \cdot (h - hc)}{r(hc)}$ $\quad kLr = 43.2$ $\quad Cc := \sqrt{\frac{2 \cdot \pi^2 \cdot Es}{fy}}$

$$Fa := \begin{cases} \dfrac{\left(1 - \dfrac{kLr^2}{2 \cdot Cc^2}\right) \cdot fy}{\dfrac{5}{3} + \dfrac{3 \cdot kLr}{8 \cdot Cc} - \dfrac{kLr^3}{8 \cdot Cc^3}} & \text{if } kLr \le Cc \\ \dfrac{12 \cdot \pi^2 \cdot Es}{23 \cdot kLr^2} & \text{otherwise} \end{cases}$$

$r(z) = 3.112\,m$

$r(z) = 122.5\,in$

$Cc = 106.1$

$Fa = 174.5\,MPa$

$Fa = 25.3\,ksi$

Unity Check for Wind Load: $\frac{fa(z)}{Fa} = 0.059$ $\quad \frac{fv(z) + fvt(z)}{Fv} = 0.027$

Combine Stress Ratio for fa/Fa <0.15 $\quad DCRsw(z) := \frac{fa(z)}{Fa} + \frac{fb(z)}{Fb} \cdot \delta swb$ $\quad DCRsw(z) = 0.425$

Unity Check for Earthquake Load: $\frac{faq(z)}{Fa} = 0.057$ $\quad \frac{fvq(z)}{Fv} = 0.028$

Combine Stress Ratio for fa/Fa <0.15 $\quad DCRsq(z) := \frac{faq(z)}{Fa} + \frac{fbq(z)}{Fb} \cdot \delta sqb$ $\quad DCRsq(z) = 0.39$

Buckling Stress (wind energy hand book):

Elastic Tube Buckling Stress: $\sigma cr(z) := 0.605 \cdot Es \cdot \frac{t(z)}{R(z)}$ $\quad \sigma cr(z) = 986\,MPa$ $\quad \sigma cr(z) = 143\,ksi$

Reduction Coefficient for Axial

$$\alpha 0(z) := \begin{cases} \dfrac{0.83}{\sqrt{1 + 0.01 \cdot \dfrac{R(z)}{t(z)}}} & \text{if } \dfrac{R(z)}{t(z)} < 212 \\ \dfrac{0.7}{\sqrt{0.1 + 0.01 \cdot \dfrac{R(z)}{t(z)}}} & \text{if } \dfrac{R(z)}{t(z)} \ge 212 \end{cases}$$

$\alpha 0(z) = 0.559$

Reduction Coefficient for Bending $\quad \alpha B(z) := 0.1887 + 0.8113 \cdot \alpha 0(z)$ $\quad \alpha B(z) = 0.642$

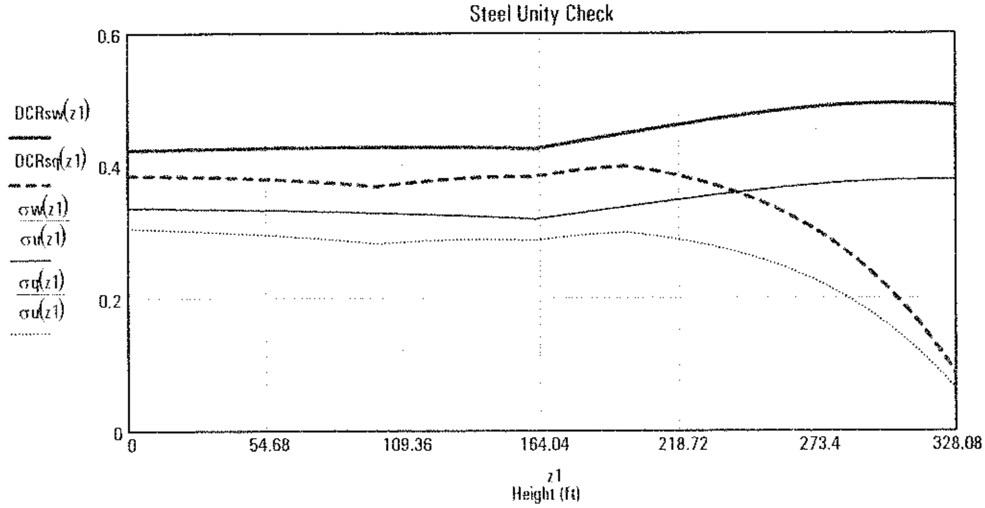
Combined Buckling Stress

$$\sigma u(z) := \begin{cases} fy \cdot \left[1 - 0.4123 \cdot \left(\dfrac{fy}{\alpha B(z) \cdot \sigma cr(z)}\right)^{0.6}\right] & \text{if } \alpha B(z) \cdot \sigma cr(z) > \dfrac{fy}{2} \\ 0.75 \cdot \alpha B(z) \cdot \sigma cr(z) & \text{if } \alpha B(z) \cdot \sigma cr(z) \le \dfrac{fy}{2} \end{cases}$$

$\sigma u(z) = 246.1\,\text{MPa}$ $\sigma u(z) = 35.7\,\text{ksi}$ $\frac{\sigma u(z)}{fy} = 0.714$

Combined Buckling Stress Ratio $\frac{\sigma w(z)}{\sigma u(z)} = 0.338$ $\frac{\sigma q(z)}{\sigma u(z)} = 0.307$

Buckling Unity Check Diagram:



$DCRswmax = 0.494$ $DCRsqmax = 0.4$ $DCRbwmax = 0.379$ $DCRbqmax = 0.304$

Steel Fatigue Design:

Design Cycle: $N1 := 5.29\cdot 10^{8}$ $\gamma ss := 1.265$ $\Delta\sigma y := 301\cdot\text{MPa}$

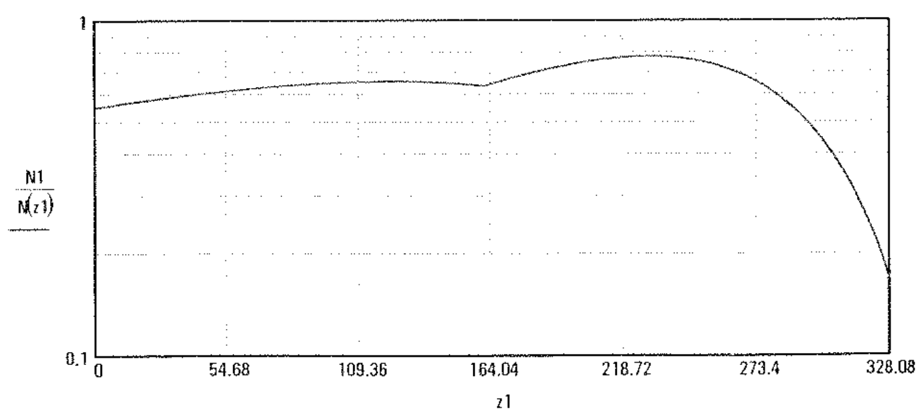
Initial Cycle without Degradation: $N0 := 10000$ Slope Rate: $n := 4$

Yielding Moment: $Mfs(z) := \Delta\sigma y\cdot S(z)$ $Mfs(z0) = 491288.9\,\text{kips}\cdot\text{ft}$ $Mfs(z0) = 666083.7\,\text{kN}\cdot\text{m}$

Extrapolated Yielding Moment: $Mss(z) := Mfs(z)\cdot\sqrt[n]{N0}$ $\sqrt[n]{N0} = 10$

Number of Cycle at Applied Moment: $N(z) := \left(\frac{Mf(z)\cdot\gamma ss}{Mss(z)}\right)^{-n}$ $N(z0) = 9.625\times 10^{8}$ $Mf(z) = 29894\,\text{kN}\cdot\text{m}$

$DCRfat = 0.78$



Moment Magnification Factors $\delta swb = 1.043$ $\delta sqb = 1.042$

P-Δ factors $\delta wb = 1.023$ $\delta qb = 1.022$

Concrete Spread Footing Design

Footing Area: $Af := B \cdot L$ $Af = 417\,m^2$ $Af = 4489\,ft^2$

Footing Weight: $Wft := Af \cdot D \cdot \rho c$ $Wft = 35942\,kN$ $Wft = 8080\,kips$

Footing Section Modulus: $Sft := \frac{1}{6} \cdot B \cdot L^2$

Service Load for Wind:

soil pressure under wind load: $Pft := Ps(z0) + \rho c \cdot D \cdot Af$ $Pft = 46271\,kN$ $Pft = 10402\,kips$

Eccentricity: $eft := \frac{Ms(z0)}{Pft}$ $eft = 3.471\,m$ $eft = 11.389\,ft$

Soil Pressure: $pmax := \frac{Pft}{Af} + \frac{Ms(z0)}{Sft}$ $pmax = 0.224\,MPa$ $pmax = 4681\,psf$

$pmin := \frac{Pft}{Af} - \frac{Ms(z0)}{Sft}$ $pmin = -0.002\,MPa$ $pmin = -46\,psf$

$$ptmax := \begin{cases} pmax & \text{if } pmin > 0 \\ \frac{2 \cdot Pft}{3 \cdot B \cdot \left(\frac{L}{2} - eft\right)} & \text{otherwise} \end{cases}$$

$ptmax = 0.224\,MPa$ $ptmax = 4681\,psf$

DCR for Soil Pressure: $DCRsoilw := \frac{ptmax}{cso}$ $DCRsoilw = 0.78$ $\frac{eft}{L} = 0.17$

Depth of Footing for Shear Capacity:
(One way action):

$$p := \frac{pmax - pmin}{L} \cdot \left(\frac{L}{2} + \frac{d(z0)}{2} + D\right) + pmin$$

Shear Force due to Soil Pressure:

$$Vpft := \frac{p + pmax}{2} \cdot \left[\frac{L}{2} - \left(\frac{d(z0)}{2} + D\right)\right] \cdot B \cdot \gamma WL$$

$Vpft = 14800\,kN$ $Vpft = 3327\,kips$

Shear Capacity of Concrete Footing: $Vcft := 0.85 \cdot 2 \cdot \sqrt{\frac{fcft}{ksi} \cdot 1000} \cdot psi \cdot B \cdot D$ $Vcft = 55370\,kN$ $Vcft = 12448\,kips$

DCR for Shear Capacity: $DCRvftw := \frac{Vpft}{Vcft}$ $DCRvftw = 0.267$

Bending Moment at Face of Footing:

$$Mpft := \left[p \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B + \frac{pmax - p}{3} \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B^l\right] \cdot \gamma WL$$

$Mpft = 14204\,kN \cdot m$ $Mpft = 10477\,kips \cdot ft$

Bending Reinforcement Ratio Required:

$$\rho ft := \frac{0.85 \cdot fcft}{60\,ksi} \left(1 - \sqrt{1 - \frac{2 \cdot Mpft}{0.85 \cdot fcft \cdot B \cdot D^2 \cdot 0.7}}\right)$$

$\rho ft = 0.00018$

$Asft := \max(\rho ft, 0.0018) \cdot B \cdot D$ $Asft = 1344.5\,cm^2$ $Asft = 208.4\,in^2$

The Reinforcement Weight: $2Asft \cdot L \cdot \rho s = 43101\,kgf$ $2Asft \cdot L \cdot \rho s = 95\,kips$

Ultimate Load forEQ:

soil pressure under EQ load: $Pftq := Pu(z0) + \rho c \cdot D \cdot Af \cdot \gamma DL$ $Pftq = 55569\,kN$ $Pftq = 12493\,kips$

Eccentricity: $eftq := \frac{Mzq(z0)}{Pftq}$ $eftq = 3.718\,m$ $eftq = 12.199\,ft$

Soil Pressure: $pmaxq := \frac{Pftq}{Af} + \frac{Mzq(z0)}{Sft}$ $pmaxq = 0.279\,MPa$ $pmaxq = 5823\,psf$

$pminq := \frac{Pftq}{Af} - \frac{Mzq(z0)}{Sft}$ $pminq = -0.012\,MPa$ $pminq = -257\,psf$

$$ptmaxq := \begin{cases} pmaxq & \text{if } pminq > 0 \\ \dfrac{2 \cdot Pftq}{3 \cdot B \cdot \left(\dfrac{L}{2} - eftq\right)} & \text{otherwise} \end{cases}$$

$ptmaxq = 0.279\,MPa$ $ptmaxq = 5836\,psf$

DCR for Soil Pressure: $DCRsoilq := \frac{ptmaxq}{cso \cdot \gamma soq}$ $DCRsoilq = 0.486$ $\frac{eftq}{L} = 0.182$

Govern Design: if(DCRsoilq > DCRsoilw, "Seismic Load Control", "Wind Load Control") = "Wind Load Control"

Depth of Footing for Shear Capacity:
(One way action):

$$pq := \frac{pmaxq - pminq}{L} \cdot \left(\frac{L}{2} + \frac{d(z0)}{2} + D\right) + pminq$$

Shear Force due to Soil Pressure:

$$Vpftq := \frac{pq + pmaxq}{2} \cdot \left[\frac{L}{2} - \left(\frac{d(z0)}{2} + D\right)\right] \cdot B$$

$Vpftq = 11486\,kN$ $Vpftq = 2582\,kips$

DCR for Shear Capacity: $DCRvftq := \frac{Vpftq}{Vcft}$ $DCRvftq = 0.207$

Bending Moment at Face of Footing:

$$Mpftq := pq \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B + \frac{pmaxq - pq}{3} \cdot \left(\frac{L}{2} - R1\right)^2 \cdot B$$

$Mpftq = 11016\,kN \cdot m$ $Mpftq = 8125\,kips \cdot ft$

Bending Reinforcement Ratio Required:

$$\rho ftq := \frac{0.85 \cdot fcft}{60\,ksi} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot Mpftq}{0.85 \cdot fcft \cdot B \cdot D^2 \cdot 0.7}}\right)$$

$\rho ftq = 0.00014$

$Asftq := \max(\rho ftq, 0.0018) \cdot B \cdot D$ $Asftq = 1344.5\,cm^2$ $Asftq = 208.4\,in^2$

The Reinforcement Weight: $2Asftq \cdot L \cdot \rho s = 43101\,kgf$ $2Asftq \cdot L \cdot \rho s = 95\,kips$

Results Summary:

Total Structure Weight:	W = 10039kN	W = 2257kips
Steel Tower Weight:	Wz(z0) = 5282kN	Wz(z0) = 1188kips
Natural Frequency:	Fq = 0.397Hz	$\frac{1}{Fq}$ = 2.517sec

Tower Forces for Earthquake Load:

Shear Force at Base:	Vzq(z0) = 2791kN	Vzq(z0) = 627kips
Shear Force at hc:	Vzq(hc) = 2658kN	Vzq(hc) = 598kips
Overturning Moment at Base:	Mzq(z0) = 206628kN·m	Mzq(z0) = 152404ftkips
Overturning Moment at hc:	Mzq(hc) = 114280kN·m	Mzq(hc) = 84291ftkips
Deflection at Top:	QDisT = 0.736m	QDisT = 2.413ft

Tower Forces for Wind Load:

Ultimate Wind Load:

xz := 0·m	Pu(xz) = 12439kN	Pu(xz) = 2796kips
at base of concrete tower	Vu(xz) = 1928kN	Vu(xz) = 434kips
	Mu(xz) = 223500kN·m	Mu(xz) = 164849ftkips
xz := hc	Pu(xz) = 8447kN	Pu(xz) = 1899kips
at base of steel tower	Vu(xz) = 1258kN	Vu(xz) = 283kips
	Mu(xz) = 122199kN·m	Mu(xz) = 90132ftkips

Service Wind Load:

xz := 0·m	Ps(xz) = 10329kN	Ps(xz) = 2322kips
at base of concrete tower	Vs(xz) = 1268kN	Vs(xz) = 285kips
	Ms(xz) = 160625kN·m	Ms(xz) = 118474ftkips
xz := hc	Ps(xz) = 7003kN	Ps(xz) = 1574kips
at base of steel tower	Vs(xz) = 862kN	Vs(xz) = 194kips
	Ms(xz) = 89489kN·m	Ms(xz) = 66005ftkips

Operation Wind Load:

xz := 0·m	Po(xz) = 10210kN	Po(xz) = 2295kips
at base of concrete tower	Vo(xz) = 1238kN	Vo(xz) = 278kips
	Mo(xz) = 153572kN·m	Mo(xz) = 113272ftkips
xz := hc	Po(xz) = 6884kN	Po(xz) = 1548kips
at base of steel tower	Vo(xz) = 1151kN	Vo(xz) = 259kips
	Mo(xz) = 85678kN·m	Mo(xz) = 63194ftkips

Fatigue Load:

xz := 0·m	Pf(xz) = 10039kN	Pf(xz) = 2257kips
at base of concrete tower	Vf(xz) = 197kN	Vf(xz) = 44kips
	Mf(xz) = 29894kN·m	Mf(xz) = 22049ftkips
xz := hc	Pf(xz) = 6713kN	Pf(xz) = 1509kips
at base of steel tower	Vf(xz) = 197kN	Vf(xz) = 44kips
	Mf(xz) = 17018kN·m	Mf(xz) = 12552ftkips
Deflection at Top:	WDisT = 0.608m	WDisT = 1.994ft

Ratio of Ultimate Load for EQ/Wind	$\frac{Vzq(z0)}{Vu(z0)}$ = 1.447	$\frac{Mzq(z0)}{Mu(z0)}$ = 0.925

Steel Tower Stress Check:

Maximum Stress for Wind Load:	DCRswmax = 0.494	DCRbwmax = 0.379
Maximum Stress for EQ Load:	DCRsqmax = 0.4	DCRbqmax = 0.304
Fatigue Ratio:	DCRfat = 0.78	
DCR for Soil Bearing Capacity:	DCRsoilw = 0.78	DCRsoilq = 0.486
DCR for Footing Shear Capacity:	DCRvftw = 0.267	DCRvftq = 0.207
Footing Reinforcement Weight:	2Asft·L·ρs = 43101kgf	2Asft·L·ρs = 95kips

Steel Tower Fatigue Design ------- 5.0MW Tower

Units Conversion:

$kips := 1000 \cdot lbf$ $\quad ksi := \frac{kips}{in^2}$ $\quad psf := \frac{lbf}{ft^2}$ $\quad kN := 1000 \cdot newton$ $\quad MPa := 10^6 \cdot Pa$

Steel Fatigue Properties:

Fatigue Design Life for 20 years: $nf := 5.29 \cdot 10^8$

Steel Material Factor: $\gamma s := 1.15$

Model Factor: $\gamma sd := 1.1$

S-N Curve1: Eurocode 3 Fatigue Strength for Detail Category 71 (Butt-welded Joint (Wind Energy HandBook):

Maximum Stress Range: $\Delta\sigma smax := 414 \cdot MPa$ $\quad \Delta\sigma smax = 60.046\,ksi$

Slope Factor: $N1 := 4$ $\quad N2 := \log(5 \cdot 10^6)$ $\quad N3 := 8$

$m1 := 3$ $\quad m2 := 5$ $\quad m3 := 10$

Stress Range at N-Cycle:

$$\Delta\sigma s1 := 10^{\left(\log\left(\frac{\Delta\sigma smax}{MPa}\right) + \frac{N1 - N2}{m1}\right)} \cdot MPa \qquad \Delta\sigma s1 = 52.161\,MPa \qquad \Delta\sigma s1 = 7.565\,ksi$$

$$\Delta\sigma s2 := 10^{\left(\log\left(\frac{\Delta\sigma s1}{MPa}\right) + \frac{N2 - N3}{m2}\right)} \cdot MPa \qquad \Delta\sigma s2 = 28.651\,MPa \qquad \Delta\sigma s2 = 4.155\,ksi$$

S-N Curve:

$$\Delta\sigma sf(NN) := \begin{cases} \Delta\sigma smax & \text{if } NN < N1 \\ 10^{\left(\log\left(\frac{\Delta\sigma smax}{MPa}\right) + \frac{N1 - NN}{m1}\right)} \cdot MPa & \text{if } N1 \le NN < N2 \\ 10^{\left(\log\left(\frac{\Delta\sigma s1}{MPa}\right) + \frac{N2 - NN}{m2}\right)} \cdot MPa & \text{if } N2 \le NN < N3 \\ \Delta\sigma s2 & \text{if } NN \ge N3 \end{cases}$$

$\Delta\sigma sf(\log(nf)) = 28.651\,MPa$ $\quad \Delta\sigma sf(\log(nf)) = 4.155\,ksi$

$\Delta\sigma sf(\log(2 \cdot 10^6)) = 70.793\,MPa$ $\quad \Delta\sigma sf(\log(2 \cdot 10^6)) = 10.268\,ksi$

Note: if $\Delta\sigma > \Delta\sigma smax$ Fatigue Failure (N=1)
if $\Delta\sigma < \Delta\sigma\sigma 2$ Flat m3=10

$$M(\Delta\sigma) := \begin{cases} 1 & \text{if } \Delta\sigma > \Delta\sigma smax \\ N1 - m1 \cdot \left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma smax}{MPa}\right)\right) & \text{if } \Delta\sigma s1 < \Delta\sigma \le \Delta\sigma smax \\ N2 - m2 \cdot \left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma s1}{MPa}\right)\right) & \text{if } \Delta\sigma s2 \le \Delta\sigma \le \Delta\sigma s1 \\ N3 - m3 \cdot \left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma s2}{MPa}\right)\right) & \text{if } \Delta\sigma < \Delta\sigma s2 \end{cases}$$

S-N Curve2: Use for DEL (m=4) -GEC Curve :

Slope Factor for DEL: $m0 := 4$

Maximum Stress Range: $\Delta\sigma smax2 := 301 \cdot MPa$ $\Delta\sigma smax2 = 43.656\,ksi$

S-N Curve for DEL:

$$\Delta\sigma sf2(NN) := \begin{cases} \Delta\sigma smax2 & \text{if } NN < N1 \\ 10^{\left(\log\left(\frac{\Delta\sigma smax2}{MPa}\right) + \frac{N1-NN}{m0}\right)} \cdot MPa \end{cases}$$

For N=2E6 Δσ=80MPa:

$\Delta\sigma sf2\left(\log\left(2\cdot 10^6\right)\right) = 80.04\,MPa$ $\Delta\sigma sf2\left(\log\left(2\cdot 10^6\right)\right) = 11.609\,ksi$

$\Delta\sigma sf2(\log(nf)) = 19.847\,MPa$ $\Delta\sigma sf2(\log(nf)) = 2.879\,ksi$

$$M2(\Delta\sigma) := N1 - m0\cdot\left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma smax2}{MPa}\right)\right)$$

S-N Curve3: Eurocode 3 Fatigue Strength for Detail Category 80:

Maximum Stress Range: $\Delta\sigma smax3 := 468 \cdot MPa$ $\Delta\sigma smax = 60.046\,ksi$

Stress Range at N-Cycle: $\Delta\sigma s1a := 10^{\left(\log\left(\frac{\Delta\sigma smax3}{MPa}\right) + \frac{N1-N2}{m1}\right)} \cdot MPa$ $\Delta\sigma s1a = 58.964\,MPa$ $\Delta\sigma s1a = 8.552\,ksi$

S-N Curve:

$$\Delta\sigma sf3(NN) := \begin{cases} \Delta\sigma smax3 & \text{if } NN < N1 \\ 10^{\left(\log\left(\frac{\Delta\sigma smax3}{MPa}\right) + \frac{N1-NN}{m1}\right)} \cdot MPa & \text{if } N1 \le NN < N2 \\ 10^{\left(\log\left(\frac{\Delta\sigma s1a}{MPa}\right) + \frac{N2-NN}{m2}\right)} \cdot MPa & \text{if } N2 \le NN \end{cases}$$

$\Delta\sigma sf3(\log(nf)) = 23.211\,MPa$ $\Delta\sigma sf3(\log(nf)) = 3.366\,ksi$

For N=2E6 Δσ=80MPa:

$\Delta\sigma sf3\left(\log\left(2\cdot 10^6\right)\right) = 80.027\,MPa$ $\Delta\sigma sf3\left(\log\left(2\cdot 10^6\right)\right) = 11.607\,ksi$

Note: if $\Delta\sigma > \Delta\sigma smax$ Fatigue Failure (N=1)

$$M3(\Delta\sigma) := \begin{cases} 1 & \text{if } \Delta\sigma > \Delta\sigma smax3 \\ \left[N1 - m1\cdot\left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma smax3}{MPa}\right)\right)\right] & \text{if } \Delta\sigma s1a < \Delta\sigma \le \Delta\sigma smax3 \\ \left[N2 - m2\cdot\left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma s1a}{MPa}\right)\right)\right] & \text{if } \Delta\sigma \le \Delta\sigma s1a \end{cases}$$

Applied Stress Range on Steel Tower (Fatigue Spectrum):

Number of Fatigue Spectrum: $nB := 41$ $iB := 1..nB$ $nT := 48$ $iT := 1..nT$

Stress Range at Base: $\Delta\sigma yB_{iB} := \frac{MyBD_{iB}\cdot kN\cdot m\cdot \gamma s\cdot \gamma sd}{S(z0)}$ $nff_{iB} := CyclB_{iB}$

Fatigue Index at Tower Base:

$$\sum_{iB=1}^{nB} \frac{nff_{iB}}{10^{M(\Delta\sigma yB_{iB})}} = 0.885 \qquad \sum_{iB=1}^{nB} \frac{nff_{iB}}{10^{M2(\Delta\sigma yB_{iB})}} = 0.548 \qquad \sum_{iB=1}^{nB} \frac{nff_{iB}}{10^{M3(\Delta\sigma yB_{iB})}} = 0.536$$

Prestressed Concrete Fatigue Design (Model Code 90) ---- 5.0MW (Tower Base)

Units Conversion:

$kips := 1000 \cdot lbf$ $\quad ksi := \frac{kips}{in^2}$ $\quad psf := \frac{lbf}{ft^2}$ $\quad kN := 1000 \cdot newton$ $\quad MPa := 10^6 \cdot Pa$ $\quad h := 100 \cdot m$ $\quad hc := 49 \cdot m$

Concrete Tower Properties:

Fatigue Design Life 20 years: $nf := 5.29 \cdot 10^8$

Concrete Strength: $fck := 48 \cdot MPa$ $\quad fck = 6.962\,ksi$

Concrete Reference Strength: $fck0 := 10 \cdot MPa$ $\quad fck0 = 1.45\,ksi$

Concrete Material Factor: $\gamma c := 1.5$

Model Factor: $\gamma sd := 1.1$

Age of Concrete at Begin Fatigue Loading: $Day := 60$

Concrete High Strength Factor: $s := 0.2$

Advancing Hydratication Factor: $\beta cc := \exp\left(s \cdot \sqrt{1 - \frac{28}{Day}}\right)$ $\quad \beta cc = 1.157$

Concrete Fatigue Stress:

$$fat := 0.85 \cdot \beta cc \cdot fck \cdot \left(1 - \frac{fck}{25 \cdot fck0}\right) \frac{1}{\gamma c}$$

$fat = 25.434\,MPa$ $\quad fat = 3.689\,ksi$

Fatigue Parameter:

$\alpha f := 0.5$ *Absolute stress ratio within 300mm;1 for constant compression*

$\eta c := \frac{1}{1.5 - 0.5 \cdot \alpha f}$ *1 for reinforcement and nearly constant amplitude; 0.5 for others*

$\eta c := 1$ $\quad \frac{fat}{fck} = 0.53$

Concrete Fatigue Stress (DEL):

$ffcmax := 9.314 \cdot MPa$ $\quad ffcmin := 6.983 \cdot MPa$

Simplified Method for Checking:

$\gamma sd \cdot ffcmax \cdot \eta c = 1.486\,ksi$ $\quad 0.45 \cdot fat = 1.66\,ksi$

Detail calculation required for concrete compression

Fatigue Stress Ratio:

$Scdmin(ffcmin) := \frac{ffcmin \cdot \gamma sd}{fat} \eta c$ $\quad Scdmin(ffcmin) = 0.302$

$Scdmax(ffcmax) := \frac{ffcmax \cdot \gamma sd}{fat} \cdot \eta c$ $\quad Scdmax(ffcmax) = 0.403$

$\Delta Scd(ffcmax, ffcmin) := Scdmax(ffcmax) - Scdmin(ffcmin)$

Set M1 = logN1; M2 = logN2 and M3 = logN3

$$M1(ffcmax, ffcmin) := \left(12 + 16 \cdot Scdmin(ffcmin) + 8 \cdot Scdmin(ffcmin)^2\right) \cdot (1 - Scdmax(ffcmax))$$

$M2(ffcmax, ffcmin) := 0.2 \cdot M1(ffcmax, ffcmin) \cdot (M1(ffcmax, ffcmin) - 1)$ $\quad$ *0 < Scdmin <0.8*

$$M3(ffcmax, ffcmin) := \frac{M2(ffcmax, ffcmin)}{\Delta Scd(ffcmax, ffcmin)} \cdot \left(0.3 - \frac{3}{8} \cdot Scdmin(ffcmin)\right)$$

$$M(ffcmax, ffcmin) := \begin{cases} M1(ffcmax, ffcmin) & \text{if } M1(ffcmax, ffcmin) \le 6 \\ M2(ffcmax, ffcmin) & \text{if } \left(M1(ffcmax, ffcmin) > 6 \wedge \Delta Scd(ffcmax, ffcmin) \ge 0.3 - \frac{3}{8} \cdot Scdmin(ffcmin) \right) \\ M3(ffcmax, ffcmin) & \text{if } \left(M1(ffcmax, ffcmin) > 6 \wedge \Delta Scd(ffcmax, ffcmin) < 0.3 - \frac{3}{8} \cdot Scdmin(ffcmin) \right) \end{cases}$$

$$M(ffcmax, ffcmin) = 36.9$$

Fatigue Index for DEL: $\frac{nf}{10^{M(ffcmax, ffcmin)}} = 0$

Full Concrete Tower at Base:

$Sc\_base := 25.645 \cdot m^3$ — *Cross Section at Tower Base*

$fc\_base := 8.149 \cdot MPa$ — *Concrete Stress at Tower Base without lateral load*

$m1 := 41$ $\quad i := 1..m1$ $\quad nff_i := CyclB_i$

$$ffCmax_i := fc\_base + \frac{MyBD_i \cdot kN \cdot m}{Sc\_base} \qquad ffCmin_i := fc\_base - \frac{MyBD_i \cdot kN \cdot m}{Sc\_base}$$

$$MFC_i := M(ffCmax_i, ffCmin_i)$$

Fatigue Life Index:

$$DCRC_i := \begin{cases} \frac{nff_i}{10^{MFC_i}} & \text{if } MFC_i < 100 \\ 0 & \text{otherwise} \end{cases} \qquad \sum_{i=1}^{m1} DCRC_i = 0.139$$

Full Concrete Tower at Mid:

$Sc\_hc := 11.829 \cdot m^3$ — *Cross Section at Mid of Tower (hc)*

$fc\_hc := 7.221 \cdot MPa$ — *Concrete Stress at Mid of Tower (hc) without lateral load*

Stress Range at Middle of Tower:

$$MyF(N) := \frac{FMyB(N) - FMyT(N)}{h} \cdot (h - hc) + FMyT(N)$$ Linear Interpolation:

$m2 := 40$ $\quad ii := 1..m2$

Interpolation of number of cycles:

$$nffM_{ii} := 10^{0.115(ii-1)+3.6} \qquad \sum_{k=1}^{m2} nffM_k = 5.228 \times 10^8$$

$$ffMmax_{ii} := fc\_hc + \frac{MyF(nffM_{ii}) \cdot kN \cdot m}{Sc\_hc} \qquad ffMmin_{ii} := fc\_hc - \frac{MyF(nffM_{ii}) \cdot kN \cdot m}{Sc\_hc}$$

$$MFM_{ii} := M(ffMmax_{ii}, ffMmin_{ii})$$

$$DCRM_{ii} := \begin{cases} \frac{nffM_{ii}}{10^{MFM_{ii}}} & \text{if } 0 < MFM_{ii} < 100 \\ 0 & \text{otherwise} \end{cases} \qquad \sum_{ii=1}^{m2} DCRM_{ii} = 0.886$$

Hybrid Concrete Tower at Base:

$Sh\_base := 38.862 \cdot m^3$ — *Cross Section at Tower Base*

$fh\_base := 6.521 \cdot MPa$ — *Concrete Stress at Tower Base without lateral load*

$$ffHmax_i := fh\_base + \frac{MyBD_i \cdot kN \cdot m}{Sh\_base} \qquad ffHmin_i := fh\_base - \frac{MyBD_i \cdot kN \cdot m}{Sh\_base}$$

$MFH_i := M(ffHmax_i, ffHmin_i)$

Fatigue Life Index:

$$DCRH_i := \begin{cases} \dfrac{nff_i}{10^{MFH_i}} & \text{if } MFH_i < 100 \\ 0 & \text{otherwise} \end{cases} \qquad \sum_{i=1}^{m1} DCRH_i = 3.554 \times 10^{-6}$$

Fatigue Life of Concrete Tower:

$ScdCMax_i := Scdmax(ffCmax_i)$ $\quad ScdCMin_i := Scdmin(ffCmin_i)$

$ScdHMax_i := Scdmax(ffHmax_i)$ $\quad ScdHMin_i := Scdmin(ffHmin_i)$

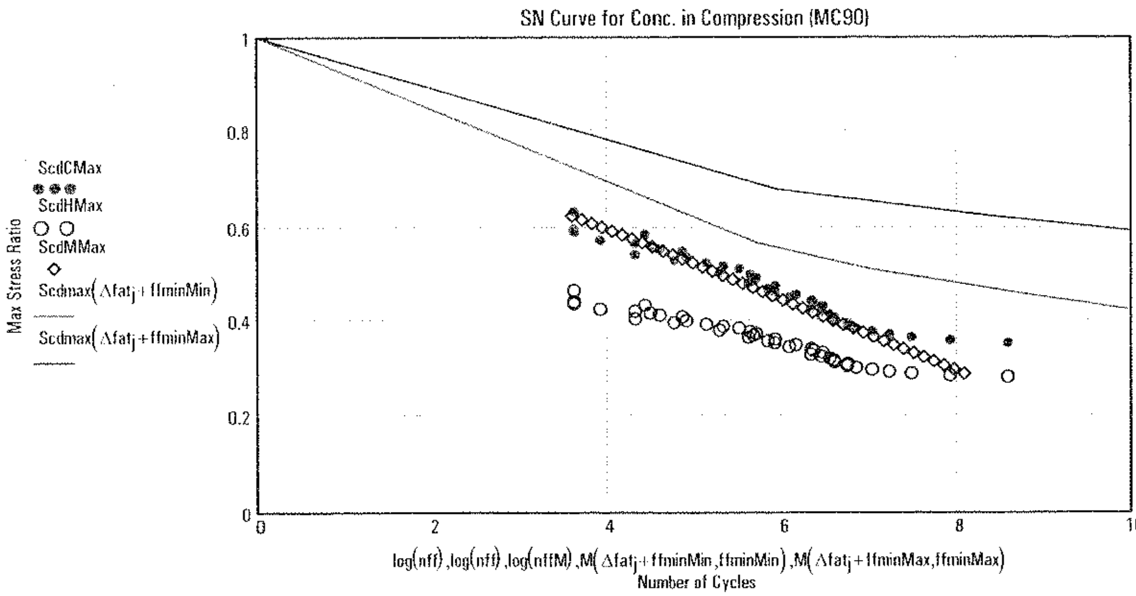
$ScdMMax_{ii} := Scdmax(ffMmax_{ii})$

$\min(ScdCMin, ScdHMin) = 0.073$ $\quad \max(ScdCMin, ScdHMin) = 0.349$

$N := 20$ $\quad j := 1..N$ $\quad \Delta ff := \dfrac{fat}{N}$ $\quad \Delta fat_j := j \cdot \Delta ff$

$ffminMin := \min(ffCmin, ffHmin)$ $\quad ffminMin = 1.677\,MPa$

$ffminMax := \max(ffCmin, ffHmin)$ $\quad ffminMax = 8.079\,MPa$



Steel Tendon Fatigue Stress:

Area ratio of prestress tendon with reinforcement rebar: $Aps := 30$

Diameter ratio of prestress tendon with reinforcement rebar: $Dps := 5$

For smooth strands: $\zeta := 0.2$

$$\eta s := \frac{1 + Aps}{1 + Aps \cdot \sqrt{Dps \cdot \zeta}} \qquad \eta s = 1$$

$\gamma s := 1.15$

Effective Tendon Stress: $fse := 160 \cdot ksi$

Max and Min tendon stress: $ffsmax := 162 \cdot ksi$ $\quad ffsmin := 158 \cdot ksi$

$ffsmax = 1117\,MPa$ $\quad ffsmin = 1089\,MPa$

$\Delta\sigma s := ffsmax - ffsmin$

$\Delta\sigma s = 4\,ksi$ $\quad \Delta\sigma s = 27.579\,MPa$

Parameters of S_N curve for prestressing steel:

Straight Tendons:

$Ns1 := 6$ $\Delta\sigma RskN := 160\cdot MPa$ $\Delta\sigma RskN = 23.206\,ksi$ $\Delta\sigma RskN := \frac{\Delta\sigma RskN}{\gamma s}$

$Ns2 := 8$ $\Delta\sigma Rsk := 95\cdot MPa$ $\Delta\sigma Rsk = 13.779\,ksi$ $\Delta\sigma Rsk := \frac{\Delta\sigma Rsk}{\gamma s}$

$Ns0 := 4$ $k1 := 5$ $k2 := 9$ $k3 := 20$

$$\Delta\sigma st(NN) := \begin{cases} 10^{\left(\log\left(\frac{\Delta\sigma RskN}{MPa}\right)+\frac{Ns1-NN}{k1}\right)}\cdot MPa & \text{if } NN < Ns1 \\ 10^{\left(\log\left(\frac{\Delta\sigma RskN}{MPa}\right)+\frac{Ns1-NN}{k2}\right)}\cdot MPa & \text{otherwise} \end{cases}$$

$\Delta\sigma st(Ns0)\cdot\gamma s = 58.3\,ksi$ $\Delta\sigma st(Ns1)\cdot\gamma s = 23.2\,ksi$ $\Delta\sigma st(Ns2)\cdot\gamma s = 13.9\,ksi$

$\Delta\sigma st(Ns0)\cdot\gamma s = 401.9\,MPa$ $\Delta\sigma st(Ns1)\cdot\gamma s = 160\,MPa$ $\Delta\sigma st(Ns2)\cdot\gamma s = 95.9\,MPa$

Fatigue Stress Range at 5.29E8: $\Delta\sigma st(\log(nf)) = 10.1\,ksi$ $\Delta\sigma st(\log(nf)) = 69.3\,MPa$

$$Mst(\Delta\sigma) := \begin{cases} 1 & \text{if } \Delta\sigma > \Delta\sigma st(Ns0) \\ Ns0 - k1\cdot\left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma st(Ns0)}{MPa}\right)\right) & \text{if } \Delta\sigma st(Ns1) < \Delta\sigma \le \Delta\sigma st(Ns0) \\ Ns1 - k2\cdot\left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma st(Ns1)}{MPa}\right)\right) & \text{if } \Delta\sigma st(Ns2) < \Delta\sigma \le \Delta\sigma st(Ns1) \\ Ns2 - k3\cdot\left(\log\left(\frac{\Delta\sigma}{MPa}\right) - \log\left(\frac{\Delta\sigma st(Ns2)}{MPa}\right)\right) & \text{if } 0 < \Delta\sigma \le \Delta\sigma st(Ns2) \\ 20 & \text{otherwise} \end{cases}$$

Coupler Anchor:

$\Delta\sigma RskN1 := 80\cdot MPa$ $\Delta\sigma RskN1 = 11.603\,ksi$ $\Delta\sigma RskN1 := \frac{\Delta\sigma RskN1}{\gamma s}$

$\Delta\sigma Rsk1 := 30\cdot MPa$ $\Delta\sigma Rsk1 = 4.351\,ksi$ $\Delta\sigma Rsk1 := \frac{\Delta\sigma Rsk1}{\gamma s}$

$ki1 := 3$ $ki2 := 5$ $ki3 := 12$

$$\Delta\sigma st1(NN) := \begin{cases} 10^{\left(\log\left(\frac{\Delta\sigma RskN1}{MPa}\right)+\frac{Ns1-NN}{ki1}\right)}\cdot MPa & \text{if } NN < Ns1 \\ 10^{\left(\log\left(\frac{\Delta\sigma RskN1}{MPa}\right)+\frac{Ns1-NN}{ki2}\right)}\cdot MPa & \text{otherwise} \end{cases}$$

$\Delta\sigma st1(Ns0)\cdot\gamma s = 53.9\,ksi$ $\Delta\sigma st1(Ns1)\cdot\gamma s = 11.6\,ksi$ $\Delta\sigma st1(Ns2)\cdot\gamma s = 4.6\,ksi$

$\Delta\sigma st1(Ns0)\cdot\gamma s = 371.3\,MPa$ $\Delta\sigma st1(Ns1)\cdot\gamma s = 80\,MPa$ $\Delta\sigma st1(Ns2)\cdot\gamma s = 31.8\,MPa$

Fatigue Stress Range at 5.29E8: $\Delta\sigma st1(\log(nf)) = 2.9\,ksi$ $\Delta\sigma st1(\log(nf)) = 19.8\,MPa$

Full Concrete Tower at Base:

$Ix\_base := 100.264\cdot m^4$ *Moment of inertia at Tower Base*

$yc\_base := 3.429\cdot m$ *out most tendon location*

$ffSmax_i := fse + \frac{MyBD_i\cdot kN\cdot m\cdot yc\_base\cdot\gamma sd}{Ix\_base}\cdot\frac{Es}{Ec}$ $ffSmin_i := fse - \frac{MyBD_i\cdot kN\cdot m\cdot yc\_base\cdot\gamma sd}{Ix\_base}\cdot\frac{Es}{Ec}$

$\Delta\sigma sr_i := ffSmax_i - ffSmin_i$

Fatigue Life Index:

$$DCRS_i := \begin{cases} \frac{nff_i}{10^{Mst(\Delta\sigma sr_i)}} & \text{if } Mst(\Delta\sigma sr_i) < 100 \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{i=1}^{m1} DCRS_i = 1.791\times 10^{-6}$$

Full Concrete Tower at Mid:

$Ix\_hc := 34.168 \cdot m^4$ *Moment of inertia at Tower Base*

$yc\_hc := 2.489 \cdot m$ *out most tendon location*

$$ffSMmax_{ii} := fse + \frac{MyF(nffM_{ii}) \cdot kN \cdot m \cdot yc\_hc \cdot \gamma sd}{Ix\_hc} \cdot \frac{Es}{Ec}$$

$$ffSMmin_{ii} := fse - \frac{MyF(nffM_{ii}) \cdot kN \cdot m \cdot yc\_hc \cdot \gamma sd}{Ix\_hc} \cdot \frac{Es}{Ec}$$

$$\Delta\sigma srM_{ii} := ffSMmax_{ii} - ffSMmin_{ii}$$

Fatigue Life Index:

$$DCRSM_{ii} := \begin{cases} \dfrac{nffM_{ii}}{10^{Mst(\Delta\sigma srM_{ii})}} & \text{if } \Delta\sigma srM_{ii} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \sum_{ii=1}^{m2} DCRSM_{ii} = 2.868 \times 10^{-5}$$

Hybrid Concrete Tower at Base:

$Ix\_hybr := 181.494 \cdot m^4$ *Moment of inertia at Tower Base*

$yc\_hybr := 4.191 \cdot m$ *out most tendon location*

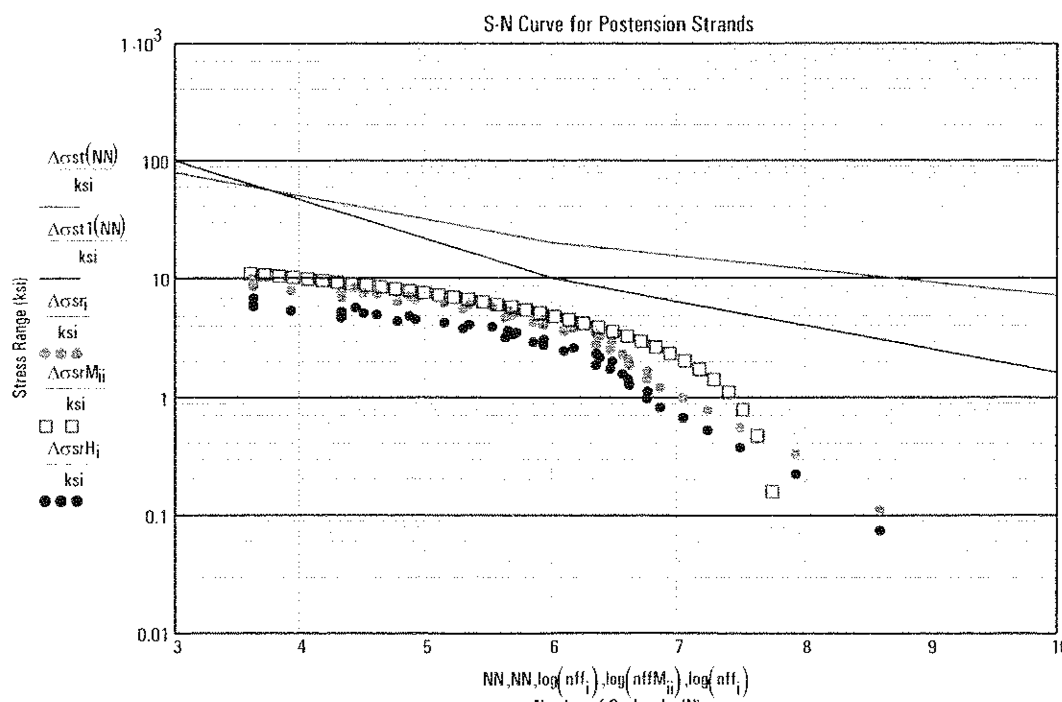
$$ffSHmax_i := fse + \frac{MyBD_i \cdot kN \cdot m \cdot yc\_hybr \cdot \gamma sd}{Ix\_hybr} \cdot \frac{Es}{Ec} \qquad ffSHmin_i := fse - \frac{MyBD_i \cdot kN \cdot m \cdot yc\_hybr \cdot \gamma sd}{Ix\_hybr} \cdot \frac{Es}{Ec}$$

$$\Delta\sigma srH_i := ffSHmax_i - ffSHmin_i$$

Fatigue Life Index:

$$DCRSH_i := \begin{cases} \dfrac{nff_i}{10^{Mst(\Delta\sigma srH_i)}} & \text{if } Mst(\Delta\sigma srH_i) < 100 \\ 0 & \text{otherwise} \end{cases} \qquad \sum_{i=1}^{m1} DCRSH_i = 6.946 \times 10^{-10}$$

$NN := 3, 3.5 .. 10$



Appendix C – Cost Estimating Background

Basic 50 Tower Installation Conceptual Cost Estimates

1.5 MW – 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100m All Precast Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Cast-in-Place Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Steel Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Cast- In -Place Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Steel Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Steel Wind Turbine Tower (Designed for Wind) 50 Tower Installation – 28 Month Schedule

Towers Designed for Earthquake - 50 Tower Installation Conceptual Cost Estimates

1.5 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Cast-in-Place Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

25 Tower Installation Conceptual Cost Estimates

Cost Comparison 50 Tower Installation versus 25 Tower Installation

1.5 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake) 25 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Steel Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

3.6 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower (Design for Earthquake) 25 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Steel Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

5.0 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake) 25 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Precast Concrete Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Steel Wind Turbine Tower (Designed for Wind) 25 Tower Installation – 28 Month Schedule

50 Tower Installation – March 2004 Higher Steel Costs - Conceptual Cost Estimates

1.5 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Precast Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

1.5 MW – 100 m All Steel Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m Hybrid Steel Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Precast Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Cast-In-Place Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

3.6 MW – 100 m All Steel Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m Hybrid Steel Wind Turbine Tower March 2004 Steel Costs (Designed for Earthquake) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Precast Concrete Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All cast-In-Place Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

5.0 MW – 100 m All Steel Wind Turbine Tower March 2004 Steel Costs (Designed for Wind) 50 Tower Installation – 28 Month Schedule

Notes to Estimates

These notes apply to all estimate spreadsheets.

Note 1 — Basic estimate is based on constructing (50) turbine towers under one contract, at a single site, over a 24 month construction period with four months of site mobilization, start up, and procurement.

Note 2 — The steel tube sections are fabricated by a fully qualified steel fabrication ship. The tube sections are delivered 1,200 miles by truck. Oversized sections are shipped in quarter sections.

Note 3 — Field erection and welding of steel tube sections will be planned and supervised by the steel tube fabricator.

Note 4 — The steel forms for the precast concrete segment fabrication operation are designed and fabricated by a form company that specializes in custom forms for special projects.

Note 5 — The precast concrete segments are fabricated by a fully qualified precast concrete plant. The segments are delivered to the site with a haul of 300 miles by truck

Note 6 — The hybrid steel concrete towers will use a special pedestal mounted erection crane set on top of the steel tube tower for erecting the precast concrete segments, handling materials and post tensioning the concrete tower.

Note 7 — Costs for turbine nacelle, hub, rotors, and supporting electrical and mechanical cabling and equipment are not included in estimates.

Note 8 — Tendon cut off locations for all towers based on analysis of cutoff for the 1.5 MW hybrid tower.

Note 9 — Concrete for on-site pours is assumed to the batched and delivered for a qualified concrete plant within practical delivery distance.

Note 10 — Federal, state, and local sales and use tax excluded.

Note 11 — Work is based on 8- to 10-hour days five to six days a week; Sundays and holidays excluded.

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$3,000	
	Fabricate, Assemble 3 Special Pedestal Cranes for Erecting Precast Elements.	3	Each	$250,000	$750,000	$15,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (3) 4100 W Crane to site	3	Lump Sum	$66,416	$199,248	$3,985	
	Rental for (3) 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	63	months	$13,000	$819,000	$16,380	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365	$68,250	$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780	$39,000	$780	
	Crane cribbing cost per turbine	1	per turbine	$131	$6,550	$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248	$12,400	$248	
	Fuel cost per month	63	per month	$1,429	$90,027	$1,801	
	Mobilize/Demoblize (1) LTL-600 Crane	1	Lump sum	$415,091	$415,091	$8,302	
	Rental for (1) LTL-600 Crane- For nacelle, hub and blade erection	9	months	$78,000	$702,000	$14,040	
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	9	per month	$4,222	$37,998	$760	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$107,325**	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1500	Cubic Yards	$8		$12,000	With large excavator
	Supply and Install Concrete Forms (54 ft by 54 ft by 10 ft deep)	2160	Sq Ft	$2.50		$5,400	
	Supply, Place and Consolidate Foundation Concrete	972	Cubic Yards	$89.90		$87,383	Use 90% of gross fundation volume to account for central thickening of foundationl.
	Reinforcing Steel (93 lb per cubic yard)	104000	lbs	$0.45		$46,800	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	36	Sets	$250		$9,000	
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$171,949**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	185800	lbs	$0.18		$33,444	
	Tube Section Fabrication, Rolled and Welded	150200	lbs	$0.72		$108,144	Fabrication labor and equipment. Includes allowance for NDT
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)						
	Cut, Weld, Stress Relieve	8645	lbs	$2.50		$21,613	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 123" OD X 111" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	4157		$2.00		$8,314	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	40564	lbs	$1.50		$60,846	Weight includes 33% waste

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$5,000	
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$6,000	
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$15,000	
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	1500	$/KW	$15.38		$23,070	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$302,431**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	10000	lb	$1.50	$60,000	$5,000	See Note 4 - Make 4 sets and reuse 12 times.
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 3 Tube Sections (labor)	132	man hours	$40.30		$5,320	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane
	Weld (2) Field Joints with Track-Mounted Welder = ($1.67/KW)	1500	$/KW	$1.67		$2,505	Includes allowance for NDT- 2 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for weld length.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$31,683**	
5	**Precast Concrete Operation - Includes 1050 A Segments, 900 B Segments and 150 C Segments**						
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Design and Fabricate (3) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) C Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Install 8 Forms and Start-up at Precast Plant	8	Each	$2,000	$16,000	$320	Divide Total Form Costs by 50 Towers
	Precast (42) A, B and C Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$5,040	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$12,096	
	Supply and Install Rebar (140 #/cy)	1225	Lbs	$0.35	$429	$18,008	51,490 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$9,240	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$3,360	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$3,822	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$4,200	14 Rings
	Supply and Place Concrete 11 cy/segment average	11.2	Cubic Yard	$80.00	$896	$37,632	f'c = 7000psi 460 cubic yards total
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$6,300	
	Total concrete	463	Cubic Yards		Subtotal	$102,558	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$30,767	
	General and Administrative and Profit	25.0%				$33,331	
							Equals Cost Per Cubic Yard
					Subtotal	**$166,656**	$359.95
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	42	Loads	$1,100.00		$46,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	800	Sq Ft	$20.00	$16,000	$320	Includes re-usable tie-bolt hardware
	Erect 14 Rings of 3 Segments Each	42	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	14	Sets	$250.00		$3,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	14	Rings	$175.00		$2,450	0.5 crew hour per segment

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist and Set 42 Segments	42	Segments	$175.00		$7,350	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	12254	lbs	$1.50		$18,381	4 bars and couplers per segment
	Install and stress 168 Post Tensioning Bars with Couplers	12254	lbs	$0.50		$6,127	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	42	each	$58.00		$2,436	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	1680	Welds	$4.00		$6,720	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	56	Cubic ft.	$30.00		$1,680	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	14	Sets	$350.00		$4,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	60	Cubic yards	$150.00		$9,000	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	36	Tendons				
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	72	Each	$193.00		$13,896	Installation cost is included in precast
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	4450	Lineal ft	$2.50		$11,125	Installation cost is included in precast
	Supply and install (432) Pieces of 0,6 in dia Post Tensioning Strand	51390	lbs	$0.68		$34,945	
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	36	Operations	$500.00		$18,000	Inlcudes rental of P/T jacks and pumps
	Grout 36 Post Tensioniing Tendons	306	Cubic ft	$20.00		$6,120	8.5 Cubic ft per tendon
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$15,000	
	Allowance for material handling unloading and equipment		Lump Sum			$10,000	Crane cost covered in item 1
					Subtotal	**$219,117**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$2,000	Planning, dry-runs, etc.
	Supply and Install (3) Jack-up Tendons with	4320	Lineal ft	$0.50		$2,160	9 -0.6 in strand X 160 ft.
	Anchors Top and Bottom	6	Each	$150.00		$900	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate (18) Upper Thruster Assemblies	2000	lbs	$2.50	$5,000	$200	Reusable 25 times
	Install (18) Upper Thruster Assemblies	18	Each	$200		$3,600	Labor and anchor bolts
	Fabricate (24) Lower Thruster Assemblies	1800	lbs	$2.50	$4,500	$180	Reusable 25 times
	Install (24) Lower Thruster Assemblies	24	Each	$100.00		$2,400	
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	60	man hours	$40.30		$2,418	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 6 days)	60	man hours	$40.30		$2,418	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	24	Bolts	$10.00		$240	
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$10,000	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$43,586**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$25.00		$1,050	
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	128	Each	$31.30		$4,006	
	Remove Jack-Up Tendons and Anchors	3	Each	$200.00		$600	
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$36,270**	
	Summary of Construction Costs for 1.5 MW Hybrid (Earthquake Design) Tower					**$1,079,016**	
	General Contractor Field Overhead	10.0%				$107,902	
	General Contractor Administrative Overhead	10.0%				$107,902	
	General Contractor Profit	10.0%				$107,902	
	Total Cost of Completed 1.5 MW Hybrid (Earthquake Design) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,402,721**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Management & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (5) LTL-600 Crane to site	5	Lump Sum	$415,091	$2,075,455	$41,509	
	Rental for (5) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	105	months	$78,000	$8,190,000	$163,800	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	10.4	months	$88,667	$922,137	$18,443	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	10.4	per month	$4,222	$43,909	$878	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$296,756**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1725	Cubic Yards	$8		$13,800	With large excavator
	Supply and Install Concrete Forms (55 ft by 55 ft by 10 ft deep)	2200	Sq Ft	$2.50		$5,500	
	Supply, Place and Consolidate Foundation Concrete	1008	Cubic Yards	$89.90		$90,619	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	143200	lbs	$0.45		$64,440	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$185,725**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.00		$22,264	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$28,264**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1200 A Segments, 750 B Segments and 1800 C Segments, 150 D Segments**						
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) B Forms	1	Each	$16,000	$16,000	$320	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) C Form	5	Each	$15,000	$75,000	$1,500	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) D Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Design and Fabricate (0) E Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Design and Fabricate (0) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install 11 Forms and Start-up at Precast Plant	11	Each	$2,000	$22,000	$440	Divide Total Form Costs by 50 Towers
	Precast (78) A, B, C, D Segments Per Tower				Per Segment	Per Tower	

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$9,360	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$22,464	
	Supply and Install Rebar	947	Lbs	$0.35	$331	$25,853	73931 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$17,160	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,240	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,098	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$7,800	26 Rings
	Supply and Place Concrete - cy/segment average	10.75	Cubic Yard	$80.00	$860	$67,080	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$11,700	
	Total cubic yards of PC concrete	838			Subtotal	$178,595	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$53,579	
	General and Administrative and Profit	25.0%				$58,043	
							Equals Cost Per Cubic Yard
					Subtotal	**$290,217**	$346.32
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	78	Loads	$1,100.00		$85,800	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 26 Rings of 3 Segments Each	78	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	26	Sets	$250.00		$6,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	26	Rings	$175.00		$4,550	0.5 crew hour per segment
	Hoist and Set 102 Segments	78	Segments	$175.00		$13,650	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	24998	lbs	$1.50		$37,497	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Install and stress 168 Post Tensioning Bars with Couplers	24998	lbs	$0.50		$12,499	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04)

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install Top Positioning Fixtures	78	each	$58.00		$4,524	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	4080	Welds	$4.00		$16,320	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	104	Cubic ft.	$30.00		$3,120	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	26	Sets	$350.00		$9,100	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	104	Cubic yards	$150.00		$15,600	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	30	Tendons				
	Supply (60) Post Tensioning Anchors (12 strand-0.6")	60	Each	$193.00		$11,580	Installation cost is included in precast
	Supply (30) Vertical Post Tensioning Ducts (3.5 in dia)	10137	Lineal ft	$2.50		$25,343	Installation cost is included in precast
	Supply and install (432) Pieces of 0,6 in dia Post Tensioning Strand	78490	lbs	$0.68		$53,373	
	Stress (6) Tendons teminated at Segment 50% and (24) at Top Segment	30	Operations	$500.00		$15,000	Inlcudes rental of P/T jacks and pumps
	Grout 30 Post Tensioniing Tendons	375	Cubic ft	$20.00		$7,500	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$333,563	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$26,685	
					Subtotal	**$360,248**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Precast (Designed for Wind) Tower					**$1,216,698**	
	General Contractor Field Overhead	10.0%				$121,670	
	General Contractor Administrative Overhead	10.0%				$121,670	
	General Contractor Profit	10.0%				$121,670	
	Total Cost of Completed 1.5 MW - 100m All Precast (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,581,707**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (5) LTL-600 Crane to site	Not required for this concept					
	Rental for (5) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	12.7	months	$88,667	$1,126,071	$22,521	Add 2.3 months for an additional 2 days per tower to install tower top ring with this crane.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	12.7	per month	$4,222	$53,619	$1,072	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$80,465**	

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1725	Cubic Yards	$8		$13,800	With large excavator
	Supply and Install Concrete Forms (55 ft by 55 ft by 10 ft deep)	2200	Sq Ft	$2.50		$5,500	
	Supply, Place and Consolidate Foundation Concrete	1008	Cubic Yards	$89.90		$90,619	Use 90% of gross foundation volume to acount for central thickening of foundation.
	Reinforcing Steel	143200	lbs	$0.45		$64,440	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$185,725**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.00		$22,264	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$28,264**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (1) B Forms	Not required for this concept					
	Design and Fabricate (5) C Form	Not required for this concept					
	Design and Fabricate (1) D Form	Not required for this concept					
	Design and Fabricate (0) E Form	Not required for this concept					
	Design and Fabricate (0) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
		Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Precast (78) A, B, C, D Segments Per Tower	Not required for this concept					
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$6,383,938	$127,679	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$11,650,123	$233,002	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$3,606,812	$72,136	
	Total cubic yards of concrete	804					**Equals Cost Per Cubic Yard**
					Subtotal	**$432,817**	$538.33
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 26 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Hoist and Set 102 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	30	Tendons				
	Supply (60) Post Tensioning Anchors (12 strand-0.6")	60	Each	$193.00		$11,580	Installation cost is included in precast
	Supply (30) Vertical Post Tensioning Ducts (3.5 in dia)	10137	Lineal ft	$2.50		$25,343	Installation cost is included in precast
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	78490	lbs	$0.68		$53,373	
	Stress (6) Tendons teminated at Segment 50%, and (24) at Top Segment	30	Operations	$500.00		$15,000	Inlcudes rental of P/T jacks and pumps
	Grout 46 Post Tensioniing Tendons	375	Cubic ft	$20.00		$7,500	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$123,763	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$9,901	
					Subtotal	**$133,664**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Cast in Place Concrete (Designed for Wind) Tower					**$913,962**	
	General Contractor Field Overhead	10.0%				$91,396	
	General Contractor Administrative Overhead	10.0%				$91,396	
	General Contractor Profit	10.0%				$91,396	
	Total Cost of Completed 1.5 MW - 100m All Cast in Place (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,188,150**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (3) LTL-600 Cranes to site	3	Lump Sum	$415,091	$1,245,273	$24,905	
	Rental for (3) LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	60	months	$78,000	$4,680,000	$93,600	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	60	per month	$4,222	$253,320	$5,066	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	10.4	months	$88,667	$922,137	$18,443	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	10.4	per month	$4,222	$43,909	$878	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$206,152**	

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1500	Cubic Yards	$8		$12,000	With large excavator
	Supply and Install Concrete Forms (54 ft by 54 ft by 10 ft deep)	2160	Sq Ft	$2.50		$5,400	
	Supply, Place and Consolidate Foundation Concrete	972	Cubic Yards	$89.90		$87,383	Use 90% of gross foundation volume to acccount for central thickening of foundation.
	Reinforcing Steel	51440	lbs	$0.45		$23,148	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$139,297**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	516100	lbs	$0.18		$92,898	
	Tube Section Fabrication, Rolled and Welded	516100	lbs	$0.72		$371,592	Fabrication labor and equipment. Includes allowance for NDT
	Base Flange Ring (Dim 245"OD X 225" ID X 5" thk)						
	Cut, Weld, Stress Relieve	13913	lbs	$2.50		$34,783	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 124" OD X 112" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	4192		$2.00		$8,384	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					
	Cut, Weld, Stress Relieve	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept				$5,000	
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$12,240	1.5 Hybrid amount X (100m/49m)
	Primer and Epoxy Finish Coats on Exterior		Lump Sum			$30,600	1.5 Hybrid amount X (100m/49m)
	Truck Delivery (See note 3) $27 per KW * (100m/86m)= 31.39/KW for 1.5MW Tower	1500	$/KW	$31.39		$47,085	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$638,102**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 10 Tube Sections (labor)	410	man hours	$40.30		$16,523	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (10sections/3 sections)
	Weld (9) Field Joints with Track-Mounted Welder =$10.71/KW	1500	$/KW	$10.71		$16,065	Includes allowance for NDT- 9 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$35,050**	
5	**Precast Concrete Operation**						

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 4 days)	120	man hours	$40.30		$4,836	Use LTL- 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 4 days)	120	man hours	$40.30		$4,836	Use LTL-850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 1.5 MW All Steel Tower (Wind Design)					**$1,053,581**	
	General Contractor Field Overhead	10.0%				$105,358	
	General Contractor Administrative Overhead	10.0%				$105,358	
	General Contractor Profit	10.0%				$105,358	
	Total Cost of Completed 1.5 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,369,656**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$3,000	
	Fabricate, Assemble 4 Special Pedestal Cranes for Erecting Precast Elements.	4	Each	$250,000	$1,000,000	$20,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Design and Develop Active Lower Guide/Force Reaction Assembly - For Use During Jack-up Operation	1	Lump Sum	$75,000	$75,000	$1,500	Required for 3.6 MW and 5.0 MW hybrid towers which do not have constant ID in concrete tower portion.
	Fabricate and Assemble Lower Guide/Force Reaction Assembly	4	Each	$100,000	$400,000	$8,000	
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (4) 4100 W Crane to site	4	Lump Sum	$66,416	$265,664	$5,313	
	Rental for (4) 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	84	months	$13,000	$1,092,000	$21,840	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365		$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780		$780	
	Crane cribbing cost per turbine	1	per turbine	$131		$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248		$248	
	Fuel cost per month	84	per month	$1,429	$120,036	$2,401	
	Mobilize/Demoblize (1) LTL-850 Crane		Lump sum		$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	13	months	$86,667	$1,126,671	$22,533	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332		$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730		$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808		$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161		$1,161	

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Fuel cost per month	13	per month	$4,222	$54,886	$1,098	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$145,081**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2765	Cubic Yards	$8		$22,120	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel (93 lb per cubic yard)	215200	lbs	$0.45		$96,840	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	42	Sets	$250		$10,500	(1.5 MW no x 1.16 based on dia's)
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$310,326**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	354500	lbs	$0.18		$63,810	
	Tube Section Fabrication, Rolled and Welded	354500	lbs	$0.72		$255,240	Fabrication labor and equipment. Includes allowance for NDT
	Weld quartered Tube sections	3600	$/kw			$17,039	WindPACT technical Area 2 for auto welding quartered sections. Adjusted for tower height.
	Base Flange Ring (Dim 239"OD X 219" ID X 5" thk)						
	Cut, Weld, Stress Relieve	13557	lbs	$2.50		$33,893	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$4,500	(1.5 MW amount X 1.5)
	Top Flange Ring (Dim 165" OD X 153" ID X 5 " thk)						

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	5649		$2.00		$11,298	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,300	1.5 MW amount X 1.1)
	Concrete Tower Top Connection Ring (Dim 305" OD X 239" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	63778	lbs	$1.50		$95,667	Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$6,000	(1.5 MW amount X 1.2)
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$7,200	(1.5 MW amount X 1.2 based on dia's)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$18,000	(1.5 MW amount X 1.2 based on dia's)
	Truck Delivery (See note 3) $48 per KW *(54m/1302.m)=$19.90/KW for 3.6 MW Tower	3600	$/KW	$19.90		$71,640	56 ft to 64 ft long Per WIndPACT Area 4 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$602,587**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	14700	lb	$1.50	$88,200	$7,350	See Note 4 - Make 4 sets and reuse 12 times. Use 1.5 MW wt X 1.47 based on tower wt.
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 6 Tube Sections (labor)	145	man hours	$40.30		$5,844	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane Use 1.1 X 1.5 MW labor
	Weld (5) Field Joints with Track-Mounted Welder = $6.25/KW	3600	$/KW	$6.25		$22,500	Includes allowance for NDT- 5 horizontal welds to connect erected tube sections. (WindPACT Area 4 Figure 4-13 adjusted for weld length)
	Grout and Torque Tower Base (labor)	48	man hours	$40.30		$1,934	(1.5 MW amount X 1.2 based on dia's)
	Grout and Torque Tower Base (Material and Equipment)					$986	Use 1.16 X 1.5 MW amount based on dia's

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$55,010**	
5	**Precast Concrete Operation - Includes1650 A Segments,1200 B Segments and 750 C, 300 D Segments**						
	Design and Fabricate (5) A Forms	5	Each	$16,000	$80,000	$1,600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) B Forms	5	Each	$16,000	$80,000	$1,600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) C Forms	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) D Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) E Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install (12) Forms and Start-up at Precast Plant	13	Each	$2,000	$26,000	$520	Divide Total Form Costs by 50 Towers
	Precast (78) A, B, C, D Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$9,360	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$22,464	
	Supply and Install Rebar	924	Lbs	$0.35	$323	$25,225	72,126 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$17,160	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,240	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,098	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$7,800	26 Rings
	Supply and Place Concrete cy/segment average	12.2	Cubic Yard	$80.00	$976	$76,128	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$11,700	
	Total concete	952.7	Cubic Yards		Subtotal	$187,795	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$56,339	
	General and Administrative and Profit	25.0%				$61,033	
							Equals Cost Per Cubic Yard
					Subtotal	**$305,167**	$320.32

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	78	Loads	$1,100.00		$85,800	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	800	Sq Ft	$20.00	$16,000	$320	Includes re-usable tie-bolt hardware
	Erect 26 Rings of 3 Segments Each	78	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	26	Sets	$250.00		$6,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	26	Rings	$175.00		$4,550	0.5 crew hour per segment
	Hoist and Set 78 Segments	78	Segments	$175.00		$13,650	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	16050	lbs	$1.50		$24,075	4 bars and couplers per segment
	Install and stress 168 Post Tensioning Bars with Couplers	16050	lbs	$0.50		$8,025	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	78	each	$58.00		$4,524	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	1680	Welds	$4.00		$6,720	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	104	Cubic ft.	$30.00		$3,120	Concurrent with rebar welding (1.31 x 1.5 MW amount)
	Attach Closure Joint Forms (1 Set = (6) leaves)	26	Sets	$350.00		$9,100	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	104	Cubic yards	$150.00		$15,600	Av 4 cubic yards / 3 joints; F'c= 6000 psi (1.31 x 1.5 MW amount)
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	29	Man Hours	$40.30		$1,169	Connection plate hoisted with strand post tensioning anchors attached. (1.21 X 1.5 MW amount based on dias')
	Install, Stress and Grout Vertical Strand Tendons	48	Tendons				
	Supply (96) Post Tensioning Anchors (12 strand-0.6")	96	Each	$193.00		$18,528	Installation cost is included in precast
	Supply (48) Vertical Post Tensioning Ducts (3.5 in dia)	5635	Lineal ft	$2.50		$14,088	Installation cost is included in precast
	Supply and install (576) Pieces of 0,6 in dia Post Tensioning Strand	65730	lbs	$0.68		$44,696	
	Stress (48) Tendons at Top Segment	48	Operations	$500.00		$24,000	Inlcudes rental of P/T jacks and pumps
	Grout 48 Post Tensioniing Tendons	408	Cubic ft	$20.00		$8,160	8.5 Cubic ft per tendon

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$15,000	
	Allowance for material handling unloading and equipment		Lump Sum			$10,000	Crane cost covered in item 1
					Subtotal	**$317,625**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$2,000	Planning, dry-runs, etc.
	Supply and Install (4) Jack-up Tendons with	8769	Lineal ft	$0.50		$4,385	12 -0.6 in strand X 160 ft. (1.5 MW wt X 2.03 based on stl tower wt.)
	Anchors Top and Bottom	8	Each	$150.00		$1,200	
	Fabricate (18) Upper Thruster Assemblies	4060	lbs	$2.50	$10,150	$406	Reusable 25 times (1.5 MW wt X 2.03 based on stl tower wt.)
	Install (18) Upper Thruster Assemblies	18	Each	$300		$5,400	Labor and anchor bolts (1.5 MW wt X 2.03 based on stl tower wt.)
	Fabricate (24) Lower Thruster Assemblies	3654	lbs	$2.50	$9,135	$365	Reusable 25 times (1.5 MW wt X 2.03 based on stl tower wt.)
	Install (24) Lower Thruster Assemblies	24	Each	$150.00		$3,600	(1.5 MW wt X 2.03 based on stl tower wt.)
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	70	man hours	$40.30		$2,821	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	(1.5 MW abount X 1.16 based on dia's)
	Erect Hub and Blades to Turbine Nacelle (crew of 3 for 3 days)	72	man hours	$40.30		$2,902	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	28	Bolts	$10.00		$280	(1.5 MW abount X 1.16 based on dia's)
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$12,500	Includes rental of hydraulic system

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$53,084**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$50.75		$2,132	(1.5 MW wt X 2.03 based on stl tower wt.)
	Supply, Install, and Torque (148) -1.5 in Diameter High Strength Bolts	259	Each	$31.30		$8,107	(1.5 MW wt X 2.03 based on stl tower wt.)
	Remove Jack-Up Tendons and Anchors	3	Each	$406.00		$1,218	(1.5 MW wt X 2.03 based on stl tower wt.)
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	24	man hours	$40.30		$967	Crew of 4 for 6 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$42,392**	
	Summary of Construction Costs for 3.6 MW Hybrid (Designed for Earthquake) Tower					$1,831,272	
	General Contractor Field Overhead	10.0%				$183,127	

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	General Contractor Administrative Overhead	10.0%				$183,127	
	General Contractor Profit	10.0%				$183,127	
	Total Cost of Completed 3.6 MW Hybrid (Designed for Earthquake) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,380,653**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	6	Lump Sum	$415,091	$2,490,546	$49,811	
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	132	months	$78,000	$10,296,000	$205,920	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	132	per month	$4,222	$557,304	$11,146	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	15	months	$88,667	$1,330,005	$26,600	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	15	per month	$4,222	$63,330	$1,267	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$358,003**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2455	Cubic Yards	$8		$19,640	With large excavator
	Supply and Install Concrete Forms (63 ft by 63 ft by 12 ft deep)	3027	Sq Ft	$2.50		$7,568	
	Supply, Place and Consolidate Foundation Concrete	1588	Cubic Yards	$89.90		$142,761	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	231500	lbs	$0.45		$104,175	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$285,510**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1200 A Segments, 750 B Segments and 900 C Segments, 900 D Segments, 1050 E Segments, 150 F Segments**						
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) C Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) D Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (4) E Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) F Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Install 16 Forms and Start-up at Precast Plant	16	Each	$2,000	$32,000	$640	Divide Total Form Costs by 50 Towers
	Precast (99) A, B, C, D, E and F Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$11,880	Outer form = 11.7 ft x17 ft with 15 Ties

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$28,512	
	Supply and Install Rebar	850	Lbs	$0.35	$298	$29,453	92240 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$21,780	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$7,920	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$9,009	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$9,900	33 Rings
	Supply and Place Concrete - cy/segment average	11.05	Cubic Yard	$80.00	$884	$87,516	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$14,850	
	Total cubic yards of PC concrete	1094			Subtotal	$226,400	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$67,920	
	General and Administrative and Profit	25.0%				$73,580	
							Equals Cost Per Cubic Yard
					Subtotal	**$367,899**	$336.29
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (99 Precast Segments per Tower)	99	Loads	$1,100.00		$108,900	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 34 Rings of 3 Segments Each	99	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	33	Sets	$250.00		$8,250	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	33	Rings	$175.00		$5,775	0.5 crew hour per segment
	Hoist and Set 99 Segments	99	Segments	$175.00		$17,325	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	31728	lbs	$1.50		$47,592	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by no. of segments)
	Install and stress 168 Post Tensioning Bars with Couplers	31728	lbs	$0.50		$15,864	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by no. of segments)

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install Top Positioning Fixtures	99	each	$58.00		$5,742	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	3180	Welds	$4.00		$12,720	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	132	Cubic ft.	$30.00		$3,960	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	33	Sets	$350.00		$11,550	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	132	Cubic yards	$150.00		$19,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	40	Tendons				
	Supply (80) Post Tensioning Anchors (12 strand-0.6")	80	Each	$193.00		$15,440	Installation cost is included in precast
	Supply (40) Vertical Post Tensioning Ducts (3.5 in dia)	13864	Lineal ft	$2.50		$34,660	Installation cost is included in precast
	Supply and install (480) Pieces of 0,6 in dia Post Tensioning Strand	104600	lbs	$0.68		$71,128	
	Stress (8) Tendons teminated at Segment 50% and 32 at Top Segment	40	Operations	$500.00		$20,000	Inlcudes rental of P/T jacks and pumps
	Grout 40 Post Tensioniing Tendons	340	Cubic ft	$20.00		$6,800	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$417,113	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$33,369	
					Subtotal	**$450,482**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	140	man hours	$40.30		$5,642	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	144	man hours	$40.30		$5,803	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,510**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 3.6 MW All Precast (Designed for Wind) Tower					**$1,558,929**	
	General Contractor Field Overhead	10.0%				$155,893	
	General Contractor Administrative Overhead	10.0%				$155,893	
	General Contractor Profit	10.0%				$155,893	
	Total Cost of Completed 3.6 MW - 100m All Precast (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,026,608**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	Not required for this concept					
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	17.3	months	$88,667	$1,533,939	$30,679	Add 2.3 months for an additional 2 days per tower to install tower top ring with this crane.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	17.3	per month	$4,222	$73,041	$1,461	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$89,011**	

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2445	Cubic Yards	$8		$19,560	With large excavator
	Supply and Install Concrete Forms (63 ft by 63 ft by 12 ft deep)	3024	Sq Ft	$2.50		$7,560	
	Supply, Place and Consolidate Foundation Concrete	1588	Cubic Yards	$89.90		$142,761	Use 90% of gross foundation volume to acount for central thickening of foundation.
	Reinforcing Steel	231500	lbs	$0.45		$104,175	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$285,422**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (2) B Forms	Not required for this concept					
	Design and Fabricate (2) C Form	Not required for this concept					
	Design and Fabricate (2) D Form	Not required for this concept					
	Design and Fabricate (4) E Form	Not required for this concept					
	Design and Fabricate (1) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Precast (99) A, B, C, D, E and F Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$9,076,688	$181,534	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$14,754,556	$295,091	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$3,766,249	$75,325	
	Cubic yards of concrete	1131					**Equals Cost Per Cubic Yard**
					Subtotal	**$551,950**	$488.02
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (99 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Hoist and Set 99 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	40	Tendons				
	Supply (80) Post Tensioning Anchors (12 strand-0.6")	80	Each	$193.00		$15,440	Installation cost is included in precast
	Supply (40) Vertical Post Tensioning Ducts (3.5 in dia)	13864	Lineal ft	$2.50		$34,660	Installation cost is included in precast
	Supply and install (480) Pieces of 0,6 in dia Post Tensioning Strand	104600	lbs	$0.68		$71,128	
	Stress (8) Tendons teminated at Segment 50% and 32 at Top Segment	40	Operations	$500.00		$20,000	Inlcudes rental of P/T jacks and pumps
	Grout 40 Post Tensioniing Tendons	340	Cubic ft	$20.00		$6,800	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$158,995	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$12,720	
					Subtotal	**$171,715**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	140	man hours	$40.30		$5,642	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	144	man hours	$40.30		$5,803	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,510**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-850 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 3.6 MW All Cast in Place Concrete (Designed for Wind) Tower					**$1,192,671**	
	General Contractor Field Overhead	10.0%				$119,267	
	General Contractor Administrative Overhead	10.0%				$119,267	
	General Contractor Profit	10.0%				$119,267	
	Total Cost of Completed 3.6 MW - 100m All Cast in Place Concrete (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,550,472**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (4) LTL-600 Cranes to site	4	Lump Sum	$415,091	$1,660,364	$33,207	
	Rental for (4) LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	84	months	$78,000	$6,552,000	$131,040	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	84	per month	$4,222	$354,648	$7,093	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	15	months	$88,667	$1,330,005	$26,600	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	15	per month	$4,222	$63,330	$1,267	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$262,466**	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2218	Cubic Yards	$8		$17,744	With large excavator
	Supply and Install Concrete Forms (60 ft by 60 ft by 12 ft deep)	2880	Sq Ft	$2.50		$7,200	
	Supply, Place and Consolidate Foundation Concrete	1440	Cubic Yards	$89.90		$129,456	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	76200	lbs	$0.45		$34,290	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$200,056**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	899200	lbs	$0.18		$161,856	
	Tube Section Fabrication, Rolled and Welded	899200	lbs	$0.72		$647,424	allowance for NDT
	Weld Quartered Tube Sections	3600	$/KW			$57,118	WindPACT Area 2 Figure 4-13 adjusted to tower height .
	Base Flange Ring (Dim 317"OD X 297" ID X 5" thk)						
	Cut, Weld, Stress Relieve	18178	lbs	$2.50		$45,445	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 166" OD X 154" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	5684		$2.00		$11,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept					
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$13,320	1.5 Hybrid amount 1.2 based on dia's X (100m/54m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$33,300	1.5 Hybrid amount 1.2 based on dia's X (100m/54m)
	Truck Delivery (See note 3) $48 per KW * (100m/130.2m)= $36.87/KW for 3.6 MW Tower	3600	$/KW	$36.87		$132,732	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$1,138,083**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 17 Tube Sections (labor)	748	man hours	$40.30		$30,144	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (17sections/3 sections)
	Weld (20) Field Joints with Track-Mounted Welder $26.24/KW	3600	$/KW	$26.24		$94,464	Includes allowance for NDT- 20 horizontal welds to connect erected tube sections (Fig. 4-13 Wind PACT Technical Area 2 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$127,070**	
5	**Precast Concrete Operation**						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	$0	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 4 for 4 days)	140	man hours	$40.30		$5,642	Use LTL- 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 4 for 4 days)	144	man hours	$40.30		$5,803	Use LTL-850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	**$16,354**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 3.6 MW All Steel Tower (Wind Design)					**$1,764,430**	
	General Contractor Field Overhead	10.0%				$176,443	
	General Contractor Administrative Overhead	10.0%				$176,443	
	General Contractor Profit	10.0%				$176,443	
	Total Cost of Completed 3.6 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,293,759**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$3,000	
	Fabricate, Assemble 6 Special Pedestal Cranes for Erecting Precast Elements.	6	Each	$250,000	$1,500,000	$30,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Design and Develop Active Lower Guide/Force Reaction Assembly - For Use During Jack-up Operation	1	Lump Sum	$75,000	$75,000	$1,500	Required for 3.6 MW and 5.0 MW hybrid towers which do not have constant ID in concrete tower portion.
	Fabricate and Assemble Lower Guide/Force Reaction Assembly	6	Each	$100,000	$600,000	$12,000	
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) 4100 W Crane to site	6	Lump Sum	$66,416	$398,496	$7,970	
	Rental for (6) 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	126	months	$13,000	$1,638,000	$32,760	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365	$68,250	$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780	$39,000	$780	
	Crane cribbing cost per turbine	1	per turbine	$131	$6,550	$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248	$12,400	$248	
	Fuel cost per month	126	per month	$1,429	$180,054	$3,601	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$213,824**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	3018	Cubic Yards	$8		$24,144	With large excavator
	Supply and Install Concrete Forms (70 ft by 70 ft by 12 ft deep)	3360	Sq Ft	$2.50		$8,400	
	Supply, Place and Consolidate Foundation Concrete	1960	Cubic Yards	$89.90		$176,204	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	250200	lbs	$0.45		$112,590	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	70	Sets	$250		$17,500	(1.5 MW no x 1.94 based on dia's)
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$350,204**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	533700	lbs	$0.18		$96,066	
	Tube Section Fabrication, Rolled and Welded	533700	lbs	$0.72		$384,264	Fabrication labor and equipment. Includes allowance for NDT
	Weld quartered Tube sections	5000	$/kw			$23,577	WindPACT technical Area 2 for auto welding quartered sections. Adjusted for tower height.
	Base Flange Ring (Dim 275"OD X 255" ID X 5" thk)						
	Cut, Weld, Stress Relieve	15691	lbs	$2.50		$39,228	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$5,490	(1.5 MW amount X 1.83 based on dia's))
	Top Flange Ring (Dim 189" OD X 177" ID X 5 " thk)						

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	6501		$2.00		$13,002	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$4,950	1.5 MW amount X 1.65 based on dia's)
	Concrete Tower Top Connection Ring (Dim 341" OD X 275" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	72219	lbs	$1.50		$108,329	Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$6,800	(1.5 MW amount X 1.36 based on dia's)
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$11,400	(1.5 MW amount X 1.9 based on diameter)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$28,500	(1.5 MW amount X 1.9 based on diameter)
	Truck Delivery (See note 3) $51 per KW *(54m/156.1m)=$17.64/KW for 5.0 MW Tower	5000	$/KW	$17.64		$88,200	56 ft to 64 ft long Per WIndPACT Area 4 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$824,805**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	35500	lb	$1.50	$213,000	$17,750	See Note 4 - Make 4 sets and reuse 12 times. (Use 1.5 MW wt X 1.55 based on tower wt.)
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 11 Tube Sections (labor)	198	man hours	$40.30		$7,979	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane (Use 1.5 X 1.5 MW labor)
	Weld (10) Field Joints with Track-Mounted Welder =$19.54/KW	5000	$/KW	$19.54		$97,700	Includes allowance for NDT- 10 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for weld length)
	Grout and Torque Tower Base (labor)	76	man hours	$40.30		$3,063	(1.5 MW amount X 1.9 based on dia's)
	Grout and Torque Tower Base (Material and Equipment)					$1,615	Use 1.16 X 1.9 MW amount based on dia's

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$144,503**	
5	**Precast Concrete Operation - Includes 1350 A Segments, 1500 B Segments and 1350 C Segments**						
	Design and Fabricate (8) A Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (8) B Forms	6	Each	$16,000	$96,000	$1,920	Divide Total Form Costs by 50 Towers
	Design and Fabricate (8) C Forms	6	Each	$15,000	$90,000	$1,800	Divide Total Form Costs by 50 Towers
	Install (15) Forms and Start-up at Precast Plant	15	Each	$2,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Precast (84) A, B, C, D & E Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$10,080	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$24,192	
	Supply and Install Rebar	964	Lbs	$0.35	$337	$28,342	156226 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$18,480	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,720	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,644	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$8,100	27 Rings
	Supply and Place Concrete cy/segment average	12.9	Cubic Yard	$80.00	$1,032	$86,688	f'c = 7000psi 460 cubic yards total
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$12,600	
	Total Concrete	1083.3	Cubic Yards		Subtotal	$208,126	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$62,438	
	General and Administrative and Profit	25.0%				$67,641	
							Equals Cost Per Cubic Yard
					Subtotal	**$338,204**	$312.20

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (162 Precast Segments per Tower)	162	Loads	$1,100.00		$178,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 6 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 27 Rings of 6 Segments Each	60	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	27	Sets	$250.00		$6,750	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	27	Rings	$175.00		$4,725	0.5 crew hour per segment
	Hoist and Set 162 Segments	162	Segments	$175.00		$28,350	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	25733	lbs	$1.50		$38,600	4 bars and couplers per segment (1.5 MW amount X 2.1 based on dia's)
	Install and stress 350 Post Tensioning Bars with Couplers	25733	lbs	$0.50		$12,867	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	162	each	$58.00		$9,396	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	3360	Welds	$4.00		$13,440	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	118	Cubic ft.	$30.00		$3,540	Concurrent with rebar welding (1.5 MW amount X 2.1 based on dia's)
	Attach Closure Joint Forms (1 Set = (6) leaves)	54	Sets	$350.00		$18,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	126	Cubic yards	$150.00		$18,900	Av 4 cubic yards / 3 joints; F'c= 6000 psi (1.5 MW amount x 2.1 based on dia's)
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	44	Man Hours	$40.30		$1,773	Connection plate hoisted with strand post tensioning anchors attached. (1.5 MW amount X 1.84 based on dias')
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	6590	Lineal ft	$2.50		$16,475	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	76680	lbs	$0.68		$52,142	
	Stress 56 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	476	Cubic ft	$20.00		$9,520	8.5 Cubic ft per tendon

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$22,500	54/36 = 1.5 factor
	Allowance for material handling unloading and equipment		Lump Sum			$15,000	Crane cost covered in item 1 54/36 = 1.5 factor
					Subtotal	**$501,334**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$2,000	Planning, dry-runs, etc.
	Supply and Install (4) Jack-up Tendons with	15336	Lineal ft	$0.50		$7,668	12 -0.6 in strand X 160 ft. (1.5 MW wt X 3.55 based on stl tower wt.)
	Anchors Top and Bottom	24	Each	$150.00		$3,600	
	Fabricate (18) Upper Thruster Assemblies	7100	lbs	$2.50	$17,750	$710	Reusable 25 times (1.5 MW wt X 3.55 based on stl tower wt.)
	Install (18) Upper Thruster Assemblies	18	Each	$710		$12,780	Labor and anchor bolts (1.5 MW wt X 3.55 based on stl tower wt.)
	Fabricate (24) Lower Thruster Assemblies	6390	lbs	$2.50	$15,975	$639	Reusable 25 times (1.5 MW wt X 3.55 based on stl tower wt.)
	Install (24) Lower Thruster Assemblies	24	Each	$355.00		$8,520	(1.5 MW wt X 3.55 based on stl tower wt.)
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	90	man hours	$40.30		$3,627	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	106	each	$14.20		$1,505	(1.5 MW abount X 1.65 based on dia's)
	Erect Hub and Blades to Turbine Nacelle (crew of 3 for 4 days)	96	man hours	$40.30		$3,869	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	48	Bolts	$10.00		$480	(1.5 MW abount X 1.95 based on dia's)
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$15,000	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$76,559**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$88.75		$3,728	(1.5 MW wt X 3.55 based on stl tower wt.)
	Supply, Install, and Torque (235) -1.5 in Diameter High Strength Bolts	235	Each	$31.30		$7,356	(1.5 MW wt X 1.84 based on stl tower wt.)
	Remove Jack-Up Tendons and Anchors	3	Each	$710.00		$2,130	(1.5 MW wt X 3.55 based on stl tower wt.)
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	32	man hours	$40.30		$1,290	Crew of 4 for 8 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$44,471**	
	Summary of Construction Costs for 5.0 MW Hybrid (Earthquake Design) Tower					**$2,493,904**	
	General Contractor Field Overhead	10.0%				$249,390	
	General Contractor Administrative Overhead	10.0%				$249,390	
	General Contractor Profit	10.0%				$249,390	
	Total Cost of Completed 1.5 MW Hybrid (Earthquake Design) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$3,242,075**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Cranes to site	6	Lump Sum	$415,091	$2,490,546	$49,811	
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	176	months	$58,500	$10,296,000	$205,920	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$391,454**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	3072	Cubic Yards	$8		$24,576	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3218	Sq Ft	$2.50		$8,045	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	290200	lbs	$0.45		$130,590	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$336,037**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1350 A Segments, 900 B Segments and 1200 C Segments, 900 D and 1350 E Segments**						
	Design and Fabricate (8) A Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) C Form	9	Each	$15,000	$135,000	$2,700	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) D Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) E Form	8	Each	$15,000	$120,000	$2,400	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) G Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install 27 Forms and Start-up at Precast Plant	27	Each	$2,000	$54,000	$1,080	Divide Total Form Costs by 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Precast (114) A, B, C, D, E and F G Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$13,680	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$32,832	
	Supply and Install Rebar	781	Lbs	$0.35	$273	$31,162	185134 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$25,080	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$9,120	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$10,374	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$11,400	38 Rings
	Supply and Place Concrete - cy/segment average	11.3	Cubic Yard	$80.00	$904	$103,056	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$17,100	
	Total cubic yards of PC concrete	1289			Subtotal	$263,104	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$78,931	
	General and Administrative and Profit	25.0%				$85,509	
							Equals Cost Per Cubic Yard
					Subtotal	**$427,544**	$331.69
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (114 Precast Segments per Tower)	114	Loads	$1,100.00		$125,400	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 38 Rings of 3 Segments Each	114	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	38	Sets	$250.00		$9,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	38	Rings	$175.00		$6,650	0.5 crew hour per segment
	Hoist and Set 114 Segments	114	Segments	$175.00		$19,950	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	36535	lbs	$1.50		$54,803	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by number of segments

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install and stress 168 Post Tensioning Bars with Couplers	36535	lbs	$0.50		$18,268	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by number of segments
	Install Top Positioning Fixtures	114	each	$58.00		$6,612	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	6720	Welds	$4.00		$26,880	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04 X 2 for 6 segment rings)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	152	Cubic ft.	$30.00		$4,560	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	79	Sets	$350.00		$27,650	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	252	Cubic yards	$150.00		$37,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	130500	lbs	$0.68		$88,740	
	Stress (22) Tendons teminated at Segment 50% and 34 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$550,820	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$44,066	
					Subtotal	**$594,886**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,848,406**	
	General Contractor Field Overhead	10.0%				$184,841	
	General Contractor Administrative Overhead	10.0%				$184,841	
	General Contractor Profit	10.0%				$184,841	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,402,928**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (8) LTL-600 Crane to site	Not required for this concept					
	Rental for (8) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	20.3	months	$121,333	$2,463,060	$49,261	Add 2.3 months for an additonal 2 days per tower to install tower top ring with this crane
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	20.3	per month	$4,547	$92,304	$1,846	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$126,259**	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2766	Cubic Yards	$8		$22,128	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	290200	lbs	$0.45		$130,590	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$333,584**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (8) A Forms	Not required for this concept					
	Design and Fabricate (6) B Forms	Not required for this concept					
	Design and Fabricate (6) C Form	Not required for this concept					
	Design and Fabricate (5) D Form	Not required for this concept					
	Design and Fabricate (1) E Form	Not required for this concept					
	Design and Fabricate (2) F Form	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (1) G Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
	Precast 237) A, B, C, D, E and F G Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$10,550,721	$211,014	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$16,641,852	$332,837	
	Equipment and site overhead for Cast in Place Kconcretre construction.	1	Lump Sum		$5,438,515	$108,770	
	Cubic yards of concrete	1358					**Equals Cost Per Cubic Yard**
					Subtotal	**$652,622**	$480.58
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (237 Precast Segments per Tower)	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 237 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	130500	lbs	$0.68		$88,740	
	Stress (22) Tendons teminated at Segment 50% and (34) at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$212,108	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$16,969	
					Subtotal	**$229,077**	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-1100 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,440,028**	
	General Contractor Field Overhead	10.0%				$144,003	
	General Contractor Administrative Overhead	10.0%				$144,003	
	General Contractor Profit	10.0%				$144,003	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,872,036**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (5) LTL-600 Cranes to site	5	Lump Sum	$415,091	$2,075,455	$41,509	
	Rental for (5) LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	105	months	$78,000	$8,190,000	$163,800	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$341,032**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2765	Cubic Yards	$8		$22,120	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	95020	lbs	$0.45		$42,759	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$245,745**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	1188000	lbs	$0.18		$213,840	
	Tube Section Fabrication, Rolled and Welded	1188000	lbs	$0.72		$855,360	Fabrication labor and equipment. Includes allowance for NDT
	Weld Quartered Tube Sections	5000	$/KW			$70,732	WindPACT Area 2 Figure 4-13 adjusted to tower height
	Base Flange Ring (Dim 365"OD X 345" ID X 5" thk)						
	Cut, Weld, Stress Relieve	21020	lbs	$2.50		$52,550	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 190" OD X 178" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	6536		$2.00		$13,072	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept					
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$21,090	1.5 Hybrid amount 1.9 based on dia's X (100m/54m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$52,725	1.5 Hybrid amount 1.9 based on dia's X (100m/54m)
	Truck Delivery (See note 3) $51 per KW * (100m/156.1m)= $32.67/KW	5000	$/KW	$32.67		$163,350	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$1,478,239**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 21 Tube Sections (labor)	924	man hours	$40.30		$37,237	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (21 sections/3 sections)
	Weld (20) Field Joints with Track-Mounted Welder $26.24/KW	5000	$/KW	$26.24		$131,200	Includes allowance for NDT- 20 horizontal welds to connect erected tube sections (Fig. 4-13 Wind PACT Technical Area 4 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$170,899**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
5	**Precast Concrete Operation**						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 5 for 4 days)	160	man hours	$40.30		$6,448	Use LTL- 1100 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 5 for 4 days)	160	man hours	$40.30		$6,448	Use LTL-1100 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,805**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 5.0 MW All Steel Tower (Wind Design)					**$2,274,120**	
	General Contractor Field Overhead	10.0%				$227,412	
	General Contractor Administrative Overhead	10.0%				$227,412	
	General Contractor Profit	10.0%				$227,412	
	Total Cost of Completed 5.0 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,956,356**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	6	Lump Sum	$415,091	$2,490,546	$49,811	
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	132	months	$78,000	$10,296,000	$205,920	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685		$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560		$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538		$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605		$605	
	Fuel cost per month	132	per month	$4,222	$557,304	$11,146	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	10.4	months	$88,667	$922,137	$18,443	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332		$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730		$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808		$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161		$1,161	
	Fuel cost per month	10.4	per month	$4,222	$43,909	$878	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$349,457**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2032	Cubic Yards	$8		$16,256	With large excavator
	Supply and Install Concrete Forms (60 ft by 60 ft by 11 ft deep)	2640	Sq Ft	$2.50		$6,600	
	Supply, Place and Consolidate Foundation Concrete	1320	Cubic Yards	$89.90		$118,668	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	168800	lbs	$0.45		$75,960	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$228,850**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.00		$22,264	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$28,264**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1500 A Segments, 750 B Segments and 750 C Segments, 750 D Segments, 1200 E Segments, 150 F Segments**						
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) C Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) D Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (4) E Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) F Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Install 15 Forms and Start-up at Precast Plant	15	Each	$2,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Precast (102) A, B, C, D, E and F Segments Per Tower				Per Segment	Per Tower	

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$12,240	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$29,376	
	Supply and Install Rebar	850	Lbs	$0.35	$298	$30,345	86789 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$22,440	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$8,160	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$9,282	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$10,200	34 Rings
	Supply and Place Concrete - cy/segment average	9.55	Cubic Yard	$80.00	$764	$77,928	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$15,300	
	Total cubic yards of PC concrete	974			Subtotal	$220,811	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$66,243	
	General and Administrative and Profit	25.0%				$71,764	
							Equals Cost Per Cubic Yard
					Subtotal	**$358,818**	$368.40
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (102 Precast Segments per Tower)	102	Loads	$1,100.00		$112,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 34 Rings of 3 Segments Each	102	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	34	Sets	$250.00		$8,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	34	Rings	$175.00		$5,950	0.5 crew hour per segment
	Hoist and Set 102 Segments	102	Segments	$175.00		$17,850	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	24998	lbs	$1.50		$37,497	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Install and stress 168 Post Tensioning Bars with Couplers	24998	lbs	$0.50		$12,499	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04)

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install Top Positioning Fixtures	102	each	$58.00		$5,916	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	4080	Welds	$4.00		$16,320	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	136	Cubic ft.	$30.00		$4,080	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	34	Sets	$350.00		$11,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	136	Cubic yards	$150.00		$20,400	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	48	Tendons				
	Supply (96) Post Tensioning Anchors (12 strand-0.6")	96	Each	$193.00		$18,528	Installation cost is included in precast
	Supply (46) Vertical Post Tensioning Ducts (3.5 in dia)	14971	Lineal ft	$2.50		$37,428	Installation cost is included in precast
	Supply and install (576) Pieces of 0,6 in dia Post Tensioning Strand	116100	lbs	$0.68		$78,948	
	Stress (16) Tendons teminated at Segment 50% and 32 at Top Segment	48	Operations	$500.00		$24,000	Inlcudes rental of P/T jacks and pumps
	Grout 48 Post Tensioniing Tendons	768	Cubic ft	$20.00		$15,360	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$438,983	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$35,119	
					Subtotal	**$474,101**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Precast (Designed for Earthquake) Tower					**$1,494,978**	
	General Contractor Field Overhead	10.0%				$149,498	
	General Contractor Administrative Overhead	10.0%				$149,498	
	General Contractor Profit	10.0%				$149,498	
	Total Cost of Completed 1.5 MW - 100m All Precast (Designed for Earthquake) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,943,472**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	Not required for this concept					
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	12.7	months	$88,667	$1,126,071	$22,521	Add 2.3 months for an additional 2 days per tower to install tower top ring.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332		$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730		$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808		$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161		$1,161	
	Fuel cost per month	12.7	per month	$4,222	$53,619	$1,072	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$80,465**	

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2032	Cubic Yards	$8		$16,256	With large excavator
	Supply and Install Concrete Forms (60 ft by 60 ft by 11 ft deep)	2640	Sq Ft	$2.50		$6,600	
	Supply, Place and Consolidate Foundation Concrete	1320	Cubic Yards	$89.90		$118,668	Use 90% of gross foundation volume to account for central thickening of fdn.
	Reinforcing Steel	168800	lbs	$0.45		$75,960	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$228,850**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.00		$22,264	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$28,264**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast In Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (2) B Forms	Not required for this concept					
	Design and Fabricate (2) C Form	Not required for this concept					
	Design and Fabricate (2) D Form	Not required for this concept					
	Design and Fabricate (4) E Form	Not required for this concept					
	Design and Fabricate (1) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
	Precast (102) A, B, C, D, E and F Segments Per Tower	Not required for this concept			Per Segment	Per Tower	

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$7,096,882	$141,938	Concrete and reinforcing
	Direct Labor costs for Cast in Place Concrete construction	1	Lump Sum		$12,981,506	$259,630	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$4,015,678	$80,314	
	Total cubic yards of concrete	924					**Equals Cost Per Cubic Yard**
					Subtotal	**$481,881**	$521.52
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (102 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 102 Segments	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	48	Tendons				
	Supply (96) Post Tensioning Anchors (12 strand-0.6")	96	Each	$193.00		$18,528	Installation cost is included in precast
	Supply (48) Vertical Post Tensioning Ducts (3.5 in dia)	14972	Lineal ft	$2.50		$37,430	Installation cost is included in precast
	Supply and install (576) Pieces of 0,6 in dia Post Tensioning Strand	116100	lbs	$0.68		$78,948	
	Stress (16) Tendons teminated at Segment 50% and 32 at Top Segment	48	Operations	$500.00		$24,000	Inlcudes rental of P/T jacks and pumps
	Grout 48 Post Tensioniing Tendons	768	Cubic ft	$20.00		$15,360	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$185,233	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$14,819	
					Subtotal	**$200,052**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-850 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Cast in Place (Designed for Earthquake) Tower					**$1,072,538**	
	General Contractor Field Overhead	10.0%				$107,254	
	General Contractor Administrative Overhead	10.0%				$107,254	
	General Contractor Profit	10.0%				$107,254	
	Total Cost of Completed 1.5 MW - 100m All Cast In Place (Designed for Earthquake) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,394,300**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Management & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (8) LTL-600 Crane to site	8	Lump Sum	$415,091	$3,320,728	$66,415	
	Rental for (8) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	176	months	$78,000	$13,728,000	$274,560	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$476,697**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	3754	Cubic Yards	$8		$30,032	With large excavator
	Supply and Install Concrete Forms (75 ft by 75 ft by 13 ft deep)	3900	Sq Ft	$2.50		$9,750	
	Supply, Place and Consolidate Foundation Concrete	2437	Cubic Yards	$89.90		$219,086	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	347400	lbs	$0.45		$156,330	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$426,564**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 3300 A Segments, 1350 B Segments and 1350 C Segments, 1050 D and 750 E Segments**						
	Design and Fabricate (8) A Forms	6	Each	$16,000	$96,000	$1,920	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) B Forms	5	Each	$16,000	$80,000	$1,600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) C Form	5	Each	$15,000	$75,000	$1,500	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) D Form	5	Each	$15,000	$75,000	$1,500	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) E Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) G Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install 25 Forms and Start-up at Precast Plant	25	Each	$2,000	$50,000	$1,000	Divide Total Form Costs by 50 Towers
	Precast (156) A, B, C, D, E Segments Per Tower				Per Segment	Per Tower	

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$18,720	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$44,928	
	Supply and Install Rebar	781	Lbs	$0.35	$273	$42,643	185134 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$34,320	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$12,480	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$14,196	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$15,600	52 Rings
	Supply and Place Concrete - cy/segment average	10.5	Cubic Yard	$80.00	$840	$131,040	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$23,400	
	Total cubic yards of PC concrete	1643			Subtotal	$346,047	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$103,814	
	General and Administrative and Profit	25.0%				$112,465	
							Equals Cost Per Cubic Yard
					Subtotal	**$562,326**	$342.26
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (156 Precast Segments per Tower)	156	Loads	$1,100.00		$171,600	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 52 Rings of 3 Segments Each	156	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	52	Sets	$250.00		$13,000	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	52	Rings	$175.00		$9,100	0.5 crew hour per segment
	Hoist and Set 156 Segments	156	Segments	$175.00		$27,300	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	51466	lbs	$1.50		$77,199	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X 2 for 6 segment rings)

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install and stress 168 Post Tensioning Bars with Couplers	51466	lbs	$0.50		$25,733	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X 2 for 6 segment rings)
	Install Top Positioning Fixtures	156	each	$58.00		$9,048	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	6720	Welds	$4.00		$26,880	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04 X 2 for 6 segment rings)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	208	Cubic ft.	$30.00		$6,240	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	79	Sets	$350.00		$27,650	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	252	Cubic yards	$150.00		$37,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (864) Pieces of 0,6 in dia Post Tensioning Strand	142300	lbs	$0.68		$96,764	
	Stress (14) Tendons teminated at Segment 50% and 42 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$652,322	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$52,186	
					Subtotal	**$704,508**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$2,268,581**	
	General Contractor Field Overhead	10.0%				$226,858	
	General Contractor Administrative Overhead	10.0%				$226,858	
	General Contractor Profit	10.0%				$226,858	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,949,155**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (8) LTL-600 Crane to site	Not required for this concept					
	Rental for (8) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	20.3	months	$121,333	$2,463,060	$49,261	Add 2.3 months for an additonal 2 days per tower to install tower top ring with this crane
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	20.3	per month	$4,547	$92,304	$1,846	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$126,259**	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	3753	Cubic Yards	$8		$30,024	With large excavator
	Supply and Install Concrete Forms (75 ft by 75 ft by 13 ft deep)	3900	Sq Ft	$2.50		$9,750	
	Supply, Place and Consolidate Foundation Concrete	2437	Cubic Yards	$89.90		$219,086	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	347400	lbs	$0.45		$156,330	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$426,556**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (8) A Forms	Not required for this concept					
	Design and Fabricate (6) B Forms	Not required for this concept					
	Design and Fabricate (6) C Form	Not required for this concept					
	Design and Fabricate (5) D Form	Not required for this concept					
	Design and Fabricate (1) E Form	Not required for this concept					
	Design and Fabricate (2) F Form	Not required for this concept					

Conceptual Cost Estimate

5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)

50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Design and Fabricate (1) G Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
	Precast 237) A, B, C, D, E and F G Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$12,842,272	$256,845	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$18,272,062	$365,441	
	Equipment and site overhead for Cast in Place Kconcretre construction.	1	Lump Sum		$6,222,867	$124,457	
	Cubic yards of concrete	1654					**Equals Cost Per Cubic Yard**
					Subtotal	**$746,744**	$451.48
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (237 Precast Segments per Tower)	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 237 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (864) Pieces of 0,6 in dia Post Tensioning Strand	142300	lbs	$0.68		$96,764	
	Stress (14) Tendons teminated at Segment 50% and 42 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$220,132	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$17,611	
					Subtotal	**$237,743**	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-1100 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,635,788**	
	General Contractor Field Overhead	10.0%				$163,579	
	General Contractor Administrative Overhead	10.0%				$163,579	
	General Contractor Profit	10.0%				$163,579	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,126,524**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$150,000	$6,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$75,000	$3,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$6,000	
	Fabricate, Assemble 3 Special Pedestal Cranes for Erecting Precast Elements.	2	Each	$250,000	$500,000	$20,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize 4100 W Cranes to site	2	Lump Sum	$66,416	$132,832	$5,313	
	Rental for 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	42	months	$13,000	$546,000	$21,840	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365	$68,250	$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780	$39,000	$780	
	Crane cribbing cost per turbine	1	per turbine	$131	$6,550	$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248	$12,400	$248	
	Fuel cost per month	42	per month	$1,429	$60,018	$2,401	
	Mobilize/Demoblize (1) LTL-600 Crane	1	Lump sum	$415,091	$415,091	$16,604	
	Rental for (1) LTL-600 Crane- For nacelle, hub and blade erection	4	months	$78,000	$312,000	$12,480	
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	4	per month	$4,222	$16,888	$676	
	Other Equipment Rental	28	months	$7,500	$210,000	$8,400	
					Subtotal	**$139,171**	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	1500	Cubic Yards	$8		$12,000	With large excavator
	Supply and Install Concrete Forms (54 ft by 54 ft by 10 ft deep)	2160	Sq Ft	$2.50		$5,400	
	Supply, Place and Consolidate Foundation Concrete	972	Cubic Yards	$89.90		$87,383	Use 90% of gross fundation volume to account for central thickening of foundationl.
	Reinforcing Steel (93 lb per cubic yard)	104000	lbs	$0.45		$46,800	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	36	Sets	$250		$9,000	
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$171,949**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	185800	lbs	$0.18		$33,444	
	Tube Section Fabrication, Rolled and Welded	150200	lbs	$0.72		$108,144	Fabrication labor and equipment. Includes allowance for NDT
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)						
	Cut, Weld, Stress Relieve	8645	lbs	$2.50		$21,613	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 123" OD X 111" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	4157		$2.00		$8,314	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	40564	lbs	$1.50		$60,846	Weight includes 33% waste

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$5,000	
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$6,000	
	Primer and Epoxy Finish Coats on Exterior		Lump Sum			$15,000	
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	1500	$/KW	$15.38		$23,070	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$302,431**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	10000	lb	$1.50	$30,000	$2,500	See Note 4 - Make 2 sets and reuse 12 times.
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 3 Tube Sections (labor)	132	man hours	$40.30		$5,320	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane
	Weld (2) Field Joints with Track-Mounted Welder = ($1.67/KW)	1500	$/KW	$1.67		$2,505	Includes allowance for NDT- 2 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for weld length.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$29,183**	
5	**Precast Concrete Operation - Includes 525 A Segments, 450 B Segments and 75 C Segments**						
	Design and Fabricate (4) A Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (3) B Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers
	Design and Fabricate (1) C Form	1	Each	$15,000	$15,000	$600	Divide Total Form Costs by 25 Towers
	Install 8 Forms and Start-up at Precast Plant	5	Each	$2,000	$10,000	$400	Divide Total Form Costs by 25 Towers
	Precast (42) A, B and C Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$5,040	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$12,096	
	Supply and Install Rebar (140 #/cy)	1225	Lbs	$0.35	$429	$18,008	51,490 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$9,240	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$3,360	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$3,822	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$4,200	14 Rings
	Supply and Place Concrete 11 cy/segment average	11.2	Cubic Yard	$80.00	$896	$37,632	f'c = 7000psi 460 cubic yards total
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$6,300	
	Total concrete	463	Cubic Yards		Subtotal	$103,258	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$30,977	
	General and Administrative and Profit	25.0%				$33,559	
							Equals Cost Per Cubic Yard
					Subtotal	**$167,793**	$362.40
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	42	Loads	$1,100.00		$46,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	600	Sq Ft	$20.00	$12,000	$480	Includes re-usable tie-bolt hardware
	Erect 14 Rings of 3 Segments Each	42	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	14	Sets	$250.00		$3,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	14	Rings	$175.00		$2,450	0.5 crew hour per segment

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist and Set 42 Segments	42	Segments	$175.00		$7,350	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	12254	lbs	$1.50		$18,381	4 bars and couplers per segment
	Install and stress 168 Post Tensioning Bars with Couplers	12254	lbs	$0.50		$6,127	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	42	each	$58.00		$2,436	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	1680	Welds	$4.00		$6,720	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	56	Cubic ft.	$30.00		$1,680	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	14	Sets	$350.00		$4,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	60	Cubic yards	$150.00		$9,000	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	36	Tendons				
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	72	Each	$193.00		$13,896	Installation cost is included in precast
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	4450	Lineal ft	$2.50		$11,125	Installation cost is included in precast
	Supply and install (432) Pieces of 0,6 in dia Post Tensioning Strand	51390	lbs	$0.68		$34,945	
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	36	Operations	$500.00		$18,000	Inlcudes rental of P/T jacks and pumps
	Grout 36 Post Tensioniing Tendons	306	Cubic ft	$20.00		$6,120	8.5 Cubic ft per tendon
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$15,000	
	Allowance for material handling unloading and equipment		Lump Sum			$10,000	Crane cost covered in item 1
					Subtotal	**$219,277**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$4,000	Planning, dry-runs, etc.
	Supply and Install (3) Jack-up Tendons with	4320	Lineal ft	$0.50		$2,160	9 -0.6 in strand X 160 ft.
	Anchors Top and Bottom	6	Each	$150.00		$900	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate (18) Upper Thruster Assemblies	2000	lbs	$2.50	$5,000	$200	Reusable 25 times
	Install (18) Upper Thruster Assemblies	18	Each	$200		$3,600	Labor and anchor bolts
	Fabricate (24) Lower Thruster Assemblies	1800	lbs	$2.50	$4,500	$180	Reusable 25 times
	Install (24) Lower Thruster Assemblies	24	Each	$100.00		$2,400	
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	60	man hours	$40.30		$2,418	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 6 days)	60	man hours	$40.30		$2,418	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	24	Bolts	$10.00		$240	
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$10,000	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$45,586**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$25.00		$1,050	
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	128	Each	$31.30		$4,006	
	Remove Jack-Up Tendons and Anchors	3	Each	$200.00		$600	
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$36,270**	
	Summary of Construction Costs for 1.5 MW Hybrid (Earthquake Design) Tower					**$1,111,659**	
	General Contractor Field Overhead	10.0%				$111,166	
	General Contractor Administrative Overhead	10.0%				$111,166	
	General Contractor Profit	10.0%				$111,166	
	Total Cost of Completed 1.5 MW Hybrid (Earthquake Design) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,445,157**	Assuming 25 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 25-Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$150,000	$6,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$75,000	$3,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize LTL-600 Cranes to site	3	Lump Sum	$415,091	$1,245,273	$49,811	
	Rental for LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	63	months	$78,000	$4,914,000	$196,560	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	63	per month	$4,222	$265,986	$10,639	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$19,389	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	4	months	$88,667	$354,668	$14,187	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	4	per month	$4,222	$16,888	$676	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$357,427**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	1725	Cubic Yards	$8		$13,800	With large excavator
	Supply and Install Concrete Forms (55 ft by 55 ft by 10 ft deep)	2200	Sq Ft	$2.50		$5,500	
	Supply, Place and Consolidate Foundation Concrete	1008	Cubic Yards	$89.90		$90,619	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	143200	lbs	$0.45		$64,440	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$185,725**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.00		$22,264	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$28,264**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 600 A Segments, 362 B Segments and 900 C Segments, 75 D Segments**						
	Design and Fabricate (4) A Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers
	Design and Fabricate (1) B Forms	1	Each	$16,000	$16,000	$640	Divide Total Form Costs by 25 Towers
	Design and Fabricate (5) C Form	3	Each	$15,000	$45,000	$1,800	Divide Total Form Costs by 25 Towers
	Design and Fabricate (1) D Form	1	Each	$15,000	$15,000	$600	Divide Total Form Costs by 25 Towers
	Design and Fabricate (0) E Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 25 Towers
	Design and Fabricate (0) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 25 Towers
	Install 7 Forms and Start-up at Precast Plant	7	Each	$2,000	$14,000	$560	Divide Total Form Costs by 25 Towers
	Precast (78) A, B, C, D Segments Per Tower				Per Segment	Per Tower	

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$9,360	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$22,464	
	Supply and Install Rebar	947	Lbs	$0.35	$331	$25,853	73931 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$17,160	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,240	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,098	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$7,800	26 Rings
	Supply and Place Concrete - cy/segment average	10.75	Cubic Yard	$80.00	$860	$67,080	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$11,700	
	Total cubic yards of PC concrete	838			Subtotal	$179,635	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$53,891	
	General and Administrative and Profit	25.0%				$58,381	
							Equals Cost Per Cubic Yard
					Subtotal	**$291,907**	$348.34
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	78	Loads	$1,100.00		$85,800	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1200	Sq Ft	$20.00	$24,000	$960	Includes re-usable tie-bolt hardware
	Erect 26 Rings of 3 Segments Each	78	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	26	Sets	$250.00		$6,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	26	Rings	$175.00		$4,550	0.5 crew hour per segment
	Hoist and Set 102 Segments	78	Segments	$175.00		$13,650	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	24998	lbs	$1.50		$37,497	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Install and stress 168 Post Tensioning Bars with Couplers	24998	lbs	$0.50		$12,499	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04)

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install Top Positioning Fixtures	78	each	$58.00		$4,524	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	4080	Welds	$4.00		$16,320	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	104	Cubic ft.	$30.00		$3,120	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	26	Sets	$350.00		$9,100	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	104	Cubic yards	$150.00		$15,600	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	30	Tendons				
	Supply (60) Post Tensioning Anchors (12 strand-0.6")	60	Each	$193.00		$11,580	Installation cost is included in precast
	Supply (30) Vertical Post Tensioning Ducts (3.5 in dia)	10137	Lineal ft	$2.50		$25,343	Installation cost is included in precast
	Supply and install (432) Pieces of 0,6 in dia Post Tensioning Strand	78490	lbs	$0.68		$53,373	
	Stress (6) Tendons teminated at Segment 50% and (24) at Top Segment	30	Operations	$500.00		$15,000	Inlcudes rental of P/T jacks and pumps
	Grout 30 Post Tensioniing Tendons	375	Cubic ft	$20.00		$7,500	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$333,883	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$26,711	
					Subtotal	**$360,594**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Precast (Designed for Wind) Tower					**$1,240,959**	
	General Contractor Field Overhead	10.0%				$124,096	
	General Contractor Administrative Overhead	10.0%				$124,096	
	General Contractor Profit	10.0%				$124,096	
	Total Cost of Completed 1.5 MW - 100m All Precast (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,613,247**	Assuming 25 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$150,000	$6,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$75,000	$3,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize (5) LTL-600 Crane to site	Not required for this concept					
	Rental for (5) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$19,389	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	7	months	$88,667	$620,669	$24,827	Add 2.3 months for an additional 2 days per tower to install tower top ring with this crane.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	7	per month	$4,222	$29,554	$1,182	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$105,175**	

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	1725	Cubic Yards	$8		$13,800	With large excavator
	Supply and Install Concrete Forms (55 ft by 55 ft by 10 ft deep)	2200	Sq Ft	$2.50		$5,500	
	Supply, Place and Consolidate Foundation Concrete	1008	Cubic Yards	$89.90		$90,619	Use 90% of gross foundation volume to acount for central thickening of foundation.
	Reinforcing Steel	143200	lbs	$0.45		$64,440	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$185,725**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.00		$22,264	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$28,264**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (1) B Forms	Not required for this concept					
	Design and Fabricate (5) C Form	Not required for this concept					
	Design and Fabricate (1) D Form	Not required for this concept					
	Design and Fabricate (0) E Form	Not required for this concept					
	Design and Fabricate (0) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
		Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Precast (78) A, B, C, D Segments Per Tower	Not required for this concept					
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$3,201,017	$128,041	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$5,925,494	$237,020	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$1,916,567	$76,663	
	Total cubic yards of concrete	804					**Equals Cost Per Cubic Yard**
					Subtotal	**$441,723**	$549.41
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 26 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Hoist and Set 102 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	30	Tendons				
	Supply (60) Post Tensioning Anchors (12 strand-0.6")	60	Each	$193.00		$11,580	Installation cost is included in precast
	Supply (30) Vertical Post Tensioning Ducts (3.5 in dia)	10137	Lineal ft	$2.50		$25,343	Installation cost is included in precast
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	78490	lbs	$0.68		$53,373	
	Stress (6) Tendons teminated at Segment 50%, and (24) at Top Segment	30	Operations	$500.00		$15,000	Inlcudes rental of P/T jacks and pumps
	Grout 46 Post Tensioniing Tendons	375	Cubic ft	$20.00		$7,500	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$123,763	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$9,901	
					Subtotal	**$133,664**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Cast in Place Concrete (Designed for Wind) Tower					**$909,132**	
	General Contractor Field Overhead	10.0%				$90,913	
	General Contractor Administrative Overhead	10.0%				$90,913	
	General Contractor Profit	10.0%				$90,913	
	Total Cost of Completed 1.5 MW - 100m All Cast in Place (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,181,872**	Assuming 25 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$150,000	$6,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$75,000	$3,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize LTL-600 Cranes to site	2	Lump Sum	$415,091	$830,182	$33,207	
	Rental for LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	40	months	$78,000	$3,120,000	$124,800	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	40	per month	$4,222	$168,880	$6,755	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$19,389	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	5	months	$88,667	$443,335	$17,733	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	5	per month	$4,222	$21,110	$844	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$268,894**	

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	1500	Cubic Yards	$8		$12,000	With large excavator
	Supply and Install Concrete Forms (54 ft by 54 ft by 10 ft deep)	2160	Sq Ft	$2.50		$5,400	
	Supply, Place and Consolidate Foundation Concrete	972	Cubic Yards	$89.90		$87,383	Use 90% of gross foundation volume to acccount for central thickening of foundation.
	Reinforcing Steel	51440	lbs	$0.45		$23,148	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$139,297**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	516100	lbs	$0.18		$92,898	
	Tube Section Fabrication, Rolled and Welded	516100	lbs	$0.72		$371,592	Fabrication labor and equipment. Includes allowance for NDT
	Base Flange Ring (Dim 245"OD X 225" ID X 5" thk)						
	Cut, Weld, Stress Relieve	13913	lbs	$2.50		$34,783	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 124" OD X 112" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	4192		$2.00		$8,384	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					
	Cut, Weld, Stress Relieve	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept				$5,000	
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$12,240	1.5 Hybrid amount X (100m/49m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$30,600	1.5 Hybrid amount X (100m/49m)
	Truck Delivery (See note 3) $27 per KW * (100m/86m)= 31.39/KW for 1.5MW Tower	1500	$/KW	$31.39		$47,085	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$638,102**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 10 Tube Sections (labor)	410	man hours	$40.30		$16,523	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (10sections/3 sections)
	Weld (9) Field Joints with Track-Mounted Welder =$10.71/KW	1500	$/KW	$10.71		$16,065	Includes allowance for NDT- 9 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$35,050**	
5	**Precast Concrete Operation**						

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 4 days)	120	man hours	$40.30		$4,836	Use LTL- 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 4 days)	120	man hours	$40.30		$4,836	Use LTL-850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 1.5 MW All Steel Tower (Wind Design)					**$1,116,323**	
	General Contractor Field Overhead	10.0%				$111,632	
	General Contractor Administrative Overhead	10.0%				$111,632	
	General Contractor Profit	10.0%				$111,632	
	Total Cost of Completed 1.5 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,451,220**	Assuming 25 Towers

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$175,000	$7,000	
	Management & Supervision Recruitment and Relocation		Lump Sum		$75,000	$3,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$6,000	
	Fabricate, Assemble 4 Special Pedestal Cranes for Erecting Precast Elements.	3	Each	$250,000	$750,000	$30,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Design and Develop Active Lower Guide/Force Reaction Assembly - For Use During Jack-up Operation	1	Lump Sum	$75,000	$75,000	$3,000	Required for 3.6 MW and 5.0 MW hybrid towers which do not have constant ID in concrete tower portion.
	Fabricate and Assemble Lower Guide/Force Reaction Assembly	3	Each	$100,000	$300,000	$12,000	
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize 4100 W Cranes to site	3	Lump Sum	$66,416	$199,248	$7,970	
	Rental for 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	63	months	$13,000	$819,000	$32,760	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365		$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780		$780	
	Crane cribbing cost per turbine	1	per turbine	$131		$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248		$248	
	Fuel cost per month	63	per month	$1,429	$90,027	$3,601	
	Mobilize/Demoblize (1) LTL-850 Crane		Lump sum		$484,727	$19,389	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	9	months	$86,667	$780,003	$31,200	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332		$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730		$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808		$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161		$1,161	

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fuel cost per month	9	per month	$4,222	$37,998	$1,520	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$210,741**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	2765	Cubic Yards	$8		$22,120	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel (93 lb per cubic yard)	215200	lbs	$0.45		$96,840	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	42	Sets	$250		$10,500	(1.5 MW no x 1.16 based on dia's)
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$310,326**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	354500	lbs	$0.18		$63,810	
	Tube Section Fabrication, Rolled and Welded	354500	lbs	$0.72		$255,240	Fabrication labor and equipment. Includes allowance for NDT
	Weld quartered Tube sections	3600	$/kw			$17,039	WindPACT technical Area 2 for auto welding quartered sections. Adjusted for tower height.
	Base Flange Ring (Dim 239"OD X 219" ID X 5" thk)						
	Cut, Weld, Stress Relieve	13557	lbs	$2.50		$33,893	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$4,500	(1.5 MW amount X 1.5)
	Top Flange Ring (Dim 165" OD X 153" ID X 5 " thk)						

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	5649		$2.00		$11,298	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,300	1.5 MW amount X 1.1)
	Concrete Tower Top Connection Ring (Dim 305" OD X 239" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	63778	lbs	$1.50		$95,667	Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$6,000	(1.5 MW amount X 1.2)
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$7,200	(1.5 MW amount X 1.2 based on dia's)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$18,000	(1.5 MW amount X 1.2 based on dia's)
	Truck Delivery (See note 3) $48 per KW *(54m/1302.m)=$19.90/KW for 3.6 MW Tower	3600	$/KW	$19.90		$71,640	56 ft to 64 ft long Per WIndPACT Area 4 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$602,587**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	14700	lb	$1.50	$66,150	$5,513	See Note 4 - Make 3 sets and reuse 12 times. Use 1.5 MW wt X 1.47 based on tower wt.
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 6 Tube Sections (labor)	145	man hours	$40.30		$5,844	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane Use 1.1 X 1.5 MW labor
	Weld (5) Field Joints with Track-Mounted Welder = $6.25/KW	3600	$/KW	$6.25		$22,500	Includes allowance for NDT- 5 horizontal welds to connect erected tube sections. (WindPACT Area 4 Figure 4-13 adjusted for weld length)
	Grout and Torque Tower Base (labor)	48	man hours	$40.30		$1,934	(1.5 MW amount X 1.2 based on dia's)
	Grout and Torque Tower Base (Material and Equipment)					$986	Use 1.16 X 1.5 MW amount based on dia's

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$53,172**	
5	**Precast Concrete Operation - Includes825 A Segments,600 B Segments and 362 C, 150 D Segments**						
	Design and Fabricate (5) A Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers
	Design and Fabricate (5) B Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers
	Design and Fabricate (2) C Forms	2	Each	$15,000	$30,000	$1,200	Divide Total Form Costs by 25 Towers
	Design and Fabricate (1) D Form	1	Each	$15,000	$15,000	$600	Divide Total Form Costs by 25 Towers
	Design and Fabricate (1) E Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 25 Towers
	Install (7) Forms and Start-up at Precast Plant	7	Each	$2,000	$14,000	$560	Divide Total Form Costs by 25 Towers
	Precast (78) A, B, C, D Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$9,360	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$22,464	
	Supply and Install Rebar	924	Lbs	$0.35	$323	$25,225	72,126 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$17,160	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,240	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,098	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$7,800	26 Rings
	Supply and Place Concrete cy/segment average	12.2	Cubic Yard	$80.00	$976	$76,128	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$11,700	
	Total concete	952.7	Cubic Yards		Subtotal	$188,095	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$56,429	
	General and Administrative and Profit	25.0%				$61,131	
							Equals Cost Per Cubic Yard
					Subtotal	**$305,655**	$320.83

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	78	Loads	$1,100.00		$85,800	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	600	Sq Ft	$20.00	$12,000	$480	Includes re-usable tie-bolt hardware
	Erect 26 Rings of 3 Segments Each	78	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	26	Sets	$250.00		$6,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	26	Rings	$175.00		$4,550	0.5 crew hour per segment
	Hoist and Set 78 Segments	78	Segments	$175.00		$13,650	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	16050	lbs	$1.50		$24,075	4 bars and couplers per segment
	Install and stress 168 Post Tensioning Bars with Couplers	16050	lbs	$0.50		$8,025	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	78	each	$58.00		$4,524	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	1680	Welds	$4.00		$6,720	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	104	Cubic ft.	$30.00		$3,120	Concurrent with rebar welding (1.31 x 1.5 MW amount)
	Attach Closure Joint Forms (1 Set = (6) leaves)	26	Sets	$350.00		$9,100	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	104	Cubic yards	$150.00		$15,600	Av 4 cubic yards / 3 joints; F'c= 6000 psi (1.31 x 1.5 MW amount)
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	29	Man Hours	$40.30		$1,169	Connection plate hoisted with strand post tensioning anchors attached. (1.21 X 1.5 MW amount based on dias')
	Install, Stress and Grout Vertical Strand Tendons	48	Tendons				
	Supply (96) Post Tensioning Anchors (12 strand-0.6")	96	Each	$193.00		$18,528	Installation cost is included in precast
	Supply (48) Vertical Post Tensioning Ducts (3.5 in dia)	5635	Lineal ft	$2.50		$14,088	Installation cost is included in precast
	Supply and install (576) Pieces of 0,6 in dia Post Tensioning Strand	65730	lbs	$0.68		$44,696	
	Stress (48) Tendons at Top Segment	48	Operations	$500.00		$24,000	Inlcudes rental of P/T jacks and pumps
	Grout 48 Post Tensioniing Tendons	408	Cubic ft	$20.00		$8,160	8.5 Cubic ft per tendon
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$15,000	

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Allowance for material handling unloading and equipment		Lump Sum			$10,000	Crane cost covered in item 1
					Subtotal	**$317,785**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$4,000	Planning, dry-runs, etc.
	Supply and Install (4) Jack-up Tendons with	8769	Lineal ft	$0.50		$4,385	12 -0.6 in strand X 160 ft. (1.5 MW wt X 2.03 based on stl tower wt.)
	Anchors Top and Bottom	8	Each	$150.00		$1,200	
	Fabricate (18) Upper Thruster Assemblies	4060	lbs	$2.50	$10,150	$406	Reusable 25 times (1.5 MW wt X 2.03 based on stl tower wt.)
	Install (18) Upper Thruster Assemblies	18	Each	$300		$5,400	Labor and anchor bolts (1.5 MW wt X 2.03 based on stl tower wt.)
	Fabricate (24) Lower Thruster Assemblies	3654	lbs	$2.50	$9,135	$365	Reusable 25 times (1.5 MW wt X 2.03 based on stl tower wt.)
	Install (24) Lower Thruster Assemblies	24	Each	$150.00		$3,600	(1.5 MW wt X 2.03 based on stl tower wt.)
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	70	man hours	$40.30		$2,821	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	(1.5 MW abount X 1.16 based on dia's)
	Erect Hub and Blades to Turbine Nacelle (crew of 3 for 3 days)	72	man hours	$40.30		$2,902	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	28	Bolts	$10.00		$280	(1.5 MW abount X 1.16 based on dia's)
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$12,500	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$55,084**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$50.75		$2,132	(1.5 MW wt X 2.03 based on stl tower wt.)
	Supply, Install, and Torque (148) -1.5 in Diameter High Strength Bolts	259	Each	$31.30		$8,107	(1.5 MW wt X 2.03 based on stl tower wt.)
	Remove Jack-Up Tendons and Anchors	3	Each	$406.00		$1,218	(1.5 MW wt X 2.03 based on stl tower wt.)
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	24	man hours	$40.30		$967	Crew of 4 for 6 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$42,392**	
	Summary of Construction Costs for 3.6 MW Hybrid (Designed for Earthquake) Tower					**$1,897,742**	
	General Contractor Field Overhead	10.0%				$189,774	
	General Contractor Administrative Overhead	10.0%				$189,774	
	General Contractor Profit	10.0%				$189,774	
	Total Cost of Completed 3.6 MW Hybrid (Designed for Earthquake) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,467,065**	Assuming 25 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$175,000	$7,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$4,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize LTL-600 Cranes to site	3	Lump Sum	$415,091	$1,245,273	$49,811	
	Rental for LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	66	months	$78,000	$5,148,000	$205,920	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	66	per month	$4,222	$278,652	$11,146	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$19,389	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	8	months	$88,667	$709,336	$28,373	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	8	per month	$4,222	$33,776	$1,351	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$384,156**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	2455	Cubic Yards	$8		$19,640	With large excavator
	Supply and Install Concrete Forms (63 ft by 63 ft by 12 ft deep)	3027	Sq Ft	$2.50		$7,568	
	Supply, Place and Consolidate Foundation Concrete	1588	Cubic Yards	$89.90		$142,761	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	231500	lbs	$0.45		$104,175	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$285,510**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 600 A Segments, 362 B Segments and 450 C Segments, 450 D Segments, 525 E Segments, 75 F Segments**						
	Design and Fabricate (4) A Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers
	Design and Fabricate (2) B Forms	2	Each	$16,000	$32,000	$1,280	Divide Total Form Costs by 25 Towers
	Design and Fabricate (2) C Form	1	Each	$15,000	$15,000	$600	Divide Total Form Costs by 25 Towers
	Design and Fabricate (2) D Form	1	Each	$15,000	$15,000	$600	Divide Total Form Costs by 25 Towers
	Design and Fabricate (4) E Form	2	Each	$15,000	$30,000	$1,200	Divide Total Form Costs by 25 Towers
	Design and Fabricate (1) F Form	1	Each	$15,000	$15,000	$600	Divide Total Form Costs by 25 Towers
	Install 9 Forms and Start-up at Precast Plant	9	Each	$2,000	$18,000	$720	Divide Total Form Costs by 25 Towers
	Precast (99) A, B, C, D, E and F Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$11,880	Outer form = 11.7 ft x17 ft with 15 Ties

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$28,512	
	Supply and Install Rebar	850	Lbs	$0.35	$298	$29,453	92240 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$21,780	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$7,920	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$9,009	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$9,900	33 Rings
	Supply and Place Concrete - cy/segment average	11.05	Cubic Yard	$80.00	$884	$87,516	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$14,850	
	Total cubic yards of PC concrete	1094			Subtotal	$227,100	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$68,130	
	General and Administrative and Profit	25.0%				$73,807	
							Equals Cost Per Cubic Yard
					Subtotal	**$369,037**	$337.33
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (99 Precast Segments per Tower)	99	Loads	$1,100.00		$108,900	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1200	Sq Ft	$20.00	$24,000	$960	Includes re-usable tie-bolt hardware
	Erect 34 Rings of 3 Segments Each	99	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	33	Sets	$250.00		$8,250	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	33	Rings	$175.00		$5,775	0.5 crew hour per segment
	Hoist and Set 99 Segments	99	Segments	$175.00		$17,325	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	31728	lbs	$1.50		$47,592	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by no. of segments)
	Install and stress 168 Post Tensioning Bars with Couplers	31728	lbs	$0.50		$15,864	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by no. of segments)

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install Top Positioning Fixtures	99	each	$58.00		$5,742	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	3180	Welds	$4.00		$12,720	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	132	Cubic ft.	$30.00		$3,960	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	33	Sets	$350.00		$11,550	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	132	Cubic yards	$150.00		$19,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	40	Tendons				
	Supply (80) Post Tensioning Anchors (12 strand-0.6")	80	Each	$193.00		$15,440	Installation cost is included in precast
	Supply (40) Vertical Post Tensioning Ducts (3.5 in dia)	13864	Lineal ft	$2.50		$34,660	Installation cost is included in precast
	Supply and install (480) Pieces of 0,6 in dia Post Tensioning Strand	104600	lbs	$0.68		$71,128	
	Stress (8) Tendons teminated at Segment 50% and 32 at Top Segment	40	Operations	$500.00		$20,000	Inlcudes rental of P/T jacks and pumps
	Grout 40 Post Tensioniing Tendons	340	Cubic ft	$20.00		$6,800	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$417,433	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$33,395	
					Subtotal	**$450,828**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	140	man hours	$40.30		$5,642	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	144	man hours	$40.30		$5,803	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,510**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 3.6 MW All Precast (Designed for Wind) Tower					**$1,543,870**	
	General Contractor Field Overhead	10.0%				$154,387	
	General Contractor Administrative Overhead	10.0%				$154,387	
	General Contractor Profit	10.0%				$154,387	
	Total Cost of Completed 3.6 MW - 100m All Precast (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,007,031**	Assuming 25 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$150,000	$6,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$75,000	$3,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	Not required for this concept					
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$19,389	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	9	months	$88,667	$798,003	$31,920	Add 2.3 months for an additional 2 days per tower to install tower top ring with this crane.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	9	per month	$4,222	$37,998	$1,520	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$112,606**	

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	2445	Cubic Yards	$8		$19,560	With large excavator
	Supply and Install Concrete Forms (63 ft by 63 ft by 12 ft deep)	3024	Sq Ft	$2.50		$7,560	
	Supply, Place and Consolidate Foundation Concrete	1588	Cubic Yards	$89.90		$142,761	Use 90% of gross foundation volume to acount for central thickening of foundation.
	Reinforcing Steel	231500	lbs	$0.45		$104,175	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$285,422**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (2) B Forms	Not required for this concept					
	Design and Fabricate (2) C Form	Not required for this concept					
	Design and Fabricate (2) D Form	Not required for this concept					
	Design and Fabricate (4) E Form	Not required for this concept					
	Design and Fabricate (1) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Precast (99) A, B, C, D, E and F Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$4,557,071	$182,283	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$7,518,605	$300,744	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$2,535,892	$101,436	
	Cubic yards of concrete	1131					**Equals Cost Per Cubic Yard**
					Subtotal	**$584,463**	$516.77
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (99 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist and Set 99 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	40	Tendons				
	Supply (80) Post Tensioning Anchors (12 strand-0.6")	80	Each	$193.00		$15,440	Installation cost is included in precast
	Supply (40) Vertical Post Tensioning Ducts (3.5 in dia)	13864	Lineal ft	$2.50		$34,660	Installation cost is included in precast
	Supply and install (480) Pieces of 0,6 in dia Post Tensioning Strand	104600	lbs	$0.68		$71,128	
	Stress (8) Tendons teminated at Segment 50% and 32 at Top Segment	40	Operations	$500.00		$20,000	Inlcudes rental of P/T jacks and pumps
	Grout 40 Post Tensioniing Tendons	340	Cubic ft	$20.00		$6,800	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$158,995	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$12,720	
					Subtotal	**$171,715**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	140	man hours	$40.30		$5,642	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	144	man hours	$40.30		$5,803	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,510**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-850 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 3.6 MW All Cast in Place Concrete (Designed for Wind) Tower					**$1,206,084**	
	General Contractor Field Overhead	10.0%				$120,608	
	General Contractor Administrative Overhead	10.0%				$120,608	
	General Contractor Profit	10.0%				$120,608	
	Total Cost of Completed 3.6 MW - 100m All Cast in Place Concrete (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,567,909**	Assuming 25 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25-Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$175,000	$7,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$4,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize LTL-600 Cranes to site	2	Lump Sum	$415,091	$830,182	$33,207	
	Rental for LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	44	months	$78,000	$3,432,000	$137,280	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	44	per month	$4,222	$185,768	$7,431	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$19,389	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	7	months	$88,667	$620,669	$24,827	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	7	per month	$4,222	$29,554	$1,182	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$291,481**	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2218	Cubic Yards	$8		$17,744	With large excavator
	Supply and Install Concrete Forms (60 ft by 60 ft by 12 ft deep)	2880	Sq Ft	$2.50		$7,200	
	Supply, Place and Consolidate Foundation Concrete	1440	Cubic Yards	$89.90		$129,456	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	76200	lbs	$0.45		$34,290	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$200,056**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	899200	lbs	$0.18		$161,856	
	Tube Section Fabrication, Rolled and Welded	899200	lbs	$0.72		$647,424	allowance for NDT
	Weld Quartered Tube Sections	3600	$/KW	$39.94		$57,118	WindPACT Area 2 Figure 4-13 adjusted to tower height
	Base Flange Ring (Dim 317"OD X 297" ID X 5" thk)						
	Cut, Weld, Stress Relieve	18178	lbs	$2.50		$45,445	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 166" OD X 154" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	5684		$2.00		$11,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept					
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$13,320	1.5 Hybrid amount 1.2 based on dia's X (100m/54m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$33,300	1.5 Hybrid amount 1.2 based on dia's X (100m/54m)
	Truck Delivery (See note 3) $48 per KW * (100m/130.2m)= $36.87/KW for 3.6 MW Tower	3600	$/KW	$36.87		$132,732	56 ft to 64 ft long Per WindPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$1,138,083**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 17 Tube Sections (labor)	748	man hours	$40.30		$30,144	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (17sections/3 sections)
	Weld (20) Field Joints with Track-Mounted Welder $26.24/KW	3600	$/KW	$26.24		$94,464	Includes allowance for NDT- 20 horizontal welds to connect erected tube sections (Fig. 4-13 Wind PACT Technical Area 2 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	**$127,070**	
5	**Precast Concrete Operation**						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	$0	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 4 for 4 days)	140	man hours	$40.30		$5,642	Use LTL- 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 4 for 4 days)	144	man hours	$40.30		$5,803	Use LTL-850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,354**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 3.6 MW All Steel Tower (Wind Design)					**$1,793,444**	
	General Contractor Field Overhead	10.0%				$179,344	
	General Contractor Administrative Overhead	10.0%				$179,344	
	General Contractor Profit	10.0%				$179,344	
	Total Cost of Completed 3.6 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,331,478**	Assuming 25 Towers

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 25-Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$8,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$4,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$6,000	
	Fabricate, Assemble 6 Special Pedestal Cranes for Erecting Precast Elements.	3	Each	$250,000	$750,000	$30,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Design and Develop Active Lower Guide/Force Reaction Assembly - For Use During Jack-up Operation	1	Lump Sum	$75,000	$75,000	$3,000	Required for 3.6 MW and 5.0 MW hybrid towers which do not have constant ID in concrete tower portion.
	Fabricate and Assemble Lower Guide/Force Reaction Assembly	3	Each	$100,000	$300,000	$12,000	
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize 4100 W Cranes to site	3	Lump Sum	$66,416	$199,248	$7,970	
	Rental for 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	63	months	$13,000	$819,000	$32,760	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365	$68,250	$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780	$39,000	$780	
	Crane cribbing cost per turbine	1	per turbine	$131	$6,550	$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248	$12,400	$248	
	Fuel cost per month	63	per month	$1,429	$90,027	$3,601	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$44,281	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection	9	months	$121,333	$1,091,997	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fuel cost per month	9	per month	$4,547	$40,923	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$256,064**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	3018	Cubic Yards	$8		$24,144	With large excavator
	Supply and Install Concrete Forms (70 ft by 70 ft by 12 ft deep)	3360	Sq Ft	$2.50		$8,400	
	Supply, Place and Consolidate Foundation Concrete	1960	Cubic Yards	$89.90		$176,204	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	250200	lbs	$0.45		$112,590	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	70	Sets	$250		$17,500	(1.5 MW no x 1.94 based on dia's)
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$350,204**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	533700	lbs	$0.18		$96,066	
	Tube Section Fabrication, Rolled and Welded	533700	lbs	$0.72		$384,264	Fabrication labor and equipment. Includes allowance for NDT
	Weld quartered Tube sections	5000	$/kw			$26,577	WindPACT technical Area 2 for auto welding quartered sections. Adjusted for tower height.
	Base Flange Ring (Dim 275"OD X 255" ID X 5" thk)						
	Cut, Weld, Stress Relieve	15691	lbs	$2.50		$39,228	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$5,490	(1.5 MW amount X 1.83 based on dia's))
	Top Flange Ring (Dim 189" OD X 177" ID X 5 " thk)						

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	6501		$2.00		$13,002	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$4,950	1.5 MW amount X 1.65 based on dia's)
	Concrete Tower Top Connection Ring (Dim 341" OD X 275" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	72219	lbs	$1.50		$108,329	Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$6,800	(1.5 MW amount X 1.36 based on dia's)
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$11,400	(1.5 MW amount X 1.9 based on diameter)
	Primer and Epoxy Finish Coats on Exterior		Lump Sum			$28,500	(1.5 MW amount X 1.9 based on diameter)
	Truck Delivery (See note 3) $51 per KW *(54m/156.1m)=$17.64/KW for 5.0 MW Tower	5000	$/KW	$17.64		$88,200	56 ft to 64 ft long Per WIndPACT Area 4 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$827,805**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	35500	lb	$1.50	$159,750	$13,313	See Note 4 - Make 3 sets and reuse 12 times. (Use 1.5 MW wt X 1.55 based on tower wt.)
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 11 Tube Sections (labor)	198	man hours	$40.30		$7,979	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane (Use 1.5 X 1.5 MW labor)
	Weld (10) Field Joints with Track-Mounted Welder =$19.54/KW	5000	$/KW	$19.54		$97,700	Includes allowance for NDT- 10 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for weld length)
	Grout and Torque Tower Base (labor)	76	man hours	$40.30		$3,063	(1.5 MW amount X 1.9 based on dia's)
	Grout and Torque Tower Base (Material and Equipment)					$1,615	Use 1.16 X 1.9 MW amount based on dia's
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	**$140,066**	
5	**Precast Concrete Operation - Includes 675 A Segments, 750 B Segments and 675 C Segments**						
	Design and Fabricate (8) A Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (8) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (8) C Forms	3	Each	$15,000	$45,000	$900	Divide Total Form Costs by 50 Towers
	Install (9) Forms and Start-up at Precast Plant	9	Each	$2,000	$18,000	$360	Divide Total Form Costs by 50 Towers
	Precast (84) A, B, C, D & E Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$10,080	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$24,192	
	Supply and Install Rebar	964	Lbs	$0.35	$337	$28,342	156226 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$18,480	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,720	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,644	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$8,100	27 Rings
	Supply and Place Concrete cy/segment average	12.9	Cubic Yard	$80.00	$1,032	$86,688	f'c = 7000psi 460 cubic yards total
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$12,600	
	Total Concrete	1083.3	Cubic Yards		Subtotal	$206,026	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$61,808	
	General and Administrative and Profit	25.0%				$66,958	
							Equals Cost Per Cubic Yard
					Subtotal	**$334,792**	$309.05
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (162 Precast Segments per Tower)	162	Loads	$1,100.00		$178,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate Joint Closure Forms (4 Sets of 6 Forms)	1200	Sq Ft	$20.00	$24,000	$960	Includes re-usable tie-bolt hardware
	Erect 27 Rings of 6 Segments Each	60	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	27	Sets	$250.00		$6,750	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	27	Rings	$175.00		$4,725	0.5 crew hour per segment
	Hoist and Set 162 Segments	162	Segments	$175.00		$28,350	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	25733	lbs	$1.50		$38,600	4 bars and couplers per segment (1.5 MW amount X 2.1 based on dia's)
	Install and stress 350 Post Tensioning Bars with Couplers	25733	lbs	$0.50		$12,867	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	162	each	$58.00		$9,396	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	3360	Welds	$4.00		$13,440	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	118	Cubic ft.	$30.00		$3,540	Concurrent with rebar welding (1.5 MW amount X 2.1 based on dia's)
	Attach Closure Joint Forms (1 Set = (6) leaves)	54	Sets	$350.00		$18,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	126	Cubic yards	$150.00		$18,900	Av 4 cubic yards / 3 joints; F'c= 6000 psi (1.5 MW amount x 2.1 based on dia's)
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	44	Man Hours	$40.30		$1,773	Connection plate hoisted with strand post tensioning anchors attached. (1.5 MW amount X 1.84 based on dias')
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	6590	Lineal ft	$2.50		$16,475	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	76680	lbs	$0.68		$52,142	
	Stress 56 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioning Tendons	476	Cubic ft	$20.00		$9,520	8.5 Cubic ft per tendon
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$22,500	54/36 = 1.5 factor
	Allowance for material handling unloading and equipment		Lump Sum			$15,000	Crane cost covered in item 1 54/36 = 1.5 factor

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	**$501,654**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$4,000	Planning, dry-runs, etc.
	Supply and Install (4) Jack-up Tendons with	15336	Lineal ft	$0.50		$7,668	12 -0.6 in strand X 160 ft. (1.5 MW wt X 3.55 based on stl tower wt.)
	Anchors Top and Bottom	24	Each	$150.00		$3,600	
	Fabricate (18) Upper Thruster Assemblies	7100	lbs	$2.50	$17,750	$710	Reusable 25 times (1.5 MW wt X 3.55 based on stl tower wt.)
	Install (18) Upper Thruster Assemblies	18	Each	$710		$12,780	Labor and anchor bolts (1.5 MW wt X 3.55 based on stl tower wt.)
	Fabricate (24) Lower Thruster Assemblies	6390	lbs	$2.50	$15,975	$639	Reusable 25 times (1.5 MW wt X 3.55 based on stl tower wt.)
	Install (24) Lower Thruster Assemblies	24	Each	$355.00		$8,520	(1.5 MW wt X 3.55 based on stl tower wt.)
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	90	man hours	$40.30		$3,627	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	106	each	$14.20		$1,505	(1.5 MW abount X 1.65 based on dia's)
	Erect Hub and Blades to Turbine Nacelle (crew of 3 for 4 days)	96	man hours	$40.30		$3,869	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	48	Bolts	$10.00		$480	(1.5 MW abount X 1.95 based on dia's)
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$15,000	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$78,559**	

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$88.75		$3,728	(1.5 MW wt X 3.55 based on stl tower wt.)
	Supply, Install, and Torque (235) -1.5 in Diameter High Strength Bolts	235	Each	$31.30		$7,356	(1.5 MW wt X 1.84 based on stl tower wt.)
	Remove Jack-Up Tendons and Anchors	3	Each	$710.00		$2,130	(1.5 MW wt X 3.55 based on stl tower wt.)
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	32	man hours	$40.30		$1,290	Crew of 4 for 8 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$44,471**	
	Summary of Construction Costs for 5.0 MW Hybrid (Earthquake Design) Tower					**$2,533,614**	
	General Contractor Field Overhead	10.0%				$253,361	
	General Contractor Administrative Overhead	10.0%				$253,361	
	General Contractor Profit	10.0%				$253,361	
	Total Cost of Completed 1.5 MW Hybrid (Earthquake Design) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$3,293,699**	Assuming 25 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$499,650	$19,986	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$8,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$4,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize LTL-600 Cranes to site	3	Lump Sum	$415,091	$1,245,273	$49,811	
	Rental for LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	88	months	$29,250	$2,574,000	$102,960	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	88	per month	$4,222	$371,536	$14,861	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$44,281	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	9	months	$121,333	$1,091,997	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	9	per month	$4,547	$40,923	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$332,670**	
2	**Foundation Construction Per Tower**						

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	3072	Cubic Yards	$8		$24,576	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3218	Sq Ft	$2.50		$8,045	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	290200	lbs	$0.45		$130,590	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$336,037**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 675 A Segments,450 B Segments and 600 C Segments, 450 D and 675 E Segments**						
	Design and Fabricate (8) A Forms	2	Each	$16,000	$32,000	$640	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) B Forms	2	Each	$16,000	$32,000	$640	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) C Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) D Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) E Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) G Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install 14 Forms and Start-up at Precast Plant	14	Each	$2,000	$28,000	$560	Divide Total Form Costs by 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Precast (114) A, B, C, D, E and F G Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$13,680	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$32,832	
	Supply and Install Rebar	781	Lbs	$0.35	$273	$31,162	185134 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$25,080	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$9,120	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$10,374	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$11,400	38 Rings
	Supply and Place Concrete - cy/segment average	11.3	Cubic Yard	$80.00	$904	$103,056	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$17,100	
	Total cubic yards of PC concrete	1288			Subtotal	$258,644	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$77,593	
	General and Administrative and Profit	25.0%				$84,059	
							Equals Cost Per Cubic Yard
					Subtotal	**$420,296**	$326.32
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (114 Precast Segments per Tower)	114	Loads	$1,100.00		$125,400	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1200	Sq Ft	$20.00	$24,000	$960	Includes re-usable tie-bolt hardware
	Erect 38 Rings of 3 Segments Each	114	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	38	Sets	$250.00		$9,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	38	Rings	$175.00		$6,650	0.5 crew hour per segment
	Hoist and Set 114 Segments	114	Segments	$175.00		$19,950	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	36535	lbs	$1.50		$54,803	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by number of segments

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Install and stress 168 Post Tensioning Bars with Couplers	36535	lbs	$0.50		$18,268	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by number of segments
	Install Top Positioning Fixtures	114	each	$58.00		$6,612	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	6720	Welds	$4.00		$26,880	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04 X 2 for 6 segment rings)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	152	Cubic ft.	$30.00		$4,560	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	79	Sets	$350.00		$27,650	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	252	Cubic yards	$150.00		$37,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	130500	lbs	$0.68		$88,740	
	Stress (22) Tendons teminated at Segment 50% and 34 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$551,140	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$44,091	
					Subtotal	**$595,231**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,740,026**	
	General Contractor Field Overhead	10.0%				$174,003	
	General Contractor Administrative Overhead	10.0%				$174,003	
	General Contractor Profit	10.0%				$174,003	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,262,033**	Assuming 25 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 25-Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$8,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$4,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize (8) LTL-600 Crane to site	Not required for this concept					
	Rental for (8) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$44,281	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	11	months	$121,333	$1,334,663	$53,387	Add 2.3 months for an additonal 2 days per tower to install tower top ring with this crane
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	11	per month	$4,547	$50,017	$2,001	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$168,280**	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	2766	Cubic Yards	$8		$22,128	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	290200	lbs	$0.45		$130,590	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$333,584**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.00		$29,368	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$35,368**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (8) A Forms	Not required for this concept					
	Design and Fabricate (6) B Forms	Not required for this concept					
	Design and Fabricate (6) C Form	Not required for this concept					
	Design and Fabricate (5) D Form	Not required for this concept					
	Design and Fabricate (1) E Form	Not required for this concept					
	Design and Fabricate (2) F Form	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Design and Fabricate (1) G Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
	Precast 237) A, B, C, D, E and F G Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$5,299,916	$211,997	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$8,490,741	$339,630	
	Equipment and site overhead for Cast in Place Kconcretre construction.	1	Lump Sum		$2,896,038	$115,842	
	Cubic yards of concrete	1358					**Equals Cost Per Cubic Yard**
					Subtotal	**$667,468**	$491.51
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (237 Precast Segments per Tower)	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 237 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	130500	lbs	$0.68		$88,740	
	Stress (22) Tendons teminated at Segment 50% and (34) at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$212,108	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$16,969	
					Subtotal	**$229,077**	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-1100 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,454,200**	
	General Contractor Field Overhead	10.0%				$145,420	
	General Contractor Administrative Overhead	10.0%				$145,420	
	General Contractor Profit	10.0%				$145,420	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,890,460**	Assuming 25 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 25 -Tower Site**						
	Access Road		Lump Sum		$488,650	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$8,000	
	Management & Supervision Recruitment and Relocation		Lump Sum		$100,000	$4,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$4,000	
	Other Mobilization and Site Development Cost				$100,000	$4,000	
	Mobilize/Demobilize LTL-600 Cranes to site	3	Lump Sum	$415,091	$1,245,273	$49,811	
	Rental for LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	63	months	$78,000	$4,914,000	$196,560	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	63	per month	$4,222	$265,986	$10,639	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$44,281	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection	9	months	$121,333	$1,091,997	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	9	per month	$4,547	$40,923	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$11,200	
					Subtotal	**$421,608**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	25	Each	$1,000	$25,000	$1,000	
	Excavation	2765	Cubic Yards	$8		$22,120	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	95020	lbs	$0.45		$42,759	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$245,745**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	1188000	lbs	$0.18		$213,840	
	Tube Section Fabrication, Rolled and Welded	1188000	lbs	$0.72		$855,360	Fabrication labor and equipment. Includes allowance for NDT
	Weld Quartered Tube Sections	5000	$/KW			$70,732	WindPACT Area 2 Figure 4-13 adjusted to tower height .
	Base Flange Ring (Dim 365"OD X 345" ID X 5" thk)						
	Cut, Weld, Stress Relieve	21020	lbs	$2.50		$52,550	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 190" OD X 178" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	6536		$2.00		$13,072	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept					
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$21,090	1.5 Hybrid amount 1.9 based on dia's X (100m/54m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$52,725	1.5 Hybrid amount 1.9 based on dia's X (100m/54m)
	Truck Delivery (See note 3) $51 per KW * (100m/156.1m)= $32.67/KW	5000	$/KW	$32.67		$163,350	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$1,478,239**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 21 Tube Sections (labor)	924	man hours	$40.30		$37,237	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (21 sections/3 sections)
	Weld (20) Field Joints with Track-Mounted Welder $26.24/KW	5000	$/KW	$26.24		$131,200	Includes allowance for NDT- 20 horizontal welds to connect erected tube sections (Fig. 4-13 Wind PACT Technical Area 2 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$170,899**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
5	**Precast Concrete Operation**						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 5 for 4 days)	160	man hours	$40.30		$6,448	Use LTL- 1100 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 5 for 4 days)	160	man hours	$40.30		$6,448	Use LTL-1100 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,805**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
25 Tower Installation - 28 month schedule

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 5.0 MW All Steel Tower (Wind Design)					**$2,354,696**	
	General Contractor Field Overhead	10.0%				$235,470	
	General Contractor Administrative Overhead	10.0%				$235,470	
	General Contractor Profit	10.0%				$235,470	
	Total Cost of Completed 5.0 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$3,061,105**	Assuming 25 Towers

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$3,000	
	Fabricate, Assemble 3 Special Pedestal Cranes for Erecting Precast Elements.	3	Each	$250,000	$750,000	$15,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (3) 4100 W Crane to site	3	Lump Sum	$66,416	$199,248	$3,985	
	Rental for (3) 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	63	months	$13,000	$819,000	$16,380	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365	$68,250	$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780	$39,000	$780	
	Crane cribbing cost per turbine	1	per turbine	$131	$6,550	$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248	$12,400	$248	
	Fuel cost per month	63	per month	$1,429	$90,027	$1,801	
	Mobilize/Demoblize (1) LTL-600 Crane	1	Lump sum	$415,091	$415,091	$8,302	
	Rental for (1) LTL-600 Crane- For nacelle, hub and blade erection	9	months	$78,000	$702,000	$14,040	
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	9	per month	$4,222	$37,998	$760	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$107,325**	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1500	Cubic Yards	$8		$12,000	With large excavator
	Supply and Install Concrete Forms (54 ft by 54 ft by 10 ft deep)	2160	Sq Ft	$2.50		$5,400	
	Supply, Place and Consolidate Foundation Concrete	972	Cubic Yards	$89.90		$87,383	Use 90% of gross fundation volume to account for central thickening of foundationl.
	Reinforcing Steel (93 lb per cubic yard)	104000	lbs	$0.54		$56,160	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	36	Sets	$250		$9,000	
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$181,309**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	185800	lbs	$0.40		$74,320	
	Tube Section Fabrication, Rolled and Welded	150200	lbs	$0.72		$108,144	Fabrication labor and equipment. Includes allowance for NDT
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)						
	Cut, Weld, Stress Relieve	8645	lbs	$2.72		$23,514	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 123" OD X 111" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	4157		$2.22		$9,229	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	40564	lbs	$1.72		$69,770	Weight includes 33% waste

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$5,000	
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$6,000	
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$15,000	
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	1500	$/KW	$15.38		$23,070	56 ft to 64 ft long Per WindPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$355,047**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	10000	lb	$1.72	$68,800	$5,733	See Note 4 - Make 4 sets and reuse 12 times.
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 3 Tube Sections (labor)	132	man hours	$40.30		$5,320	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane
	Weld (2) Field Joints with Track-Mounted Welder = ($1.67/KW)	1500	$/KW	$1.67		$2,505	Includes allowance for NDT- 2 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for weld length.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$32,416**	
5	**Precast Concrete Operation - Includes 1050 A Segments, 900 B Segments and 150 C Segments**						

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers
	Design and Fabricate (3) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) C Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Install 8 Forms and Start-up at Precast Plant	8	Each	$2,000	$16,000	$320	Divide Total Form Costs by 50 Towers
	Precast (42) A, B and C Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$5,040	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$12,096	
	Supply and Install Rebar (140 #/cy)	1225	Lbs	$0.44	$539	$22,638	51,490 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$9,240	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$3,360	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$3,822	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$4,200	14 Rings
	Supply and Place Concrete 11 cy/segment average	11.2	Cubic Yard	$80.00	$896	$37,632	f'c = 7000psi 460 cubic yards total
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$6,300	
	Total concrete	463	Cubic Yards		Subtotal	$107,188	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$32,156	
	General and Administrative and Profit	25.0%				$34,836	
							Equals Cost Per Cubic Yard
					Subtotal	**$174,181**	$376.20
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	42	Loads	$1,100.00		$46,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	800	Sq Ft	$20.00	$16,000	$320	Includes re-usable tie-bolt hardware
	Erect 14 Rings of 3 Segments Each	42	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	14	Sets	$250.00		$3,500	Concurrent with leveling and shimming

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Set Shims with Level and Glue Gaskets	14	Rings	$175.00		$2,450	0.5 crew hour per segment
	Hoist and Set 42 Segments	42	Segments	$175.00		$7,350	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	12254	lbs	$1.95		$23,895	4 bars and couplers per segment
	Install and stress 168 Post Tensioning Bars with Couplers	12254	lbs	$0.50		$6,127	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	42	each	$58.00		$2,436	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	1680	Welds	$4.00		$6,720	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	56	Cubic ft.	$30.00		$1,680	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	14	Sets	$350.00		$4,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	60	Cubic yards	$150.00		$9,000	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	36	Tendons				
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	72	Each	$193.00		$13,896	Installation cost is included in precast
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	4450	Lineal ft	$2.50		$11,125	Installation cost is included in precast
	Supply and install (432) Pieces of 0,6 in dia Post Tensioning Strand	51390	lbs	$0.85		$43,682	
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	36	Operations	$500.00		$18,000	Inlcudes rental of P/T jacks and pumps
	Grout 36 Post Tensioniing Tendons	306	Cubic ft	$20.00		$6,120	8.5 Cubic ft per tendon
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$15,000	
	Allowance for material handling unloading and equipment		Lump Sum			$10,000	Crane cost covered in item 1
					Subtotal	**$233,368**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$2,000	Planning, dry-runs, etc.

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Supply and Install (3) Jack-up Tendons with	4320	Lineal ft	$0.67		$2,894	9 -0.6 in strand X 160 ft.
	Anchors Top and Bottom	6	Each	$150.00		$900	
	Fabricate (18) Upper Thruster Assemblies	2000	lbs	$2.72	$5,440	$218	Reusable 25 times
	Install (18) Upper Thruster Assemblies	18	Each	$200		$3,600	Labor and anchor bolts
	Fabricate (24) Lower Thruster Assemblies	1800	lbs	$2.72	$4,896	$196	Reusable 25 times
	Install (24) Lower Thruster Assemblies	24	Each	$100.00		$2,400	
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	60	man hours	$40.30		$2,418	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 6 days)	60	man hours	$40.30		$2,418	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	24	Bolts	$10.00		$240	
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$10,000	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$44,353**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$25.00		$1,050	
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	128	Each	$31.30		$4,006	
	Remove Jack-Up Tendons and Anchors	3	Each	$200.00		$600	

Conceptual Cost Estimate
1.5 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$36,270**	
	Summary of Construction Costs for 1.5 MW Hybrid (Earthquake Design) Tower					**$1,164,269**	
	General Contractor Field Overhead	10.0%				$116,427	
	General Contractor Administrative Overhead	10.0%				$116,427	
	General Contractor Profit	10.0%				$116,427	
	Total Cost of Completed 1.5 MW Hybrid (Earthquake Design) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,513,550**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (5) LTL-600 Crane to site	5	Lump Sum	$415,091	$2,075,455	$41,509	
	Rental for (5) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	105	months	$78,000	$8,190,000	$163,800	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	10.4	months	$88,667	$922,137	$18,443	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	10.4	per month	$4,222	$43,909	$878	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$296,756**	

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1725	Cubic Yards	$8		$13,800	With large excavator
	Supply and Install Concrete Forms (55 ft by 55 ft by 10 ft deep)	2200	Sq Ft	$2.50		$5,500	
	Supply, Place and Consolidate Foundation Concrete	1008	Cubic Yards	$89.90		$90,619	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	143200	lbs	$0.54		$77,328	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$198,613**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.22		$24,713	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$30,713**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1200 A Segments, 750 B Segments and 1800 C Segments, 150 D Segments**						
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) B Forms	1	Each	$16,000	$16,000	$320	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) C Form	5	Each	$15,000	$75,000	$1,500	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) D Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Design and Fabricate (0) E Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (0) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install 11 Forms and Start-up at Precast Plant	11	Each	$2,000	$22,000	$440	Divide Total Form Costs by 50 Towers
	Precast (78) A, B, C, D Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$9,360	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$22,464	
	Supply and Install Rebar	947	Lbs	$0.44	$417	$32,501	73931 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$17,160	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,240	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,098	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$7,800	26 Rings
	Supply and Place Concrete - cy/segment average	10.75	Cubic Yard	$80.00	$860	$67,080	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$11,700	
	Total cubic yards of PC concrete	838			Subtotal	$185,243	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$55,573	
	General and Administrative and Profit	25.0%				$60,204	
							Equals Cost Per Cubic Yard
					Subtotal	**$301,020**	$359.21
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	78	Loads	$1,100.00		$85,800	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 26 Rings of 3 Segments Each	78	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	26	Sets	$250.00		$6,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	26	Rings	$175.00		$4,550	0.5 crew hour per segment

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist and Set 102 Segments	78	Segments	$175.00		$13,650	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	24998	lbs	$1.95		$48,746	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Install and stress 168 Post Tensioning Bars with Couplers	24998	lbs	$0.50		$12,499	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Install Top Positioning Fixtures	78	each	$58.00		$4,524	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	4080	Welds	$4.00		$16,320	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	104	Cubic ft.	$30.00		$3,120	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	26	Sets	$350.00		$9,100	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	104	Cubic yards	$150.00		$15,600	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	30	Tendons				
	Supply (60) Post Tensioning Anchors (12 strand-0.6")	60	Each	$193.00		$11,580	Installation cost is included in precast
	Supply (30) Vertical Post Tensioning Ducts (3.5 in dia)	10137	Lineal ft	$2.50		$25,343	Installation cost is included in precast
	Supply and install (432) Pieces of 0,6 in dia Post Tensioning Strand	78490	lbs	$0.85		$66,717	
	Stress (6) Tendons teminated at Segment 50% and (24) at Top Segment	30	Operations	$500.00		$15,000	Inlcudes rental of P/T jacks and pumps
	Grout 30 Post Tensioniing Tendons	375	Cubic ft	$20.00		$7,500	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$358,155	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$28,652	
					Subtotal	**$386,808**	

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						

Conceptual Cost Estimate
1.5 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Precast (Designed for Wind) Tower					**$1,231,112**	
	General Contractor Field Overhead	10.0%				$123,111	
	General Contractor Administrative Overhead	10.0%				$123,111	
	General Contractor Profit	10.0%				$123,111	
	Total Cost of Completed 1.5 MW - 100m All Precast (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,600,446**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (5) LTL-600 Crane to site	Not required for this concept					
	Rental for (5) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	12.7	months	$88,667	$1,126,071	$22,521	Add 2.3 months for an additional 2 days per tower to install tower top ring with this crane.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	12.7	per month	$4,222	$53,619	$1,072	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$80,465**	

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1725	Cubic Yards	$8		$13,800	With large excavator
	Supply and Install Concrete Forms (55 ft by 55 ft by 10 ft deep)	2200	Sq Ft	$2.50		$5,500	
	Supply, Place and Consolidate Foundation Concrete	1008	Cubic Yards	$89.90		$90,619	Use 90% of gross foundation volume to acount for central thickening of foundation.
	Reinforcing Steel	143200	lbs	$0.54		$77,328	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$198,613**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 114" OD X 74" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	11132	lbs	$2.22		$24,713	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$30,713**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (1) B Forms	Not required for this concept					
	Design and Fabricate (5) C Form	Not required for this concept					
	Design and Fabricate (1) D Form	Not required for this concept					
	Design and Fabricate (0) E Form	Not required for this concept					

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (0) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
		Not required for this concept					
	Precast (78) A, B, C, D Segments Per Tower	Not required for this concept					
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	March 2004 increase in reinforcing cost $0.09 pre lb	73931		$0.09	$6,654		
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$6,383,938	$127,679	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$11,650,123	$233,002	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$3,606,812	$72,136	
	Total cubic yards of concrete	804					**Equals Cost Per Cubic Yard**
					Subtotal	**$432,817**	$538.33
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Truck Delivery (78 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 26 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 102 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	30	Tendons				
	Supply (60) Post Tensioning Anchors (12 strand-0.6")	60	Each	$193.00		$11,580	Installation cost is included in precast
	Supply (30) Vertical Post Tensioning Ducts (3.5 in dia)	10137	Lineal ft	$2.50		$25,343	Installation cost is included in precast
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	78490	lbs	$0.85		$66,717	
	Stress (6) Tendons teminated at Segment 50%, and (24) at Top Segment	30	Operations	$500.00		$15,000	Inlcudes rental of P/T jacks and pumps
	Grout 46 Post Tensioniing Tendons	375	Cubic ft	$20.00		$7,500	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$137,106	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$10,968	

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
					Subtotal	$148,075	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	120	man hours	$40.30		$4,836	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	$14,581	

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$5,000	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$38,445**	
	Summary of Construction Costs for 1.5 MW All Cast in Place Concrete (Designed for Wind) Tower					**$943,709**	
	General Contractor Field Overhead	10.0%				$94,371	
	General Contractor Administrative Overhead	10.0%				$94,371	
	General Contractor Profit	10.0%				$94,371	

Conceptual Cost Estimate
1.5 MW - 100m All Cast- In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Total Cost of Completed 1.5 MW - 100m All Cast in Place (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,226,822**	Assuming 50 Towers

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (3) LTL-600 Cranes to site	3	Lump Sum	$415,091	$1,245,273	$24,905	
	Rental for (3) LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	60	months	$78,000	$4,680,000	$93,600	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	60	per month	$4,222	$253,320	$5,066	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	10.4	months	$88,667	$922,137	$18,443	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	10.4	per month	$4,222	$43,909	$878	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$206,152**	

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	1500	Cubic Yards	$8		$12,000	With large excavator
	Supply and Install Concrete Forms (54 ft by 54 ft by 10 ft deep)	2160	Sq Ft	$2.50		$5,400	
	Supply, Place and Consolidate Foundation Concrete	972	Cubic Yards	$89.90		$87,383	Use 90% of gross foundation volume to acccount for central thickening of foundation.
	Reinforcing Steel	51440	lbs	$0.54		$27,778	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$143,926**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	516100	lbs	$0.40		$206,440	
	Tube Section Fabrication, Rolled and Welded	516100	lbs	$0.72		$371,592	Fabrication labor and equipment. Includes allowance for NDT
	Base Flange Ring (Dim 245"OD X 225" ID X 5" thk)						
	Cut, Weld, Stress Relieve	13913	lbs	$2.72		$37,843	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 124" OD X 112" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	4192		$2.22		$9,306	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept				$5,000	
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$12,240	1.5 Hybrid amount X (100m/49m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$30,600	1.5 Hybrid amount X (100m/49m)
	Truck Delivery (See note 3) $27 per KW * (100m/86m)= 31.39/KW for 1.5MW Tower	1500	$/KW	$31.39		$47,085	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$755,627**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 10 Tube Sections (labor)	410	man hours	$40.30		$16,523	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (10sections/3 sections)
	Weld (9) Field Joints with Track-Mounted Welder =$10.71/KW	1500	$/KW	$10.71		$16,065	Includes allowance for NDT- 9 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$35,050**	

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
5	**Precast Concrete Operation**						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 4 days)	120	man hours	$40.30		$4,836	Use LTL- 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 4 days)	120	man hours	$40.30		$4,836	Use LTL-850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$14,581**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					

Conceptual Cost Estimate
1.5 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind)- 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 1.5 MW All Steel Tower (Wind Design)					**$1,175,736**	
	General Contractor Field Overhead	10.0%				$117,574	
	General Contractor Administrative Overhead	10.0%				$117,574	
	General Contractor Profit	10.0%				$117,574	
	Total Cost of Completed 1.5 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,528,457**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$3,000	
	Fabricate, Assemble 4 Special Pedestal Cranes for Erecting Precast Elements.	4	Each	$250,000	$1,000,000	$20,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Design and Develop Active Lower Guide/Force Reaction Assembly - For Use During Jack-up Operation	1	Lump Sum	$75,000	$75,000	$1,500	Required for 3.6 MW and 5.0 MW hybrid towers which do not have constant ID in concrete tower portion.
	Fabricate and Assemble Lower Guide/Force Reaction Assembly	4	Each	$100,000	$400,000	$8,000	
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (4) 4100 W Crane to site	4	Lump Sum	$66,416	$265,664	$5,313	
	Rental for (4) 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	84	months	$13,000	$1,092,000	$21,840	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365		$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780		$780	
	Crane cribbing cost per turbine	1	per turbine	$131		$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248		$248	
	Fuel cost per month	84	per month	$1,429	$120,036	$2,401	
	Mobilize/Demoblize (1) LTL-850 Crane		Lump sum		$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	13	months	$86,667	$1,126,671	$22,533	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332		$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730		$2,730	

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Crane cribbing cost per turbine	1	per turbine	$808		$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161		$1,161	
	Fuel cost per month	13	per month	$4,222	$54,886	$1,098	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$145,081**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2765	Cubic Yards	$8		$22,120	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel (93 lb per cubic yard)	215200	lbs	$0.54		$116,208	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	42	Sets	$250		$10,500	(1.5 MW no x 1.16 based on dia's)
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$329,694**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	354500	lbs	$0.40		$141,800	
	Tube Section Fabrication, Rolled and Welded	354500	lbs	$0.72		$255,240	Fabrication labor and equipment. Includes allowance for NDT
	Weld quartered Tube sections	3600	$/kw	$21.56		$17,039	WindPACT technical Area 4 for auto welding quartered sections. Adjusted for tower height.
	Base Flange Ring (Dim 239"OD X 219" ID X 5" thk)						

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Cut, Weld, Stress Relieve	13557	lbs	$2.72		$36,875	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$4,500	(1.5 MW amount X 1.5)
	Top Flange Ring (Dim 165" OD X 153" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	5649		$2.22		$12,541	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,300	1.5 MW amount X 1.1)
	Concrete Tower Top Connection Ring (Dim 305" OD X 239" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	63778	lbs	$1.72		$109,698	Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$6,000	(1.5 MW amount X 1.2)
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$7,200	(1.5 MW amount X 1.2 based on dia's)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$18,000	(1.5 MW amount X 1.2 based on dia's)
	Truck Delivery (See note 3) $48 per KW *(54m/1302.m)=$19.90/KW for 3.6 MW Tower	3600	$/KW	$19.90		$71,640	56 ft to 64 ft long Per WIndPACT Area 4 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$698,833**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	14700	lb	$1.72	$101,136	$8,428	See Note 4 - Make 4 sets and reuse 12 times. Use 1.5 MW wt X 1.47 based on tower wt.
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 6 Tube Sections (labor)	145	man hours	$40.30		$5,844	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane Use 1.1 X 1.5 MW labor

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Weld (5) Field Joints with Track-Mounted Welder = $6.25/KW	3600	$/KW	$6.25		$22,500	Includes allowance for NDT- 5 horizontal welds to connect erected tube sections. (WindPACT Area 2 Figure 4-13 adjusted for weld length)
	Grout and Torque Tower Base (labor)	48	man hours	$40.30		$1,934	(1.5 MW amount X 1.2 based on dia's)
	Grout and Torque Tower Base (Material and Equipment)					$986	Use 1.16 X 1.5 MW amount based on dia's
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$56,088**	
5	**Precast Concrete Operation - Includes1650 A Segments,1200 B Segments and 750 C, 300 D Segments**						
	Design and Fabricate (5) A Forms	5	Each	$16,000	$80,000	$1,600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) B Forms	5	Each	$16,000	$80,000	$1,600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) C Forms	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) D Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) E Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Install (12) Forms and Start-up at Precast Plant	13	Each	$2,000	$26,000	$520	Divide Total Form Costs by 50 Towers
	Precast (78) A, B, C, D Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$9,360	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$22,464	
	Supply and Install Rebar	924	Lbs	$0.44	$407	$31,712	72,126 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$17,160	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,240	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,098	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$7,800	26 Rings

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply and Place Concrete cy/segment average	12.2	Cubic Yard	$80.00	$976	$76,128	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$11,700	
	Total concete	952.7	Cubic Yards		Subtotal	$194,282	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$58,285	
	General and Administrative and Profit	25.0%				$63,142	
							Equals Cost Per Cubic Yard
					Subtotal	**$315,708**	$331.38
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (78 Precast Segments per Tower)	78	Loads	$1,100.00		$85,800	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	800	Sq Ft	$20.00	$16,000	$320	Includes re-usable tie-bolt hardware
	Erect 26 Rings of 3 Segments Each	78	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	26	Sets	$250.00		$6,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	26	Rings	$175.00		$4,550	0.5 crew hour per segment
	Hoist and Set 78 Segments	78	Segments	$175.00		$13,650	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	16050	lbs	$1.95		$31,298	4 bars and couplers per segment
	Install and stress 168 Post Tensioning Bars with Couplers	16050	lbs	$0.50		$8,025	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	78	each	$58.00		$4,524	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	1680	Welds	$4.00		$6,720	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	104	Cubic ft.	$30.00		$3,120	Concurrent with rebar welding (1.31 x 1.5 MW amount)
	Attach Closure Joint Forms (1 Set = (6) leaves)	26	Sets	$350.00		$9,100	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	104	Cubic yards	$150.00		$15,600	Av 4 cubic yards / 3 joints; F'c= 6000 psi (1.31 x 1.5 MW amount)

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	29	Man Hours	$40.30		$1,169	Connection plate hoisted with strand post tensioning anchors attached. (1.21 X 1.5 MW amount based on dias')
	Install, Stress and Grout Vertical Strand Tendons	48	Tendons				
	Supply (96) Post Tensioning Anchors (12 strand-0.6")	96	Each	$193.00		$18,528	Installation cost is included in precast
	Supply (48) Vertical Post Tensioning Ducts (3.5 in dia)	5635	Lineal ft	$2.50		$14,088	Installation cost is included in precast
	Supply and install (576) Pieces of 0,6 in dia Post Tensioning Strand	65730	lbs	$0.85		$55,871	
	Stress (48) Tendons at Top Segment	48	Operations	$500.00		$24,000	Inlcudes rental of P/T jacks and pumps
	Grout 48 Post Tensioniing Tendons	408	Cubic ft	$20.00		$8,160	8.5 Cubic ft per tendon
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$15,000	
	Allowance for material handling unloading and equipment		Lump Sum			$10,000	Crane cost covered in item 1
					Subtotal	**$336,021**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$2,000	Planning, dry-runs, etc.
	Supply and Install (4) Jack-up Tendons with	8769	Lineal ft	$0.67		$5,875	12 -0.6 in strand X 160 ft. (1.5 MW wt X 2.03 based on stl tower wt.)
	Anchors Top and Bottom	8	Each	$150.00		$1,200	
	Fabricate (18) Upper Thruster Assemblies	4060	lbs	$2.72	$11,043	$442	Reusable 25 times (1.5 MW wt X 2.03 based on stl tower wt.)
	Install (18) Upper Thruster Assemblies	18	Each	$300		$5,400	Labor and anchor bolts (1.5 MW wt X 2.03 based on stl tower wt.)
	Fabricate (24) Lower Thruster Assemblies	3654	lbs	$2.72	$9,939	$398	Reusable 25 times (1.5 MW wt X 2.03 based on stl tower wt.)
	Install (24) Lower Thruster Assemblies	24	Each	$150.00		$3,600	(1.5 MW wt X 2.03 based on stl tower wt.)

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	70	man hours	$40.30		$2,821	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	(1.5 MW abount X 1.16 based on dia's)
	Erect Hub and Blades to Turbine Nacelle (crew of 3 for 3 days)	72	man hours	$40.30		$2,902	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	28	Bolts	$10.00		$280	(1.5 MW abount X 1.16 based on dia's)
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$12,500	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$54,643**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$50.75		$2,132	(1.5 MW wt X 2.03 based on stl tower wt.)
	Supply, Install, and Torque (148) -1.5 in Diameter High Strength Bolts	259	Each	$31.30		$8,107	(1.5 MW wt X 2.03 based on stl tower wt.)
	Remove Jack-Up Tendons and Anchors	3	Each	$406.00		$1,218	(1.5 MW wt X 2.03 based on stl tower wt.)
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	24	man hours	$40.30		$967	Crew of 4 for 6 hours

Conceptual Cost Estimate
3.6 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$42,392**	
	Summary of Construction Costs for 3.6 MW Hybrid (Designed for Earthquake) Tower					**$1,978,460**	
	General Contractor Field Overhead	10.0%				$197,846	
	General Contractor Administrative Overhead	10.0%				$197,846	
	General Contractor Profit	10.0%				$197,846	
	Total Cost of Completed 3.6 MW Hybrid (Designed for Earthquake) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,571,998**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	6	Lump Sum	$415,091	$2,490,546	$49,811	
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	132	months	$78,000	$10,296,000	$205,920	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	132	per month	$4,222	$557,304	$11,146	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	15	months	$88,667	$1,330,005	$26,600	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	15	per month	$4,222	$63,330	$1,267	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$358,003**	

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2455	Cubic Yards	$8		$19,640	With large excavator
	Supply and Install Concrete Forms (63 ft by 63 ft by 12 ft deep)	3027	Sq Ft	$2.50		$7,568	
	Supply, Place and Consolidate Foundation Concrete	1588	Cubic Yards	$89.90		$142,761	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	231500	lbs	$0.54		$125,010	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$306,345**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.22		$32,598	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$38,598**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1200 A Segments, 750 B Segments and 900 C Segments, 900 D Segments, 1050 E Segments, 150 F Segments**						
	Design and Fabricate (4) A Forms	4	Each	$16,000	$64,000	$1,280	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) C Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) D Form	2	Each	$15,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Design and Fabricate (4) E Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) F Form	1	Each	$15,000	$15,000	$300	Divide Total Form Costs by 50 Towers
	Install 16 Forms and Start-up at Precast Plant	16	Each	$2,000	$32,000	$640	Divide Total Form Costs by 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Precast (99) A, B, C, D, E and F Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$11,880	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$28,512	
	Supply and Install Rebar	850	Lbs	$0.44	$374	$37,026	92240 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$21,780	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$7,920	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$9,009	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$9,900	33 Rings
	Supply and Place Concrete - cy/segment average	11.05	Cubic Yard	$80.00	$884	$87,516	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$14,850	
	Total cubic yards of PC concrete	1094			Subtotal	$233,973	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$70,192	
	General and Administrative and Profit	25.0%				$76,041	
							Equals Cost Per Cubic Yard
					Subtotal	**$380,206**	$347.54
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (99 Precast Segments per Tower)	99	Loads	$1,100.00		$108,900	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 34 Rings of 3 Segments Each	99	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	33	Sets	$250.00		$8,250	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	33	Rings	$175.00		$5,775	0.5 crew hour per segment
	Hoist and Set 99 Segments	99	Segments	$175.00		$17,325	0.5 crew hour per segment - hoist directly from delivery truck.

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply Post Tensioning Bars and Couplers	31728	lbs	$1.95		$61,870	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by no. of segments)
	Install and stress 168 Post Tensioning Bars with Couplers	31728	lbs	$0.50		$15,864	0.5 crew hour per 4 bars (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by no. of segments)
	Install Top Positioning Fixtures	99	each	$58.00		$5,742	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	3180	Welds	$4.00		$12,720	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	132	Cubic ft.	$30.00		$3,960	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	33	Sets	$350.00		$11,550	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	132	Cubic yards	$150.00		$19,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	40	Tendons				
	Supply (80) Post Tensioning Anchors (12 strand-0.6")	80	Each	$193.00		$15,440	Installation cost is included in precast
	Supply (40) Vertical Post Tensioning Ducts (3.5 in dia)	13864	Lineal ft	$2.50		$34,660	Installation cost is included in precast
	Supply and install (480) Pieces of 0,6 in dia Post Tensioning Strand	104600	lbs	$0.85		$88,910	
	Stress (8) Tendons teminated at Segment 50% and 32 at Top Segment	40	Operations	$500.00		$20,000	Inlcudes rental of P/T jacks and pumps
	Grout 40 Post Tensioniing Tendons	340	Cubic ft	$20.00		$6,800	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$449,173	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$35,934	
					Subtotal	**$485,107**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	140	man hours	$40.30		$5,642	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	144	man hours	$40.30		$5,803	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,510**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 3.6 MW All Precast (Designed for Wind) Tower					**$1,629,926**	
	General Contractor Field Overhead	10.0%				$162,993	
	General Contractor Administrative Overhead	10.0%				$162,993	
	General Contractor Profit	10.0%				$162,993	
	Total Cost of Completed 3.6 MW - 100m All Precast (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,118,904**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Crane to site	Not required for this concept					
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection at 100m level	17.3	months	$88,667	$1,533,939	$30,679	Add 2.3 months for an additional 2 days per tower to install tower top ring with this crane.
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	17.3	per month	$4,222	$73,041	$1,461	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	**$89,011**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2445	Cubic Yards	$8		$19,560	With large excavator
	Supply and Install Concrete Forms (63 ft by 63 ft by 12 ft deep)	3024	Sq Ft	$2.50		$7,560	
	Supply, Place and Consolidate Foundation Concrete	1588	Cubic Yards	$89.90		$142,761	Use 90% of gross foundation volume to acount for central thickening of foundation.
	Reinforcing Steel	231500	lbs	$0.54		$125,010	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$306,257**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.22		$32,598	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$38,598**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	Not required for this concept					
	Grout and Torque Tower Base (Material and Equipment)	Not required for this concept					
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$0**	
5	**Cast in Place Concrete Operation**						
	Design and Fabricate (4) A Forms	Not required for this concept					
	Design and Fabricate (2) B Forms	Not required for this concept					
	Design and Fabricate (2) C Form	Not required for this concept					
	Design and Fabricate (2) D Form	Not required for this concept					
	Design and Fabricate (4) E Form	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (1) F Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
	Precast (99) A, B, C, D, E and F Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	March 2004 increase in reinforcine cost of $0.09 per lb	92240		$0.09		$8,302	
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$9,076,688	$181,534	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$14,754,556	$295,091	
	Equipment and site overhead for Cast in Place Concrete construction	1	Lump Sum		$4,766,249	$95,325	
	Cubic yards of concrete	1131					**Equals Cost Per Cubic Yard**
					Subtotal	**$580,251**	$513.04

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (99 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 99 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	40	Tendons				
	Supply (80) Post Tensioning Anchors (12 strand-0.6")	80	Each	$193.00		$15,440	Installation cost is included in precast
	Supply (40) Vertical Post Tensioning Ducts (3.5 in dia)	13864	Lineal ft	$2.50		$34,660	Installation cost is included in precast
	Supply and install (480) Pieces of 0,6 in dia Post Tensioning Strand	104600	lbs	$0.85		$88,910	
	Stress (8) Tendons teminated at Segment 50% and 32 at Top Segment	40	Operations	$500.00		$20,000	Inlcudes rental of P/T jacks and pumps
	Grout 40 Post Tensioniing Tendons	340	Cubic ft	$20.00		$6,800	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$176,777	

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$14,142	
					Subtotal	**$190,919**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	140	man hours	$40.30		$5,642	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	144	man hours	$40.30		$5,803	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					

Conceptual Cost Estimate
3.6 MW - 100m All Cast in Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$16,510**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-850 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 3.6 MW All Cast in Place Concrete (Designed for Wind) Tower					**$1,264,243**	
	General Contractor Field Overhead	10.0%				$126,424	
	General Contractor Administrative Overhead	10.0%				$126,424	
	General Contractor Profit	10.0%				$126,424	
	Total Cost of Completed 3.6 MW - 100m All Cast in Place Concrete (Designed for Wind) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,643,515**	Assuming 50 Towers

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Management & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (4) LTL-600 Cranes to site	4	Lump Sum	$415,091	$1,660,364	$33,207	
	Rental for (4) LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	84	months	$78,000	$6,552,000	$131,040	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	84	per month	$4,222	$354,648	$7,093	
	Mobilize/Demoblize (1) LTL-850 Crane	1	Lump sum	$484,727	$484,727	$9,695	
	Rental for (1) LTL-850 Crane- For nacelle, hub and blade erection	15	months	$88,667	$1,330,005	$26,600	
	Labor cost to assemble crane per turbine	1	per turbine	$7,332	$366,600	$7,332	
	Labor cost to relocate crane per turbine	1	per turbine	$2,730	$136,500	$2,730	
	Crane cribbing cost per turbine	1	per turbine	$808	$40,400	$808	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,161	$58,050	$1,161	
	Fuel cost per month	15	per month	$4,222	$63,330	$1,267	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$262,466**	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2218	Cubic Yards	$8		$17,744	With large excavator
	Supply and Install Concrete Forms (60 ft by 60 ft by 12 ft deep)	2880	Sq Ft	$2.50		$7,200	
	Supply, Place and Consolidate Foundation Concrete	1440	Cubic Yards	$89.90		$129,456	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	76200	lbs	$0.54		$41,148	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$206,914**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	899200	lbs	$0.40		$359,680	
	Tube Section Fabrication, Rolled and Welded	899200	lbs	$0.72		$647,424	allowance for NDT
	Weld Quartered Tube Sections	3600	$/KW	$39.94		$57,118	WindPACT Area 2 Figure 4-13 adjusted to tower height
	Base Flange Ring (Dim 317"OD X 297" ID X 5" thk)						
	Cut, Weld, Stress Relieve	18178	lbs	$2.72		$49,444	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 166" OD X 154" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	5684		$2.22		$12,618	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept					
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$13,320	1.5 Hybrid amount 1.2 based on dia's X (100m/54m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$33,300	1.5 Hybrid amount 1.2 based on dia's X (100m/54m)
	Truck Delivery (See note 3) $48 per KW * (100m/130.2m)= $36.87/KW for 3.6 MW Tower	3600	$/KW	$36.87		$132,732	56 ft to 64 ft long Per WindPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$1,341,157**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 17 Tube Sections (labor)	748	man hours	$40.30		$30,144	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (17sections/3 sections)
	Weld (20) Field Joints with Track-Mounted Welder $26.24/KW	3600	$/KW	$26.24		$94,464	Includes allowance for NDT- 20 horizontal welds to connect erected tube sections (Fig. 4-13 Wind PACT Technical Area 2 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	$127,070	
5	Precast Concrete Operation						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
6	**Field Erection and Post Tensioing of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 4 for 4 days)	140	man hours	$40.30		$5,642	Use LTL- 850 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 4 for 4 days)	144	man hours	$40.30		$5,803	Use LTL-850 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	

Conceptual Cost Estimate
3.6 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
					Subtotal	**$16,354**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 3.6 MW All Steel Tower (Wind Design)					**$1,974,362**	
	General Contractor Field Overhead	10.0%				$197,436	
	General Contractor Administrative Overhead	10.0%				$197,436	
	General Contractor Profit	10.0%				$197,436	
	Total Cost of Completed 3.6 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,566,670**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	1	Lump Sum	$150,000	$150,000	$3,000	
	Fabricate, Assemble 6 Special Pedestal Cranes for Erecting Precast Elements.	6	Each	$250,000	$1,500,000	$30,000	Special pedestial crane cost is aprox 40% of Barnhart climbing crane described in WindPACT Area 3 Self Erecting Tower Study
	Design and Develop Active Lower Guide/Force Reaction Assembly - For Use During Jack-up Operation	1	Lump Sum	$75,000	$75,000	$1,500	Required for 3.6 MW and 5.0 MW hybrid towers which do not have constant ID in concrete tower portion.
	Fabricate and Assemble Lower Guide/Force Reaction Assembly	6	Each	$100,000	$600,000	$12,000	
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) 4100 W Crane to site	6	Lump Sum	$66,416	$398,496	$7,970	
	Rental for (6) 4100 W Crawler Crane - For steel tower erection, truck unload, and pedestal crane installation.	126	months	$13,000	$1,638,000	$32,760	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$1,365	$68,250	$1,365	
	Labor cost to relocate crane per turbine	1	per turbine	$780	$39,000	$780	
	Crane cribbing cost per turbine	1	per turbine	$131	$6,550	$131	
	Meals and lodging for crane crew per turbine	1	per turbine	$248	$12,400	$248	
	Fuel cost per month	126	per month	$1,429	$180,054	$3,601	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$213,824**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	3018	Cubic Yards	$8		$24,144	With large excavator
	Supply and Install Concrete Forms (70 ft by 70 ft by 12 ft deep)	3360	Sq Ft	$2.50		$8,400	
	Supply, Place and Consolidate Foundation Concrete	1960	Cubic Yards	$89.90		$176,204	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	250200	lbs	$0.54		$135,108	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	70	Sets	$250		$17,500	(1.5 MW no x 1.94 based on dia's)
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$372,722**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	533700	lbs	$0.40		$213,480	
	Tube Section Fabrication, Rolled and Welded	533700	lbs	$0.72		$384,264	Fabrication labor and equipment. Includes allowance for NDT
	Weld quartered Tube sections	5000	$/kw			$25,577	WindPACT technical Area 2 for auto welding quartered sections. Adjusted for tower height.
	Base Flange Ring (Dim 275"OD X 255" ID X 5" thk)						
	Cut, Weld, Stress Relieve	15691	lbs	$2.72		$42,680	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$5,490	(1.5 MW amount X 1.83 based on dia's))

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Top Flange Ring (Dim 189" OD X 177" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	6501		$2.22		$14,432	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$4,950	1.5 MW amount X 1.65 based on dia's)
	Concrete Tower Top Connection Ring (Dim 341" OD X 275" ID X 6 " thk)						
	Cut, Weld, Stress Relieve	72219	lbs	$1.72		$124,217	Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange		Lump Sum			$6,800	(1.5 MW amount X 1.36 based on dia's)
	Fabricate and Install Internal Galvanized Ladders	5000	lbs	$3.00		$15,000	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$11,400	(1.5 MW amount X 1.9 based on diameter)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$28,500	(1.5 MW amount X 1.9 based on diameter)
	Truck Delivery (See note 3) $51 per KW *(54m/156.1m)=$17.64/KW for 5.0 MW Tower	5000	$/KW	$17.64		$88,200	56 ft to 64 ft long Per WIndPACT Area 4 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$964,989**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	35500	lb	$1.72	$244,240	$20,353	See Note 4 - Make 4 sets and reuse 12 times. (Use 1.5 MW wt X 1.55 based on tower wt.)
	Install Base Support System and Jack-Up Frame		Lump Sum			$3,500	
	Rig, Erect and Fit 11 Tube Sections (labor)	198	man hours	$40.30		$7,979	Max weight of tube section, 50 kips lift height 161 ft. Use 4100W crane (Use 1.5 X 1.5 MW labor)
	Weld (10) Field Joints with Track-Mounted Welder =$19.54/KW	5000	$/KW	$19.54		$97,700	Includes allowance for NDT- 10 horizontal welds to connect erected tube sections (Wind PACT Technical Area 2 Figure 4-13 adjusted for weld length)
	Grout and Torque Tower Base (labor)	76	man hours	$40.30		$3,063	(1.5 MW amount X 1.9 based on dia's)
	Grout and Torque Tower Base (Material and Equipment)					$1,615	Use 1.16 X 1.9 MW amount based on dia's

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	320	man hours	$40.30		$12,896	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$147,107**	
5	**Precast Concrete Operation - Includes 1350 A Segments, 1500 B Segments and 1350 C Segments**						
	Design and Fabricate (8) A Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (8) B Forms	6	Each	$16,000	$96,000	$1,920	Divide Total Form Costs by 50 Towers
	Design and Fabricate (8) C Forms	6	Each	$15,000	$90,000	$1,800	Divide Total Form Costs by 50 Towers
	Install (15) Forms and Start-up at Precast Plant	15	Each	$2,000	$30,000	$600	Divide Total Form Costs by 50 Towers
	Precast (84) A, B, C, D & E Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$10,080	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$24,192	
	Supply and Install Rebar	964	Lbs	$0.44	$424	$35,629	156226 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$18,480	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$6,720	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$7,644	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$8,100	27 Rings
	Supply and Place Concrete cy/segment average	12.9	Cubic Yard	$80.00	$1,032	$86,688	f'c = 7000psi 460 cubic yards total
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$12,600	
	Total Concrete	1083.3	Cubic Yards		Subtotal	$215,413	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$64,624	
	General and Administrative and Profit	25.0%				$70,009	
							Equals Cost Per Cubic Yard
					Subtotal	**$350,047**	$323.13

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (162 Precast Segments per Tower)	162	Loads	$1,100.00		$178,200	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (4 Sets of 6 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 27 Rings of 6 Segments Each	60	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	27	Sets	$250.00		$6,750	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	27	Rings	$175.00		$4,725	0.5 crew hour per segment
	Hoist and Set 162 Segments	162	Segments	$175.00		$28,350	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	25733	lbs	$1.95		$50,179	4 bars and couplers per segment (1.5 MW amount X 2.1 based on dia's)
	Install and stress 350 Post Tensioning Bars with Couplers	25733	lbs	$0.50		$12,867	0.5 crew hour per 4 bars
	Install Top Positioning Fixtures	162	each	$58.00		$9,396	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	3360	Welds	$4.00		$13,440	Assume 20 bars per joint at 2 welds each
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	118	Cubic ft.	$30.00		$3,540	Concurrent with rebar welding (1.5 MW amount X 2.1 based on dia's)
	Attach Closure Joint Forms (1 Set = (6) leaves)	54	Sets	$350.00		$18,900	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	126	Cubic yards	$150.00		$18,900	Av 4 cubic yards / 3 joints; F'c= 6000 psi (1.5 MW amount x 2.1 based on dia's)
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	44	Man Hours	$40.30		$1,773	Connection plate hoisted with strand post tensioning anchors attached. (1.5 MW amount X 1.84 based on dias')
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	6590	Lineal ft	$2.50		$16,475	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	76680	lbs	$0.85		$65,178	
	Stress 56 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	476	Cubic ft	$20.00		$9,520	8.5 Cubic ft per tendon

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor		Lump Sum			$22,500	54/36 = 1.5 factor
	Allowance for material handling unloading and equipment		Lump Sum			$15,000	Crane cost covered in item 1 54/36 = 1.5 factor
					Subtotal	**$525,949**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	1	Lump Sum	$100,000.00		$2,000	Planning, dry-runs, etc.
	Supply and Install (4) Jack-up Tendons with	15336	Lineal ft	$0.67		$10,275	12 -0.6 in strand X 160 ft. (1.5 MW wt X 3.55 based on stl tower wt.)
	Anchors Top and Bottom	24	Each	$150.00		$3,600	
	Fabricate (18) Upper Thruster Assemblies	7100	lbs	$2.72	$19,312	$772	Reusable 25 times (1.5 MW wt X 3.55 based on stl tower wt.)
	Install (18) Upper Thruster Assemblies	18	Each	$710		$12,780	Labor and anchor bolts (1.5 MW wt X 3.55 based on stl tower wt.)
	Fabricate (24) Lower Thruster Assemblies	6390	lbs	$2.72	$17,381	$695	Reusable 25 times (1.5 MW wt X 3.55 based on stl tower wt.)
	Install (24) Lower Thruster Assemblies	24	Each	$355.00		$8,520	(1.5 MW wt X 3.55 based on stl tower wt.)
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	96	man hours	$40.30		$3,869	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Erect Transition Section and Turbine Nacelle (crew of 3 for 2 days)	90	man hours	$40.30		$3,627	Use LTL 850 crane WindPACT Area 4 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	106	each	$14.20		$1,505	(1.5 MW abount X 1.65 based on dia's)
	Erect Hub and Blades to Turbine Nacelle (crew of 3 for 4 days)	96	man hours	$40.30		$3,869	Use LTL 600 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	48	Bolts	$10.00		$480	(1.5 MW abount X 1.95 based on dia's)
	Jack-Up Steel Tube with Turbine and Blades						
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	96	man hours	$60.00		$5,760	
	Jack-up Equipment Rental		Lump Sum			$15,000	Includes rental of hydraulic system
	Monitor with Control Transits	2	Day Rate	$1,266		$2,532	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)

Conceptual Cost Estimate
5.0 MW - 100m Hybrid Steel Concrete Wind Turbine Tower (Designed for Earthquake)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Time included in jack-up time)					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$79,285**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	42	Assemblies	$88.75		$3,728	(1.5 MW wt X 3.55 based on stl tower wt.)
	Supply, Install, and Torque (235) -1.5 in Diameter High Strength Bolts	235	Each	$31.30		$7,356	(1.5 MW wt X 1.84 based on stl tower wt.)
	Remove Jack-Up Tendons and Anchors	3	Each	$710.00		$2,130	(1.5 MW wt X 3.55 based on stl tower wt.)
	Lower and remove tower base support frame. (3 days for a crew of 4)	96	man hours	$40.30		$3,869	
	Install Weather Protective Flashing Over Concrete to Steel Joint	32	man hours	$40.30		$1,290	Crew of 4 for 8 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	161	Lineal ft	$100.00		$16,100	
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$5,000	Use 4100W crane (crane costs included elsewhere)
					Subtotal	**$44,471**	
	Summary of Construction Costs for 5.0 MW Hybrid (Earthquake Design) Tower					**$2,698,393**	
	General Contractor Field Overhead	10.0%				$269,839	
	General Contractor Administrative Overhead	10.0%				$269,839	
	General Contractor Profit	10.0%				$269,839	
	Total Cost of Completed 1.5 MW Hybrid (Earthquake Design) Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$3,507,911**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (6) LTL-600 Cranes to site	6	Lump Sum	$415,091	$2,490,546	$49,811	
	Rental for (6) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	176	months	$58,500	$10,296,000	$205,920	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$391,454**	

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	3072	Cubic Yards	$8		$24,576	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3218	Sq Ft	$2.50		$8,045	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	290200	lbs	$0.54		$156,708	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$362,155**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.22		$32,598	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$38,598**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Precast Concrete Operation - Includes 1350 A Segments, 900 B Segments and 1200 C Segments, 900 D and 1350 E Segments**						
	Design and Fabricate (8) A Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) B Forms	3	Each	$16,000	$48,000	$960	Divide Total Form Costs by 50 Towers
	Design and Fabricate (6) C Form	9	Each	$15,000	$135,000	$2,700	Divide Total Form Costs by 50 Towers
	Design and Fabricate (5) D Form	4	Each	$15,000	$60,000	$1,200	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) E Form	8	Each	$15,000	$120,000	$2,400	Divide Total Form Costs by 50 Towers
	Design and Fabricate (2) F Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers
	Design and Fabricate (1) G Form	0	Each	$15,000	$0	$0	Divide Total Form Costs by 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Install 27 Forms and Start-up at Precast Plant	27	Each	$2,000	$54,000	$1,080	Divide Total Form Costs by 50 Towers
	Precast (114) A, B, C, D, E and F G Segments Per Tower				Per Segment	Per Tower	
	Daily Strip and Set Up forms	1	Segment	$120.00	$120	$13,680	Outer form = 11.7 ft x17 ft with 15 Ties
	Supply End Plates and Weld to Horizontal Rebar	48	Welds	$6.00	$288	$32,832	
	Supply and Install Rebar	781	Lbs	$0.44	$344	$39,175	185134 lb of rebar total
	Supply and Install Embedments (7) per Segment	1	Segment	$220.00	$220	$25,080	Include male/female alignment
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	4	Segment	$20.00	$80	$9,120	
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	13	Ducts/Slve	$7.00	$91	$10,374	
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	12	Anchors	$25.00	$300	$11,400	38 Rings
	Supply and Place Concrete - cy/segment average	11.3	Cubic Yard	$80.00	$904	$103,056	f'c = 7000psi
	Strip, Handle, Cure and Store Segments	1	Segment	$150.00	$150	$17,100	
	Total cubic yards of PC concrete	1289			Subtotal	$271,117	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$81,335	
	General and Administrative and Profit	25.0%				$88,113	
							Equals Cost Per Cubic Yard
					Subtotal	**$440,565**	$341.79
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (114 Precast Segments per Tower)	114	Loads	$1,100.00		$125,400	Note 5. Segment weights range from 57.3 kips to 32.4 kips
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	1600	Sq Ft	$20.00	$32,000	$640	Includes re-usable tie-bolt hardware
	Erect 38 Rings of 3 Segments Each	114	Segments				
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	38	Sets	$250.00		$9,500	Concurrent with leveling and shimming
	Set Shims with Level and Glue Gaskets	38	Rings	$175.00		$6,650	0.5 crew hour per segment

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Hoist and Set 114 Segments	114	Segments	$175.00		$19,950	0.5 crew hour per segment - hoist directly from delivery truck.
	Supply Post Tensioning Bars and Couplers	36535	lbs	$1.95		$71,243	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by number of segments
	Install and stress 168 Post Tensioning Bars with Couplers	36535	lbs	$0.50		$18,268	4 bars and couplers per segment (1.5 MW Hybrid X Factor 100m/49m=2.04 X ration by number of segments
	Install Top Positioning Fixtures	114	each	$58.00		$6,612	0.5 crew hour per 3 segments
	Place and Weld Rebar Splices and Ties in Vertical Joints	6720	Welds	$4.00		$26,880	Assume 20 bars per joint at 2 welds each (1.5 MW Hybrid X Factor 100m/49m=2.04 X 2 for 6 segment rings)
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	152	Cubic ft.	$30.00		$4,560	Concurrent with rebar welding
	Attach Closure Joint Forms (1 Set = (6) leaves)	79	Sets	$350.00		$27,650	1 crew hour per set of 3 joints
	Supply , Place and Vibrate Closure Pour Concrete	252	Cubic yards	$150.00		$37,800	Av 4 cubic yards / 3 joints; F'c= 6000 psi
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	130500	lbs	$0.85		$110,925	
	Stress (22) Tendons teminated at Segment 50% and 34 at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1
					Subtotal	$589,446	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$47,156	
					Subtotal	**$636,602**	

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						

Conceptual Cost Estimate
5.0 MW - 100m All Precast Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-600 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					Use LTL-600 crane (crane costs included elsewhere)
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,932,492**	
	General Contractor Field Overhead	10.0%				$193,249	
	General Contractor Administrative Overhead	10.0%				$193,249	
	General Contractor Profit	10.0%				$193,249	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$2,512,240**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not required for this concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not required for this concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (8) LTL-600 Crane to site	Not required for this concept					
	Rental for (8) LTL-600 Crawler Cranes - For precast segment unload and erection to 100m.	Not required for this concept					Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	Not required for this concept					
	Labor cost to relocate crane per turbine	Not required for this concept					
	Crane cribbing cost per turbine	Not required for this concept					
	Meals and lodging for crane crew per turbine	Not required for this concept					
	Fuel cost per month	Not required for this concept					
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection at 100m level	20.3	months	$121,333	$2,463,060	$49,261	Add 2.3 months for an additonal 2 days per tower to install tower top ring with this crane
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	20.3	per month	$4,547	$92,304	$1,846	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
					Subtotal	**$126,259**	
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2766	Cubic Yards	$8		$22,128	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	290200	lbs	$0.54		$156,708	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not required for this concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$359,702**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material						
	Tube Section Fabrication, Rolled and Welded	Not required for this concept					
	Base Flange Ring (Dim 156"OD X 136" ID X 5" thk)	Not required for this concept					
	Cut, Weld, Stress Relieve	Not required for this concept					
	Drill Holes, Mill After Welding First Tube Section	Not required for this concept					
	Top Flange Ring (Dim 144" OD X 104" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	14684	lbs	$2.22		$32,598	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Cut, Weld, Stress Relieve	Not required for this concept					Weight includes 33% waste
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not required for this concept					
	Fabricate and Install Internal Galvanized Ladders	Not required for this concept					Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint	Not required for this concept					
	2 Coats Primer on Interior Surfaces	Not required for this concept					
	Prmer and Epoxy Finish Coats on Exterior	Not required for this concept					
	Truck Delivery (See note 3) $27 per KW * (49m/86m)= 15.38/KW for 1.5MW Tower	Not required for this concept					
	Truck Delivery of top flange plate only		Lump Sum			$3,000	
					Subtotal	**$38,598**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not required for this concept					
	Install Base Support System and Jack-Up Frame	Not required for this concept					
	Rig, Erect and Fit 3 Tube Sections (labor)	Not required for this concept					
	Weld (3) Field Joints with Track-Mounted Welder ($1.67/KW)* (49m/86m)=$0.95/KW	Not required for this concept					
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not required for this concept					
					Subtotal	**$2,462**	
5	**Cast In Place Concrete Operation**						
	Design and Fabricate (8) A Forms	Not required for this concept					
	Design and Fabricate (6) B Forms	Not required for this concept					
	Design and Fabricate (6) C Form	Not required for this concept					
	Design and Fabricate (5) D Form	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Design and Fabricate (1) E Form	Not required for this concept					
	Design and Fabricate (2) F Form	Not required for this concept					
	Design and Fabricate (1) G Form	Not required for this concept					
	Install 15 Forms and Start-up at Precast Plant	Not required for this concept					
	Precast 237) A, B, C, D, E and F G Segments Per Tower	Not required for this concept				Per Tower	
	Daily Strip and Set Up forms	Not required for this concept					
	Supply End Plates and Weld to Horizontal Rebar	Not required for this concept					
	Supply and Install Rebar	Not required for this concept					
	Supply and Install Embedments (7) per Segment	Not required for this concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not required for this concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not required for this concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not required for this concept					
	Supply and Place Concrete - cy/segment average	Not required for this concept					
	Strip, Handle, Cure and Store Segments	Not required for this concept					
	Total cubic yards of PC concrete	Not required for this concept					
	Supervision, Quality Control, Maintenance Shop Overhead	Not required for this concept					
	General and Administrative and Profit	Not required for this concept					
	March 2004 increase in reinforcing cost $0.09 per lb	185134		$0.09		$16,662	
	Direct material costs for Cast in Place Concrete construction	1	Lump Sum		$10,550,721	$211,014	Concrete and reinforcing
	Direct labor costs for Cast in Place Concrete construction	1	Lump Sum		$16,641,852	$332,837	
	Equipment and site overhead for Cast in Place Kconcretre construction.	1	Lump Sum		$5,438,515	$108,770	
	Cubic yards of concrete	1358					**Equals Cost Per Cubic Yard**
					Subtotal	**$669,284**	$492.85

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (237 Precast Segments per Tower)	Not required for this concept					
	Fabricate Joint Closure Forms (8 Sets of 3 Forms)	Not required for this concept					
	Erect 34 Rings of 3 Segments Each	Not required for this concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not required for this concept					
	Set Shims with Level and Glue Gaskets	Not required for this concept					
	Hoist and Set 237 Segments	Not required for this concept					
	Supply Post Tensioning Bars and Couplers	Not required for this concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not required for this concept					
	Install Top Positioning Fixtures	Not required for this concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not required for this concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not required for this concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not required for this concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not required for this concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	24	Man Hours	$40.30		$967	Connection plate hoisted with strand post tensioning anchors attached.
	Install, Stress and Grout Vertical Strand Tendons	56	Tendons				
	Supply (112) Post Tensioning Anchors (12 strand-0.6")	112	Each	$193.00		$21,616	Installation cost is included in precast
	Supply (56) Vertical Post Tensioning Ducts (3.5 in dia)	17946	Lineal ft	$2.50		$44,865	Installation cost is included in precast
	Supply and install (672) Pieces of 0,6 in dia Post Tensioning Strand	130500	lbs	$0.85		$110,925	
	Stress (22) Tendons teminated at Segment 50% and (34) at Top Segment	56	Operations	$500.00		$28,000	Inlcudes rental of P/T jacks and pumps
	Grout 56 Post Tensioniing Tendons	896	Cubic ft	$20.00		$17,920	16 Cubic ft per tendon
	Allowance for material handling unloading and equipment					$10,000	Crane cost covered in item 1

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	$234,293	
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	8%				$18,743	
					Subtotal	**$253,037**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not required for this concept					
	Supply and Install (3) Jack-up Tendons with	Not required for this concept					
	Anchors Top and Bottom	Not required for this concept					
	Fabricate (18) Upper Thruster Assemblies	Not required for this concept					
	Install (18) Upper Thruster Assemblies	Not required for this concept					
	Fabricate (24) Lower Thruster Assemblies	Not required for this concept					
	Install (24) Lower Thruster Assemblies	Not required for this concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not required for this concept					
	Erect Transition Section and Turbine Nacelle (crew of 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Supply, Install, and Torque 1.25 in dia HS bolts	75	each	$14.20		$1,065	
	Erect Hub and Blades to Turbine Nacelle (crew if 3 for 5 days)	160	man hours	$40.30		$6,448	Use LTL 850 crane WindPACT Area 2 Study - crane costs elsewhere (Hybrid tower labor X 2)
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not required for this concept					
	Jack-Up Steel Tube with Turbine and Blades	Not required for this concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not required for this concept					
	Jack-up Equipment Rental	Not required for this concept					
	Monitor with Control Transits	Not required for this concept					

Conceptual Cost Estimate
5.0 MW - 100m All Cast In Place Concrete Wind Turbine Tower (Designed for Wind)
50 Tower Installation - 28 month schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not required for this concept					
	Allowance for equipment and small cranes					$4,000	
					Subtotal	**$17,961**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not required for this concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not required for this concept					
	Remove Jack-Up Tendons and Anchors	Not required for this concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not required for this concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	16	man hours	$40.30		$645	Crew of 4 for 4 hours
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	328	Lineal ft	$100.00		$32,800	
	Remove Exterior Scaffold Platforms and Connecting Ladders		Lump sum			$9,250	Use LTL-1100 crane (crane costs included elsewhere)
	Touch Up Paint on Steel Tube Exterior	Not required for this concept					
					Subtotal	**$42,695**	
	Summary of Construction Costs for 5.0 MW -100 m All Precast (Earthquake Design) Tower					**$1,509,998**	
	General Contractor Field Overhead	10.0%				$151,000	
	General Contractor Administrative Overhead	10.0%				$151,000	
	General Contractor Profit	10.0%				$151,000	
	Total Cost of Completed 5.0 MW - 100m (Earthquake Design) All Precast Tower with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$1,962,998**	Assuming 50 Towers

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
1	**Mobilization and Site Development for 50-Tower Site**						
	Access Road		Lump Sum		$977,300	$19,546	Access Road Allowance - After WindPACT Area 4 Balance of Station Study
	Site Offices and Office Equipment		Lump Sum		$200,000	$4,000	
	Managerment & Supervision Recruitment and Relocation		Lump Sum		$100,000	$2,000	
	Design/Develop Special Pedestial Cranes 30 ton Capacity	Not Required for This Concept					
	Fabricate, Assemble 2 Special Pedestal Cranes for Erecting Precast Elements.	Not Required for This Concept					
	Equipment Move-in and Set-up				$100,000	$2,000	
	Other Mobilization and Site Development Cost				$100,000	$2,000	
	Mobilize/Demobilize (5) LTL-600 Cranes to site	5	Lump Sum	$415,091	$2,075,455	$41,509	
	Rental for (5) LTL-600 Crawler Cranes - For steel tower erection, truck unload, and pedestal crane installation.	105	months	$78,000	$8,190,000	$163,800	Crane selection from Wind PACT Area 2 Turbine Rotor and Blade Logistics
	Labor cost to assemble crane per turbine	1	per turbine	$3,685	$184,250	$3,685	
	Labor cost to relocate crane per turbine	1	per turbine	$1,560	$78,000	$1,560	
	Crane cribbing cost per turbine	1	per turbine	$538	$26,900	$538	
	Meals and lodging for crane crew per turbine	1	per turbine	$605	$30,250	$605	
	Fuel cost per month	105	per month	$4,222	$443,310	$8,866	
	Mobilize/Demoblize (1) LTL-1100 Crane	1	Lump sum	$1,107,036	$1,107,036	$22,141	
	Rental for (1) LTL-1100 Crane- For nacelle, hub and blade erection	18	months	$121,333	$2,183,994	$43,680	
	Labor cost to assemble crane per turbine	1	per turbine	$10,296	$514,800	$10,296	
	Labor cost to relocate crane per turbine	1	per turbine	$4,875	$243,750	$4,875	
	Crane cribbing cost per turbine	1	per turbine	$943	$47,150	$943	
	Meals and lodging for crane crew per turbine	1	per turbine	$1,751	$87,550	$1,751	
	Fuel cost per month	18	per month	$4,547	$81,846	$1,637	
	Other Equipment Rental	28	months	$10,000	$280,000	$5,600	
					Subtotal	**$341,032**	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
2	**Foundation Construction Per Tower**						
	Survey Layout and Location					$1,266	Survey Crew 1 Day per Tower Location (A-7 1 Chief, 1 Instrument man, 1 rodman)
	Geotechnical Investigation (per tower location)	50	Each	$1,000	$50,000	$1,000	
	Excavation	2765	Cubic Yards	$8		$22,120	With large excavator
	Supply and Install Concrete Forms (67 ft by 67 ft by 12 ft deep)	3216	Sq Ft	$2.50		$8,040	
	Supply, Place and Consolidate Foundation Concrete	1796	Cubic Yards	$89.90		$161,460	Use 90% of gross foundation volume to account for central thickening of foundation.
	Reinforcing Steel	95020	lbs	$0.54		$51,311	
	A-490 Anchor Bolts and Couplers (reuse upper bolts)	Not Required for This Concept					
	Precision Locating Template for Anchor Bolts and Post Tensioning Anchors and Ducts	4	each	$12,500	$50,000	$4,000	
	Backfill and Tamp (after post tensioning)	650	Cubic Yards	$6		$3,900	Tamp 10 ft around footing
	Untamped Backfill	1200	Cubic Yards	$1		$1,200	
					Subtotal	**$254,297**	
3	**Shop Fabrication of Steel Tower (3 Tapered Tubes and Heavy Base Flange Ring, Tower Top Flange Ring & Concrete Tower Top Connection Ring)**						
	Tube Section Material	1188000	lbs	$0.40		$475,200	
	Tube Section Fabrication, Rolled and Welded	1188000	lbs	$0.72		$855,360	Fabrication labor and equipment. Includes allowance for NDT
	Weld Quartered Tube Sections	5000	$/KW	$44.20		$70,732	WindPACT Area 2 Figure 4-13 adjusted to tower height .
	Base Flange Ring (Dim 365"OD X 345" ID X 5" thk)						
	Cut, Weld, Stress Relieve	21020	lbs	$2.72		$57,174	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	
	Top Flange Ring (Dim 190" OD X 178" ID X 5 " thk)						
	Cut, Weld, Stress Relieve	6536		$2.22		$14,510	Weight includes 33% waste
	Drill Holes, Mill After Welding First Tube Section		Lump Sum			$3,000	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Concrete Tower Top Connection Ring (Dim 206" OD X 140" ID X 6 " thk)	Not Required for This Concept					
	Cut, Weld, Stress Relieve	Not Required for This Concept					
	Drill Holes to Match Tower Flange, Mill to Match Tube Flange	Not Required for This Concept					
	Fabricate and Install Internal Galvanized Ladders	9840	lbs	$3.00		$29,520	Use 30 lb per vertical ft.
	Surface Perparation , Prime and Paint						
	2 Coats Primer on Interior Surfaces		Lump Sum			$21,090	1.5 Hybrid amount 1.9 based on dia's X (100m/54m)
	Prmer and Epoxy Finish Coats on Exterior		Lump Sum			$52,725	1.5 Hybrid amount 1.9 based on dia's X (100m/54m)
	Truck Delivery (See note 3) $51 per KW * (100m/156.1m)= $32.67/KW	5000	$/KW	$32.67		$163,350	56 ft to 64 ft long Per WIndPACT Area 2 Turbine Rotor and Blade Logistics - Transport from Shreveport, LA Adjusted for tower height.
					Subtotal	**$1,745,661**	
4	**Field Erection of Steel Tube & Pedestal Crane**						
	Fabricate Jack-up Frame and Base Supports (4)	Not Required for This Concept					
	Install Base Support System and Jack-Up Frame	Not Required for This Concept					
	Rig, Erect and Fit 21 Tube Sections (labor)	924	man hours	$40.30		$37,237	Max weight of tube section, 50 kips lift height 328 ft. Use LTL-600 crane. 1.5 Hybrid amount X (21 sections/3 sections)
	Weld (20) Field Joints with Track-Mounted Welder $26.24/KW	5000	$/KW	$26.24		$131,200	Includes allowance for NDT- 20 horizontal welds to connect erected tube sections (Fig. 4-13 Wind PACT Technical Area 2 adjusted for length of weld.)
	Grout and Torque Tower Base (labor)	40	man hours	$40.30		$1,612	
	Grout and Torque Tower Base (Material and Equipment)					$850	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
	Erect Special Pedestal Crane on Top of Steel Tube (Assume 5 days with crew of 8 to fully install)	Not Required for This Concept					
					Subtotal	**$170,899**	
5	**Precast Concrete Operation**						
	Design and Fabricate (4) A Forms	Not Required for This Concept					
	Design and Fabricate (3) B Forms	Not Required for This Concept					
	Design and Fabricate (1) C Form	Not Required for This Concept					
	Install 8 Forms and Start-up at Precast Plant	Not Required for This Concept					
		Not Required for This Concept					
	Precast (42) A, B and C Segments Per Tower	Not Required for This Concept					
	Daily Strip and Set Up forms	Not Required for This Concept					
	Supply End Plates and Weld to Horizontal Rebar	Not Required for This Concept					
	Supply and Install Rebar (140 #/cy)	Not Required for This Concept					
	Supply and Install Embedments (7) per Segment	Not Required for This Concept					
	Supply Duct for Erection Post Tensioning Bars (4) per Segment	Not Required for This Concept					
	Install Strand Post Tensioning Duct Sleeves (13) Average Per Segment	Not Required for This Concept					
	Install Bar Post Tensioning Anchor Plates and Trumpets (12) per Ring	Not Required for This Concept					
	Supply and Place Concrete 11 cy/segment average	Not Required for This Concept					
	Strip, Handle, Cure and Store Segments	Not Required for This Concept					
					Subtotal	$0	
	Supervision, Quality Control, Maintenance Shop Overhead	30.0%				$0	
	General and Administrative and Profit	25.0%				$0	
							Equals Cost Per Cubic Yard
					Subtotal	**$0**	$0.00

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost $ Total	Cost $/Tower	Comments
6	**Field Erection and Post Tensioning of Precast Concrete Tower**						
	Truck Delivery (42 Precast Segments per Tower)	Not Required for This Concept					
	Fabricate Joint Closure Forms (4 Sets of 3 Forms)	Not Required for This Concept					
	Erect 14 Rings of 3 Segments Each	Not Required for This Concept					
	Strip, Clean and Oil (3) Top Fixtures and (6) Forms	Not Required for This Concept					
	Set Shims with Level and Glue Gaskets	Not Required for This Concept					
	Hoist and Set 42 Segments	Not Required for This Concept					
	Supply Post Tensioning Bars and Couplers	Not Required for This Concept					
	Install and stress 168 Post Tensioning Bars with Couplers	Not Required for This Concept					
	Install Top Positioning Fixtures	Not Required for This Concept					
	Place and Weld Rebar Splices and Ties in Vertical Joints	Not Required for This Concept					
	Inject Grout in Horizontal Joint (4 cu ft/ring joint)	Not Required for This Concept					
	Attach Closure Joint Forms (1 Set = (6) leaves)	Not Required for This Concept					
	Supply , Place and Vibrate Closure Pour Concrete	Not Required for This Concept					
	Hoist, Install, Level and Grout Concrete Tower Top Connection Plate	Not Required for This Concept					
	Install, Stress and Grout Vertical Strand Tendons	Not Required for This Concept					
	Supply (72) Post Tensioning Anchors (12 strand-0.6")	Not Required for This Concept					
	Supply (36) Vertical Post Tensioning Ducts (3.5 in dia)	Not Required for This Concept					
	Supply and install (360) Pieces of 0,6 in dia Post Tensioning Strand	Not Required for This Concept					
	Stress (12) Tendons at Segment 6, (6) at Segment 10, and 18 at Top Segment 14	Not Required for This Concept					
	Grout 36 Post Tensioniing Tendons	Not Required for This Concept					
	Supervison, Overhead, and Profit for Strand Post Tensioning Sub Contractor	Not Required for This Concept					

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
	Allowance for material handling unloading and equipment	Not Required for This Concept					
					Subtotal	**$0**	
7	**Jack-Up Steel Tube Inside of Concrete Tower**						
	Preparation for Jack-Up Operation	Not Required for This Concept					
	Supply and Install (3) Jack-up Tendons with	Not Required for This Concept					
	Anchors Top and Bottom	Not Required for This Concept					
	Fabricate (18) Upper Thruster Assemblies	Not Required for This Concept					
	Install (18) Upper Thruster Assemblies	Not Required for This Concept					
	Fabricate (24) Lower Thruster Assemblies	Not Required for This Concept					
	Install (24) Lower Thruster Assemblies	Not Required for This Concept					
	Remove Special Pedestal Crane and prepare for reinstallation (2 days with crew of 6)	Not Required for This Concept					
	Erect Transition Section and Turbine Nacelle (crew of 5 for 4 days)	160	man hours	$40.30		$6,448	Use LTL- 1100 crane WindPACT Area 2 Study - crane costs elsewhere
	Supply, Install, and Torque 1.25 in dia HS bolts	64	each	$14.20		$909	
	Erect Hub and Blades to Turbine Nacelle (crew if 5 for 4 days)	160	man hours	$40.30		$6,448	Use LTL-1100 crane WindPACT Area 2 Study - crane costs elsewhere
	Disconnect Base Flange of Steel Tube From Anchor Bolts	Not Required for This Concept					
	Jack-Up Steel Tube with Turbine and Blades	Not Required for This Concept					
	Jack-Up Steel Tube in 12 in Lifts (12 lifts per hour) (16 hour shift) 6 people X 16=	Not Required for This Concept					
	Jack-up Equipment Rental	Not Required for This Concept					
	Monitor with Control Transits	Not Required for This Concept					
	For final 24 inches inspect and adjust rotationally to assure lift frame staffing cones mate into female sockets	Not Required for This Concept					
	Allowance for equipment and small cranes					$4,000	

Conceptual Cost Estimate
5.0 MW - 100m All Steel Wind Turbine Tower
(Designed for Wind) - 50 ksi
50 Tower Installation - 28 Month Schedule
March 2004 Steel Prices

No.	Item	Quantity	Units	Unit Cost	Cost		Comments
					$ Total	$/Tower	
					Subtotal	**$17,805**	
8	**Complete Concrete to Steel Connection**						
	Remove Upper and Lower Thruster Assemblies	Not Required for This Concept					
	Supply, Install, and Torque (128) -1.5 in Diameter High Strength Bolts	Not Required for This Concept					
	Remove Jack-Up Tendons and Anchors	Not Required for This Concept					
	Lower and remove tower base support frame. (3 days for a crew of 4)	Not Required for This Concept					
	Install Weather Protective Flashing Over Concrete to Steel Joint	Not Required for This Concept					
	Supply, Hoist in and install Ladders and Platforms Inside Concrete Tower	Not Required for This Concept					
	Remove Exterior Scaffold Platforms and Connecting Towers		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
	Touch Up Paint on Steel Tube Exterior		Lump sum			$10,200	Use LTL-600 crane (crane costs included elsewhere) 1.5 hybrid amount X 100m/49m)
					Subtotal	**$20,400**	
	Summary of Construction Costs for 5.0 MW All Steel Tower (Wind Design)					**$2,550,094**	
	General Contractor Field Overhead	10.0%				$255,009	
	General Contractor Administrative Overhead	10.0%				$255,009	
	General Contractor Profit	10.0%				$255,009	
	Total Cost of Completed 5.0 MW All Steel Tower (Wind Design) with Nacelle, Hub and Blades Installed (supply cost of nacelle, hub and blades not included)					**$3,315,123**	Assuming 50 Towers

Appendix D - Preliminary Design Drawings

Drawing D-1: Tower Assembly and Drawing Key

Drawing D-2: Tower Foundation Elevation and Plan

Drawing D-3: Steel Tower Assembly and Joint Alignment Detail

Drawing D-4: Use of Concrete Tower Top Connection Ring as Jig for Welding of Steel Tower Bottom Flange Ring

Drawing D-5: Match Drilling of Concrete Tower Top Connection Ring and Steel Tower Bottom Flange Ring

Drawing D-6: Steel Tower Segment Erection

Drawing D-7: Steel Tower Base Jack Up Support Frame – Plan

Drawing D-8: Temporary Attachment of Steel Tower to Foundation – Concrete Tower Top Prior to Jack Up of Steel Tower

Drawing D-9: Precast Concrete Segment Dimensional Data – Concrete Tower for 1.5 MW Hybrid Steel/Concrete Wind Turbine Tower

Drawing D-10: Plan of Precast Concrete Segments #1 and #6

Drawing D-11: Plan of Precast Concrete Segments #10 and #14

Drawing D-12: Precast Segment Aligning and Shimming Hardware Layout

Drawing D-13: Precast Segment Aligning and Shimming Hardware Details

Drawing D-14: Plan and Elevation of Concrete Segment Form

Drawing D-15: Details of Concrete Segment Embed Locators

Drawing D-16: Details of a Single Segment Positioning Frame

Drawing D-17: Plan of Segment Positioning Frame Assembly

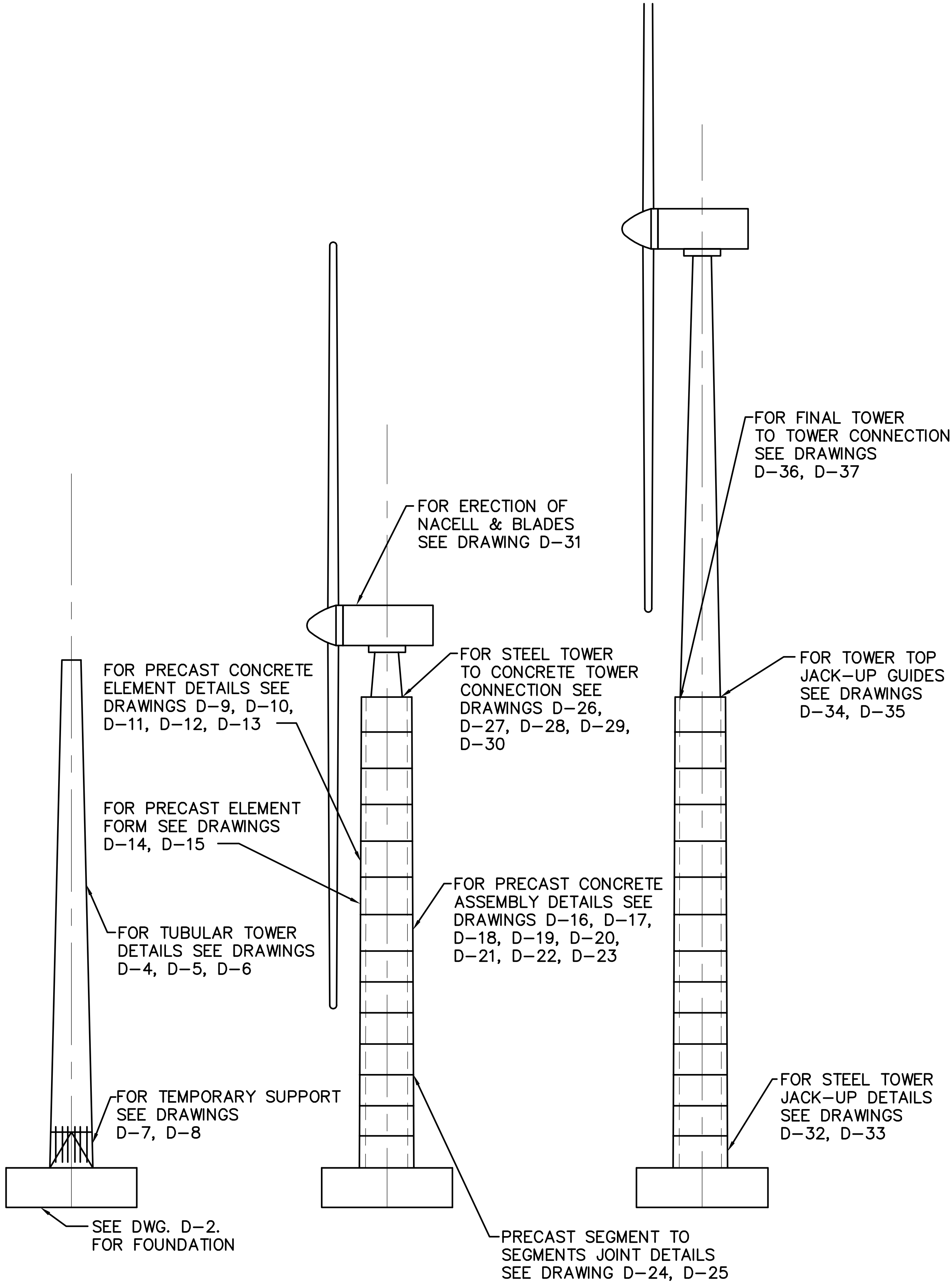
Drawing D-18: Erection of Precast Concrete Segments

Drawing D-19: Details of Erection for Precast Concrete Segments

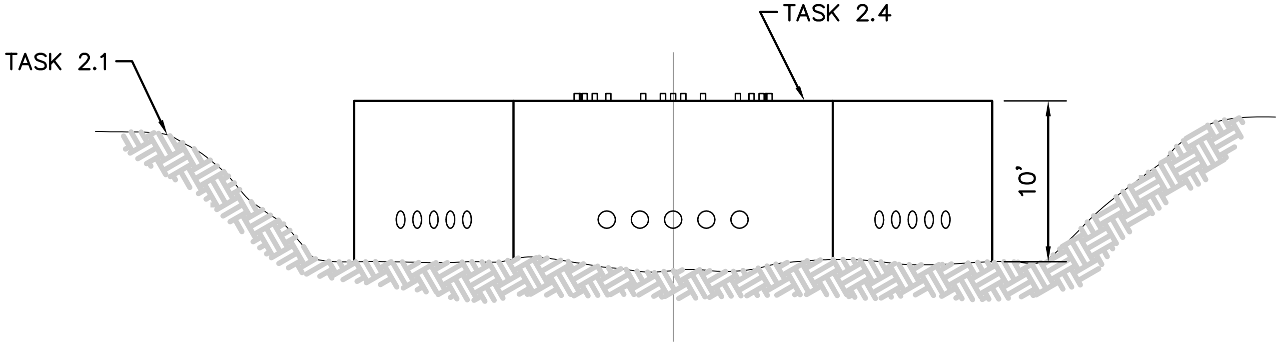
Drawing D-20: Details of Vertical Segment Joints

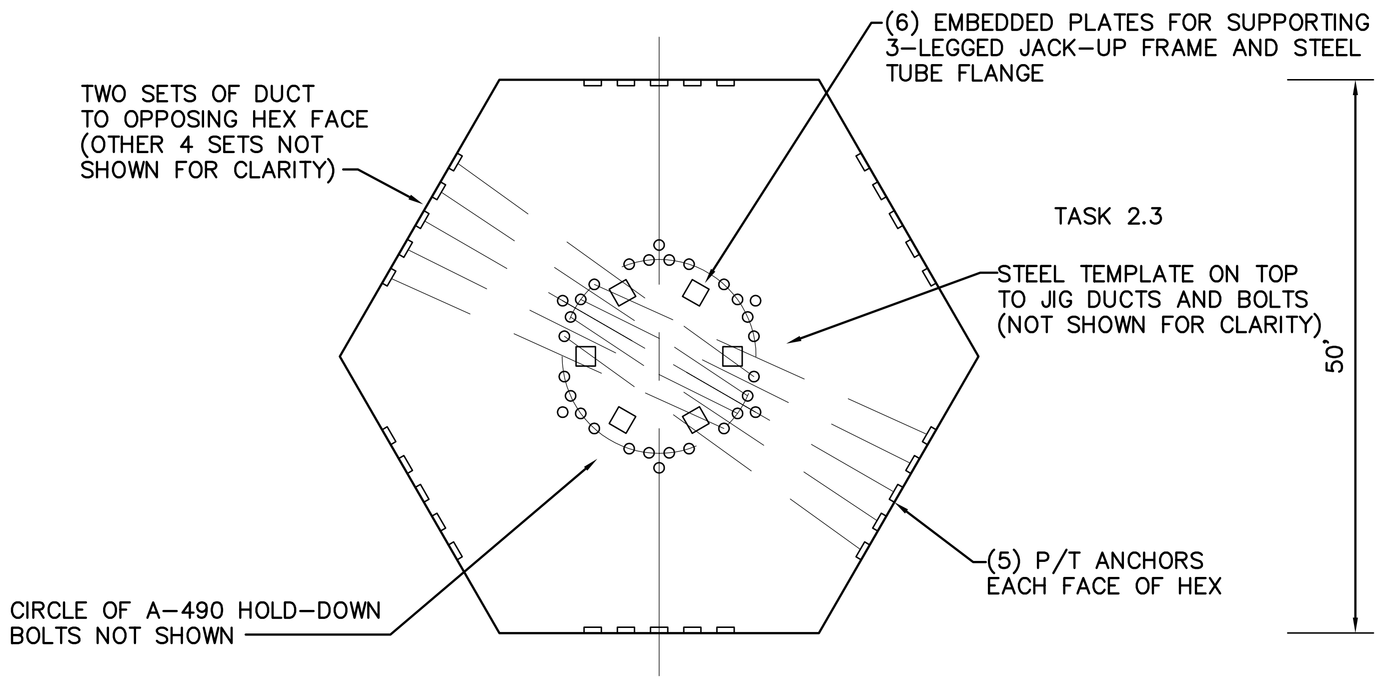
Drawing D-21: Splicing Details for Segment Hoop Reinforcing

Drawing D-22: Form Details for Segment Vertical Joint Closure Pours



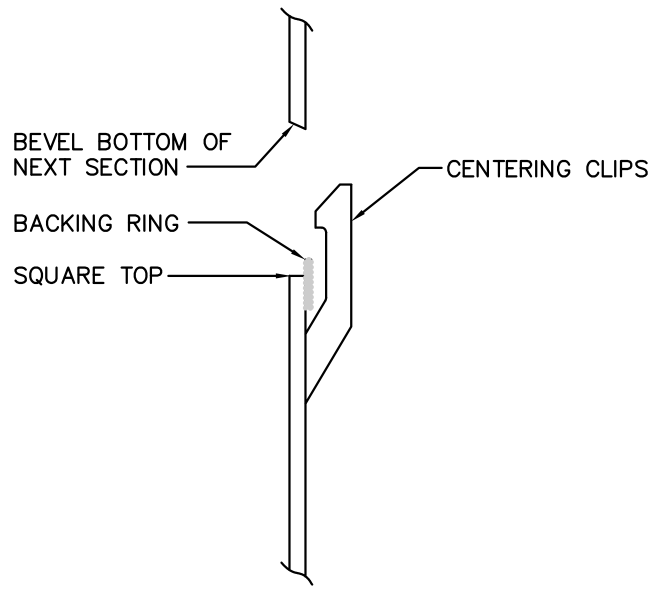
	NREL WIND TURBINE TOWER	DRAWING NO. **D-1**
	TOWER ASSEMBLY AND DRAWING KEY	PROJECT NO. NREL YAM-2-31235-01



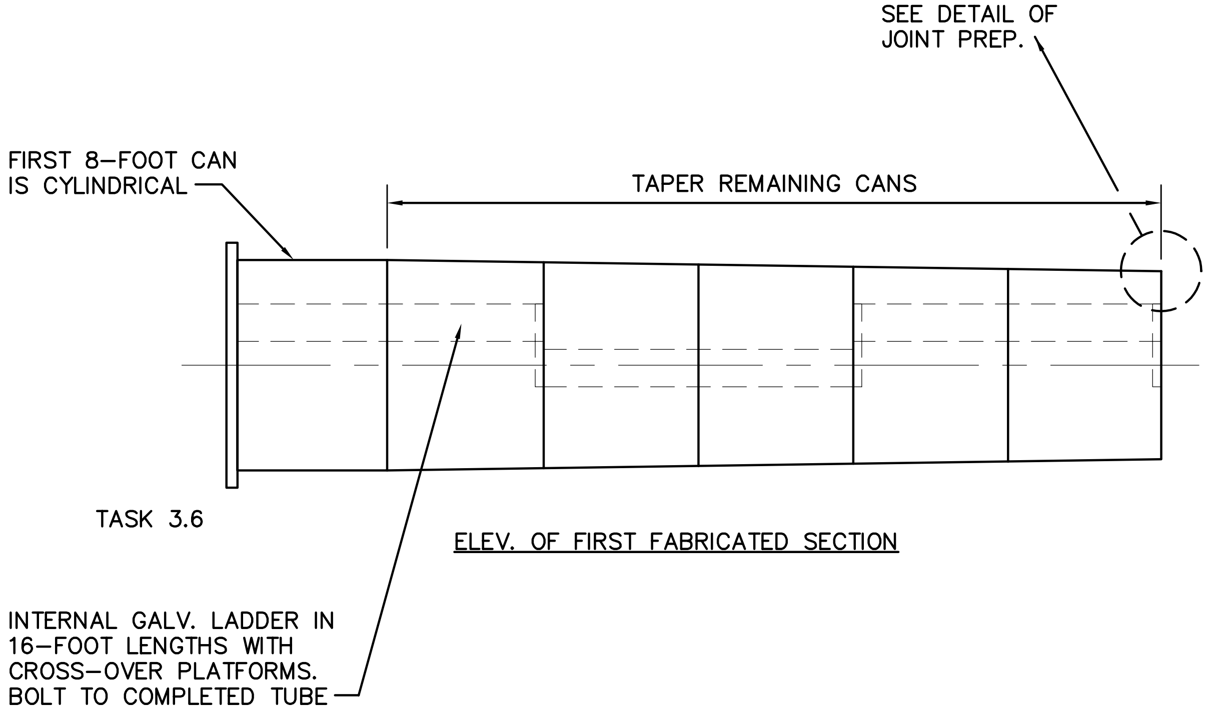


PLAN OF HEXAGONAL FOUNDATION

	NREL WIND TURBINE TOWER	DRAWING NO. **D-2**
	TOWER FOUNDATION ELEVATION AND PLAN	PROJECT NO. NREL YAM-2-31235-01

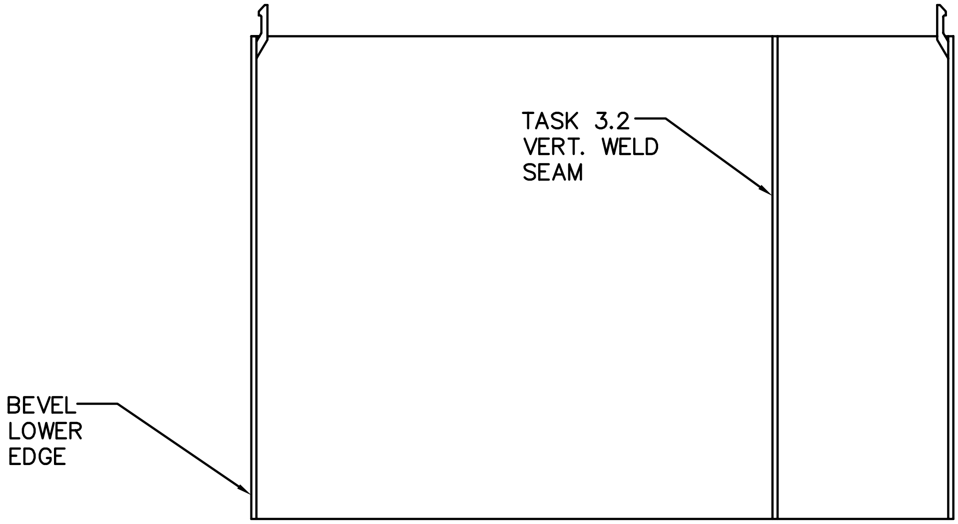


JOINT PREPARATION FOR FIELD WELD
TASK 3.8

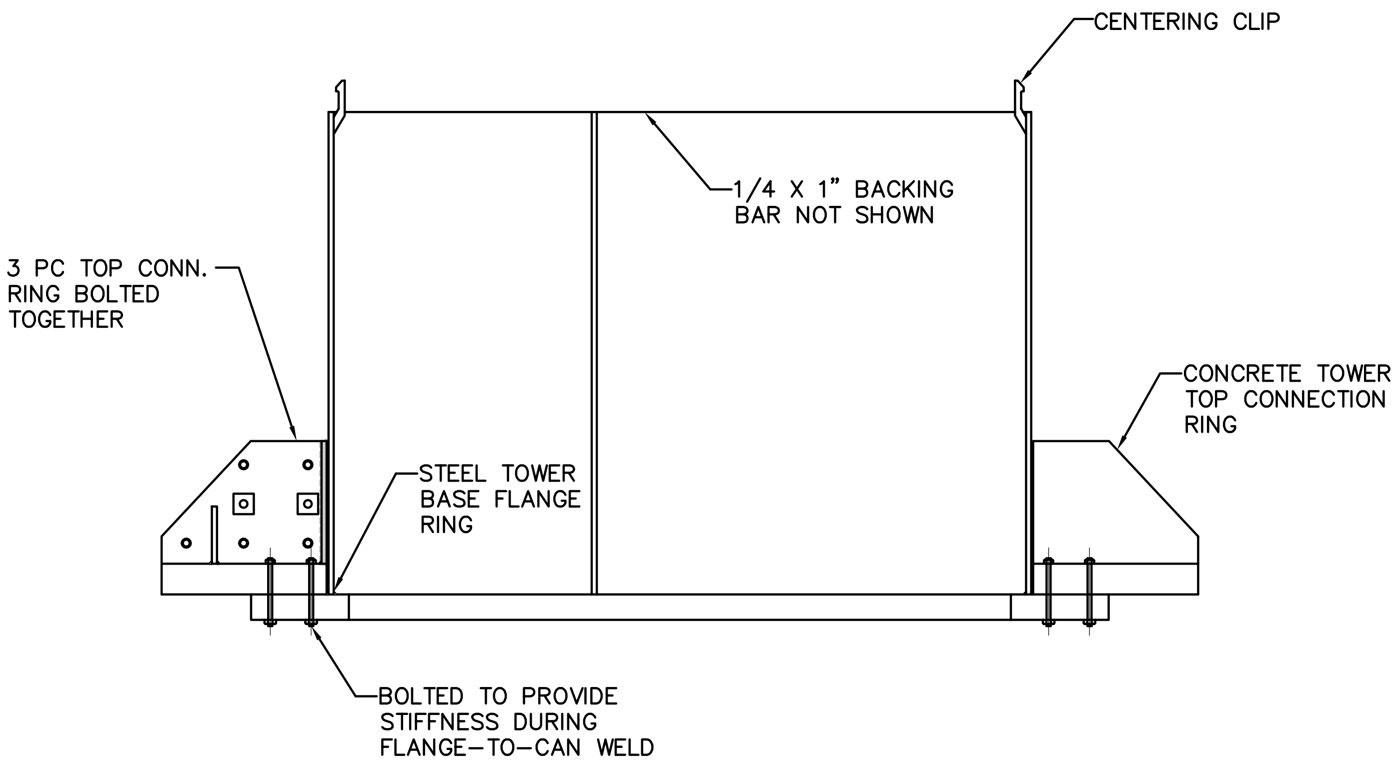


ELEV. OF FIRST FABRICATED SECTION

NREL WIND TURBINE TOWER	DRAWING NO. D-3
STEEL TOWER ASSEMBLY AND JOINT ALIGNMENT DETAIL	PROJECT NO. NREL YAM-2-31235-01

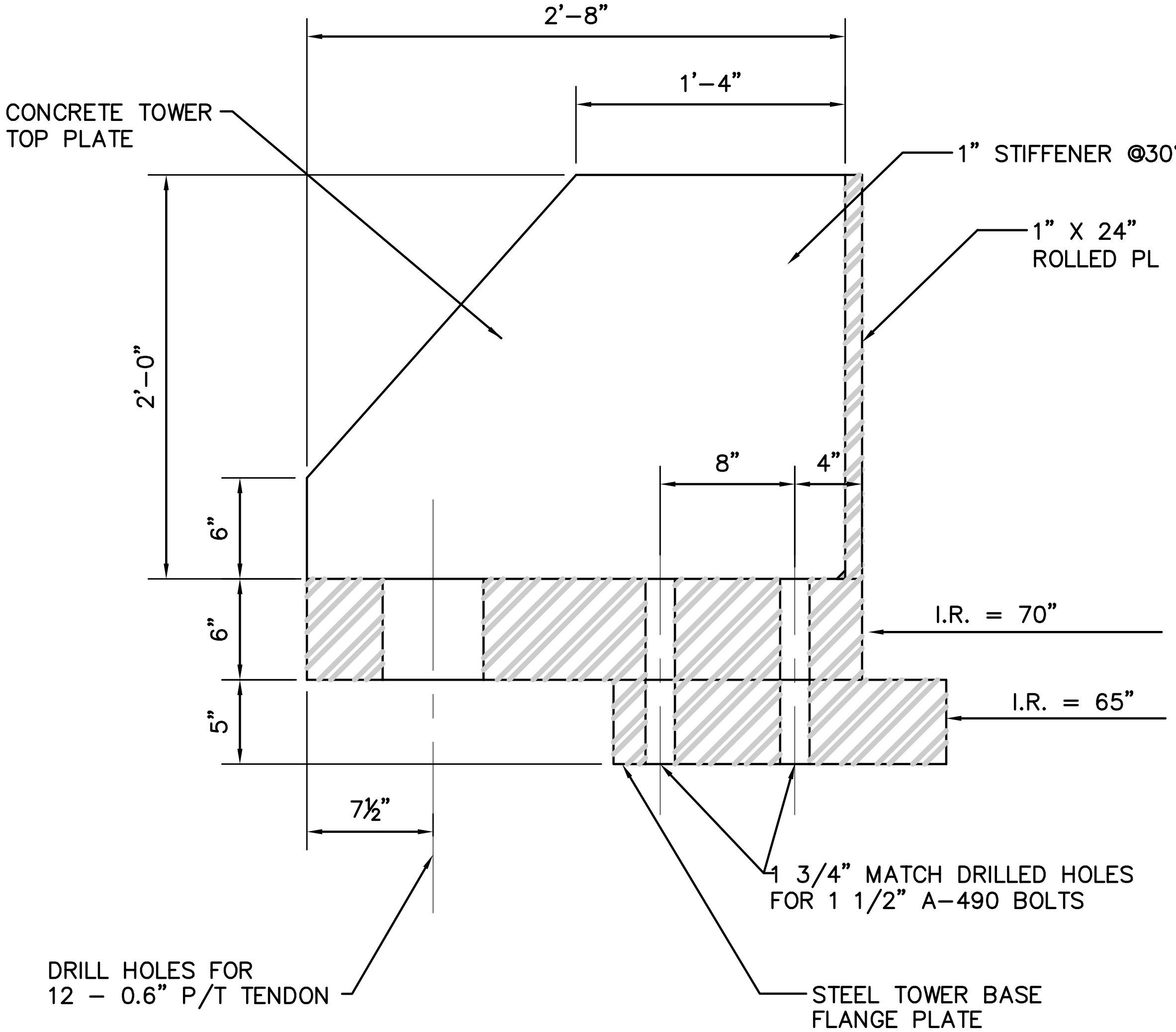


TASK 3.7: FIT & WELD
CANS INTO (3) TUBE SECTION



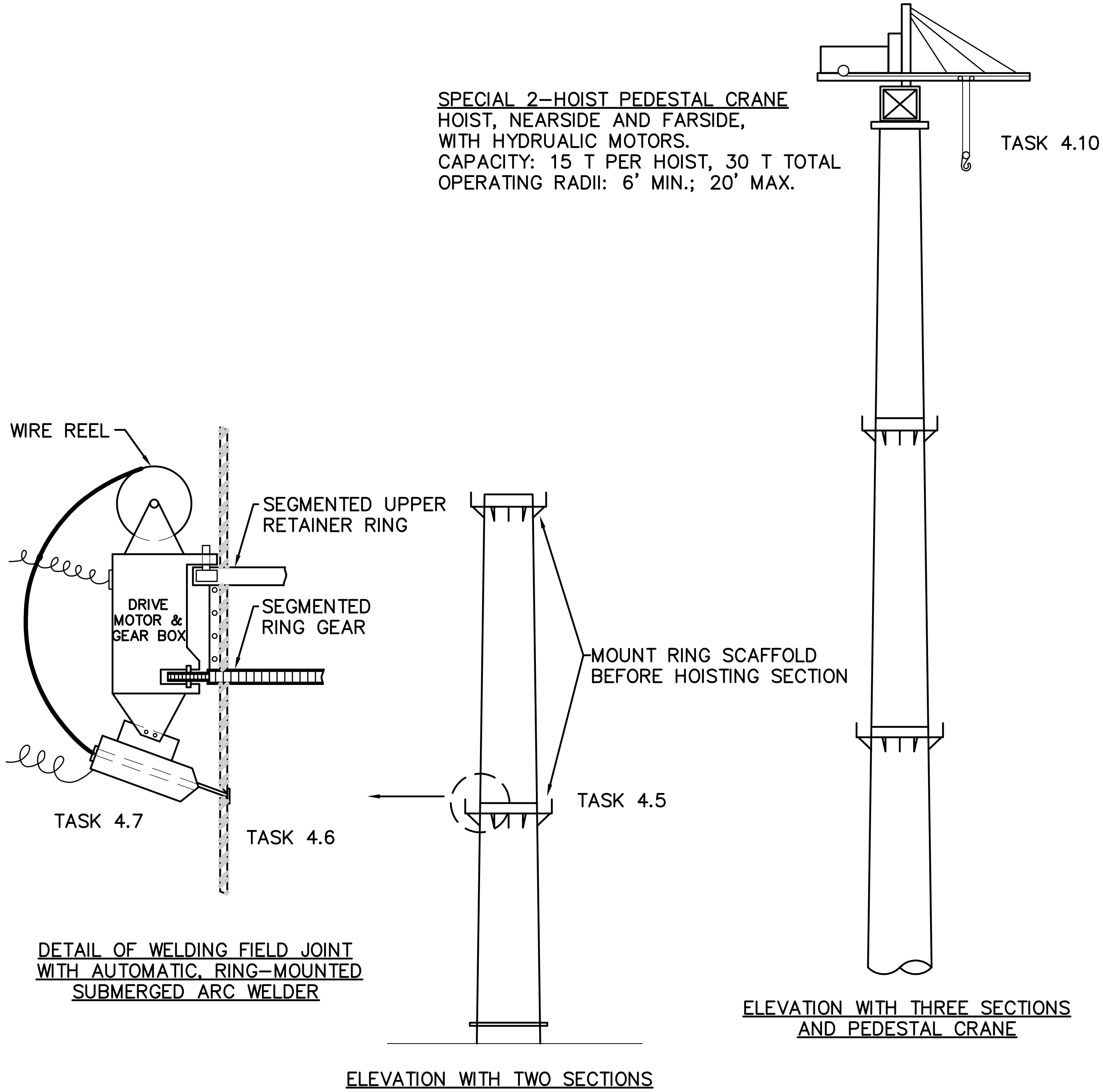
TASK 3.6: FLANGE-TO-CAN
SHOP BUTT WELD

	NREL WIND TURBINE TOWER	DRAWING NO. **D-4**
	CONC TOWER TOP CONNECTION RING JIG FOR WELDING OF STEEL TOWER BOTTOM FLANGE RING	PROJECT NO. NREL YAM-2-31235-01

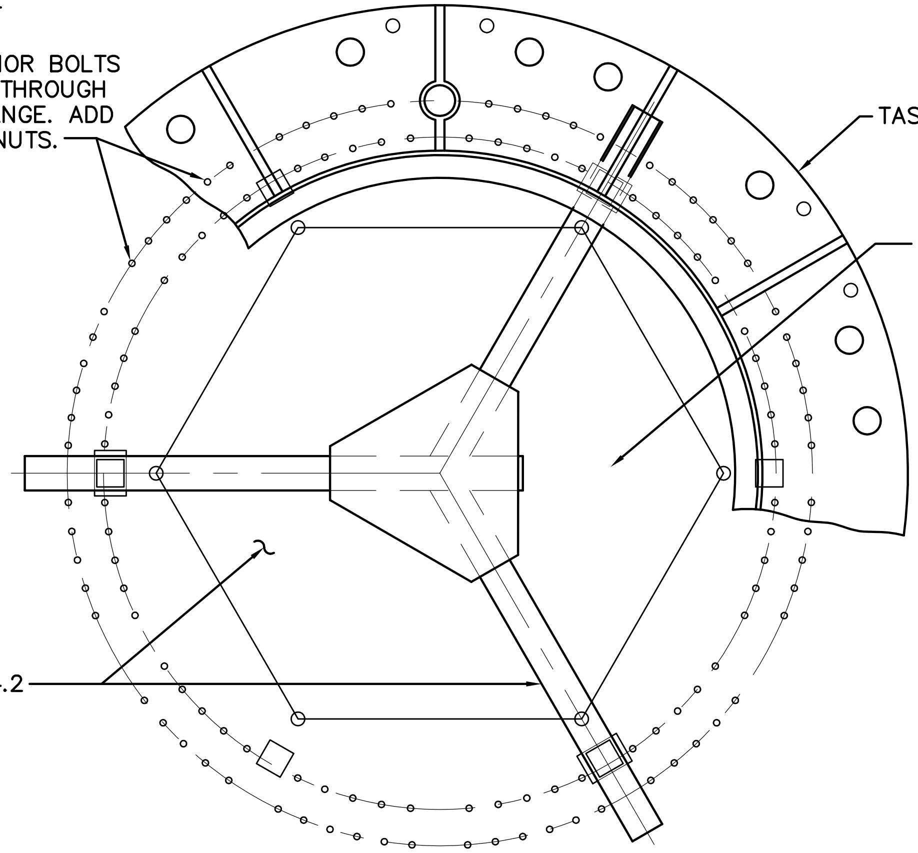


SECTION: TWO ANNULAR RINGS
MATED FOR MATCH DRILLING

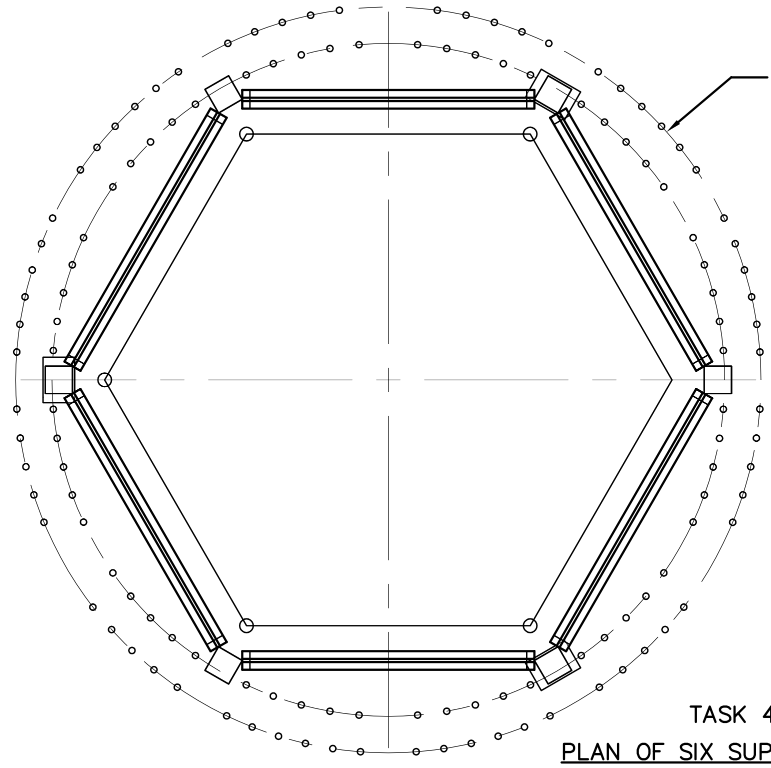
	NREL WIND TURBINE TOWER	DRAWING NO. **D-5**
	MATCH DRILLING OF CONNECTING FLANGES	PROJECT NO. NREL YAM-2-31235-01



	NREL WIND TURBINE TOWER	DRAWING NO. **D-6**
	STEEL TOWER SEGMENT ERECTION	PROJECT NO. NREL YAM-2-31235-01

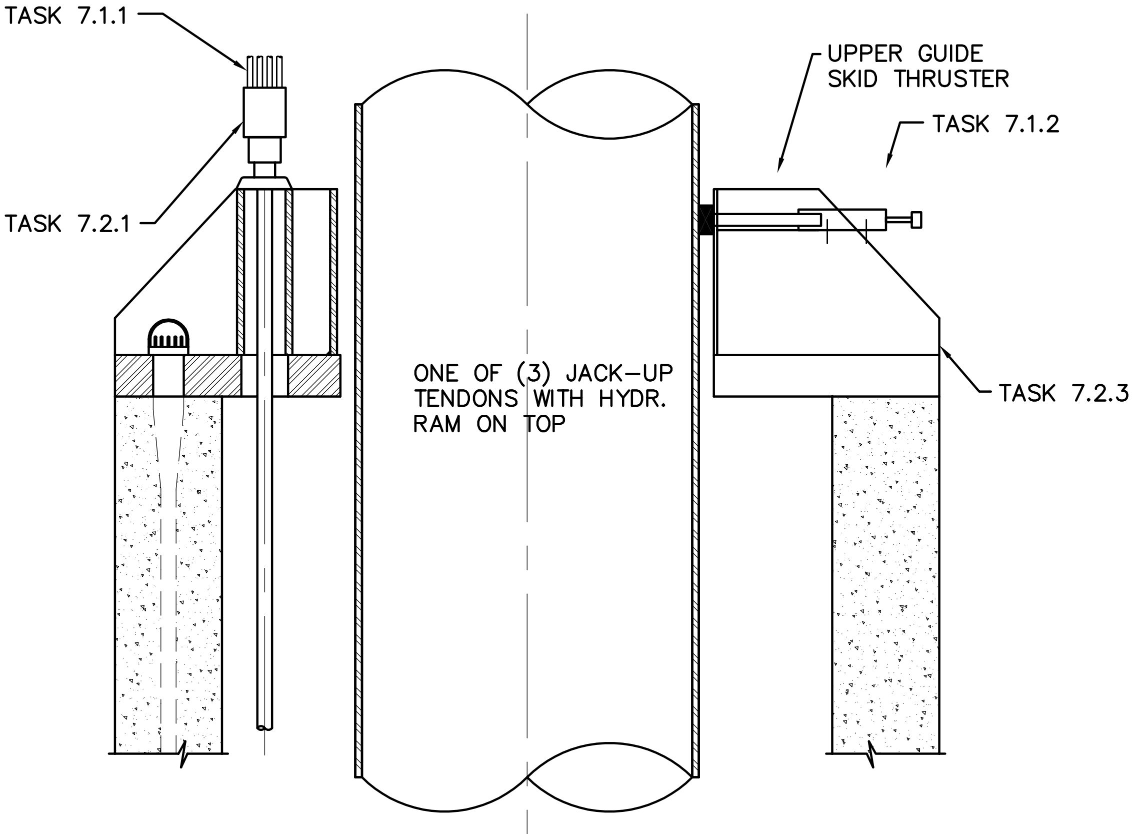


PLAN OF 3–LEGGED SUPPORT FRAME AND PARTIAL OF TOWER FLANGE

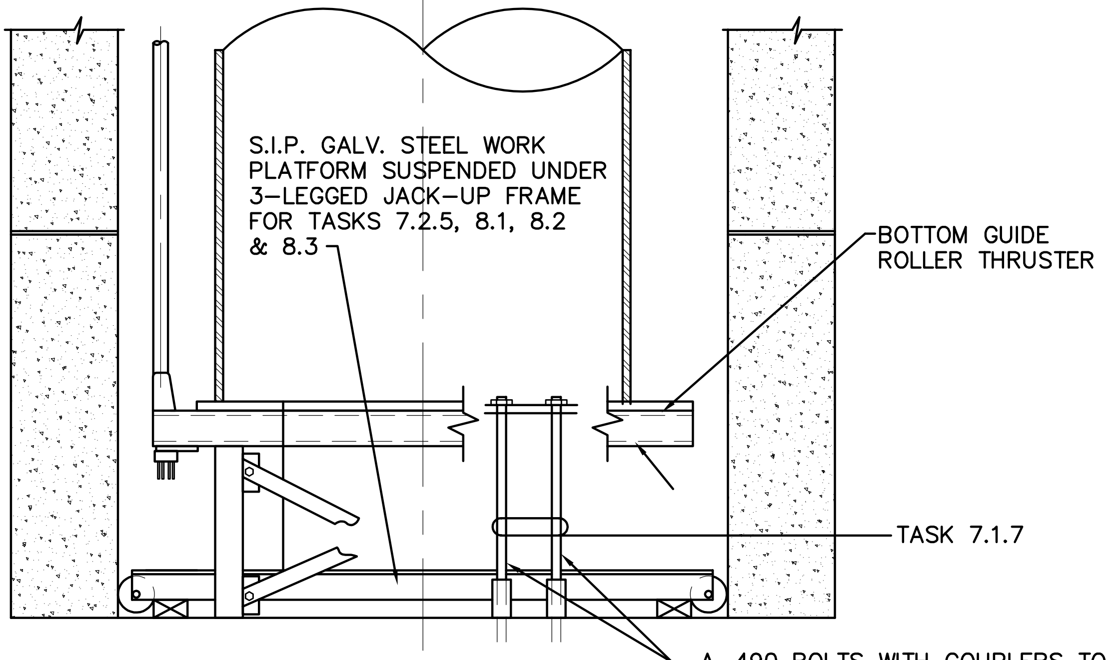


PLAN OF SIX SUPPORT POSTS AND RING OF A–490 ANCHOR BOLTS

	NREL WIND TURBINE TOWER	DRAWING NO. **D-7**
	STEEL TOWER BASE JACK-UP SUPPORT FRAME PLAN	PROJECT NO. NREL YAM-2-31235-01

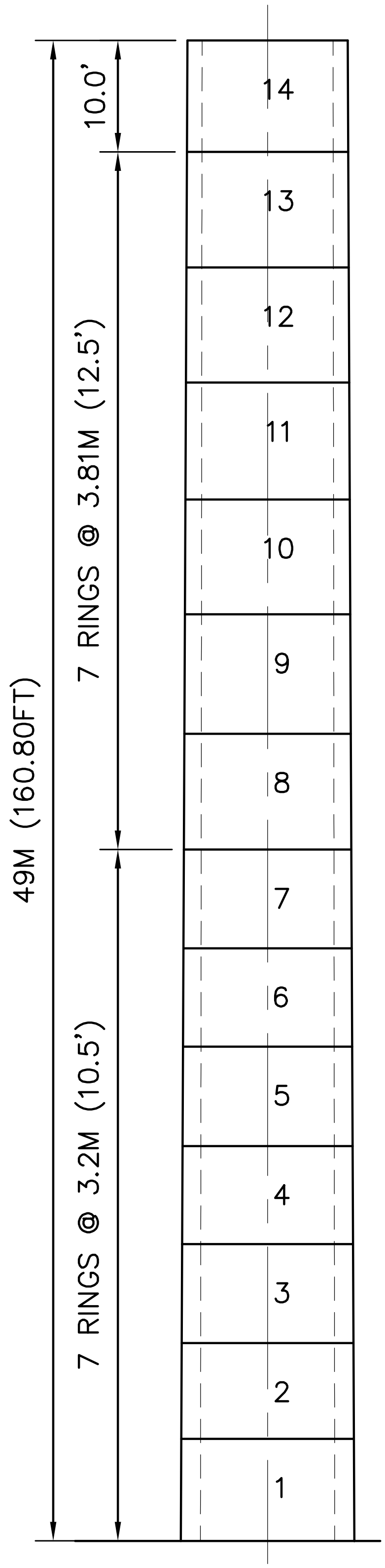


SECTION: TOP BEFORE JACK-UP



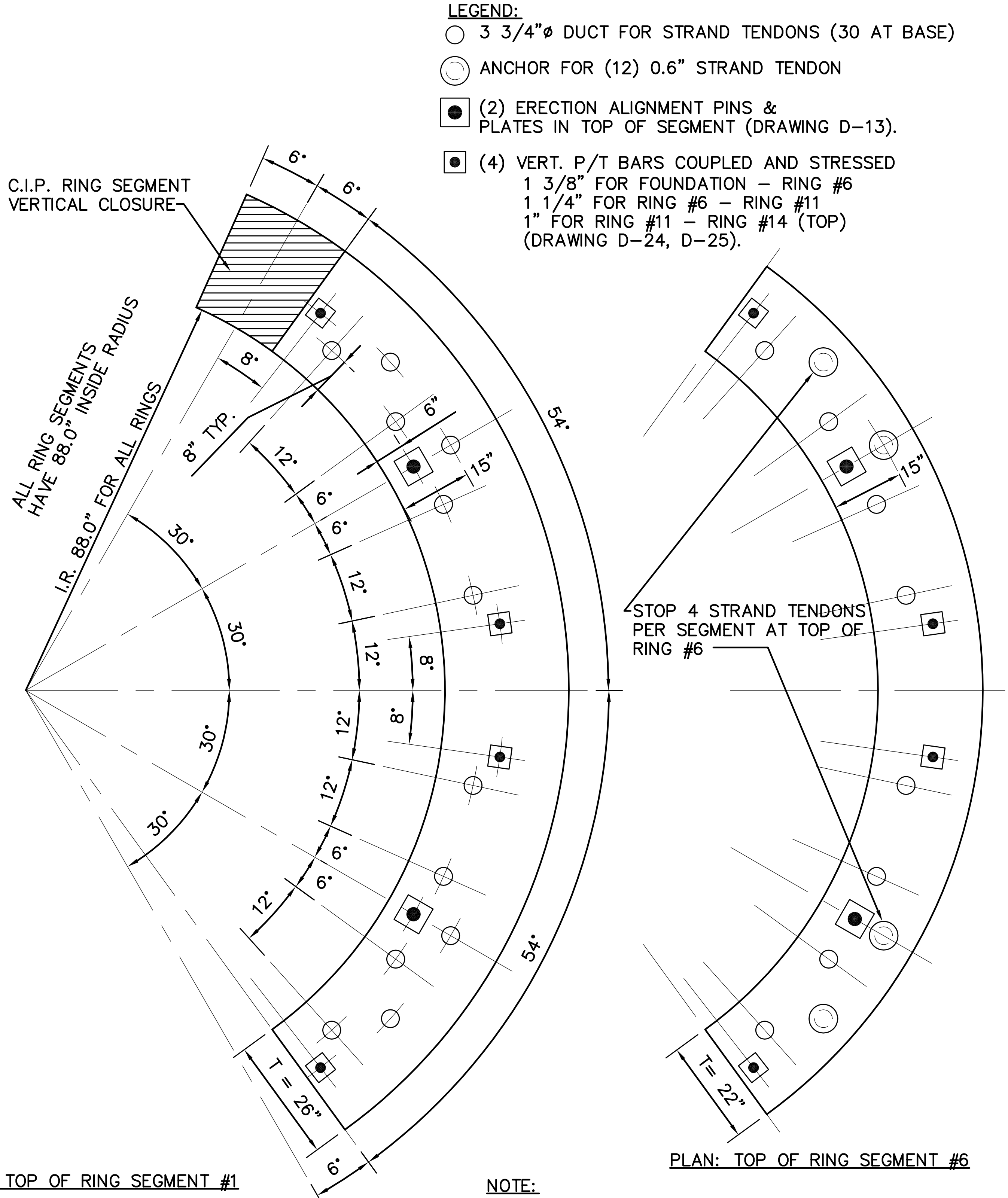
SECTION: BOTTOM BEFORE JACK-UP

	NREL WIND TURBINE TOWER	DRAWING NO. **D-8**
	TEMP ATTACH OF STEEL TOWER TO FOUNDATION CONC TOWER TOP PRIOR TO JACK UP OF STEEL TOWER	PROJECT NO. NREL YAM-2-31235-01



ELEVATION OF LOWER CONCRETE TOWER

	NREL WIND TURBINE TOWER	DRAWING NO. **D-9**
	PRECAST CONCRETE RINGS 1.5MW HYBRID STEEL/CONC	PROJECT NO. NREL YAM-2-31235-01



PLAN: TOP OF RING SEGMENT #1

PLAN: TOP OF RING SEGMENT #6

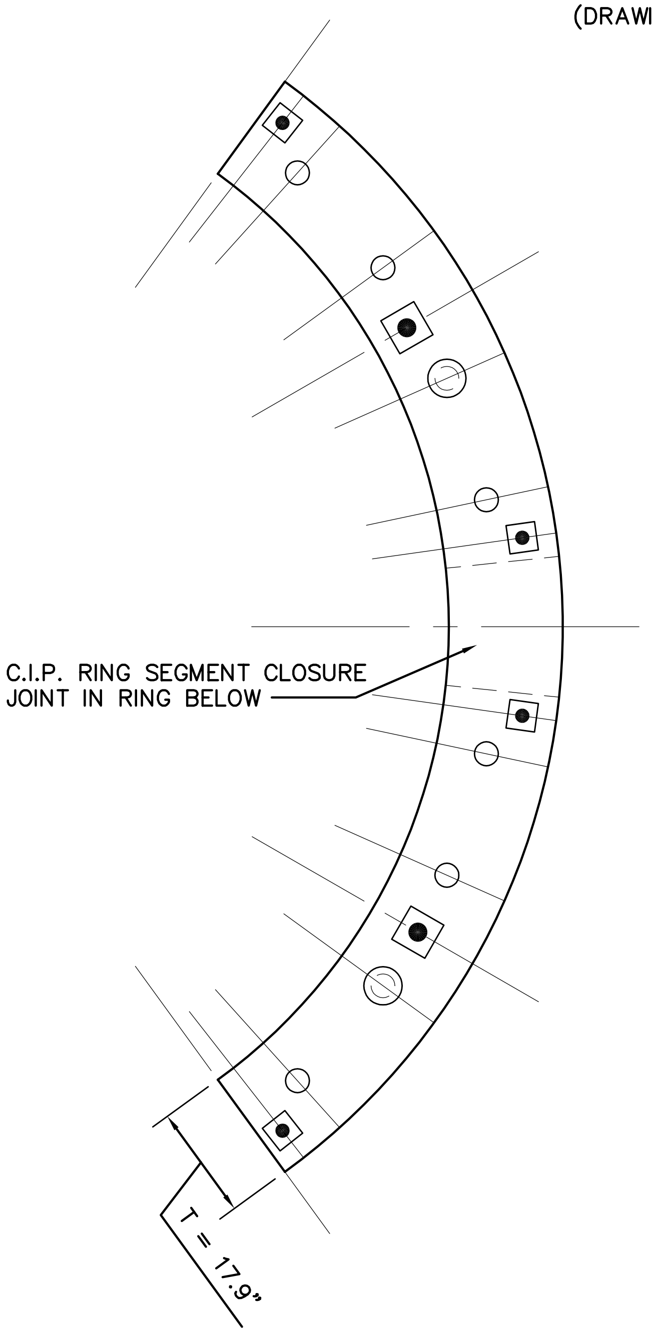
NOTE:
ALL 14 RINGS CONSIST OF THREE 108° SEGMENTS PLUS THREE 12° VERTICAL C.I.P. CLOSURE POURS. THE SEGMENTS IN ALTERNATE RINGS ARE ROTATED 60° SO THAT THE CLOSURE POURS ARE STAGGERED.

NOTE:
ALL SLEEVES, AND EMBEDS ARE DIMENSIONED FROM INSIDE FACE OF CONCRETE AND CENTER OF SEGMENT ARC. THE CRITICAL INTENTION OF THE DETAILS IS THAT THE VERTICAL TENDON AND P/T SLEEVES, AND ALIGNMENT PINS LINE UP WHEN ALTERNATE RING SEGMENTS ARE SHIFTED 60°.

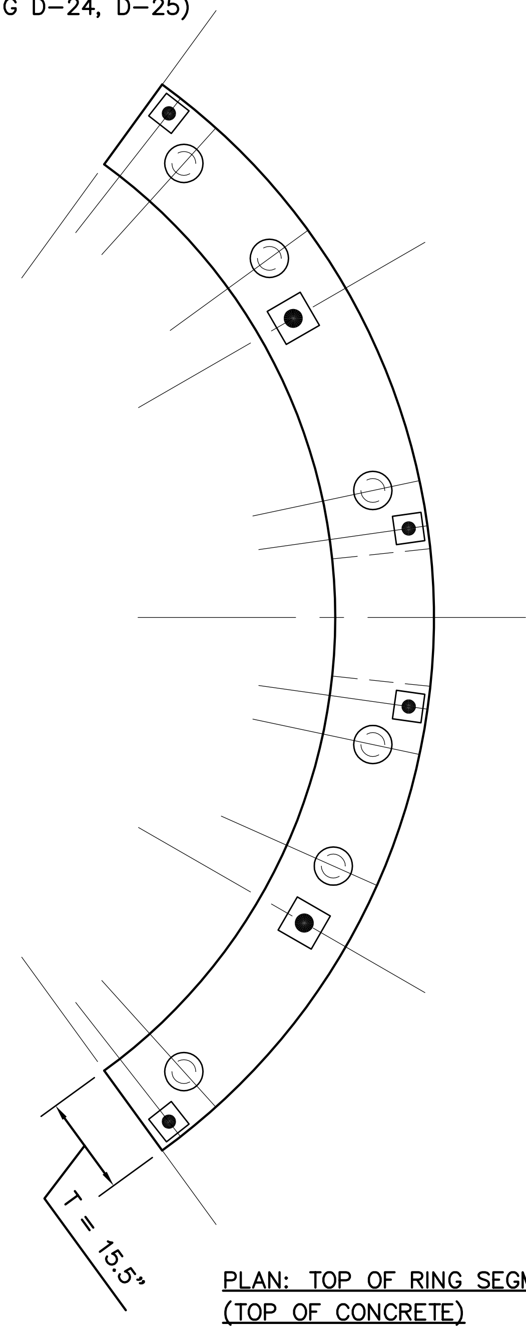
	NREL WIND TURBINE TOWER	DRAWING NO. **D-10**
	PLAN OF PRECAST CONCRETE SEGMENTS #1 AND #6	PROJECT NO. NREL YAM-2-31235-01

LEGEND:

- 3 3/4"ø DUCT FOR STRAND TENDONS (30 AT BASE)
- ANCHOR FOR (12) 0.6" STRAND TENDON
- (2) ERECTION ALIGNMENT PINS & PLATES IN TOP OF SEGMENT (DRAWING D–13)
- (4) VERT. P/T BARS COUPLED AND STRESS
  - 1 3/8" FOR FOUNDATION – RING #6
  - 1 1/4" FOR RING #6 – RING #11
  - 1" FOR RING #11 – RING #14 (TOP)
  - (DRAWING D–24, D–25)



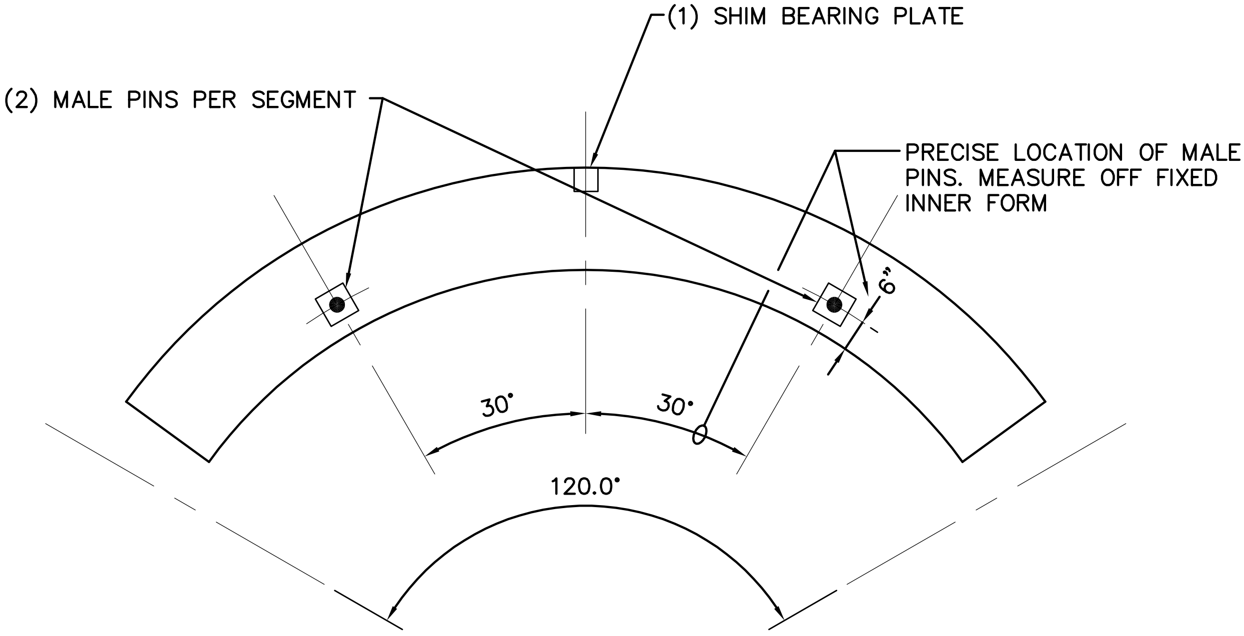
PLAN: TOP OF RING SEGMENT #10



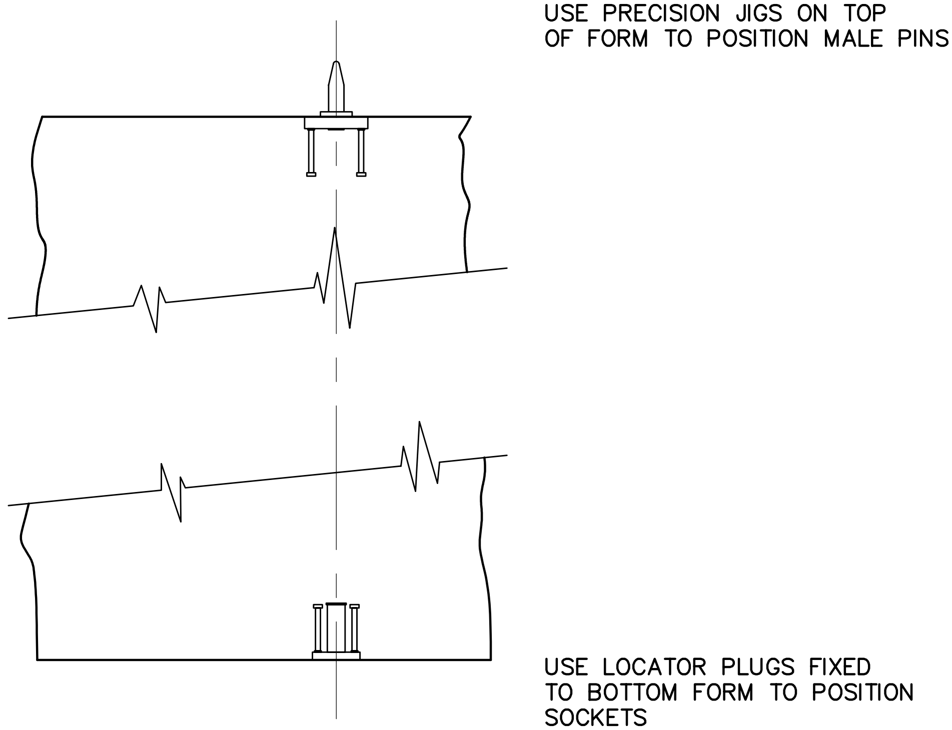
PLAN: TOP OF RING SEGMENT #14 (TOP OF CONCRETE)

NOTE: ALL SLEEVES, AND EMBEDS ARE DIMENSIONED FROM INSIDE FACE OF CONCRETE AND CENTER OF SEGMENT ARC. THE CRITICAL INTENTION OF THE DETAILS IS THAT THE VERTICAL TENDON AND P/T SLEEVES, AND ALIGNMENT PINS LINE UP WHEN ALTERNATE RING SEGMENTS ARE SHIFTED 60°.

	NREL WIND TURBINE TOWER	DRAWING NO. **D-11**
	PLAN OF PRECAST CONCRETE SEGMENTS #10 AND #14	PROJECT NO. NREL YAM-2-31235-01

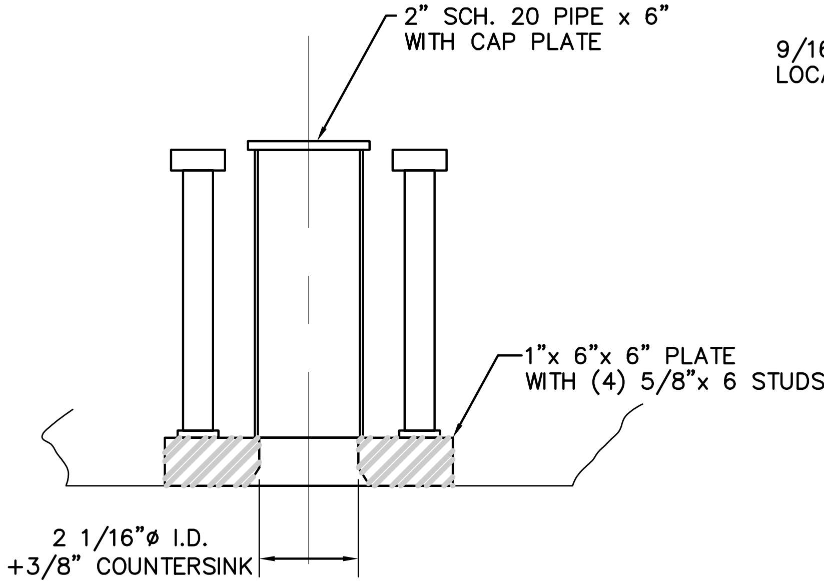


PLAN LOCATION OF ALIGNMENT PINS AND SOCKETS

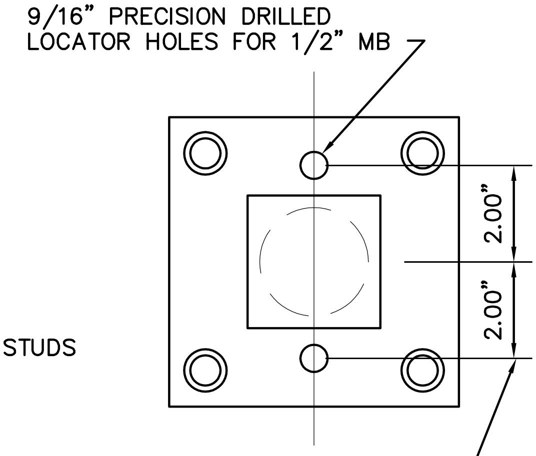


SECTION LOCATION TOP AND BOTTOM

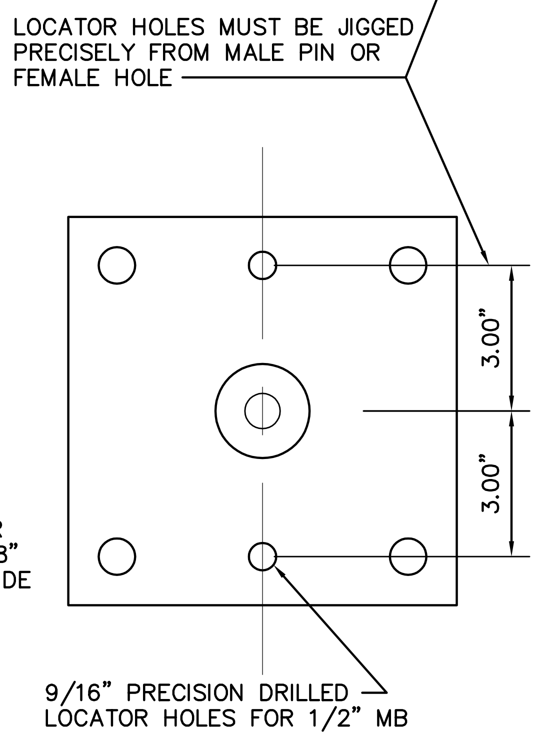
	NREL WIND TURBINE TOWER	DRAWING NO. **D-12**
	PRECAST SEGMENT ALIGNING & SHIMMING HARDWARE LAYOUT	PROJECT NO. NREL YAM-2-31235-01



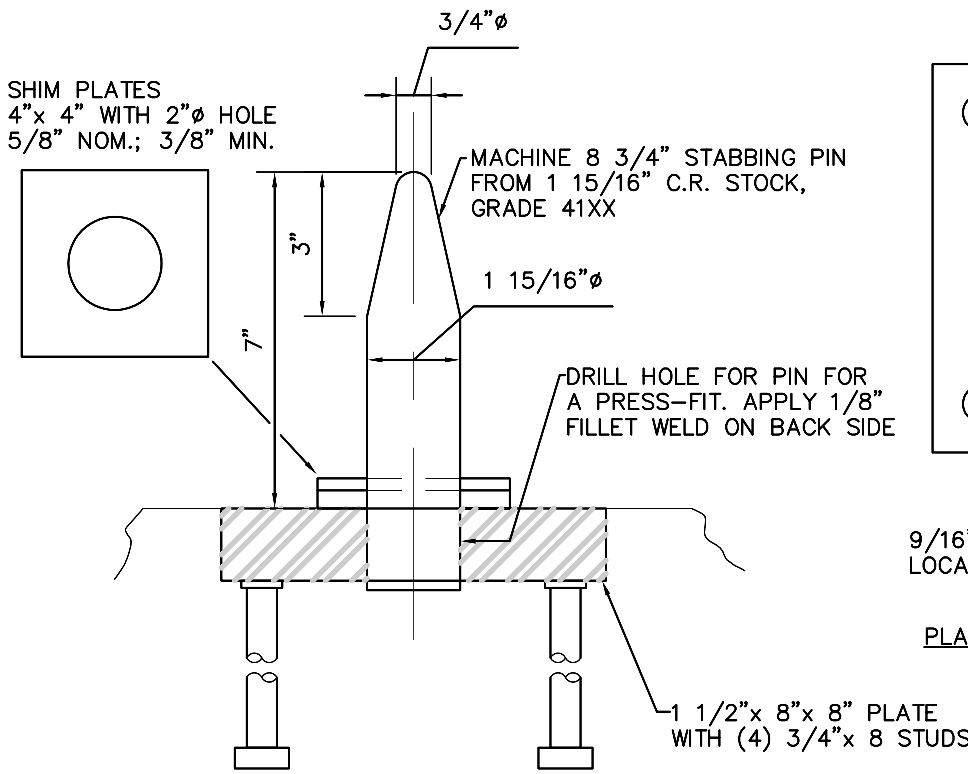
DETAIL FEMALE SOCKET



PLAN FEMALE EMBED

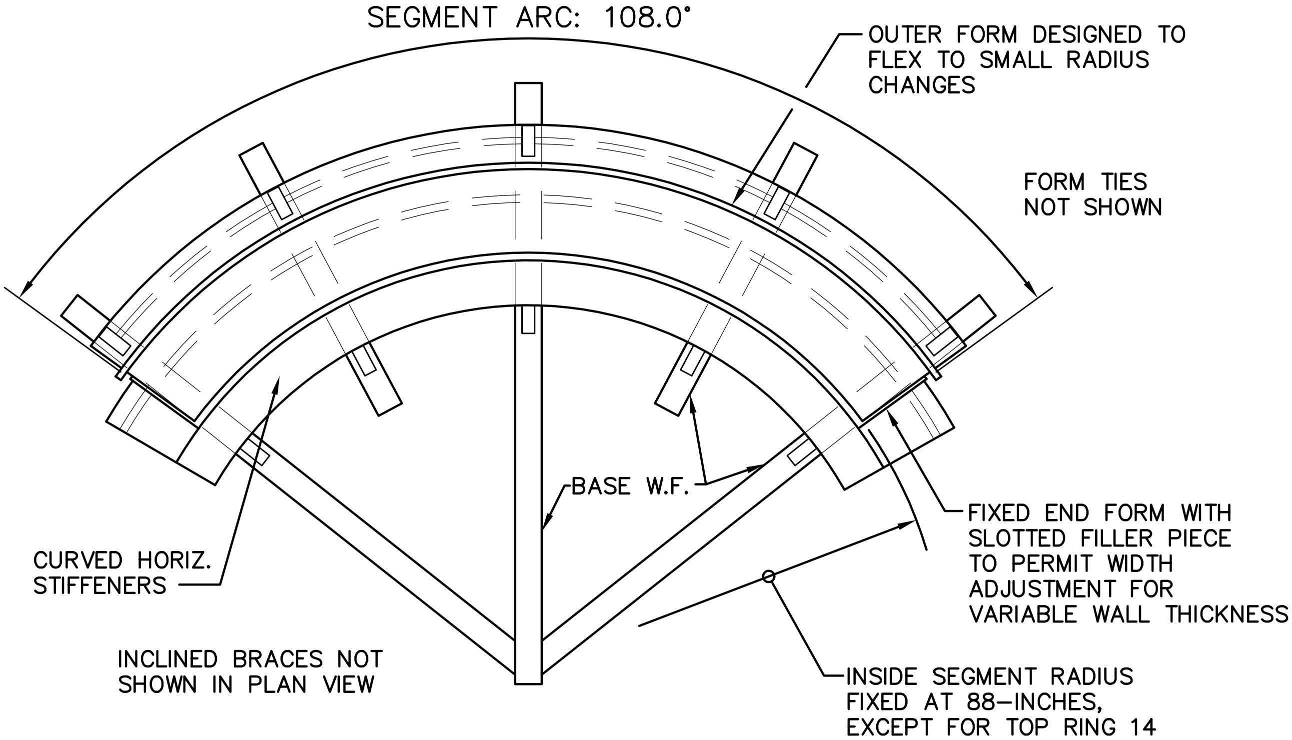


PLAN MALE ALIGNMENT PIN EMBED

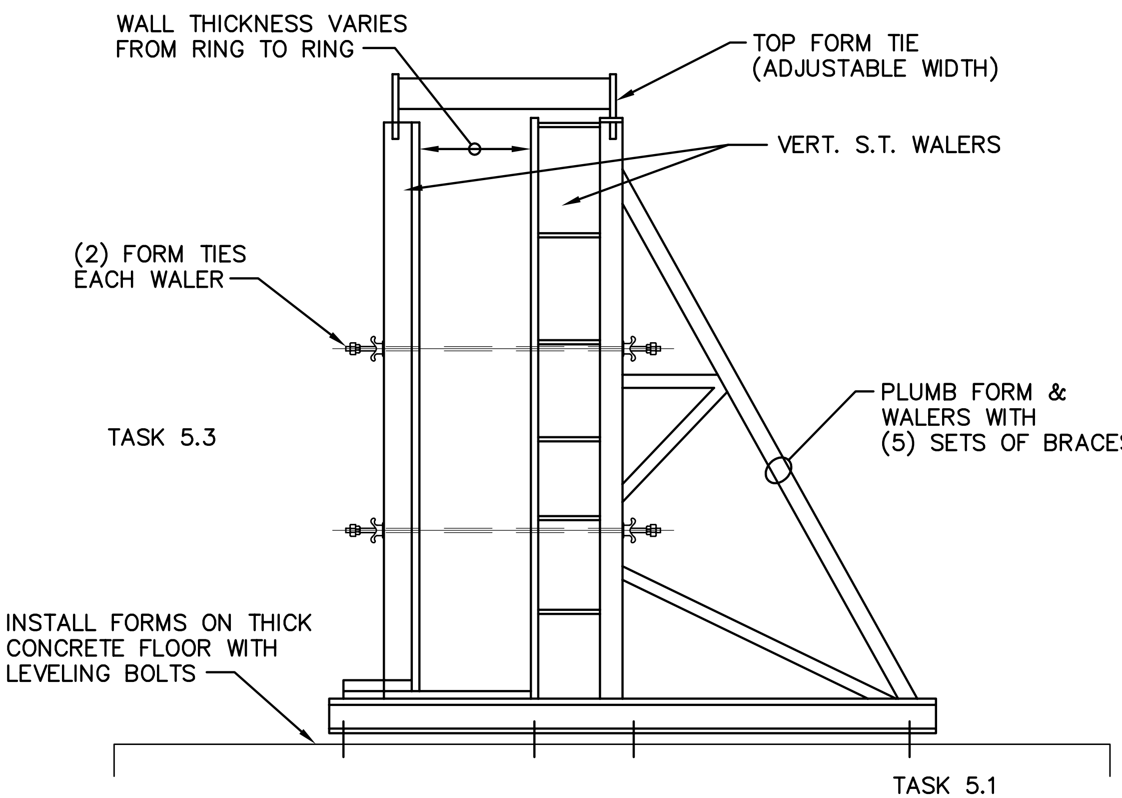


DETAIL MALE ALIGNMENT PIN

NREL WIND TURBINE TOWER	DRAWING NO.	**D-13**
PRECAST SEGMENT ALIGNING & SHIMMING HARDWARE DETAILS	PROJECT NO.	NREL YAM-2-31235-01

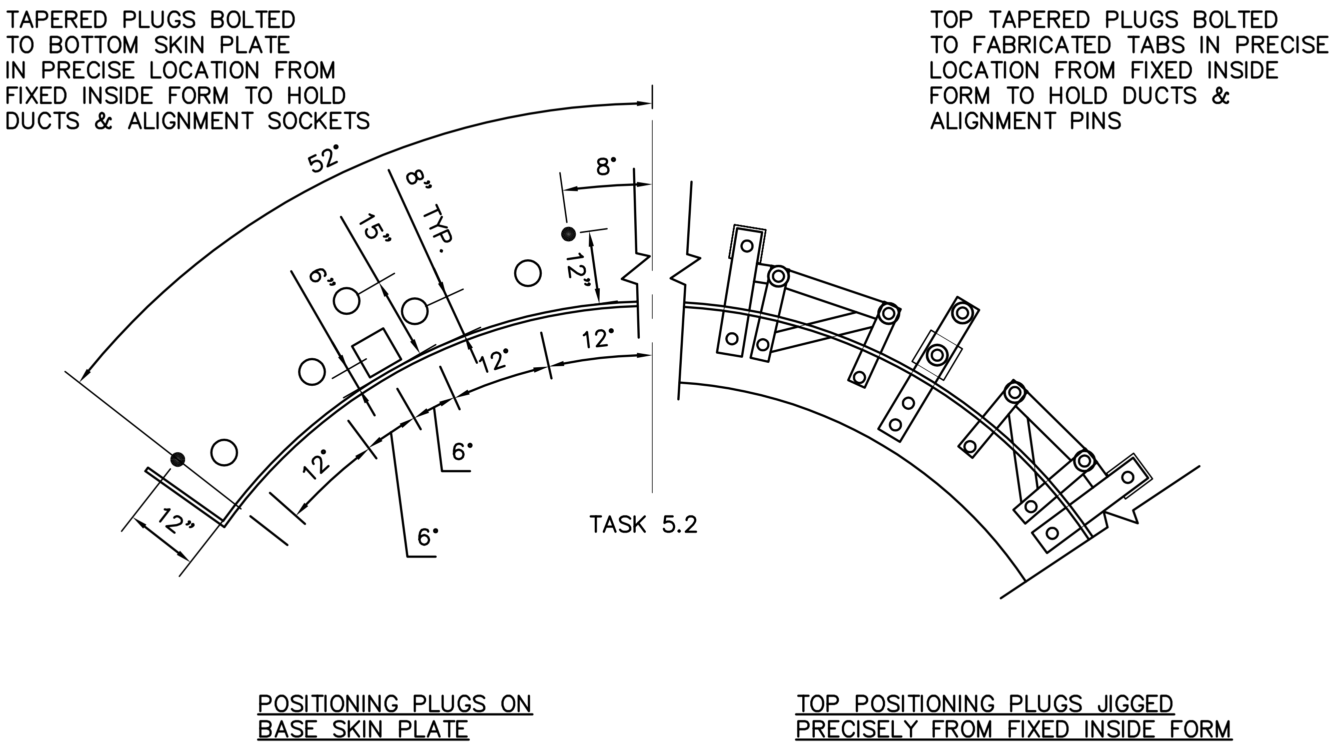


PLAN OF TYPICAL SEGMENT FORM

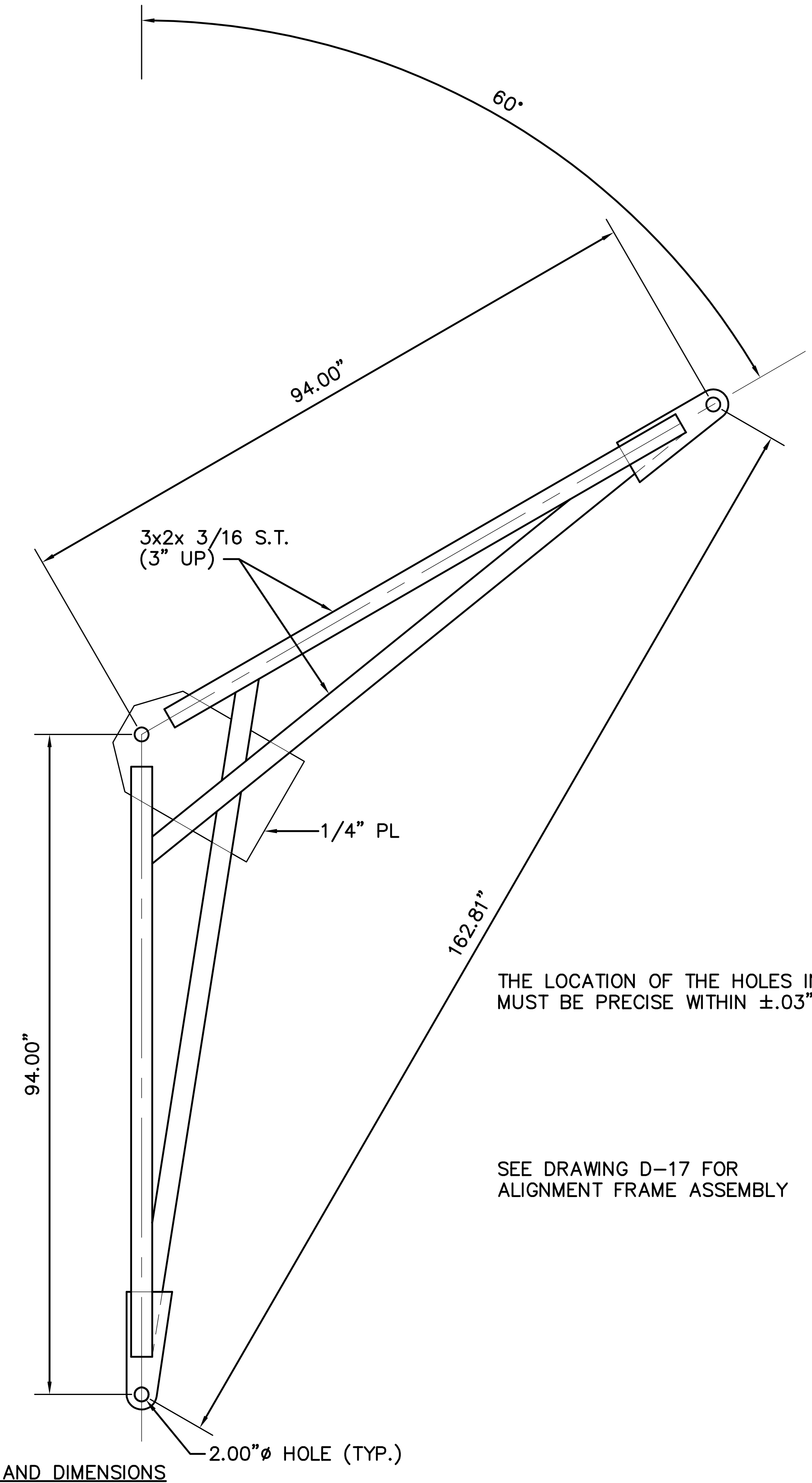


ELEVATION OF TYPICAL SEGMENT FORM

	NREL WIND TURBINE TOWER	DRAWING NO. **D-14**
	PLAN AND ELEVATION CONCRETE SEGMENT FORM	PROJECT NO. NREL YAM-2-31235-01



	NREL WIND TURBINE TOWER	DRAWING NO. **D-15**
	DETAIL OF CONCRETE SEGMENT EMBED LOCATORS	PROJECT NO. NREL YAM-2-31235-01

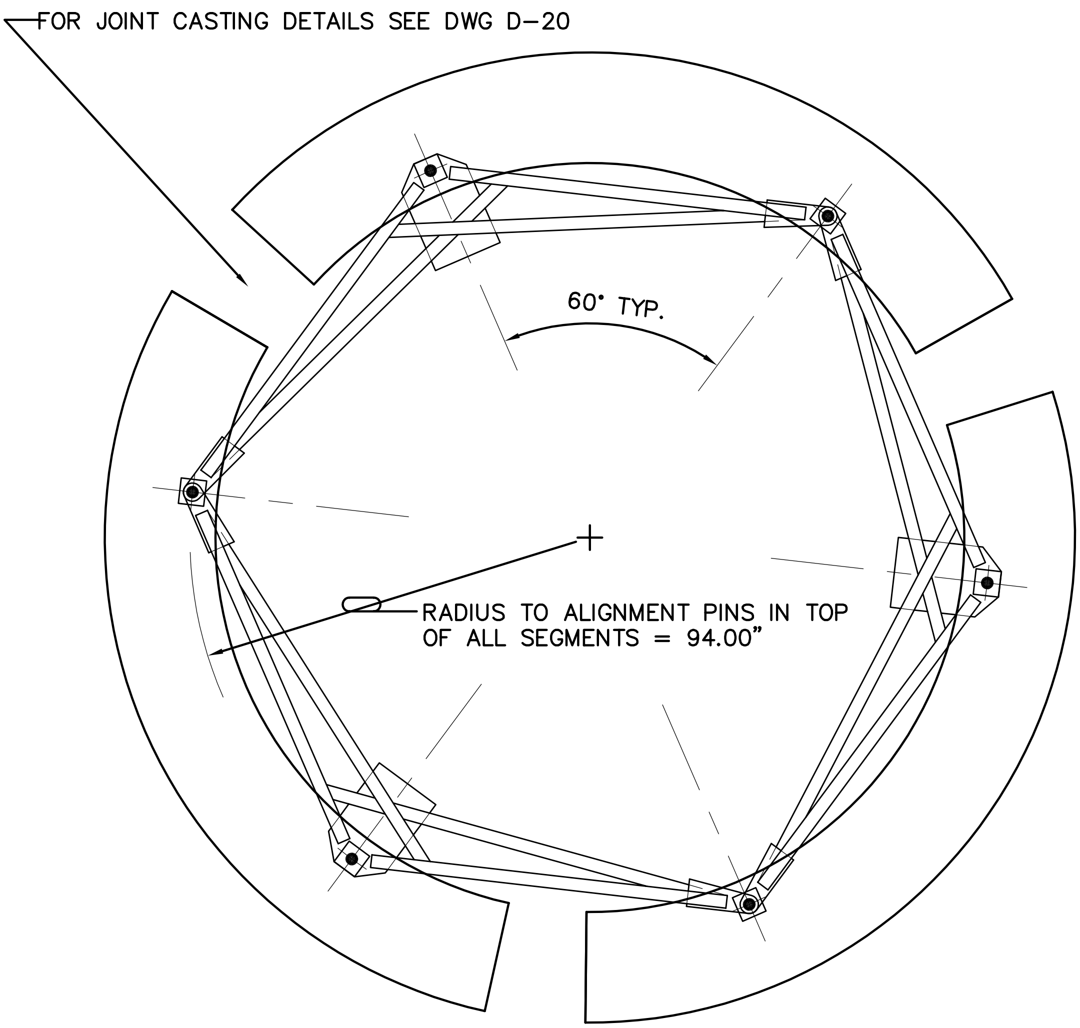


THE LOCATION OF THE HOLES IN THE FRAMES MUST BE PRECISE WITHIN ±.03"

SEE DRAWING D–17 FOR ALIGNMENT FRAME ASSEMBLY

FRAME DETAILS AND DIMENSIONS

	NREL WIND TURBINE TOWER	DRAWING NO. **D-16**
	DETAIL OF SINGLE SEGMENT POSITIONING FRAME	PROJECT NO. NREL YAM-2-31235-01

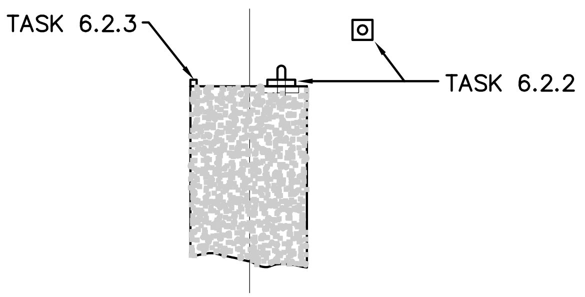


INSTALL THREE FRAMES ONTO VERTICAL ALIGNMENT PINS ON TOP OF EACH SET OF RINGS SEGMENTS TO HOLD TOP OF SEGMENTS IN TRUE CIRCLE. IT MAY BE NECESSARY TO INSTALL THE FRAMES BEFORE FINAL STRESSING OF THE (12) HOLD-DOWN P/T BARS TO LOCK DOWN THE SEGMENTS

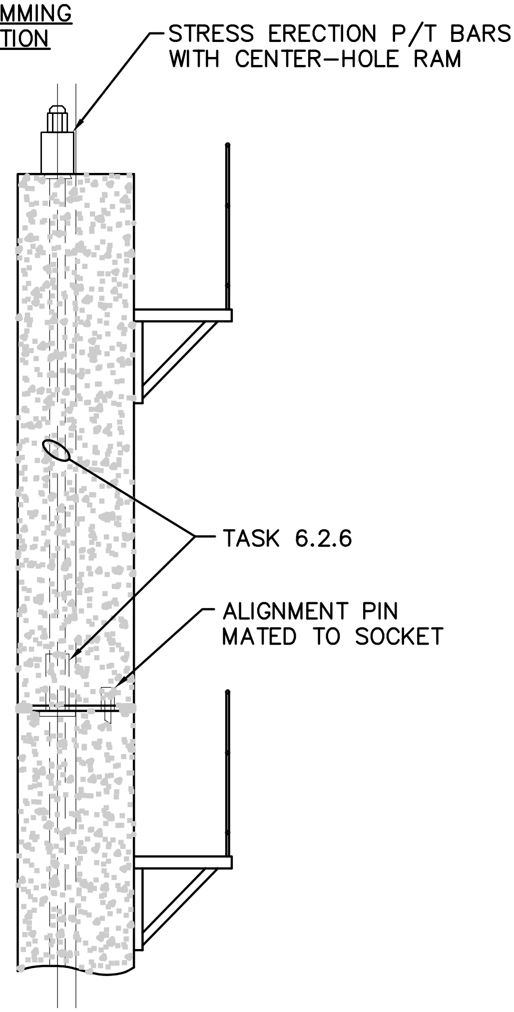
A SECOND PURPOSE OF THE TOP FRAMES IS TO PREVENT THE SEGMENT TOPS FROM SPREADING OUTWARD FROM THE CONCRETE PRESSURE ARISING FROM POURING THE CLOSURE JOINTS

PLAN: THREE POSITIONING FRAMES ON TOP OF THREE SEGMENTS

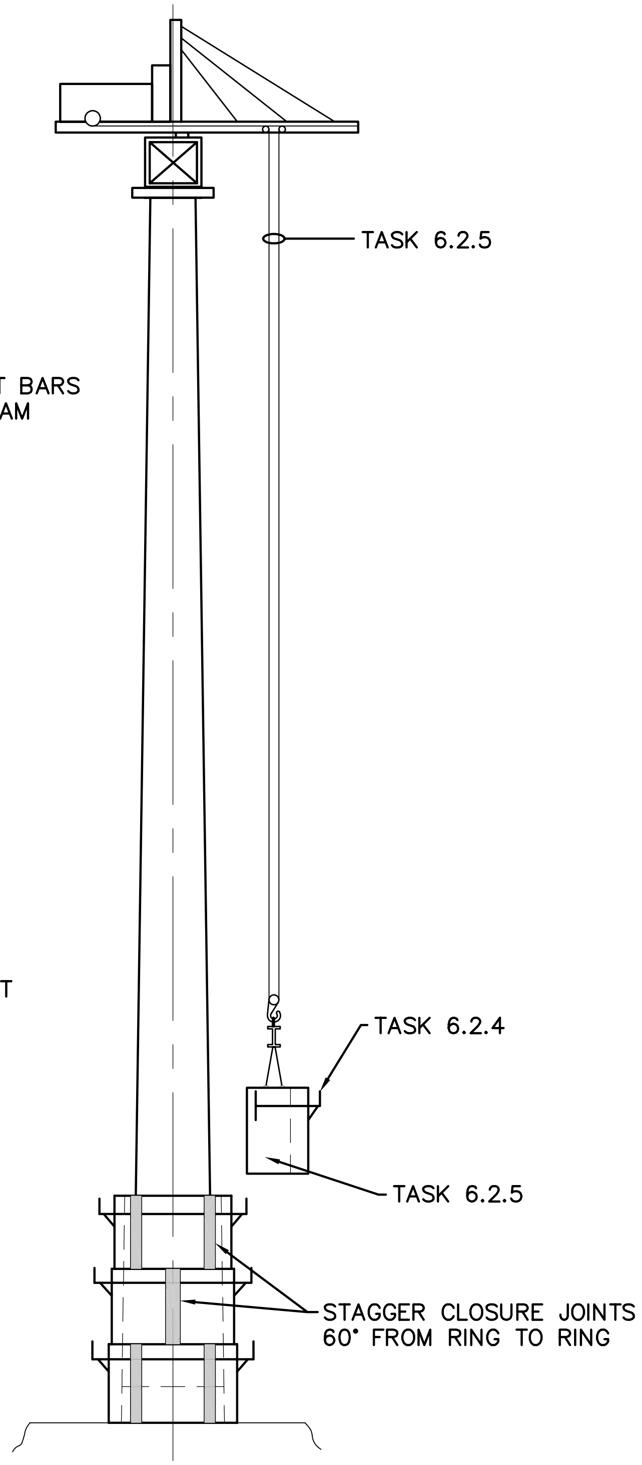
	NREL WIND TURBINE TOWER	DRAWING NO. **D-17**
	PLAN OF SEGMENT POSITIONING FRAME ASSEMBLY	PROJECT NO. NREL YAM-2-31235-01



SECTION SHOWING SHIMMING AND GASKET APPLICATION

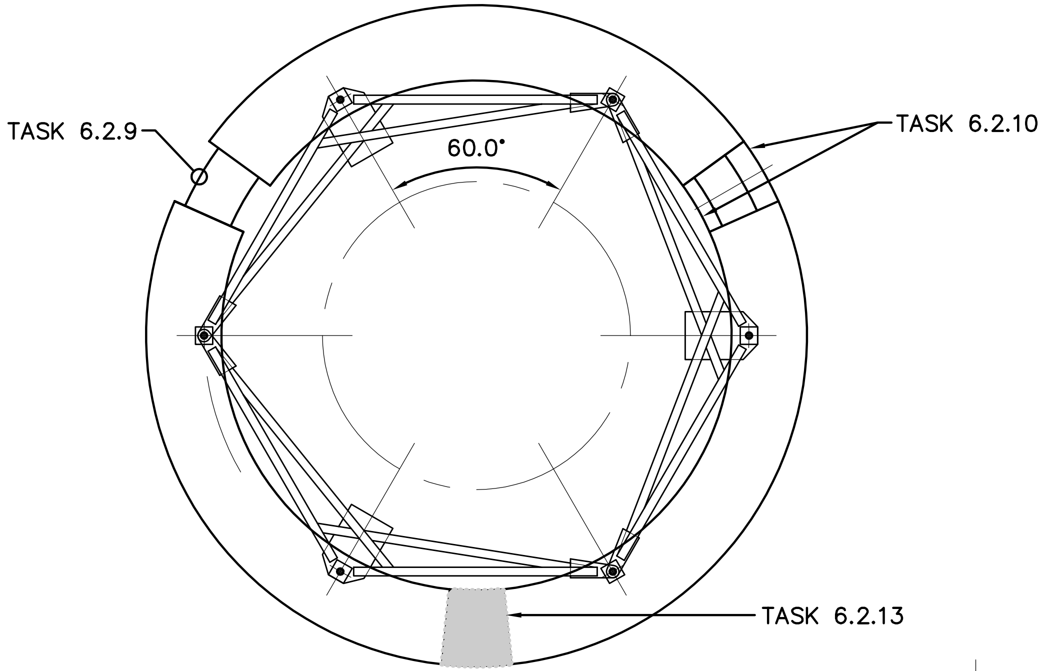


SECTION: ALIGNMENT PIN, & COUPLED P/T ERECTION BAR

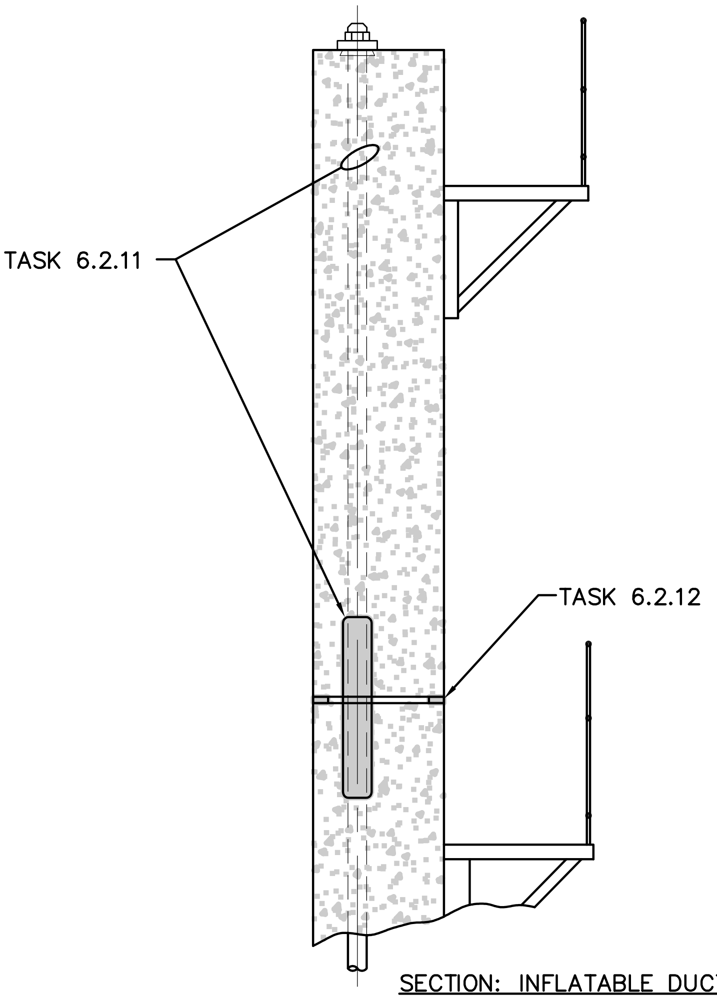


ELEVATION: ERECTION OF P/C SEGMENT WITH SPECIAL PEDESTAL CRANE

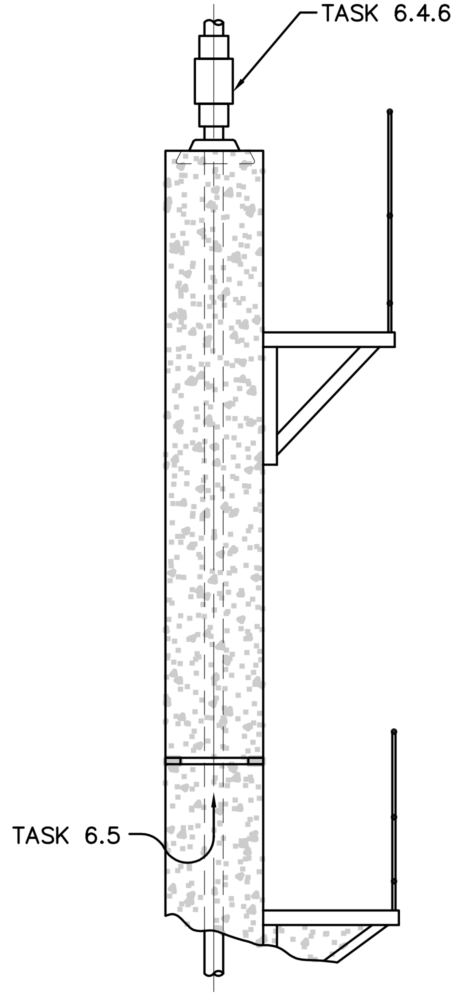
	NREL WIND TURBINE TOWER	DRAWING NO. **D-18**
	ERECTION OF PRECAST CONCRETE SEGMENTS	PROJECT NO. NREL YAM-2-31235-01



PLAN OF (3) SEGMENTS

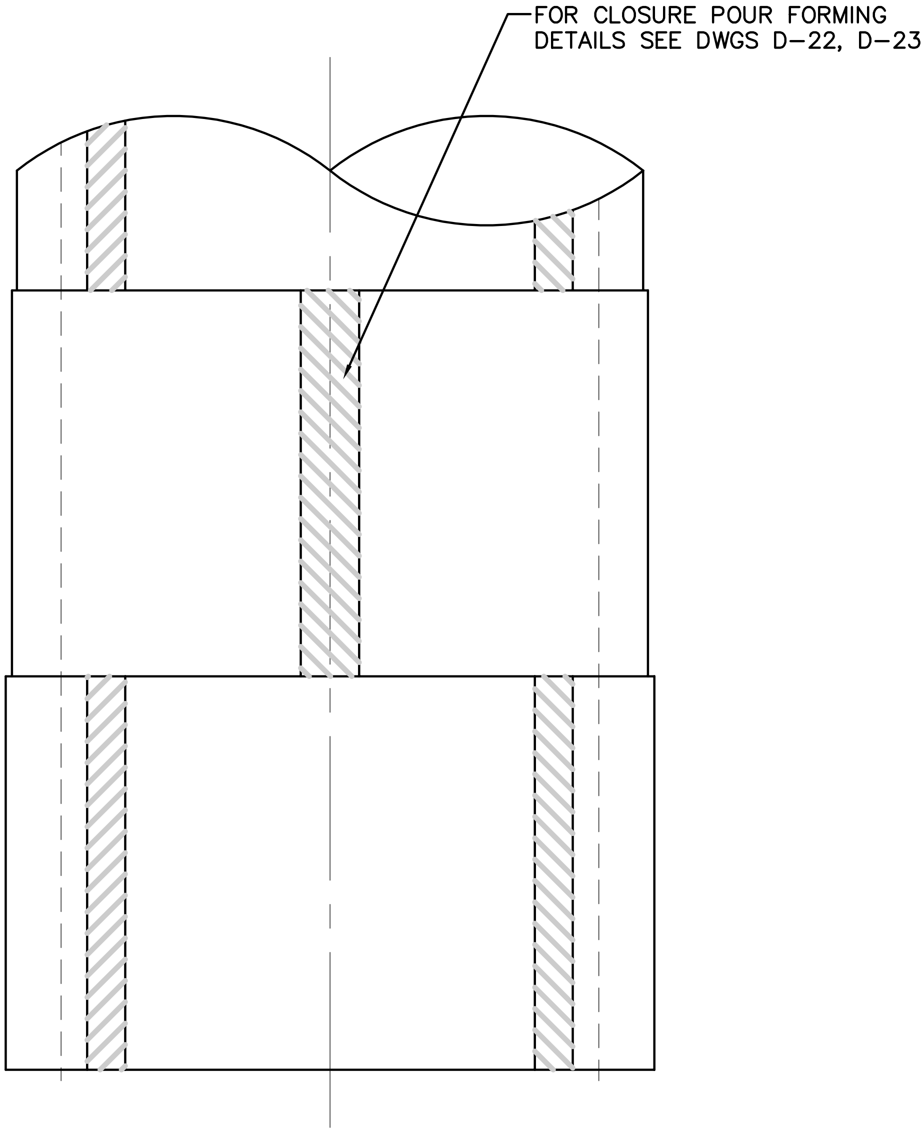


SECTION: INFLATABLE DUCT
SEALING TUBE AND JOINT GROUTING

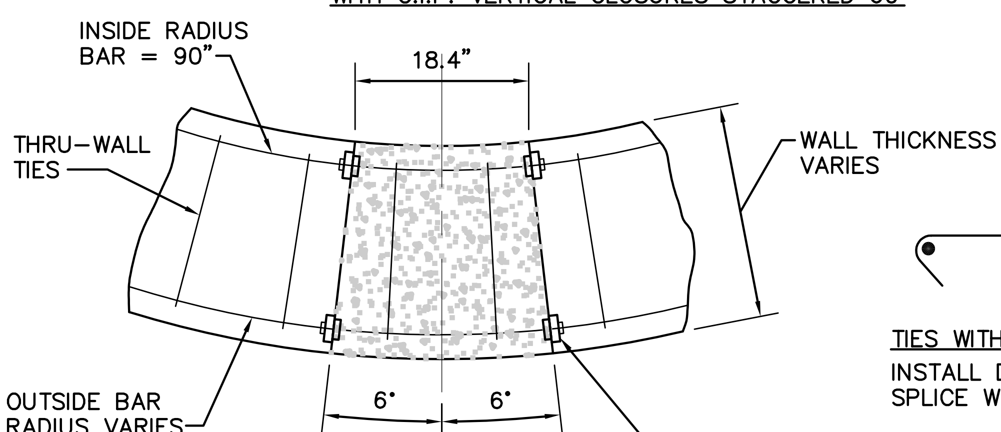


SECTION: TENDON P/T
AT TOP SEGMENT

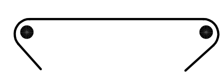
	NREL WIND TURBINE TOWER	DRAWING NO. **D-19**
	DETAILS OF ERECTION FOR PRECAST CONCRETE SEGMENTS	PROJECT NO. NREL YAM-2-31235-01



ELEVATION OF ASSEMBLED CONCRETE TOWER
WITH C.I.P. VERTICAL CLOSURES STAGGERED 60°



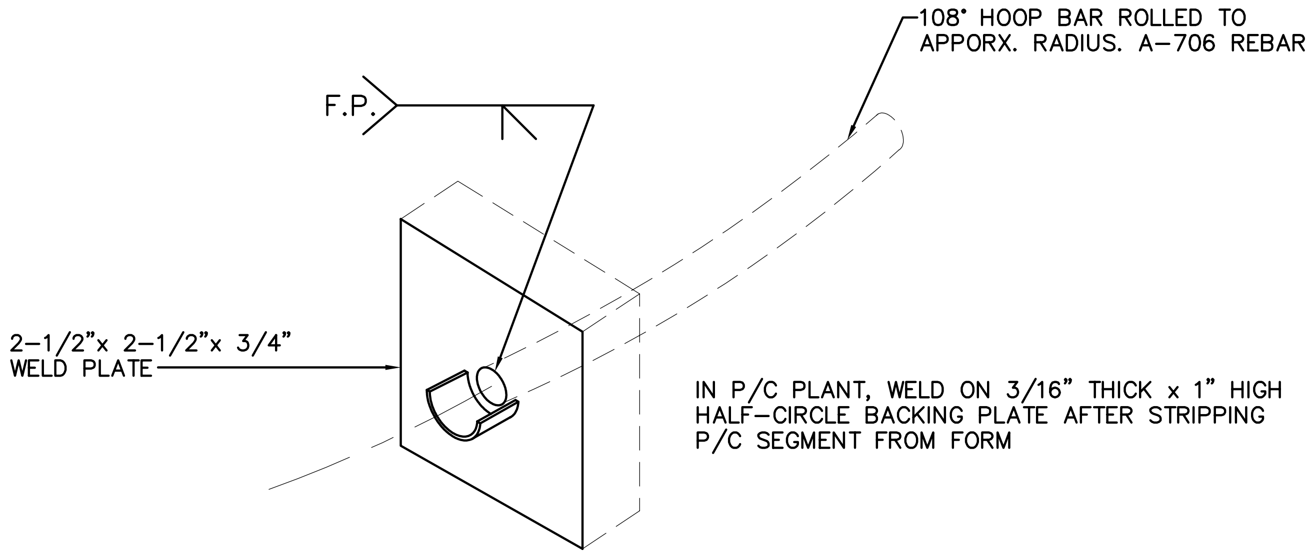
JOINT SECTION WITH SPLICED
HOOP REBAR (NO VERTICAL REBAR)



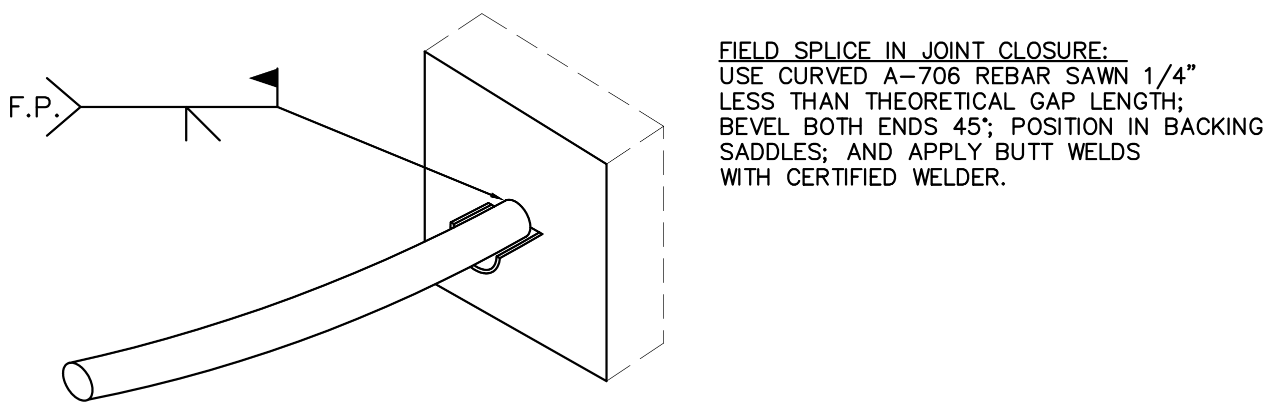
TIES WITH 135° HOOKS

INSTALL DURING HOOP
SPLICE WELDING

	NREL WIND TURBINE TOWER	DRAWING NO. **D-20**
	DETAILS OF VERTICAL SEGMENT JOINTS	PROJECT NO. NREL YAM-2-31235-01

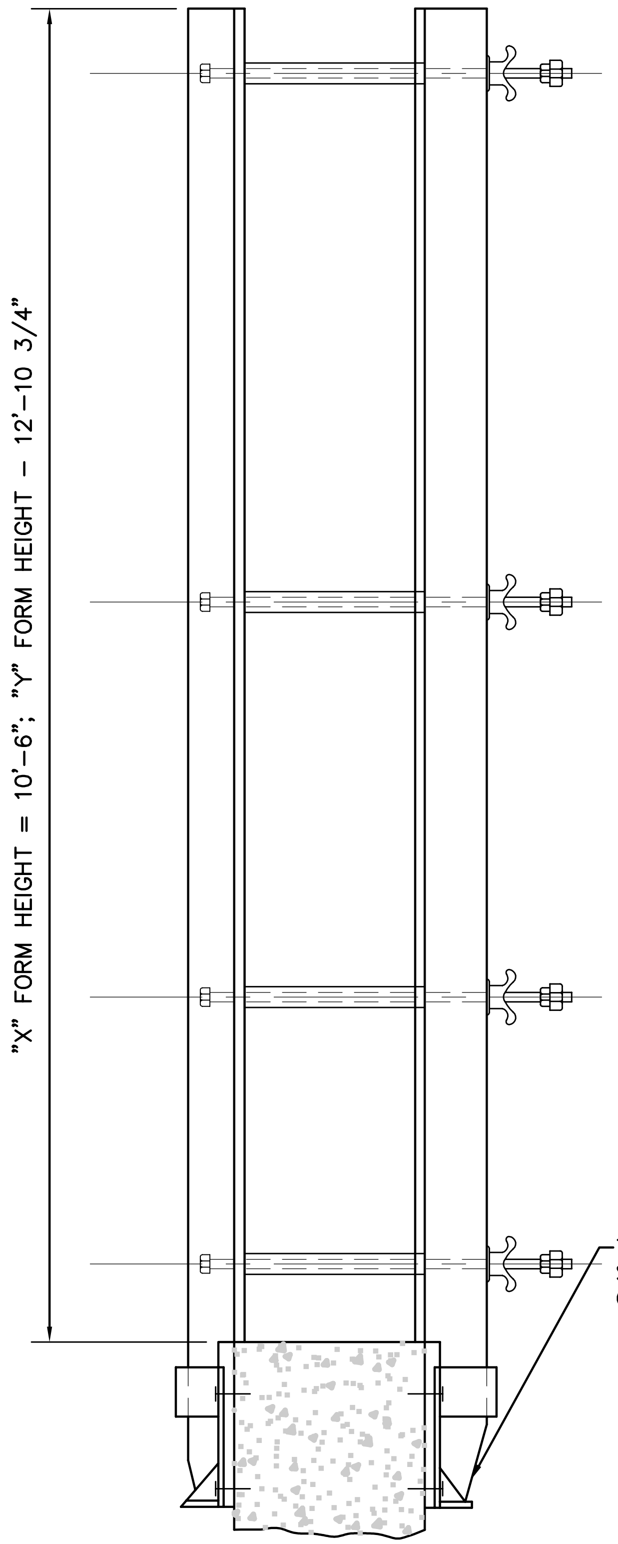


SHOP BUTT WELD OF 108° HOOP BAR
TO STEEL WELD PLATE

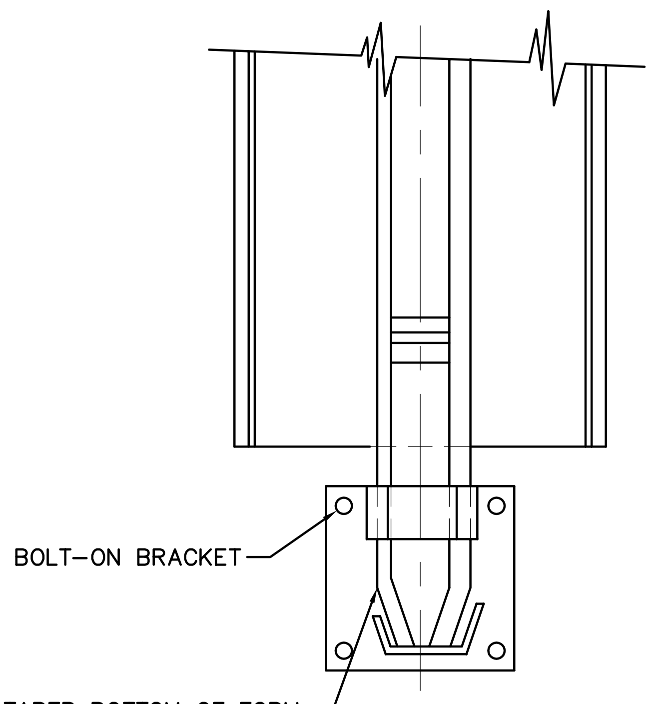


FIELD HOOP REBAR SPLICE USING
EMBEDDED PLATE AND BACKING RING

	NREL WIND TURBINE TOWER	DRAWING NO. **D-21**
	SPLICING DETAILS FOR SEGMENT HOOP REINFORCING	PROJECT NO. NREL YAM-2-31235-01

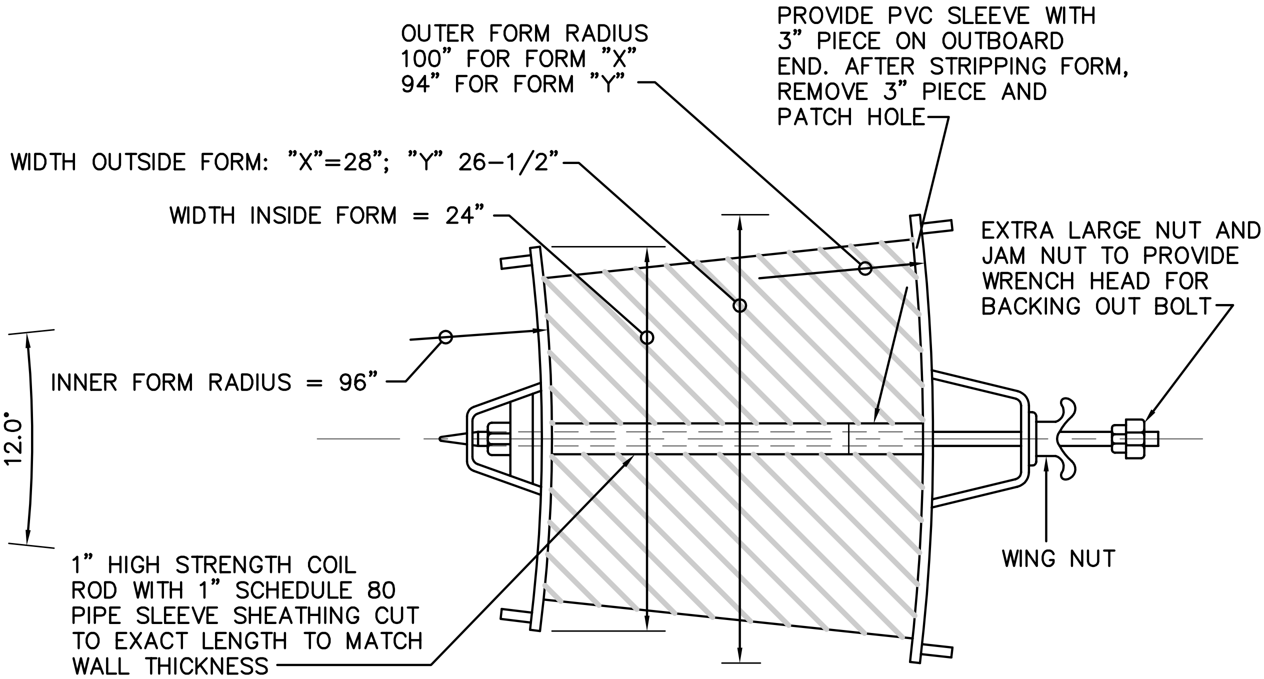


SECTION OF ASSEMBLED FORMS
SIZE "X" AND "Y"



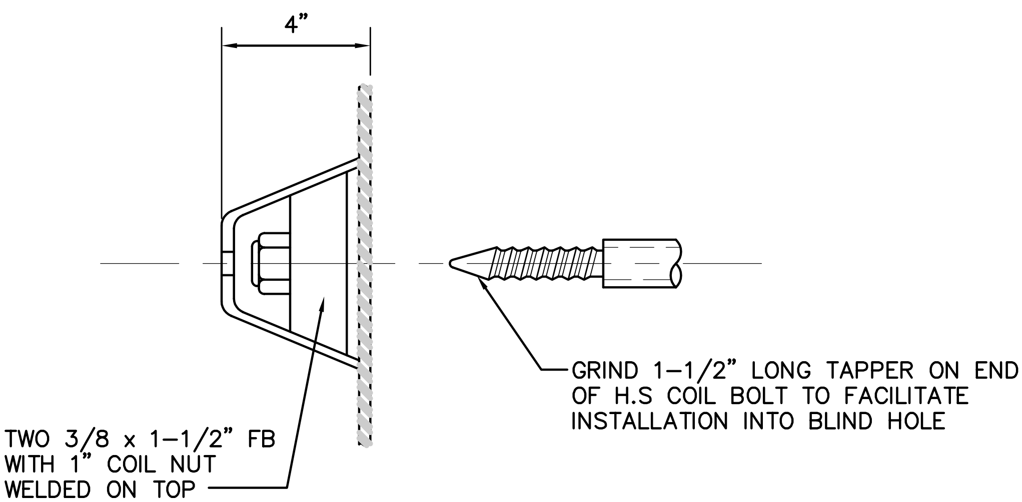
ELEVATION: FORM BOTTOM WITH
FORM SPINE FITTING INTO
CENTERING/SUPPORT BRACKET

	NREL WIND TURBINE TOWER	DRAWING NO. **D-22**
	FORM DETAILS FOR SEGMENT VERTICAL JOINT CLOSURE POURS	PROJECT NO. NREL YAM-2-31235-01



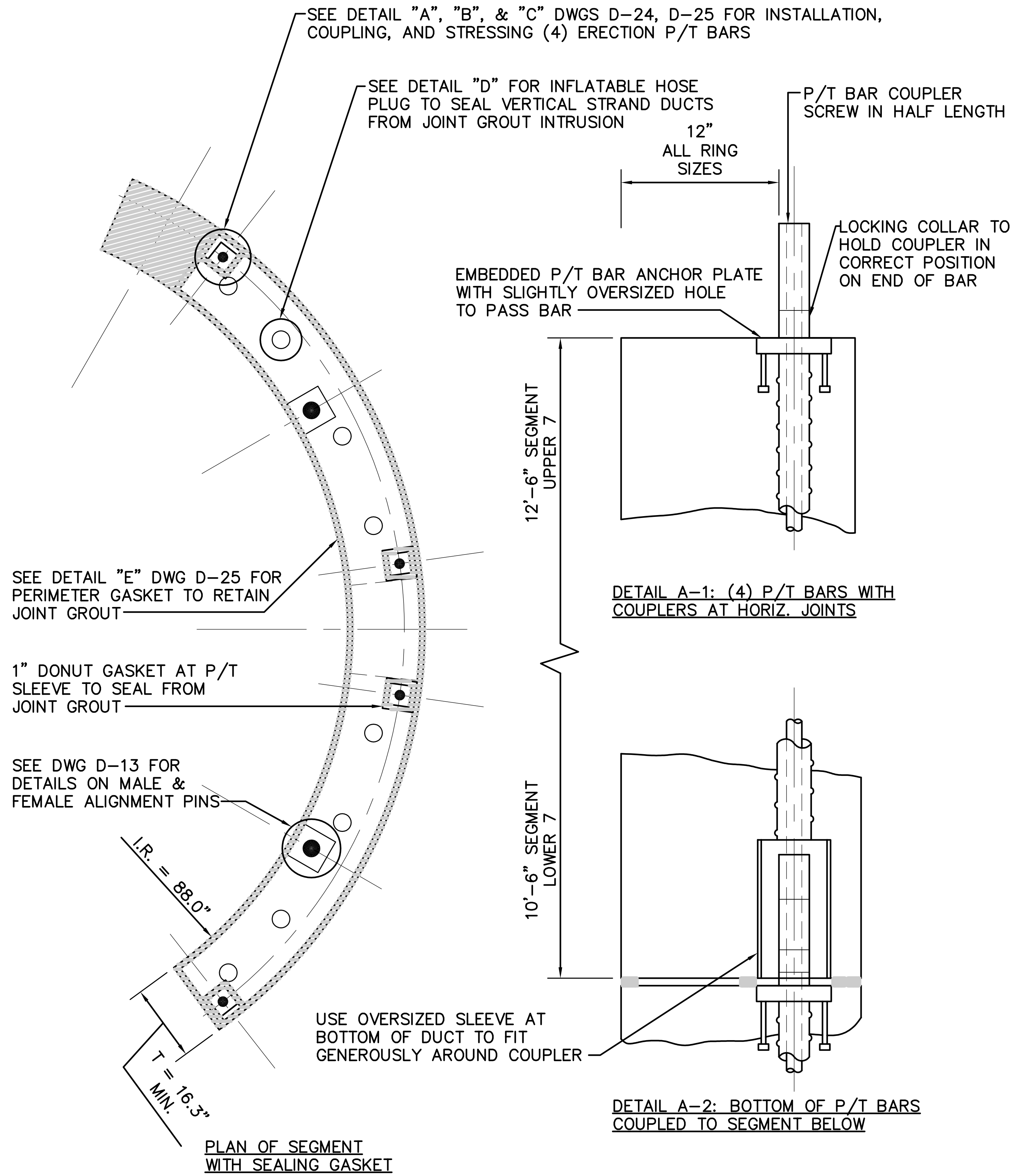
INNER JOINT FORM

OUTER JOINT FORM

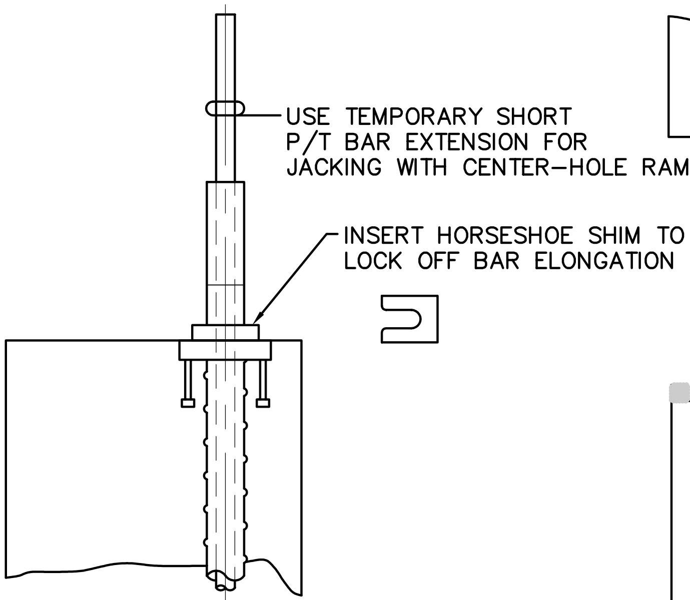


DETAILS OF INNER FORM
SPINE CHANNEL & BLIND NUT

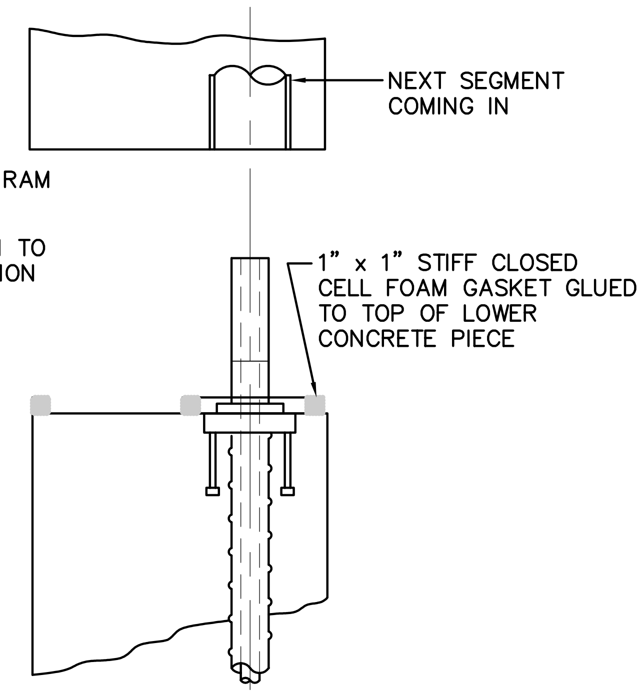
	NREL WIND TURBINE TOWER	DRAWING NO. **D-23**
	FORM DETAILS FOR SEGMENT VERTICAL JOINT CLOSURE POURS	PROJECT NO. NREL YAM-2-31235-01



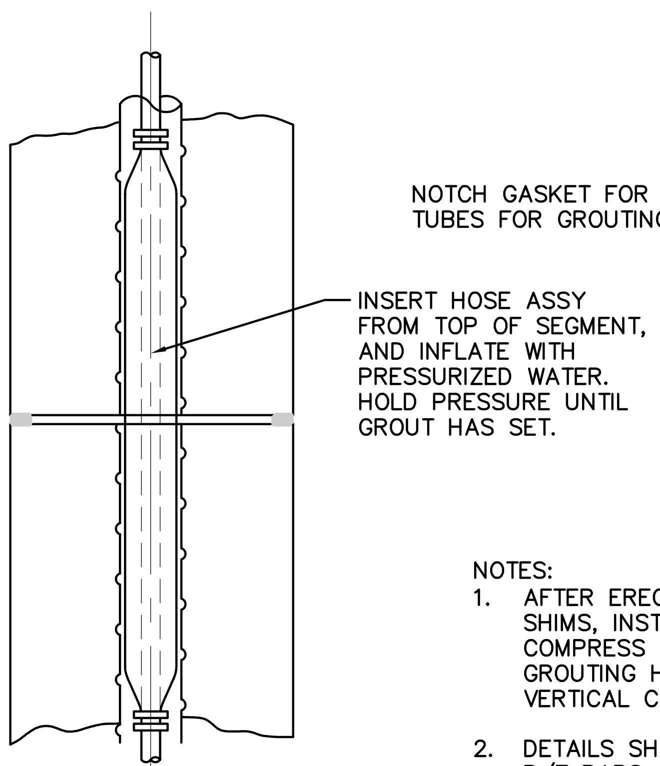
	NREL WIND TURBINE TOWER	DRAWING NO. **D-24**
	DETAILS OF HORIZONTAL GROUT JOINT BETWEEN SEGMENT RINGS	PROJECT NO. NREL YAM-2-31235-01



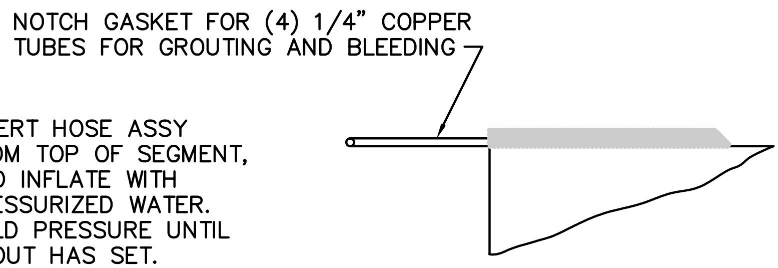
DETAIL B: (4) P/T BARS STRESSED AND SHIMMED



DETAIL C: (4) P/T BARS STRESSED & GROUTED AND READY FOR NEXT RING SEGMENT



DETAIL D: INFLATABLE RUBBER HOSE TO SEAL 4" VERTICAL STRAND DUCTS

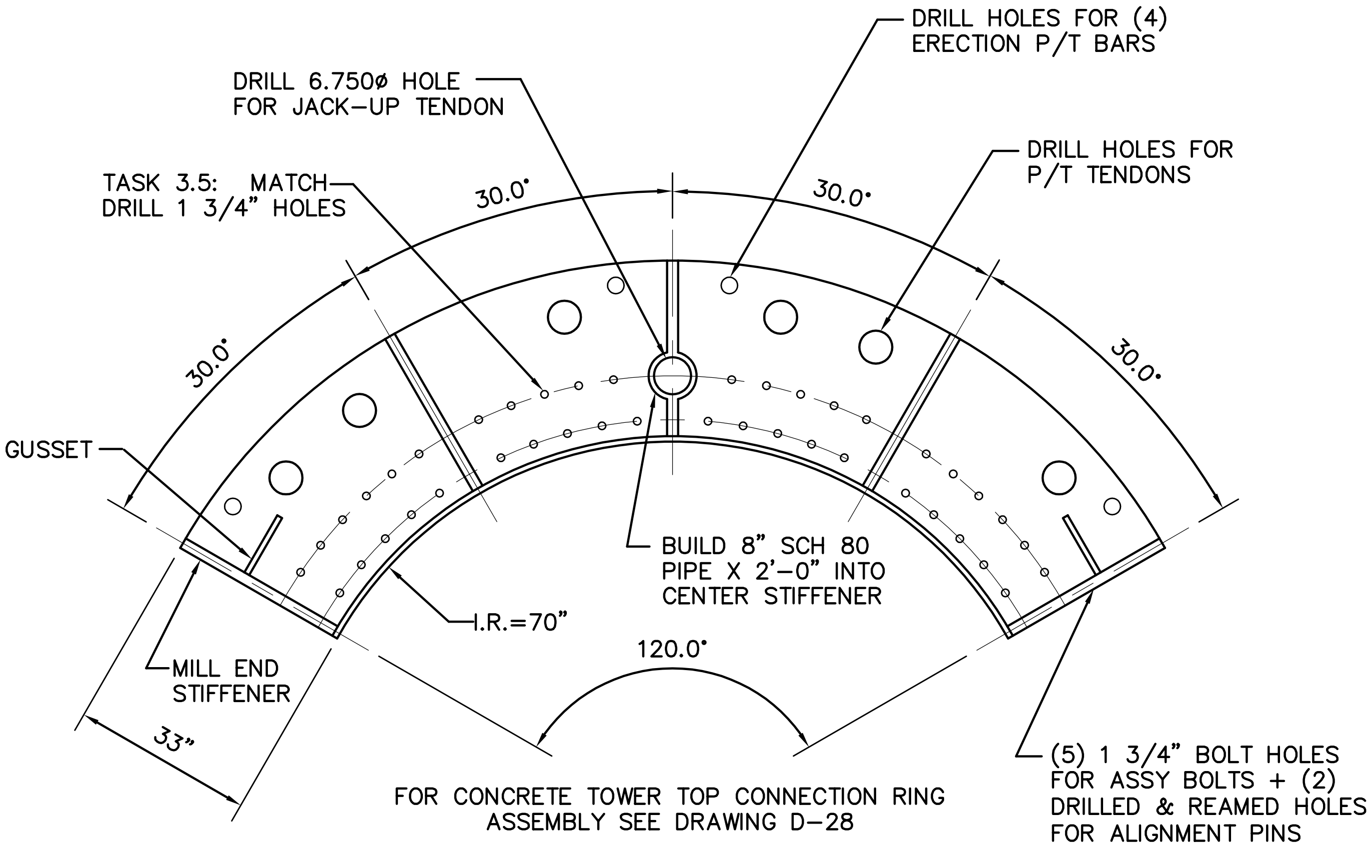


DETAIL E: 1" x 1" PERIMETER GASKET WITH TUBING FOR GROUTING HORIZ. JOINT

NOTES:

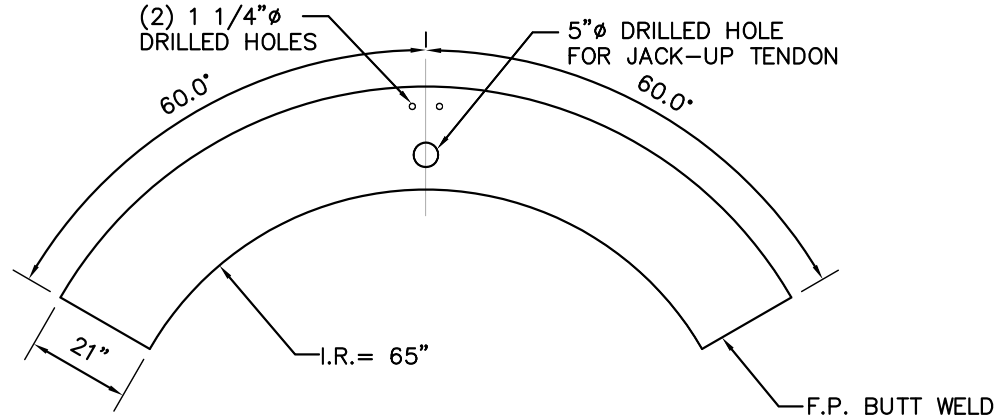
1. AFTER ERECTING (3) P/C SEGMENTS ONTO PRE–LEVELED STEEL SHIMS, INSTALL (4) P/T BARS AND STRESS TO 10% OF LOAD TO COMPRESS GASKET AND HOLD SEGMENTS IN POSITION FOR GROUTING HORIZ. JOINT AND FOR FORMING AND POURING VERTICAL CLOSURE JOINTS.
2. DETAILS SHOW 1" P/T BAR. WHEN 1 1/4" AND 1 3/8" ERECTION P/T BARS ARE USED ON LOWER SEGMENTS, SIZES OF DUCT, COUPLERS ANCHOR PLATES, ETC. MUST BE INCREASED

NREL WIND TURBINE TOWER	DRAWING NO.	D-25
DETAILS OF TEMPORARY POST TENSIONING BETWEEN SEGMENTS RINGS	PROJECT NO.	NREL YAM-2-31235-01

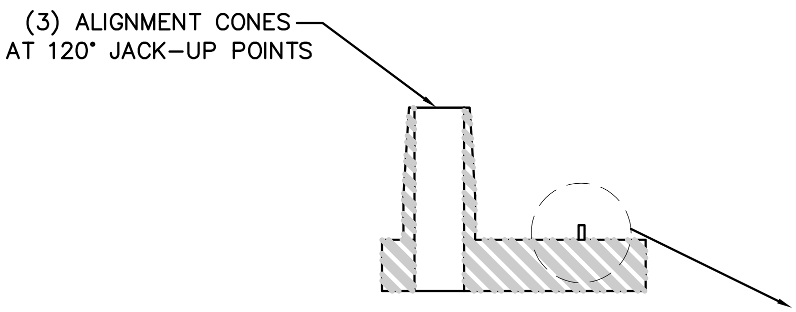


TASK 3.4: PLAN 120° SEGMENT

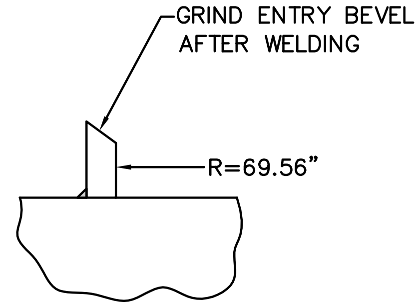
NREL WIND TURBINE TOWER	DRAWING NO. D-26
SEGMENT OF CONCRETE TOWER TOP CONNECTION RING	PROJECT NO. NREL YAM-2-31235-01



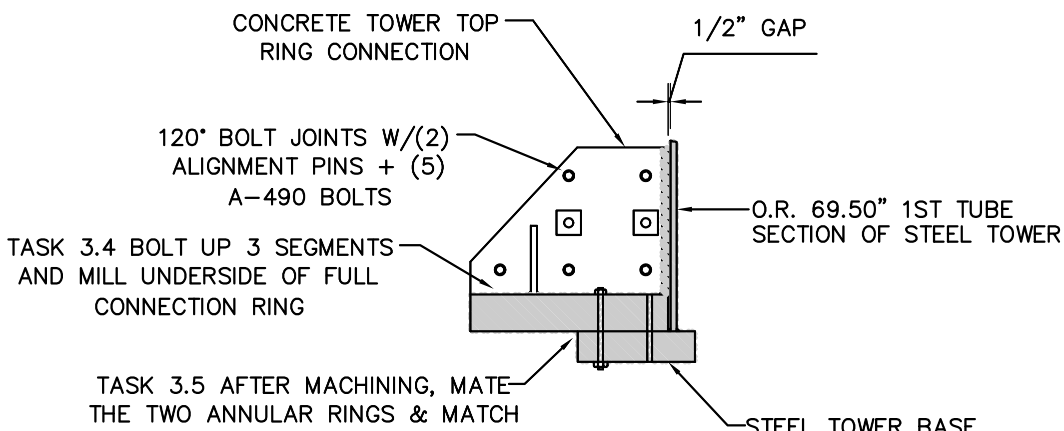
TASK 3.3: PLAN 120° SEGMENT
STEEL TOWER BASE FLANGE RING



TASK 3.3: SECTION OF ANNULAR
FLANGE FOR STEEL TUBE

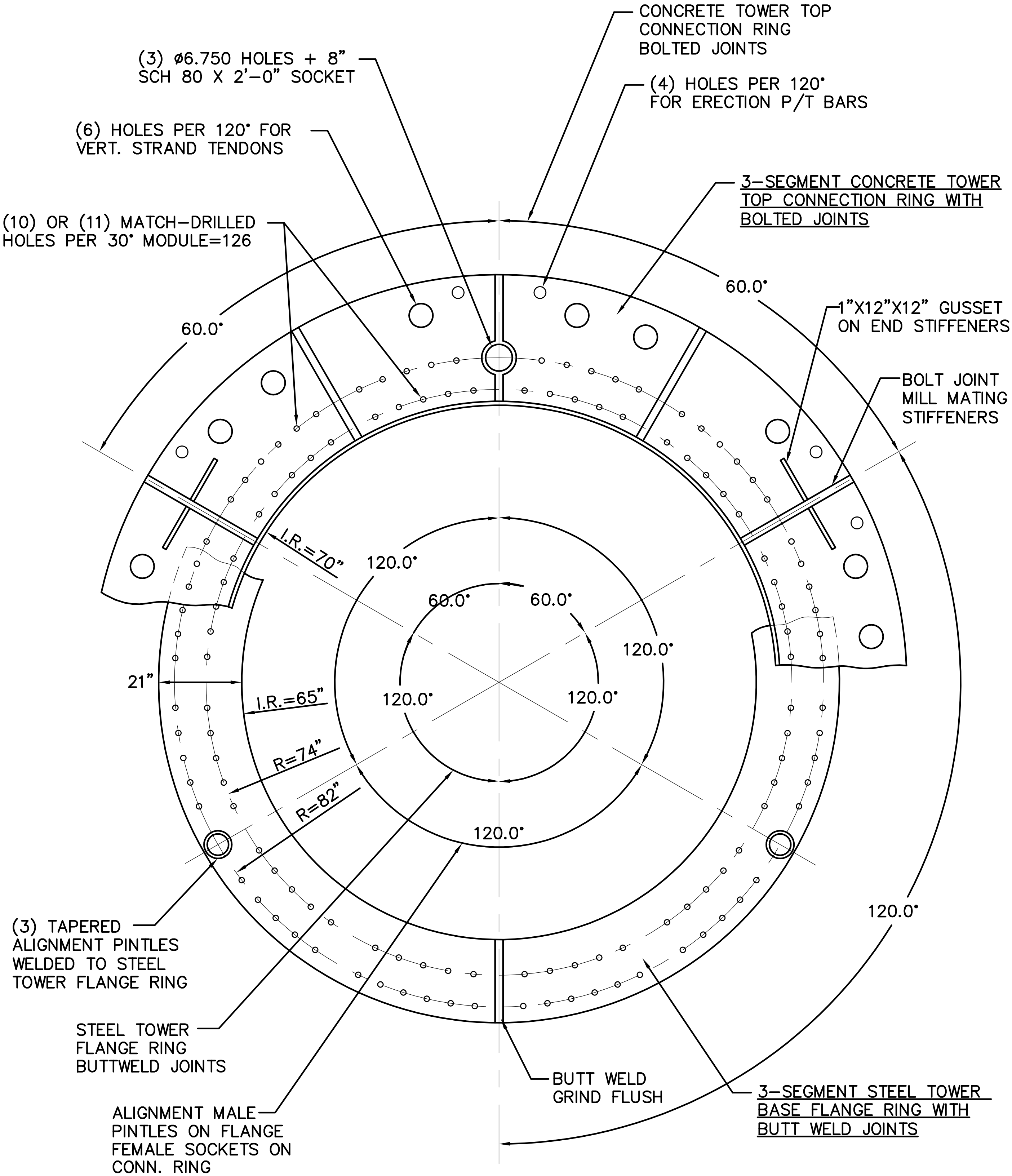


DETAIL OF 1/4"X1"
BACKING BAR RING



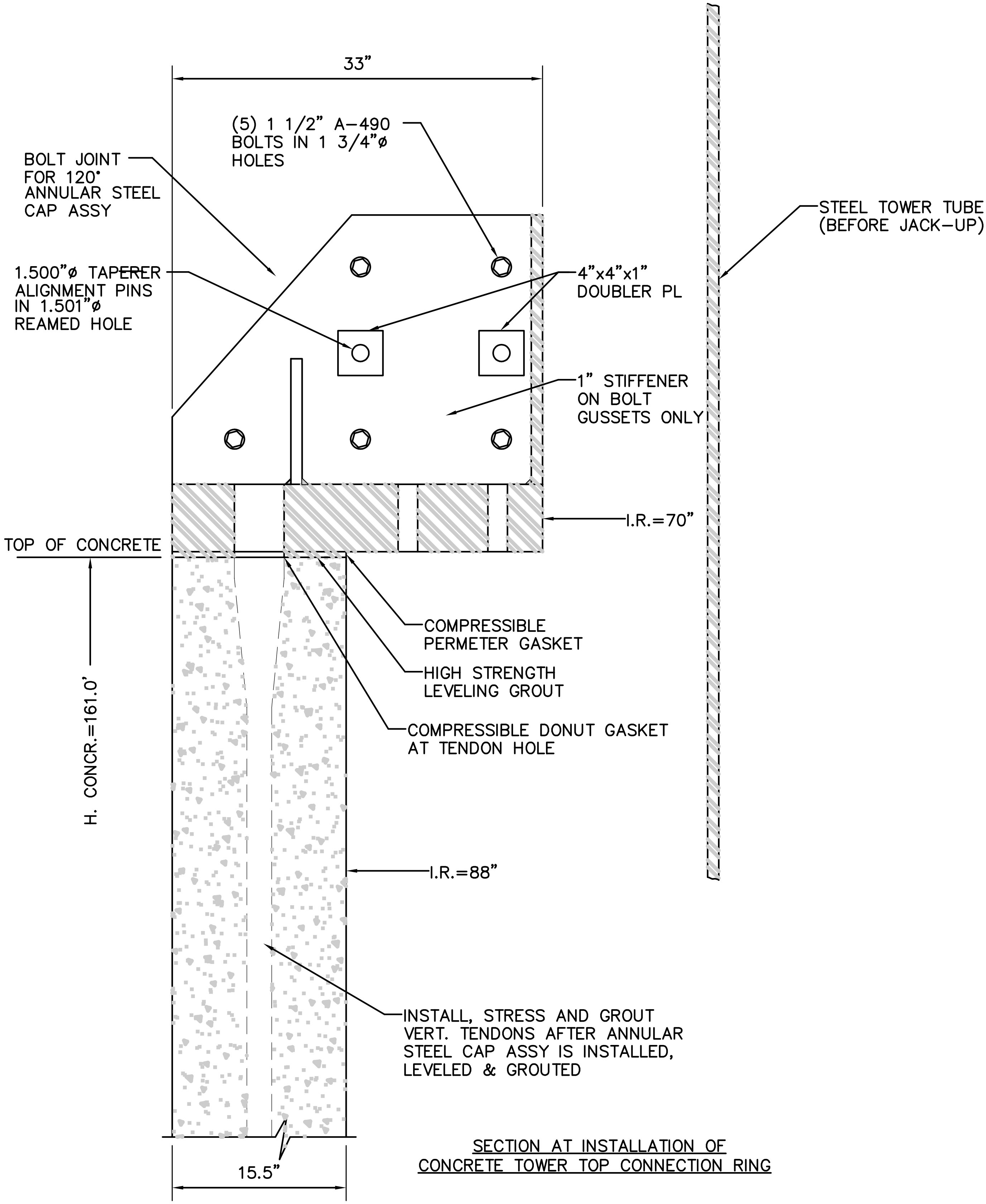
SHOP MATING MATCH DRILLING
OF BOLT HOLES WELDING 1ST TUBE
SECTION TO FLANGE

	NREL WIND TURBINE TOWER	DRAWING NO. **D-27**
	SECTION OF SHOP MATING AND MATCH DRILLING OF CONCRETE TOWER TOP CONNECTION RING AND STEEL TOWER BASE FLANGE RING	PROJECT NO. NREL YAM-2-31235-01



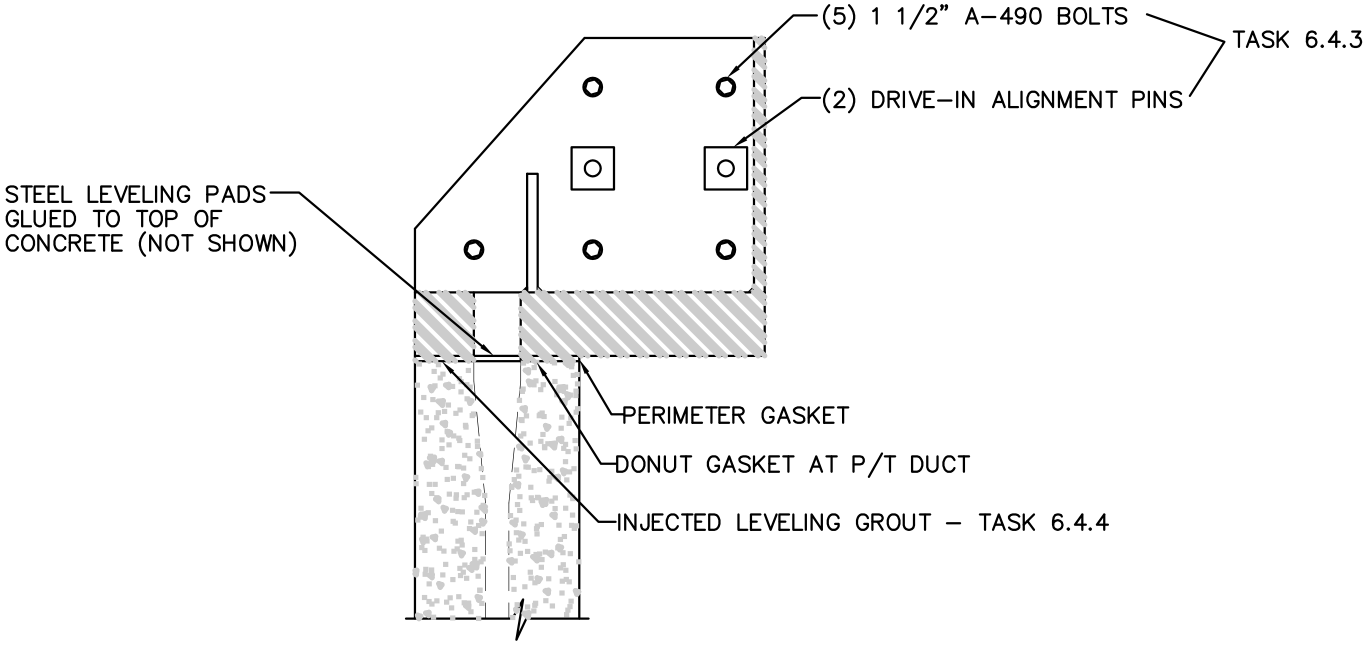
PLAN – TOP OF CONCRETE TOWER

	NREL WIND TURBINE TOWER	DRAWING NO. **D-28**
	TOWER TOP CONNECTION RING AND STEEL TOWER BASE FLANGE RING	PROJECT NO. NREL YAM-2-31235-01

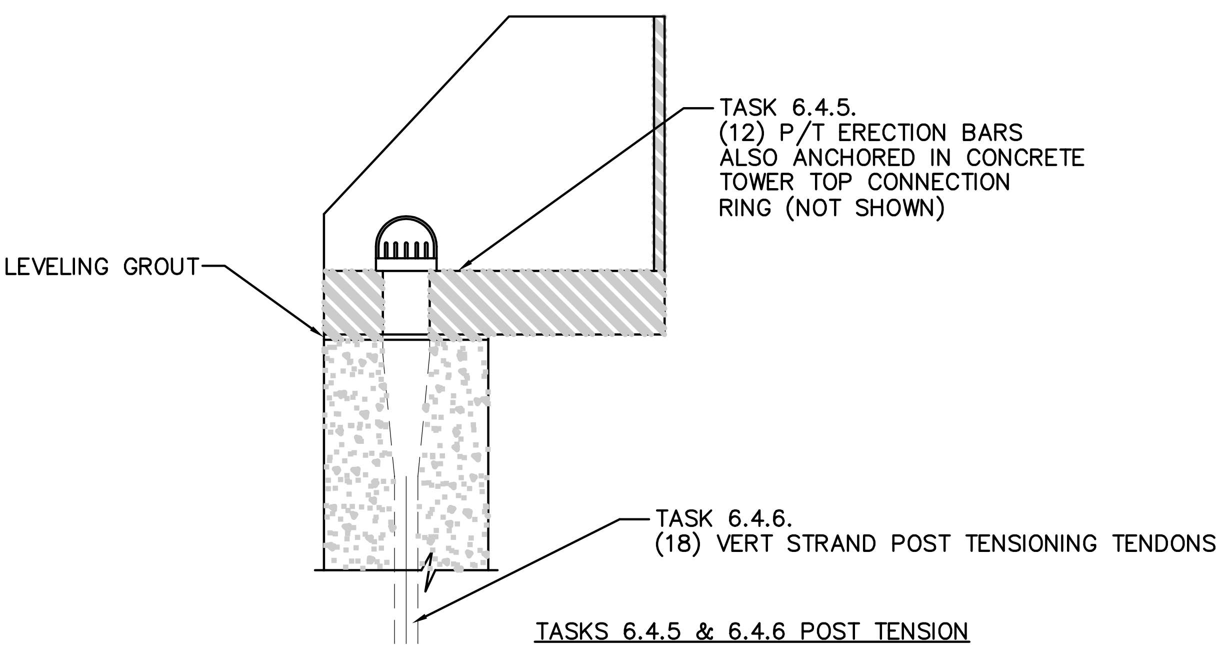


SECTION AT INSTALLATION OF
CONCRETE TOWER TOP CONNECTION RING

NREL WIND TURBINE TOWER	DRAWING NO. D-29
INSTALLATION OF CONCRETE TOWER TOP CONNECTION RING	PROJECT NO. NREL YAM-2-31235-01

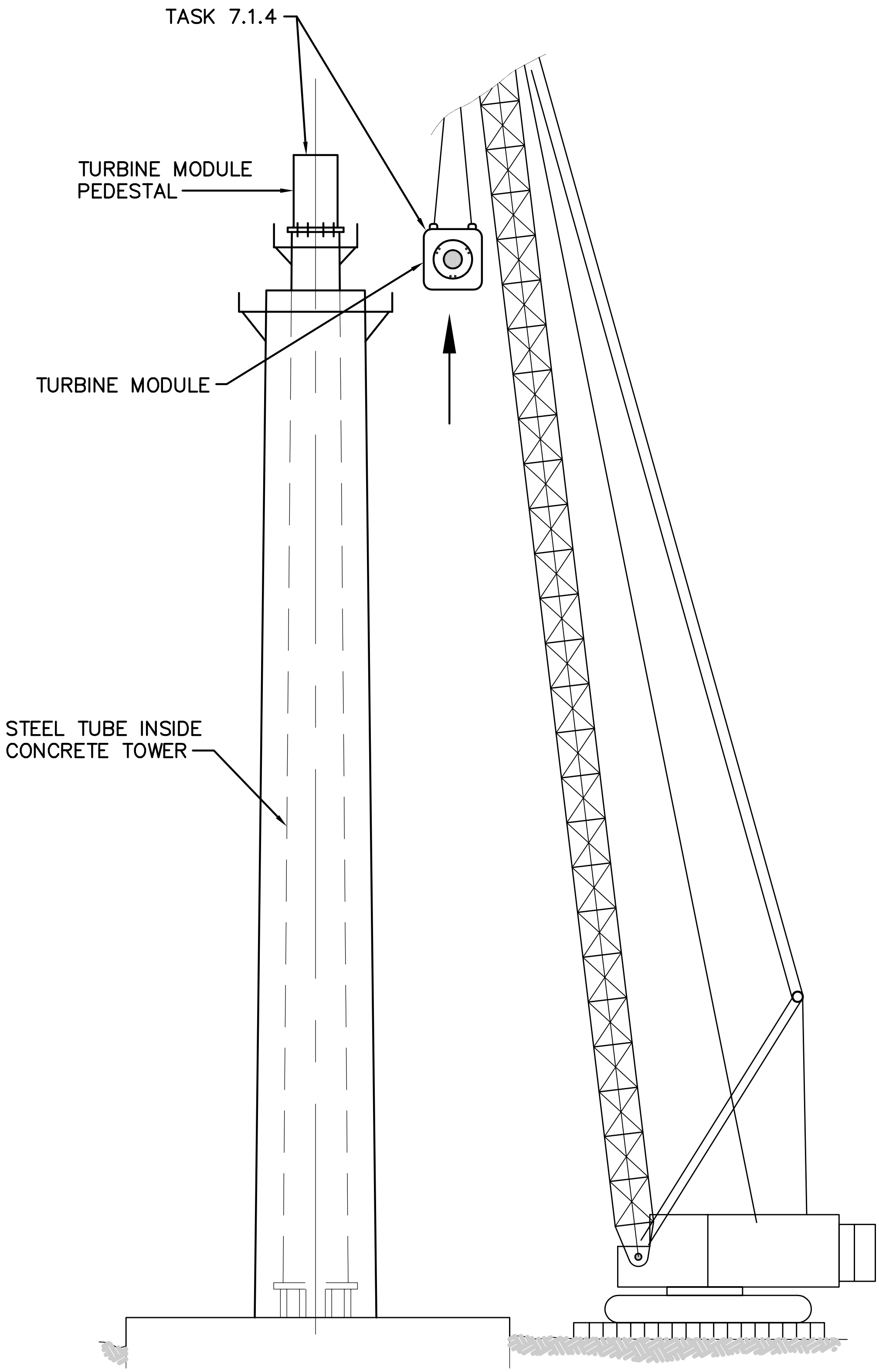


TASK 6.4 INSTALL 3–PC STEEL
CONCRETE TOWER TOP CONNECTION RING



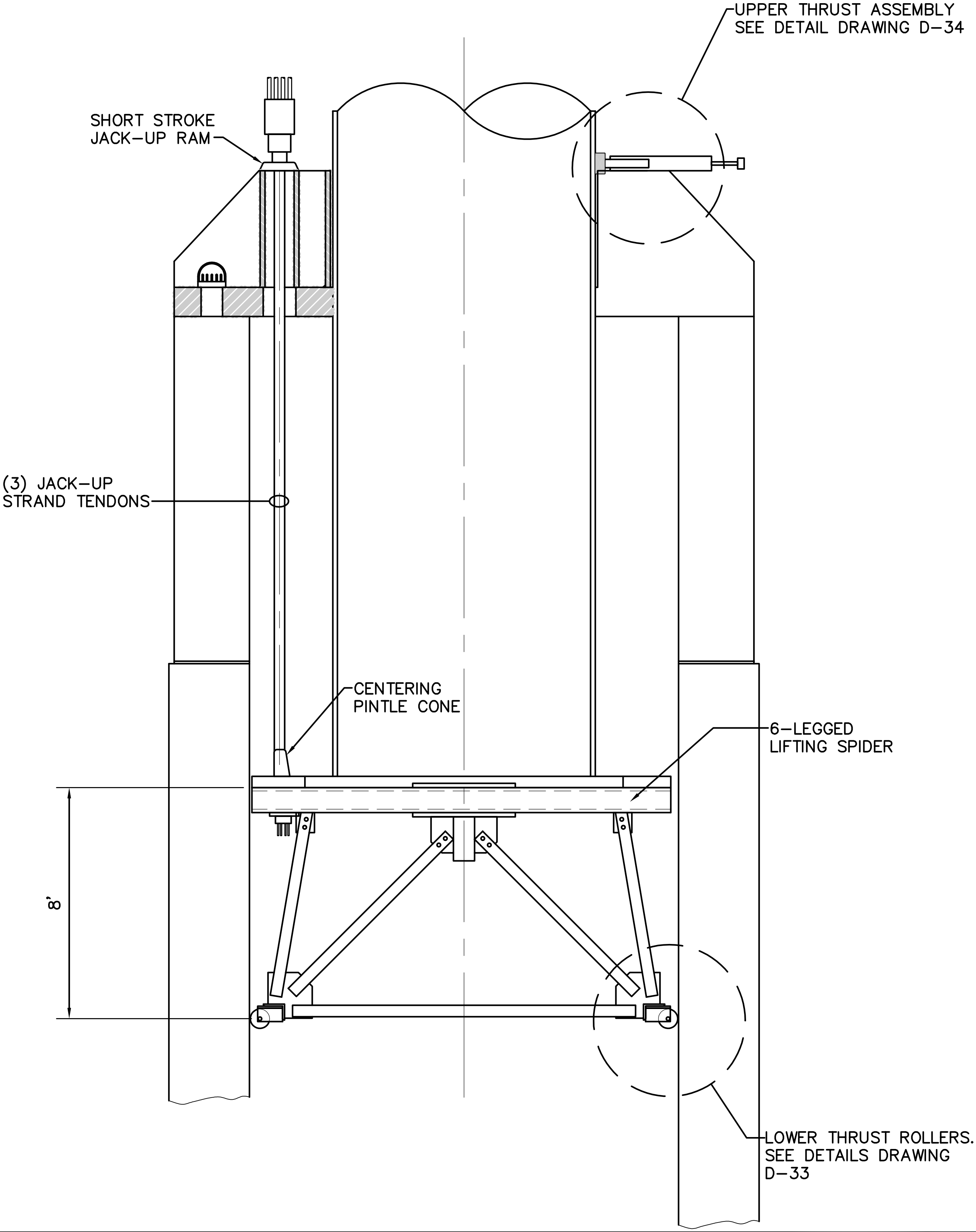
TASKS 6.4.5 & 6.4.6 POST TENSION
TOP CONNECTION RING TO CONCRETE

NREL WIND TURBINE TOWER	DRAWING NO. D-30
GROUTING AND POST TENSIONING OF CONCRETE TOWER TOP CONNECTION RING	PROJECT NO. NREL YAM-2-31235-01

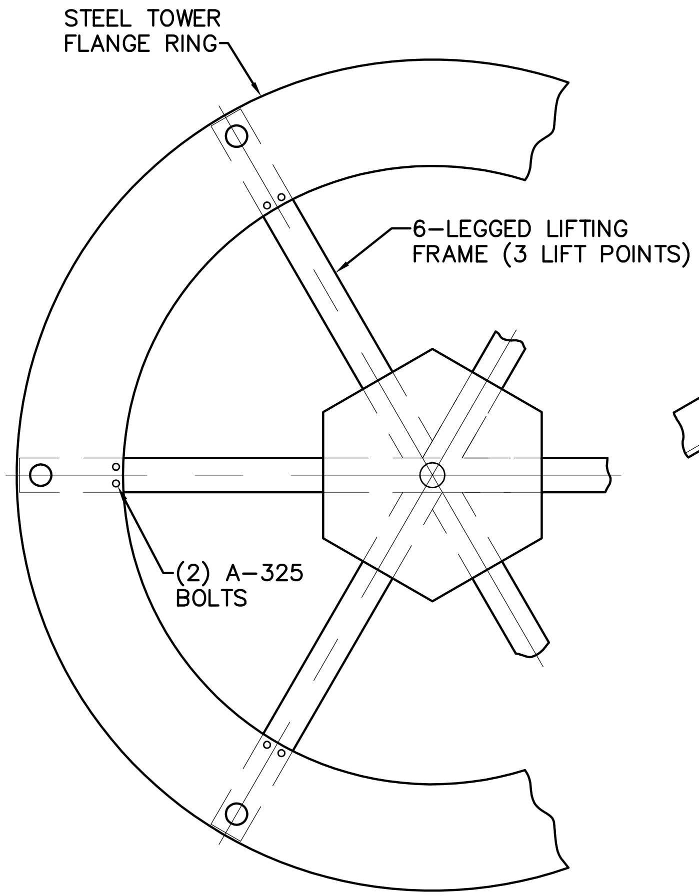


ELEVATION: SETTING TUBINE MODULE WITH CRAWLER CRANE

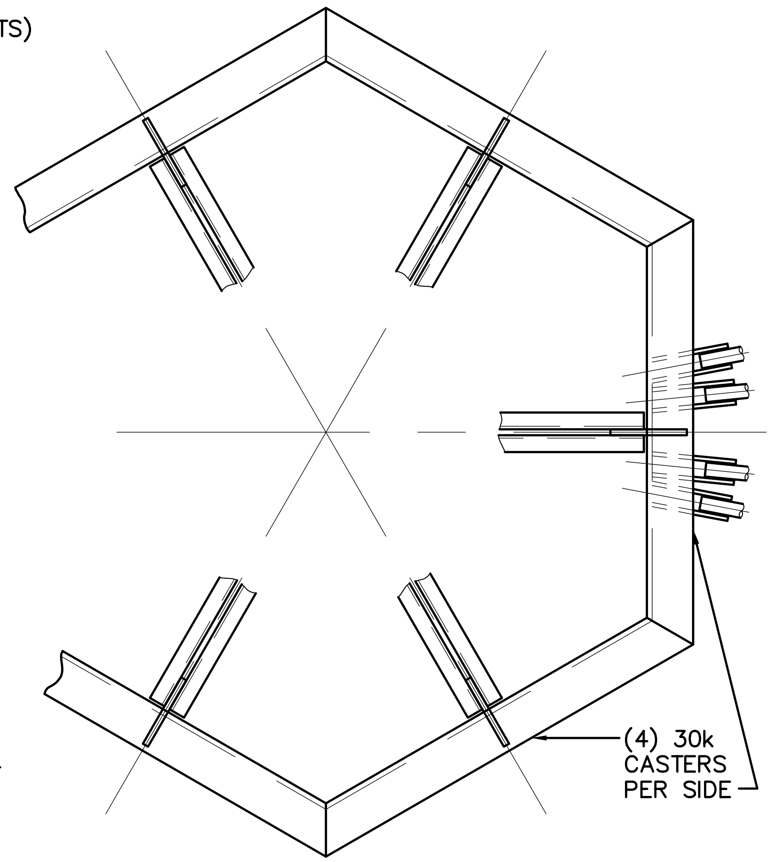
	NREL WIND TURBINE TOWER	DRAWING NO. **D-31**
	ERECTION OF TURBINE AND BLADES PRIOR TO JACK UP OF STEEL TOWER	PROJECT NO. NREL YAM-2-31235-01



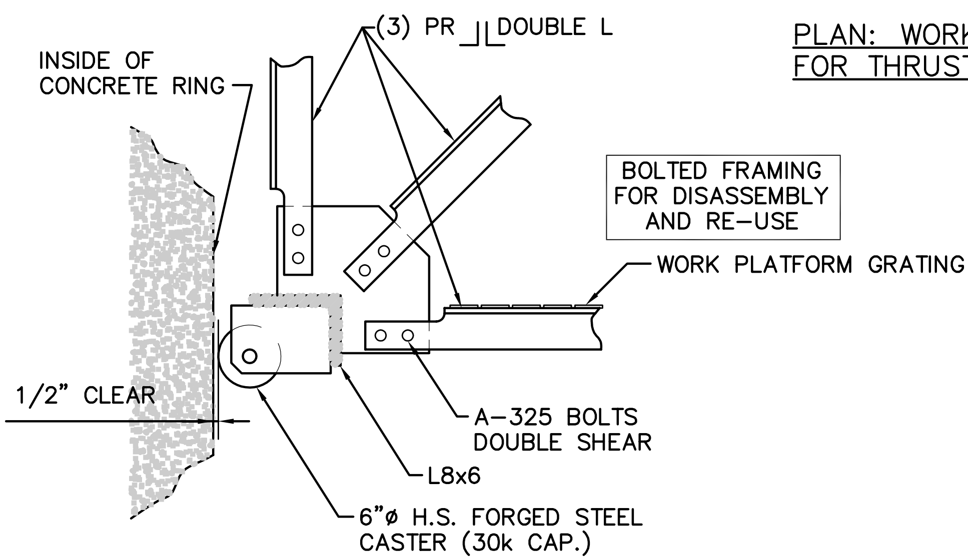
	NREL WIND TURBINE TOWER	DRAWING NO. **D-32**
	STEEL TOWER JACK-UP RIGGING	PROJECT NO. NREL YAM-2-31235-01



PLAN: 6-LEGGED LIFTING FRAME

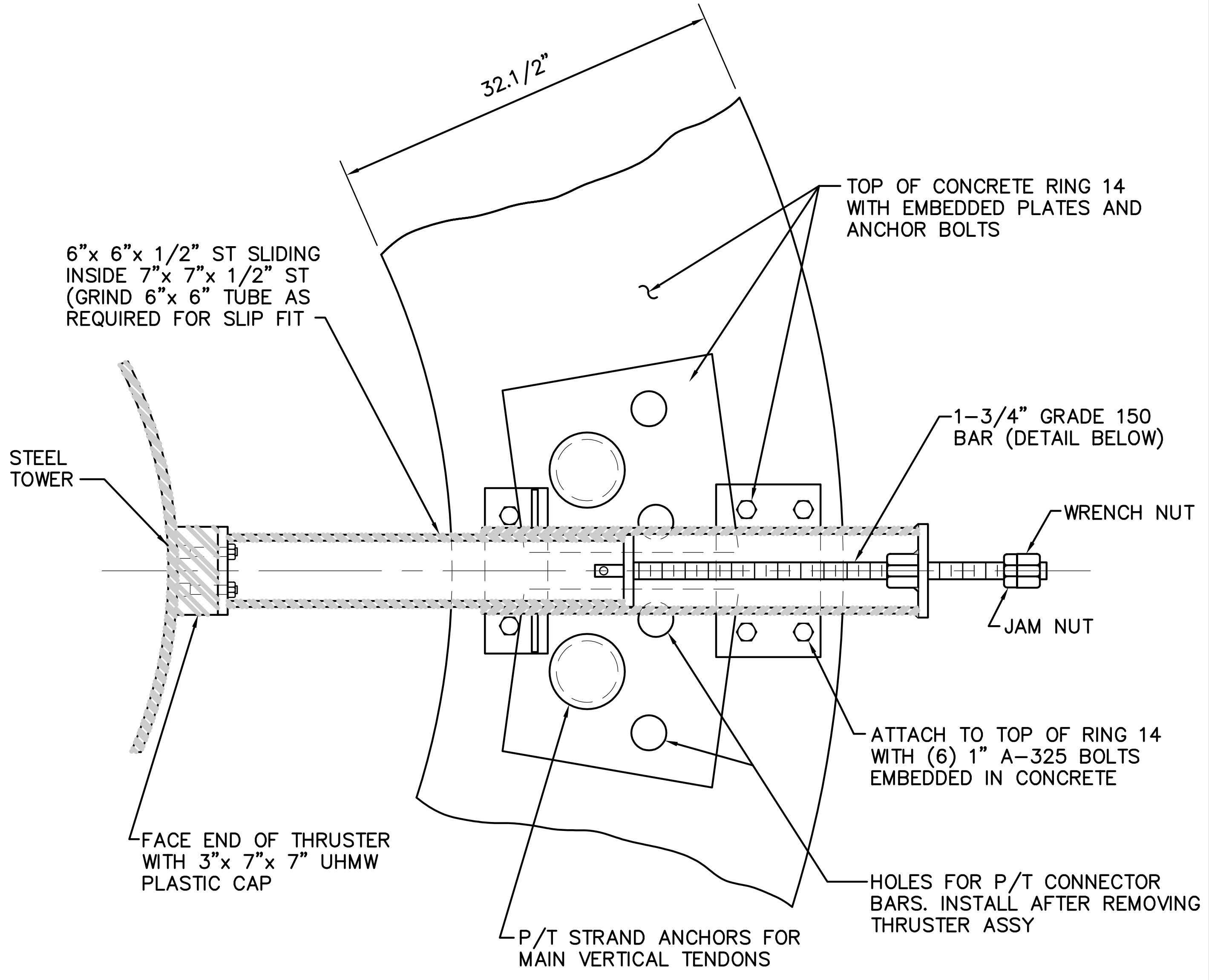


PLAN: WORK PLATFORM & SUPPORT FOR THRUST ROLLERS



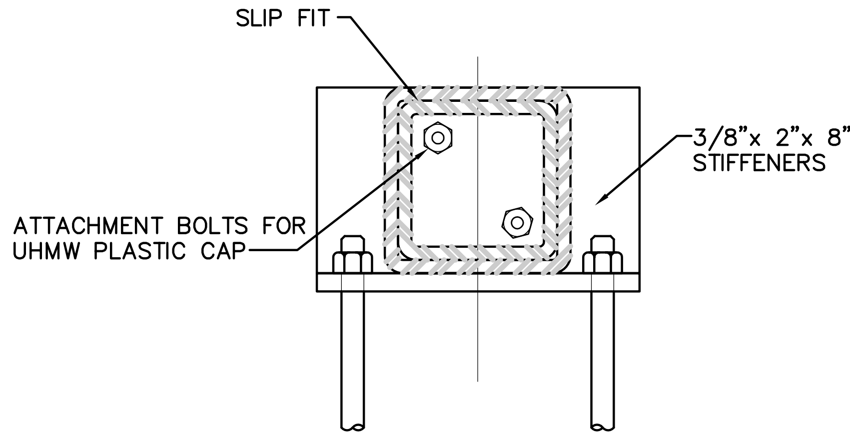
DETAIL AT LOWER THRUST ROLLERS

	NREL WIND TURBINE TOWER	DRAWING NO. **D-33**
	LOWER JACK-UP THRUST REACTION ASSEMBLIES	PROJECT NO. NREL YAM-2-31235-01

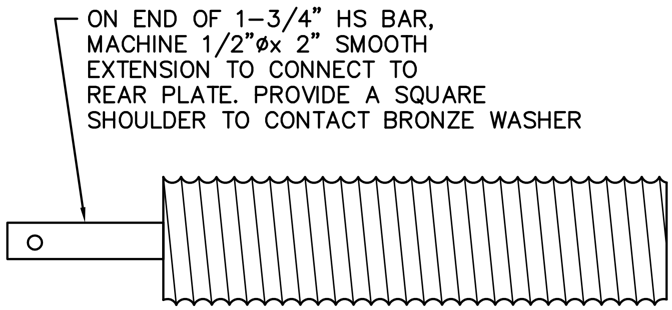


PLAN SECTION OF TOP HORIZONTAL 40-KIP THRUSTER ASSEMBLY
(18) BOLT-ON ASSYS REQUIRED; REMOVE AND RE-USE

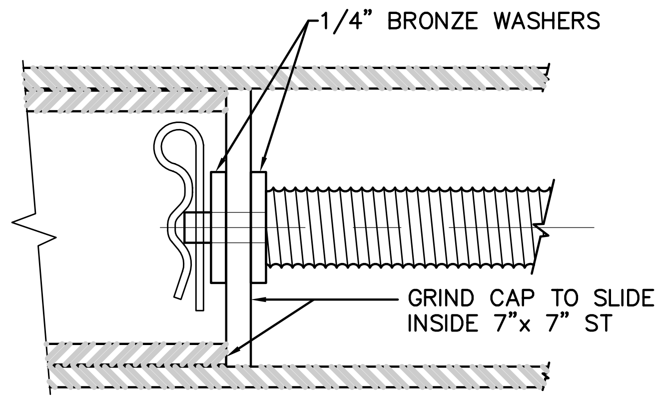
	NREL WIND TURBINE TOWER	DRAWING NO. **D-34**
	UPPER JACK-UP THRUST REACTION INSTALLATION	PROJECT NO. NREL YAM-2-31235-01



SECTION A–A OF SLIDING TUBE THRUSTER



1–3/4" GRADE 150 BAR



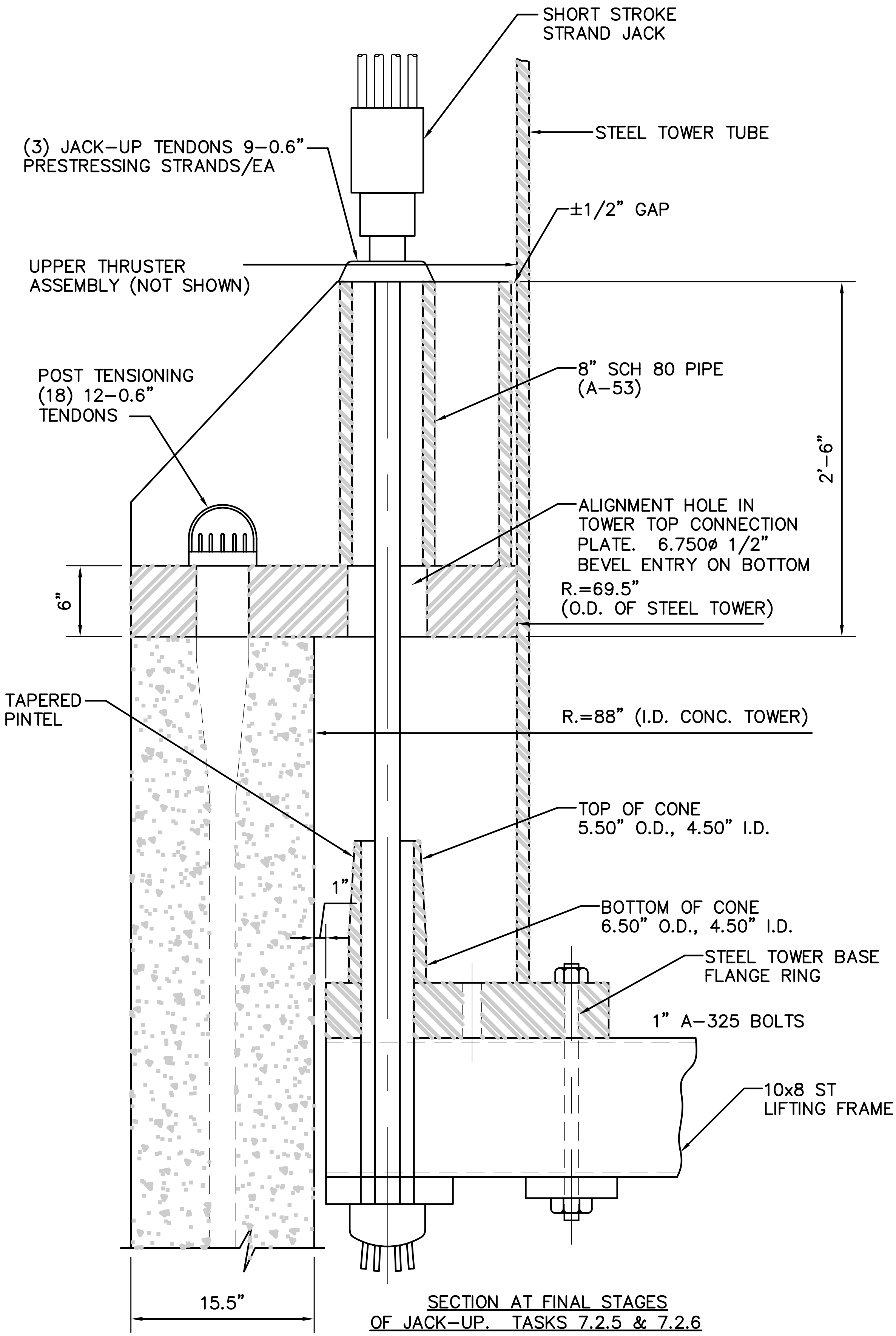
DETAIL OF THRUST BOLT CONNECTION

NREL WIND TURBINE TOWER

UPPER JACK-UP THRUST
REACTION DETAILS

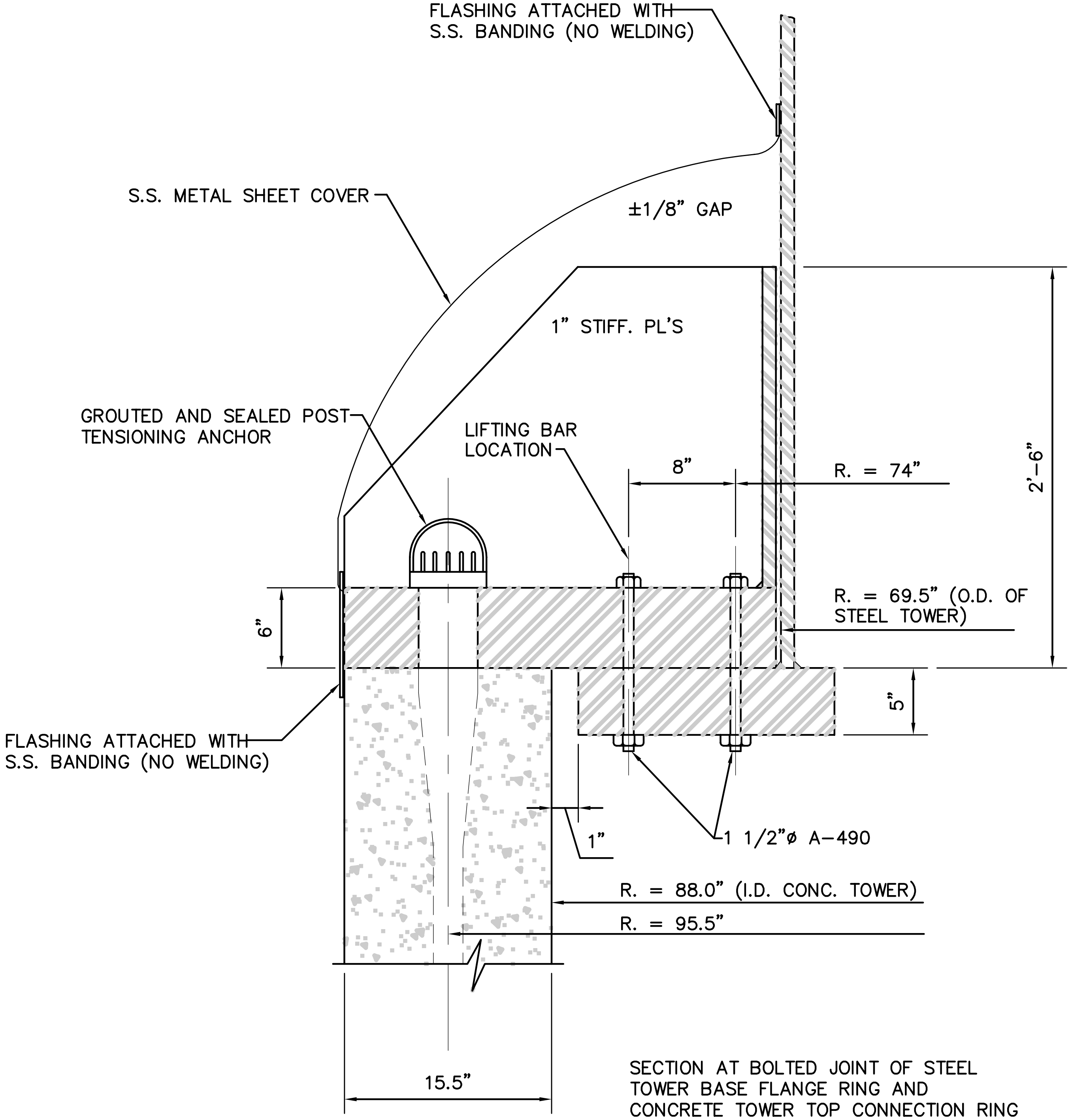
DRAWING NO.
D-35

PROJECT NO.
NREL YAM-2-31235-01



SECTION AT FINAL STAGES
OF JACK-UP. TASKS 7.2.5 & 7.2.6

	NREL WIND TURBINE TOWER	DRAWING NO. **D-36**
	ALIGNMENT PROVISIONS FOR STEEL TOWER CONNECTION TO COMPLETED CONCRETE TOWER	PROJECT NO. NREL YAM-2-31235-01



SECTION AT BOLTED JOINT OF STEEL
TOWER BASE FLANGE RING AND
CONCRETE TOWER TOP CONNECTION RING

NREL WIND TURBINE TOWER	DRAWING NO. D-37
DETAILS OF STEEL TO CONCRETE CONNECTION AT TOP OF CONCRETE TOWER	PROJECT NO. NREL YAM-2-31235-01

Appendix E – Outline Specification

- References
- General Conditions
- Project Tolerances
- Precast Production
- Precast Erection and Integration
- Tower Top Connection Ring Installation
- Steel Tube Fabrication
- Steel Tube Base Flange – Tower Top Connection Ring Integration
- Steel Tube Erection
- Installation of Pedestal Crane
- Post-Tensioning of Tower Concrete
- Installation of Turbine Nacelle, Hub, and Rotors
- Jack-Up Operations
- Completing the Concrete Tower to Steel Tower Connection
- Welding
- Electrical Mechanical Interface Requirements
- Materials

Outline Specification

This outline specification lists the operations and areas that will be addressed in a specification that would be developed as part of a final design activity for a production wind turbine tower. Generally the specifications for the various procedures and elements of the project will reference standards from one or more of the following organizations:

American Concrete Institute International (ACI)
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Association of State Highway and Transportation Officials (AASHTO)
444 N. Capital St. NW, Suite 249
Washington, D.C. 20001

American Institute of steel Construction (AISC)
One East Wacker Drive, Suite 3100
Chicago, IL 60601-2001

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

American Welding Society (AWS)
550 N.W. LeJeune Road
Miami, FL 33126

ASME International (ASME)
Three Park Avenue
New York, NY 10016-5990

Post-Tensioning Institute (PTI)
1717 West Northern Avenue, Suite 114
Phoenix, AZ 85021

Precast/Prestressed Concrete Institute (PCI)
209 West Jackson Blvd.
Chicago, IL 60606-6938

Specialty Steel Industry of North America (SSINA)
3050 K Street NW
Washington, DC 20007

The Society for Protective Coatings (SSPC)
40 24th Street, 6th Floor
Pittsburgh, PA 15222-4656

Underwriters Laboratories (UL)
333 Pfingsten Road.
Northbrook, IL 60062-2096

General Conditions

This section will outline the construction support facilities and activities that the project contractor will be expected to provide or support. It will also outline required insurances, job site labor rates if applicable, and administrative requirements of the project that the contractor must address. The content of the General Conditions will be variable from site to site.

Project Tolerances

This section will outline the installation tolerances for the various elements of the tower installation from the global position of the tower, to the global perpendicularity and elevation. This section will also address element tolerances and tolerances for elements embedded in and attached to the tower. This section will include interfacing tolerances with the various elements for the turbine to be installed on the tower.

Precast Production

This section will address the overall requirements for the precasting activity. It will include:

- Concrete formwork
- Fabrication of reinforcement cages and embedments
- Concrete batching and mixing
- Concrete transportation
- Concrete placement and consolidation
- Concrete Curing
- Element stripping and finishing
- Storage of precast elements
- Shipping of precast elements

Precast Erection and Integration

This section will address the activities associated with erecting the precast elements into the proper position and performing the tasks necessary to integrate them to form the tower structure. It will include:

- Alignment and adjustment to specified tolerances
- Installation and stressing of erection post tensioning
- Field welding of reinforcing steel
- Cast in place segment to segment closure joint construction
- Horizontal ring to ring joint grouting

Tower Top Connection Ring Installation

This section will address the activities associated with installing the tower top connection ring. It will include:

- Alignment and adjustment to specified tolerances
- Installation and stressing of erection post tensioning
- Grouting of tower top connection ring
- Installation of main tower post tensioning anchors

Steel Tube Fabrication

This section will address the activities necessary to fabricate the steel tube structure and ship it to the construction site. It will include:

- Plate forming
- Welding – including all quality and NDT requirements
- Painting
- Miscellaneous attachments
- Storage
- Shipment

Steel Tube Base Flange – Tower Top Connection Ring Integration

This section will define the required integration between these two elements of the tower. It will include:

- Flatness requirements for machined surfaces
- Finish requirements for mating surfaces
- Requirements for match drilling and marking of mating holes
- Requirements for match up of alignment provisions on each piece

Steel Tube Erection

This section will define the requirements for erecting and integrating the steel tube section on site to form the full height steel tower. It will include:

- Site welding of vertical joints (for 3.6 and 5.0 MW towers)
- Connection and support at the foundation
- Alignment requirements for the sections as erected
- Temporary strength requirements during welding
- Welding of the horizontal joints

Installation of the Pedestal Crane

This section will address the requirements for installation of the tower top pedestal crane such that the installation is correct and does not overload the steel tube during the erection process. It will include:

- Loading constraints for the erection process

Post-Tensioning of the Tower Concrete

This section will address the requirements for post tensioning the tower primary vertical post tensioning tendons. It will include:

- Installation and sealing of post tensioning ducts
- Installation of post tensioning anchors
- Installation of post tensioning steel strand
- Stressing of post tensioning tendons
- Grouting of post tensioning tendons

Installation of Turbine Nacelle, Hub, and Rotors

This section will address the requirements for hoisting and installing the turbine elements atop the tower. It will include loading constraints on the tower and picking requirements for the various elements.

- Installation of nacelle
- Installation of hub
- Installation of rotor

Jack-Up Operations

This section will address the requirements of the jack-up operation to extend the steel tube tower to full height after installation of the nacelle, hub and rotor. It will include:

- Performance and reliability requirements for the jack-up system
- Monitoring requirements for the jack-up operation
- Environmental constraints for the jack-up operation (wind speed, etc)

Completing the Concrete Tower to Steel Tower Connection

This section will address the requirements of completing this primary load transfer connection between the steel and concrete tower elements. It will include:

Installation of the connection bolts
Inspection requirements for the installation
Final touch-up of protective coatings
Installation of the weather protective cover

Welding

This section will address the welding of the elements of the tower structure that must be welded. Welding requirements will be addressed for both welds performed in the fabrication shop and those performed at the construction site. Those elements that are exposed to the primary operational loading of the tower must be fatigue qualified welds and will require the definition of detailed welding procedures, weld materials, and quality control and quality confirmation NDT requirements. It will include:

- Welding of circumferential reinforcing steel
- Welding of tower tube steel vertical joint welds
- Welding of tower tube steel horizontal joint welds
- Welding of flange rings
- Welding of tower top connection rings

Electrical Mechanical Interface Requirements

This section will address all of the tower interface requirements with the electrical and mechanical systems associated with the wind turbine installation. It will include:

- Electrical cable and conduit support and attach provisions
- Electrical equipment location and support requirements
- Mechanical equipment location and support requirements
- Maintenance access and safety requirements
  - Ladders and platforms
  - Access door

Materials

In addition to the above process or task specific specifications the specification will include the following material specifications.

- Foundation concrete
- Precast concrete
- Cast in place tower joint concrete
- Water for concrete
- Aggregates for concrete
- Cement for concrete
- Admixtures for concrete
- Curing compounds
- Material for grout gaskets
- Horizontal joint grout
- Tower top connection grout
- Post tensioning duct grout
- Reinforcing steel
- Miscellaneous inserts
- Miscellaneous metals
- Tower tube steel
- Tower flange plate steel
- Tower top connection plate steel
- Anchor bolts
- Connection bolts

APPENDIX F

Photos of Precast Concrete Elements Similar to Wind Turbine Tower Segments

The following photographs show elements of a high precision precast tunnel liner project being fabricated by Concrete Technology Corporation in Tacoma, Washington. The precast elements shown, while smaller than the segments proposed for the wind turbine towers proposed in this study, provide an example of the type of accomplishment that can be produced with precast elements.

Photograph F-1 Curved precast segments stacked in yard of precast fabrication facility

Photograph F-2 Preformed and welded reinforcing bar mats

Photograph F-3 Reinforcing cage fabrication machine

Photograph F-4 Fabricated double layer reinforcing mat

Photograph F-5 Curved precast segment form being moved into position

Photograph F-6 Curved precast segment form filled with fresh concrete

Photograph F-7 Finshers working of upper surface for precast segment

Photograph F-8 Curved precast segment forms covered for curing

Photograph F-9 Detail of precast segment showing post tensioning duct holes

Photograph F-10 Detail of precast segment showing gasket reveal

Photograph F-11 Detail showing gasket installed at precast plant

Photograph F-12 Close up of grout gasket installed on segment

Photograph F-13 Curved precast concrete segments ready for shipment

Photograph F-1

This photo shows precast arc segments very similar in concept to the segments required for the hybrid steel/concrete and all precast concrete towers proposed in this study. These units are precast tunnel liner pieces that are used to line a watertight sewer tunnel. The pieces are made to closer tolerances that required for the wind turbine towers as the completed tunnel liner circle is assembled without any cast in place closure joints.

The dimensional tolerances on these pieces are three times more precise than those that will be required for the wind turbine tower segments.

Photograph F-2

This photograph shows the pre curved and prewelded reinforcing bar mats used for this project. The mats are purchased precurved to the proper radius within close tolerances. Welding of the reinforcing mat is carefully controlled at the mat manufacturer to assure no loss of strength at the weld locations.

Photograph F-3

This photograph shows the machine that is used to assemble the inner and outer reinforcing bar mats into a cage composed of both the inner and outer mat and thru thickness shear reinforcing truss bars that are used to precisely tie the mats together. The machine automatically positions and aligns the reinforcing mats and allows for efficient tack welding of the cages.

Photograph F-4

This photograph shows a completed reinforcing cage after removal from the cage fabrication machine. This precisely manufactured cage is now ready for installation into the precast concrete segment form. The cages of the proper dimension are stockpiled in advance of their need in the days casting to assure that the production process can proceed smoothly.

Photograph F-5

This photograph shows a precast segment form being moved into position within the precast facility. These specialized forms are moved from location to location to support the production of local tunnel liner project. This allows the work to be closely coordinated on a local basis and avoids the increased cost of long distance transportation from remote fabrication facilities.

These forms are made of very heavy plate to hold the very tight tolerances associated with the fabrication of these pieces. The forms are spring mounted to the floor of the factory and each has its own form vibrator that vibrates the entire form after the concrete is placed.

Photograph F-6

This photograph shows an open segment form filled with concrete. The form is filled with concrete and the top doors are closed to allow consolidation of the concrete by form vibration. After the concrete is consolidated the top doors are opened and the upper surface is finished with a steel trowel finish. The workers in the background are finishing the upper surface.

Photograph F-7

This photo shows some of the movable elements of the form. All four sides of the form are designed to allow movement directly away from the edges of the cast and cured segment to allow it to be removed from the form. Movement is perpendicular to the surface of each edge to allow stripping without damaging the close tolerance reveals and surfaces.

The spring mounting of the form to the plant floor is visible in this photograph.

Photograph F-8

This view shows a series of segment forms that have been filled with concrete and are now curing. The tarps have been used cover the forms to retain moisture during the curing process. Note that the plant has overhead crane service to facilitate the precast construction effort.

Photograph F-9

This view shows the holes that can be used for post tensioning of the ring segments together similar to the post tensioning proposed for the wind turbine tower segments.

The segments are stacked for delivery in the order that they will be used on the construction site.

Photograph F- 10

This photograph shows the precision that can be achieved with precast concrete elements. Note the 1/16 inch (1.6 mm) high relief at the corners of the segments. Also note the gasket reveals that are used to retain the gasket that is used to achieve the grout tight/watertight joint between segments.

This view also shows insert holes in the ends of each segment that are used to connect the segments circumferentially. The circumferential connection method proposed for the wind turbine towers is via a cast in place joint that includes the welded connection of circumferential reinforcing bars within the segment.

Photograph F-11

This photograph shows the watertight grout gasket pre installed at the precast plant. Thus when the piece arrives at the construction site it is ready for installation without any further on-site work required. The gasket is attached to the concrete with adhesive and is retained by the gasket reveal formed in the concrete.

Photograph F-12

This photo shows a close up of the installed gasket and the depressed areas near the edges of the panel to avoid unintended overloading of the panel edges. On the design proposed for the precast concrete wind turbine tower we propose grouting this joint to assure uniform load transfer across the entire surface. In the tunnel liner system this joint is not grouted.

Photograph F-13

This photograph shows precast arc segments completed and ready for shipment to the site. The scale of the precasting activity can be set to support a wide range in the level of on-site construction activity.

APPENDIX G – Wind Turbine Tower Construction Project Schedules

SCHEDULES FOR BASIC 50 TURBINE PROJECT

1.5 MW 100 m Hybrid Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

1.5 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 50 Turbines – Wind Design

1.5 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

1.5 MW and 3.0 MW 100 m CIP Concrete Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

1.5 MW 100 m All Steel Wind Turbine Tower Schedule - 50 Turbines – Wind Design

3.6 MW 100 m Hybrid Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

3.6 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 50 Turbines – Wind Design

3.6 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

3.6 MW and 5.0 MW 100 m CIP Concrete Wind Turbine Tower Schedule - 50 Turbines – Wind Design

3.6 MW 100 m All Steel Wind Turbine Tower Schedule - 50 Turbines – Wind Design

5.0 MW 100 m Hybrid Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

5.0 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

5.0 MW 100 m CIP Concrete Wind Turbine Tower Schedule - 50 Turbines – Earthquake Design

5.0 MW 100 m All Steel Wind Turbine Tower Schedule - 50 Turbines – Wind Design

SCHEDULES FOR 25 TURBINE PROJECT

1.5 MW 100 m Hybrid Wind Turbine Tower Schedule - 25 Turbines – Earthquake Design

1.5 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 25 Turbines – Wind Design

1.5 MW 100 m All Cast-in-Place Concrete Wind Turbine Tower Schedule - 25 Turbines – Earthquake Design

1.5 MW 100 m All Steel Wind Turbine Tower Schedule - 25 Turbines – Wind Design

3.6 MW 100 m Hybrid Wind Turbine Tower Schedule - 25 Turbines – Earthquake Design

3.6 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 25 Turbines – Wind Design

3.6 MW 100 m All Cast-in-Place Wind Turbine Tower Schedule – 25 Turbines – Wind Design

3.6 MW 100 m All Steel Wind Turbine Tower Schedule - 25 Turbines – Wind Design

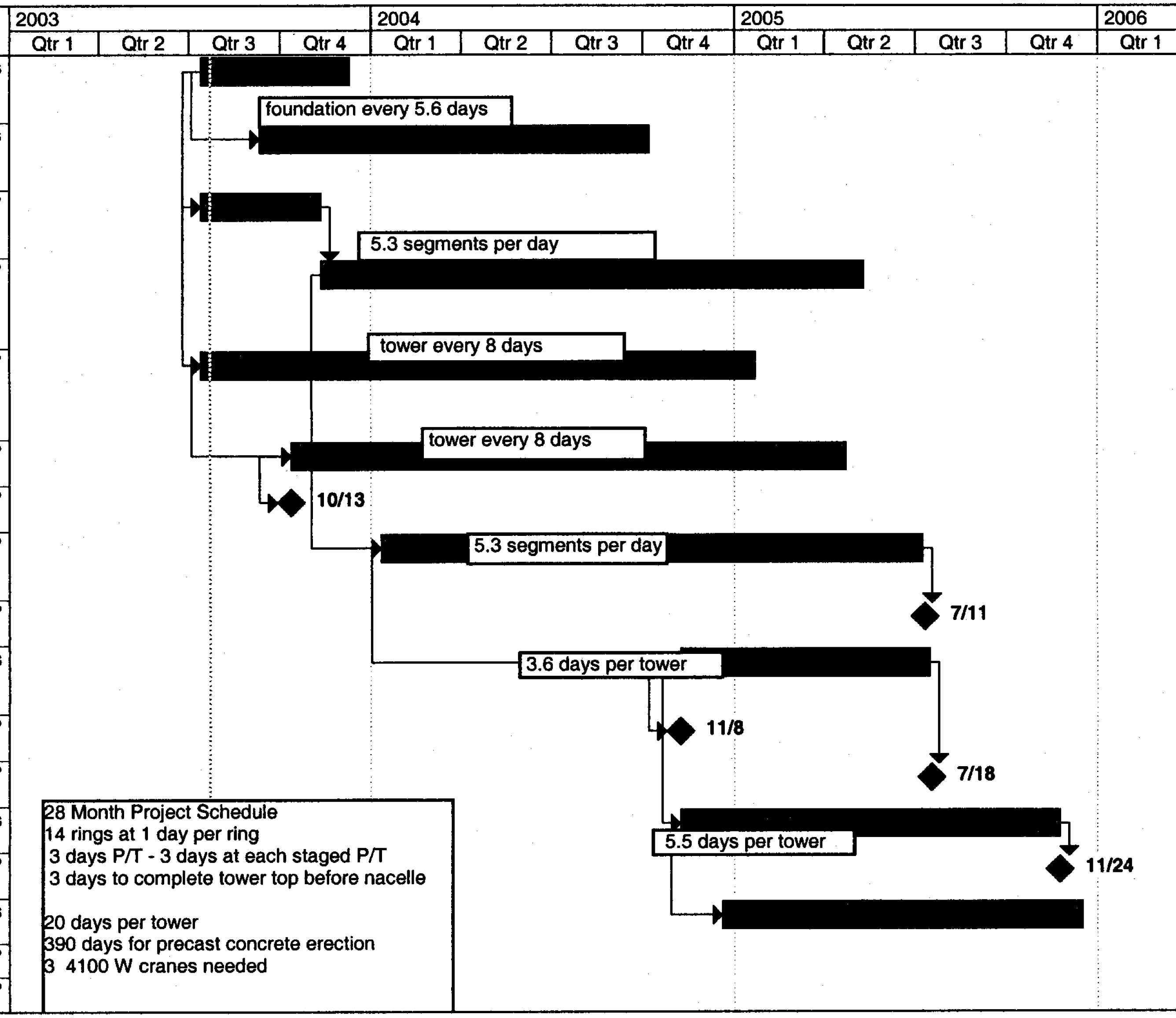
5.0 MW 100 m Hybrid Wind Turbine Tower Schedule - 25 Turbines – Earthquake Design

5.0 MW 100 m All Precast Concrete Wind Turbine Tower Schedule - 25 Turbines – Earthquake Design

5.0 MW 100 m All Cast-in-Place Concrete Wind Turbine Tower Schedule - 25 Turbines – Earthquake Design

5.0 MW 100 m All Steel Wind Turbine Tower Schedule - 25 Turbines – Wind Design

ID	ℹ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 2100 precast tower segments	390 days?
5		Fabricate 50 steel tubular towers 50 m tall	400 days?
6		Erect and site weld 50 tubular towers 50 m tall	400 days?
7		Mobilize (3) 4100 W series crane to site	1 day?
8		Erect 2100 precast segments for 50 towers - with 4100W cranes	390 days?
9		Need for (3) 4100 W series crane complete	1 day?
10		Erect nacelle, hub & rotor at 50 m height - 50 towers - With LTL-600 crane	180 days
11		Mobilize LTL- 600 cranes to site	1 day?
12		Need for LTL- 600 cranes complete	1 day?
13		Jack-up tubular steel towers to full 100 m height	273 days
14		Tower construction complete	1 day?
15		Install tower electrical and commission turbines	260 days
16			1 day?
17			1 day?

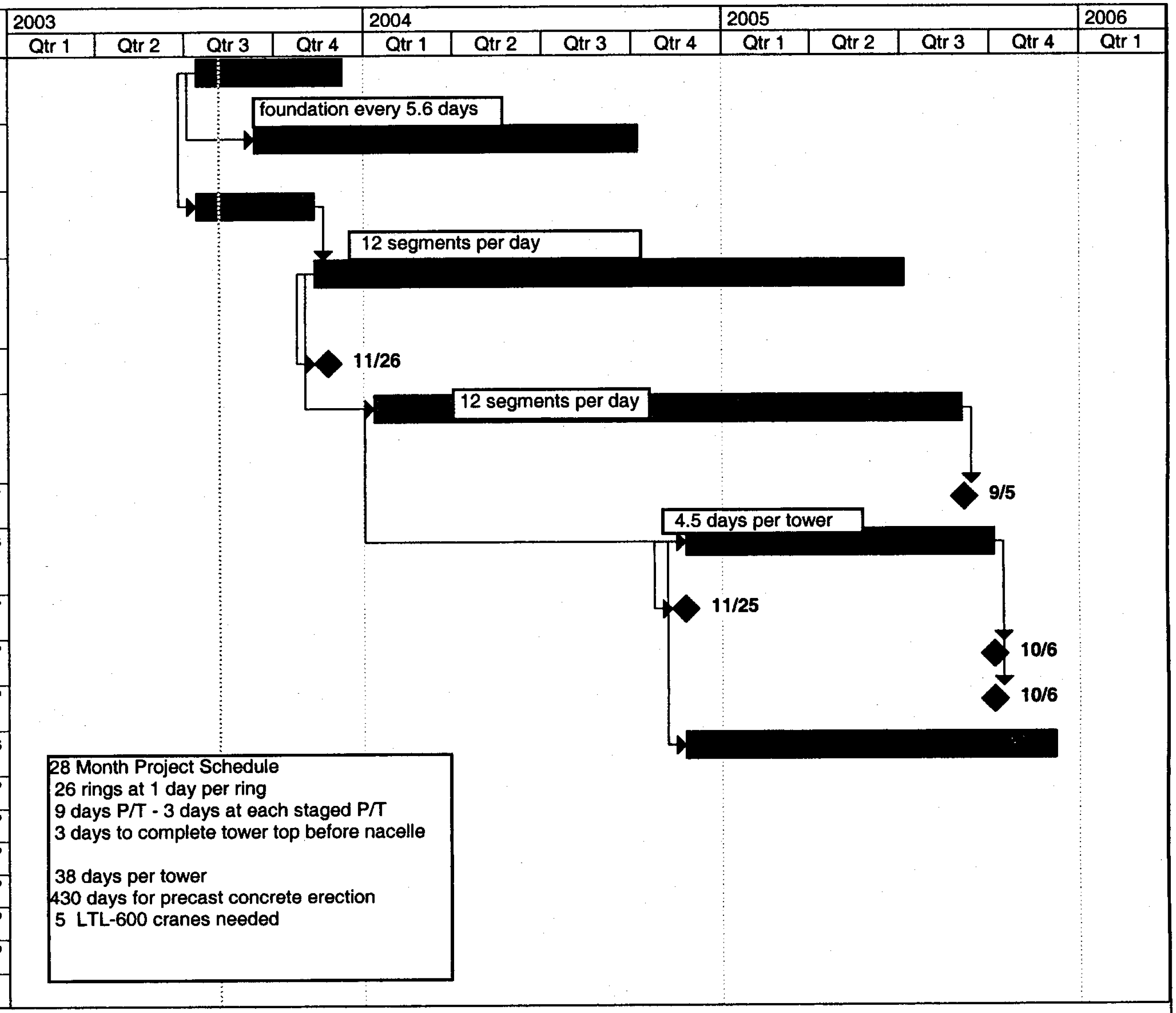


1.5 MW 100 m Hybrid
Wind Turbine Tower Schedule
50 Turbines - Earthquake Design

Task	▬	Milestone	◆	External Tasks	▒
Split	⋯⋯	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

Tue 7/22/03

ID		Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 5100 precast tower segments	430 days?
5		Mobilize 5 LTL-600 series crane to site	1 day?
6		Erect 5100 precast segments for 50 towers - 26 rings per tower - using LTL-600 cranes	430 days
7		Need for 5 LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers using LTL-850 crane	225 days
9		Mobilize 1 LTL- 850 crane to site	1 day?
10		Need for 1 LTL- 850 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	270 days
13			1 day?
14			1 day?
15			1 day?
16			1 day?
17			1 day?
18			1 day?

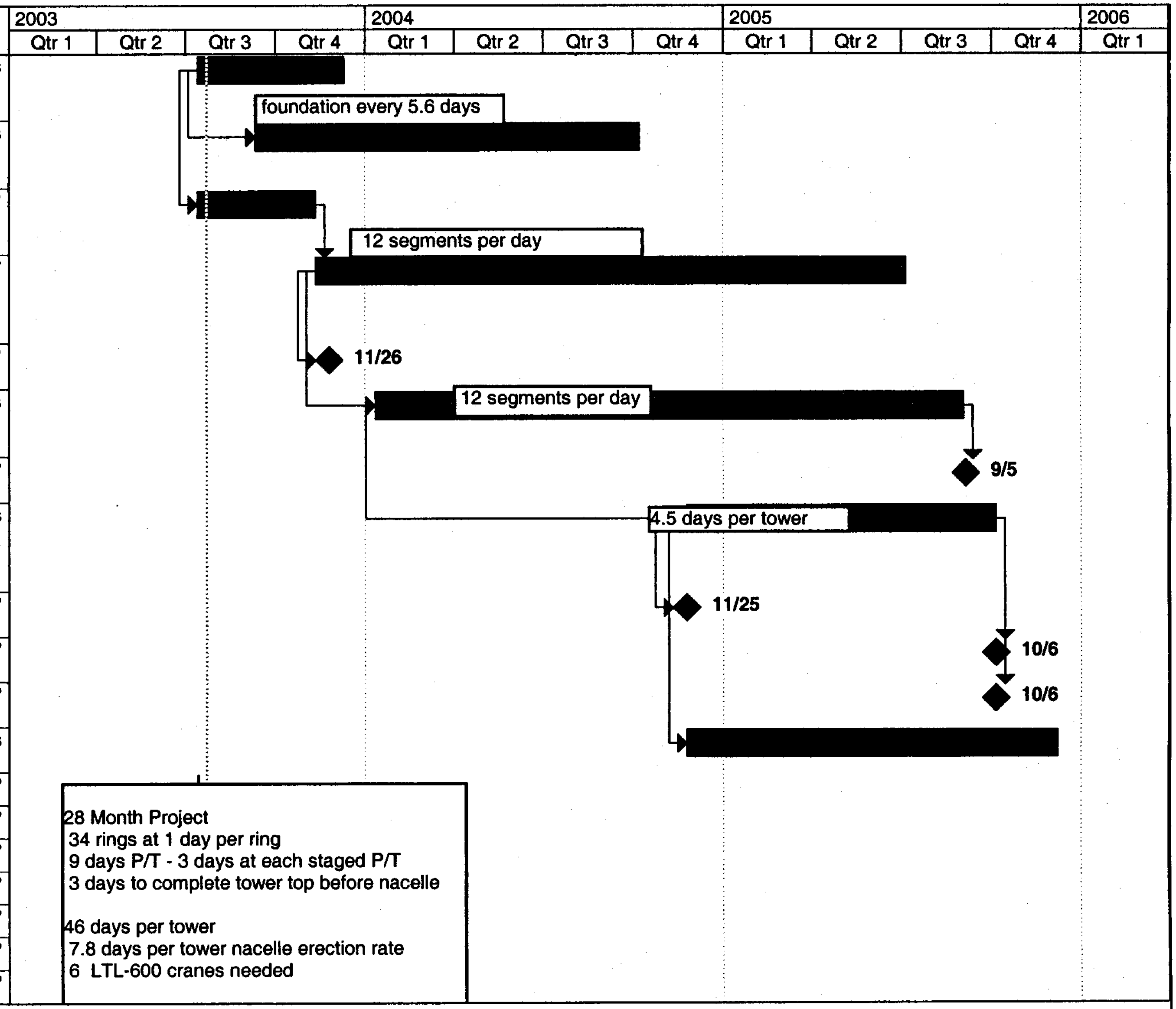


1.5 MW 100 m All Precast Concrete
Wind Turbine Tower Schedule
50 Turbines (Wind Design)

Task	■	Milestone	◆	External Tasks	▒
Split	....	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

Tue 8/5/03

ID	Task Name	Duration
1	Site development and mobilization	108 days
2	Construct 50 tower foundations	281 days
3	Construct forms for precast segments	87 days?
4	Produce 5100 precast tower segments	430 days?
5	Mobilize 6 LTL-600 series crane to site	1 day?
6	Erect 5100 precast segments for 50 towers - using LTL-600 cranes	430 days
7	Need for 6 LTL-600 series crane complete	1 day?
8	Erect nacelle, hub & rotor at 100 m height - 50 towers using LTL-850 crane	225 days
9	Mobilize 1 LTL- 850 crane to site	1 day?
10	Need for 1 LTL- 850 crane complete	1 day?
11	Tower construction complete	1 day?
12	Install tower electrical and commission turbines	270 days
13		1 day?
14		1 day?
15		1 day?
16		1 day?
17		1 day?
18		1 day?
19		1 day?

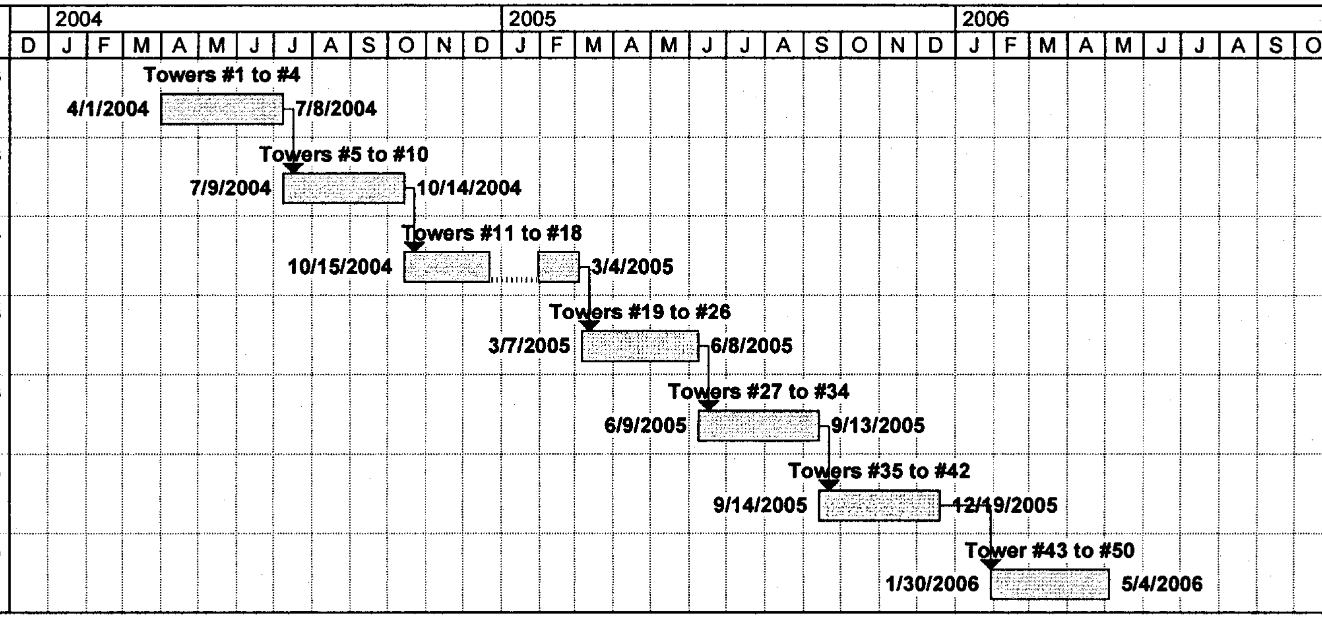


1.5 MW 100 m All Precast Concrete Wind Turbine Tower Schedule
50 Turbines - Earthquake Design

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

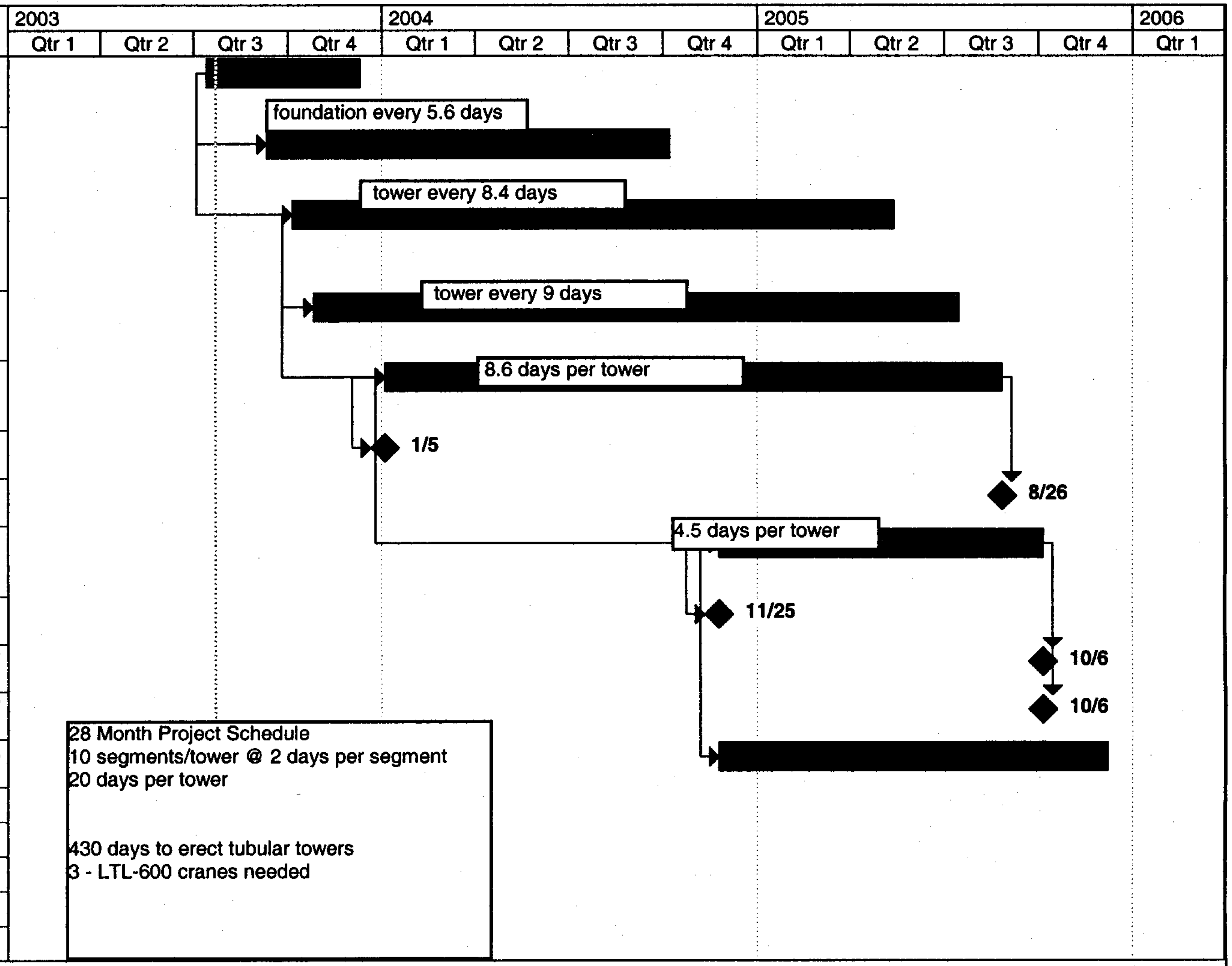
Tue 7/22/03

ID	Task Name	Duration
1	Towers #1 to #4	69 days
2	Towers #5 to #10	69 days
3	Towers #11 to #18	72 days
4	Towers #19 to #26	67 days
5	Towers #27 to #34	67 days
6	Towers #35 to #42	67 days
7	Tower #43 to #50	69 days



Cast-In-Place Concrete
Jump Formed Chimney Construction Technology

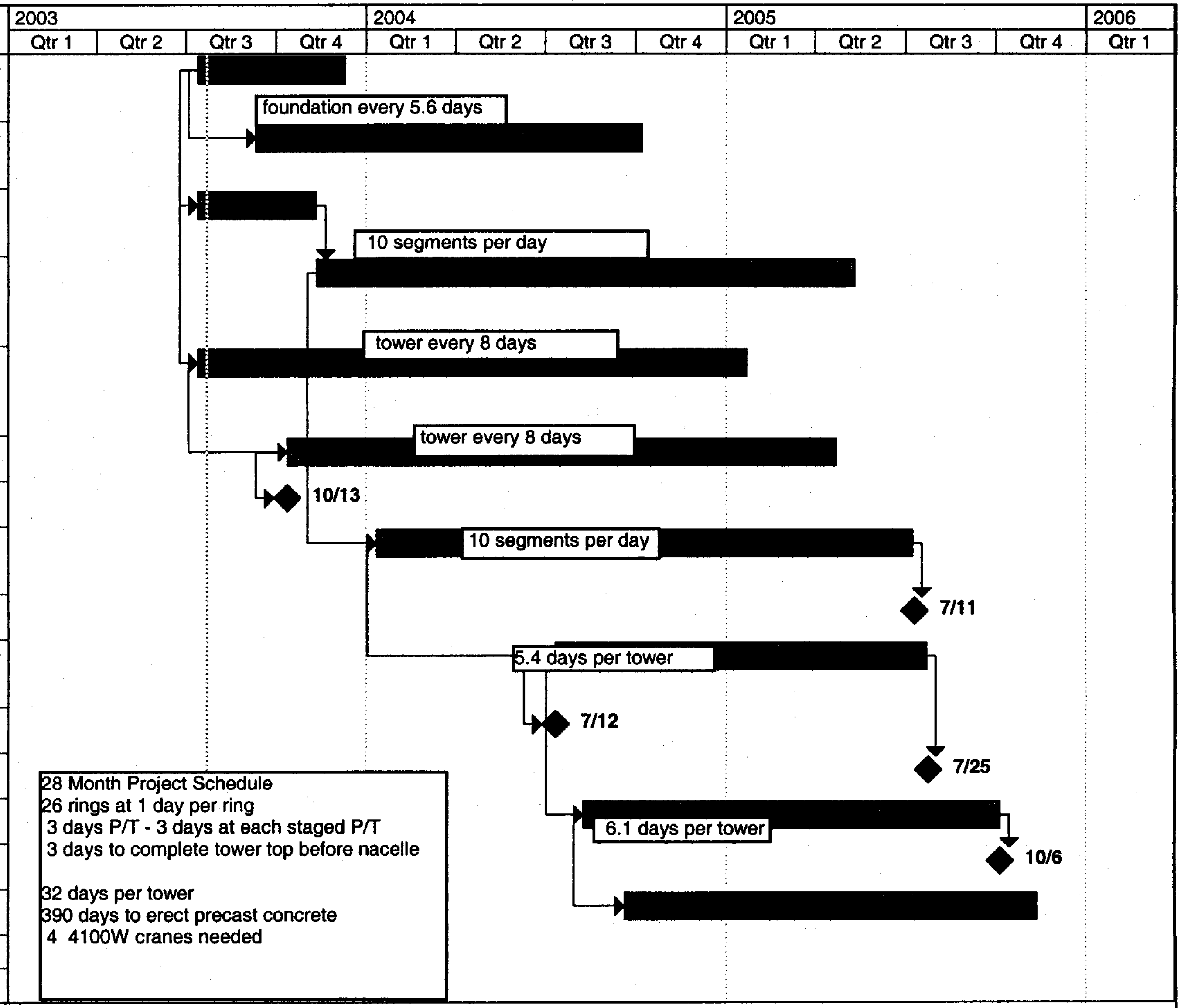
ID	ℹ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Fabricate 50 steel tubular towers 100 m tall and ship to site	420 days?
4		Weld quartered tower sectons into circular sections on-site	450 days
5		Erect and site weld 50 tubular towers 100 m tall (10 segments per tower)	430 days?
6		Mobilize (3) LTL-600 series crane to site	1 day?
7		Need for (3) LTL-600 series crane complete	0 days?
8		Erect nacelle, hub & rotor at 50 m height - 50 towers using LTL-850 crane	225 days
9		Mobilize (1) LTL- 850 cranes to site	1 day?
10		Need for (1) LTL- 850 cranes complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	270 days
13			1 day?
14			1 day?



1.5 MW 100 m All Steel
Wind Turbine Tower Schedule
50 Turbines - Wind Design

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

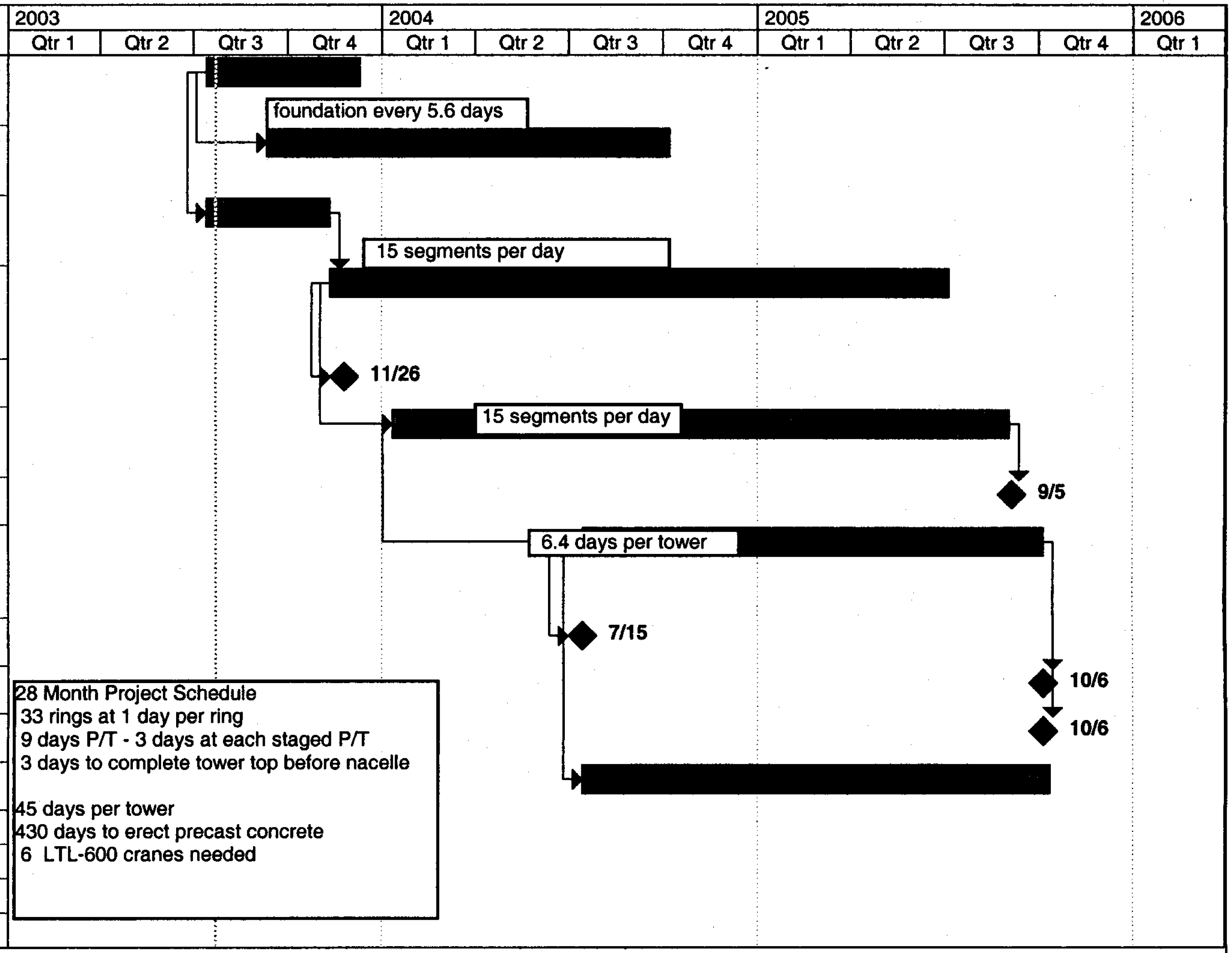
ID	ℹ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 3900 precast tower segments	390 days?
5		Fabricate 50 steel tubular towers 50 m tall	400 days?
6		Erect and site weld 50 tubular towers 50 m tall	400 days?
7		Mobilize (4) 4100 W series crane to site	1 day?
8		Erect 3900 precast segments for 50 towers - using 4100W crane	390 days?
9		Need for (4) 4100 W series crane complete	1 day?
10		Erect nacelle, hub & rotor at 50 m height - 50 towers - using LTL-850 crane	270 days
11		Mobilize LTL- 850 crane to site	1 day?
12		Need for LTL- 850 crane complete	1 day?
13		Jack-up tubular steel towers to full 100 m height	303 days?
14		Tower construction complete	1 day?
15		Install tower electrical and commission turbines	300 days?
16			1 day?
17			1 day?



3.6 MW 100 m Hybrid
Wind Turbine Tower Schedule
50 Turbines - Earthquake Design

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

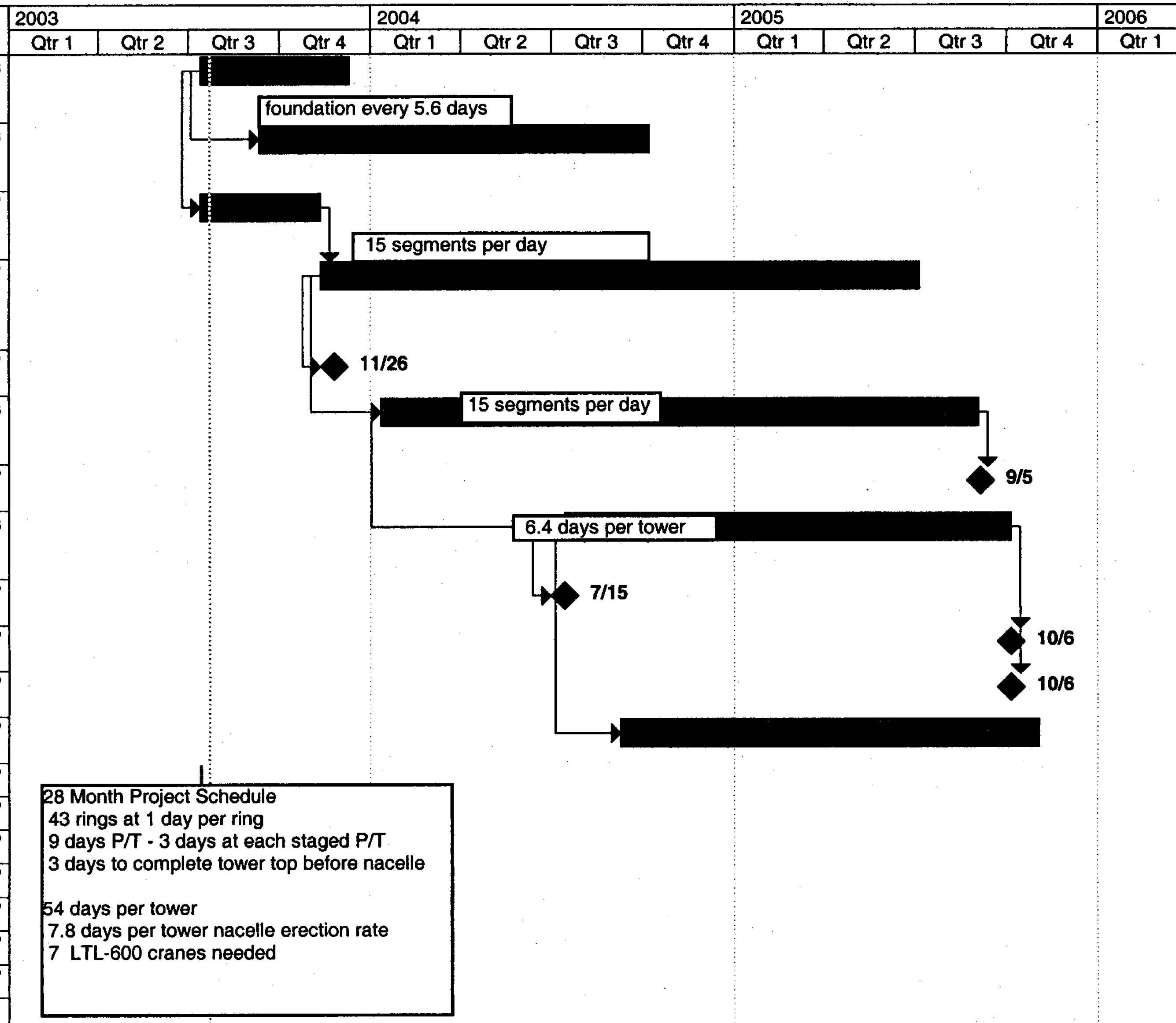
ID	Indicators	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 6450 precast tower segments	430 days?
5		Mobilize (6) LTL-600 series crane to site	1 day?
6		Erect 6450 precast segments for 50 towers - using LTL-600 cranes	430 days
7		Need for(6) LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers - Using LTL 850 crane	320 days?
9		Mobilize 1 LTL- 850 crane to site	1 day?
10		Need for 1 LTL- 850 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	324 days
13			1 day?
14			1 day?



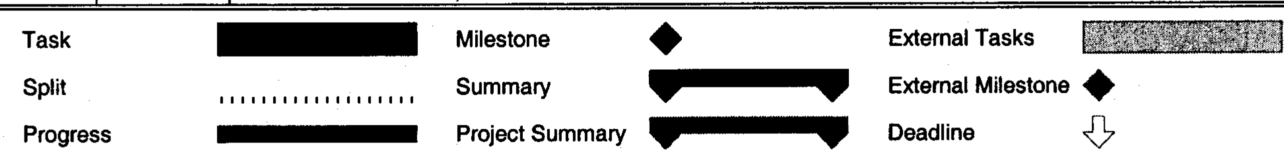
3.6 MW 100 m All Precast Concrete Wind Turbine Tower Schedule
50 Turbines - Wind Design

Task	Milestone	External Tasks
Split	Summary	External Milestone
Progress	Project Summary	Deadline

ID	(i)	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 6450 precast tower segments	430 days?
5		Mobilize (7) LTL-600 series crane to site	1 day?
6		Erect 6450 precast segments for 50 towers - using LTL-600 cranes	430 days
7		Need for(7) LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers Using LTL-850 Crane	320 days
9		Mobilize 1 LTL- 850 crane to site	1 day?
10		Need for 1 LTL- 850 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	300 days?
13			1 day?
14			1 day?
15			1 day?
16			1 day?
17			1 day?
18			1 day?
19			1 day?

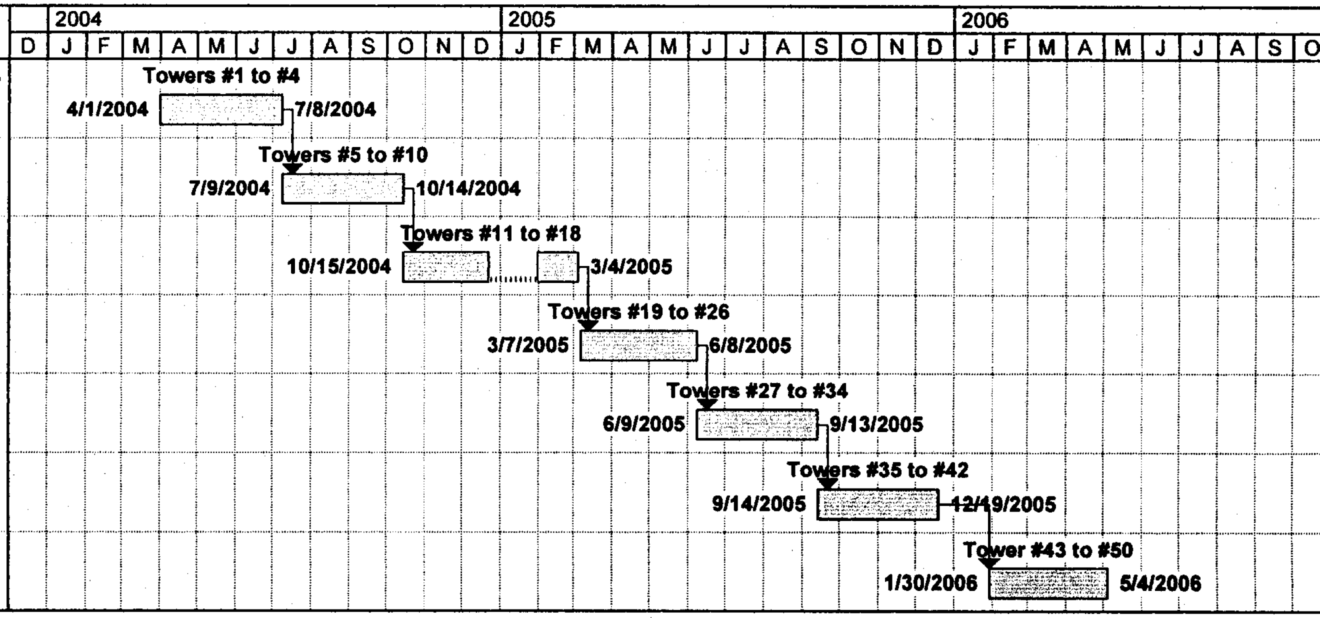


3.6 MW 100 m All Precast Concrete Wind Turbine Tower Schedule
50 Turbines - Earthquake Design



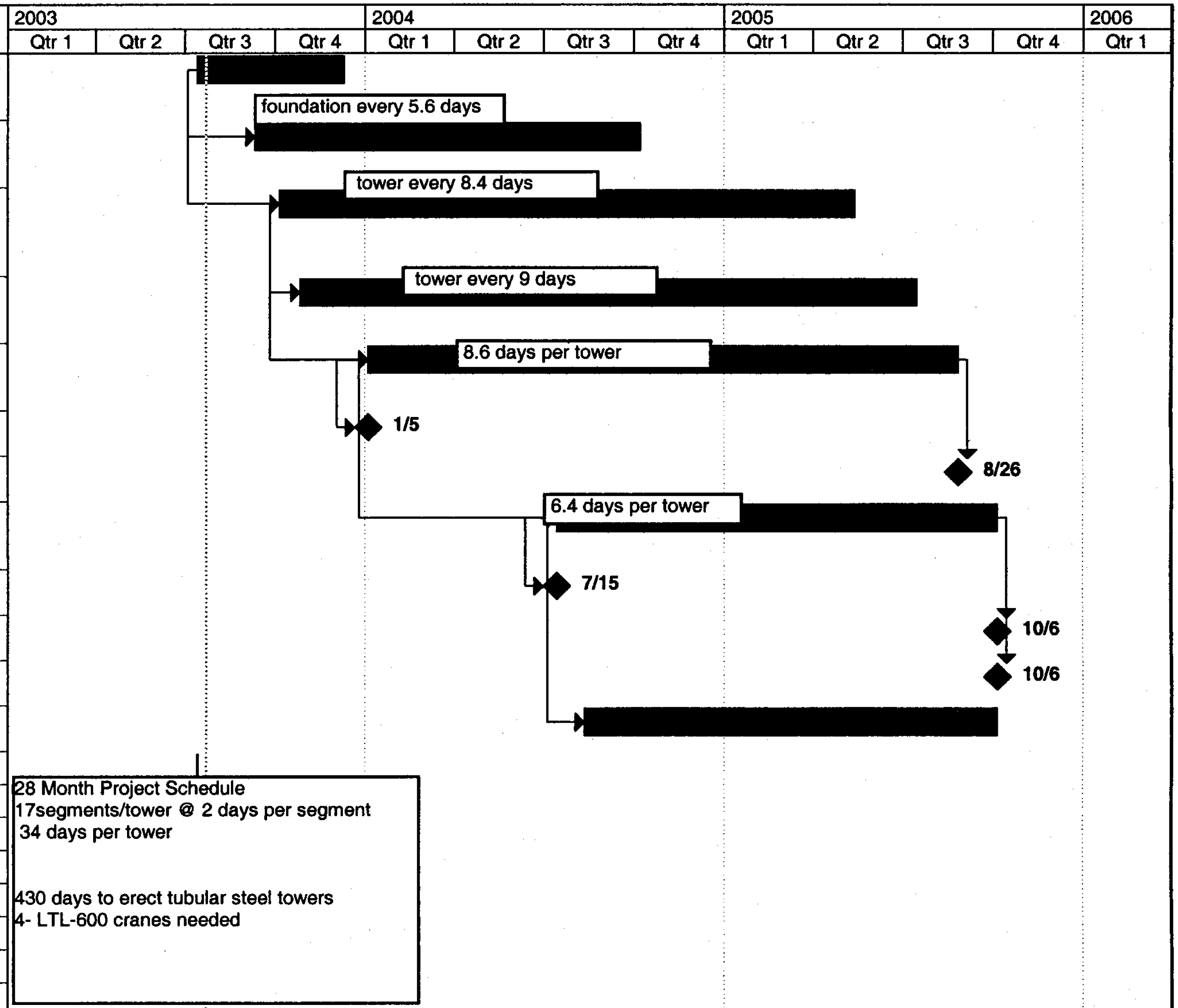
Tue 7/22/03

ID	Task Name	Duration
1	Towers #1 to #4	69 days
2	Towers #5 to #10	69 days
3	Towers #11 to #18	72 days
4	Towers #19 to #26	67 days
5	Towers #27 to #34	67 days
6	Towers #35 to #42	67 days
7	Tower #43 to #50	69 days



Cast-In-Place Concrete
Jump Formed Chimney Construction Technology

ID	Indicators	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Fabricate 50 steel tubular towers 100 m tall and ship to site	420 days?
4		Weld quartered tower sectons into circular sections on-site	450 days
5		Erect and site weld 50 tubular towers 100 m tall (17 segments per tower)	430 days?
6		Mobilize (4) LTL-600 series cranes to site	1 day?
7		Need for (4) LTL-600 series cranes complete	0 days?
8		Erect nacelle, hub & rotor at 50 m height - 50 towers using LTL-850 Crane	320 days
9		Mobilize (1) LTL- 850 cranes to site	1 day?
10		Need for (1) LTL- 850 cranes complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	300 days?
13			1 day?
14			1 day?

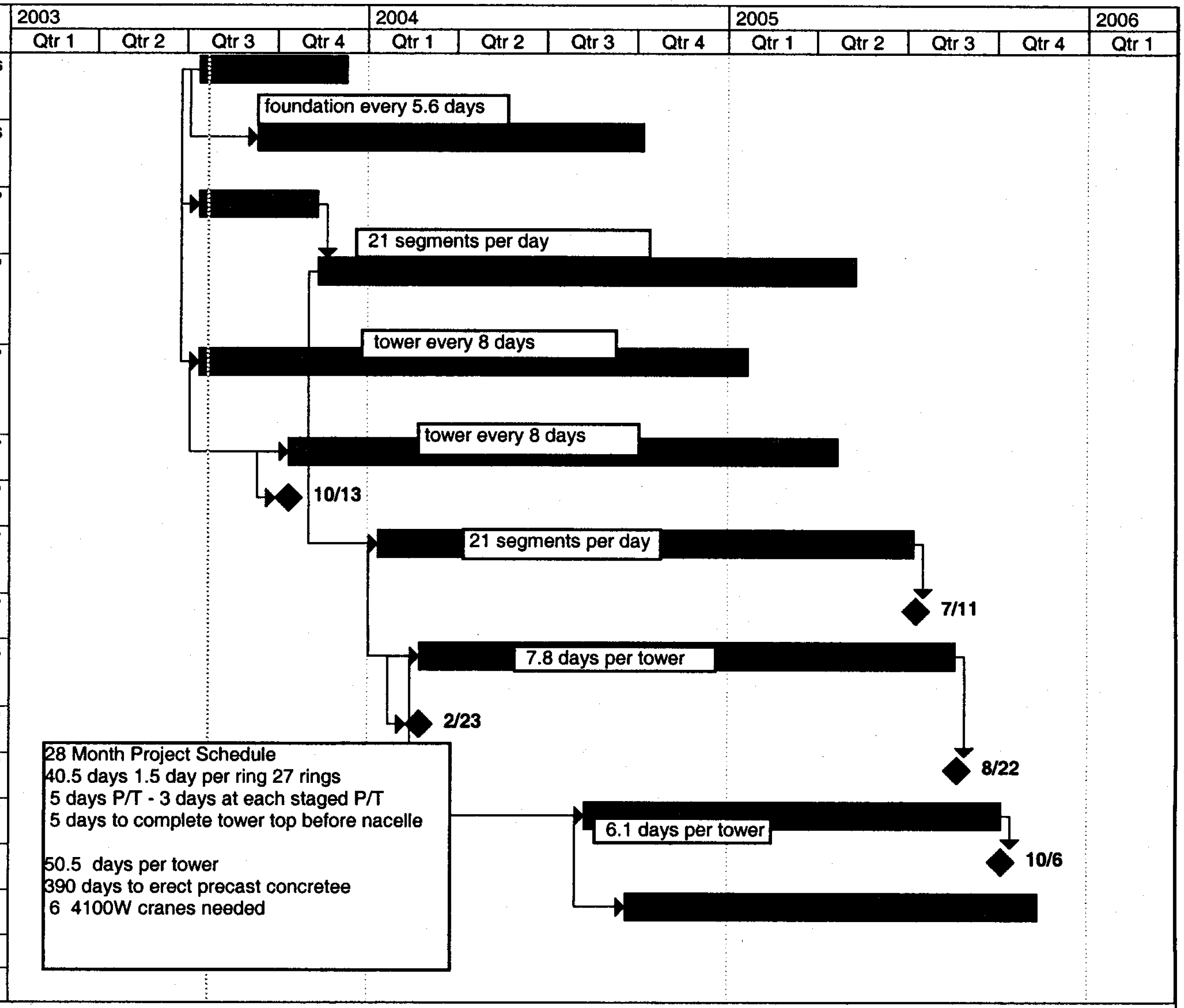


3.6 MW 100 m All Steel
Wind Turbine Tower Schedule
50 Turbines - Wind Design

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

Tue 7/22/03

ID		Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 8100 precast tower segments	390 days?
5		Fabricate 50 steel tubular towers 50 m tall	400 days?
6		Erect and site weld 50 tubular towers 50 m tall	400 days?
7		Mobilize (6) 4100 W series crane to site	1 day?
8		Erect 8100 precast segments for 50 towers - Using 4100W Crane	390 days?
9		Need for (6) 4100 W series crane complete	1 day?
10		Erect nacelle, hub & rotor at 50 m height - 50 towers - Using LTL-1100 crane	390 days
11		Mobilize LTL- 1100 crane to site	1 day?
12		Need for LTL- 1100 crane complete	1 day?
13		Jack-up tubular steel towers to full 100 m height	303 days?
14		Tower construction complete	1 day?
15		Install tower electrical and commission turbines	300 days?

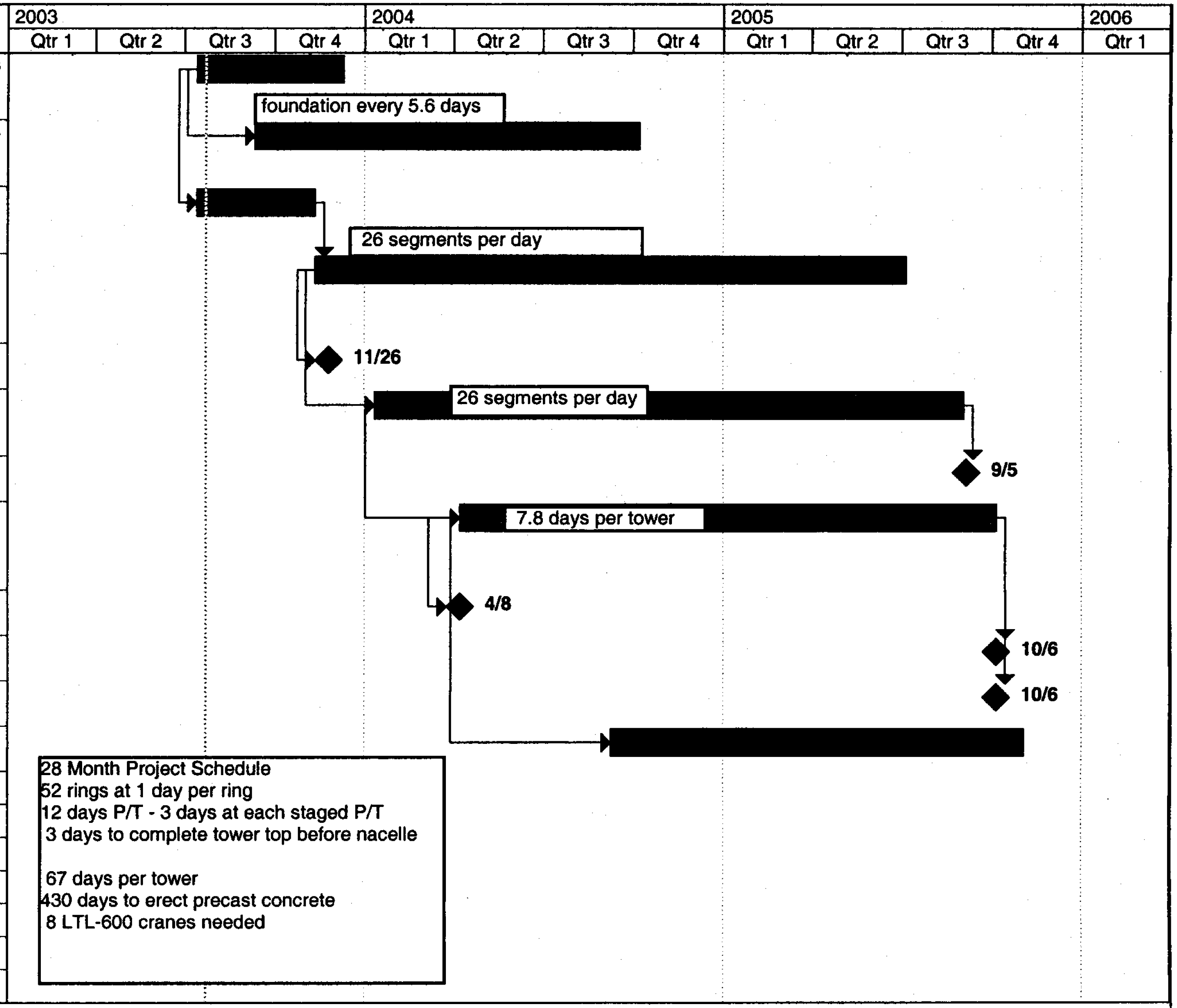


5.0 MW 100 m Hybrid
Wind Turbine Tower Schedule
50 Turbines- Earthquake Design

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Tue 7/22/03

ID	ℹ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 11850 precast tower segments	430 days?
5		Mobilize 8 LTL-600 series crane to site	1 day?
6		Erect 11850 precast segments for 50 towers - Using LTL-600 cranes	430 days
7		Need for 8 LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers - Using LTL-850 crane	390 days?
9		Mobilize 1 LTL- 1100 crane to site	1 day?
10		Need for 1 LTL- 1100 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	300 days?
13			1 day?
14			1 day?
15			1 day?
16			1 day?
17			1 day?
18			1 day?

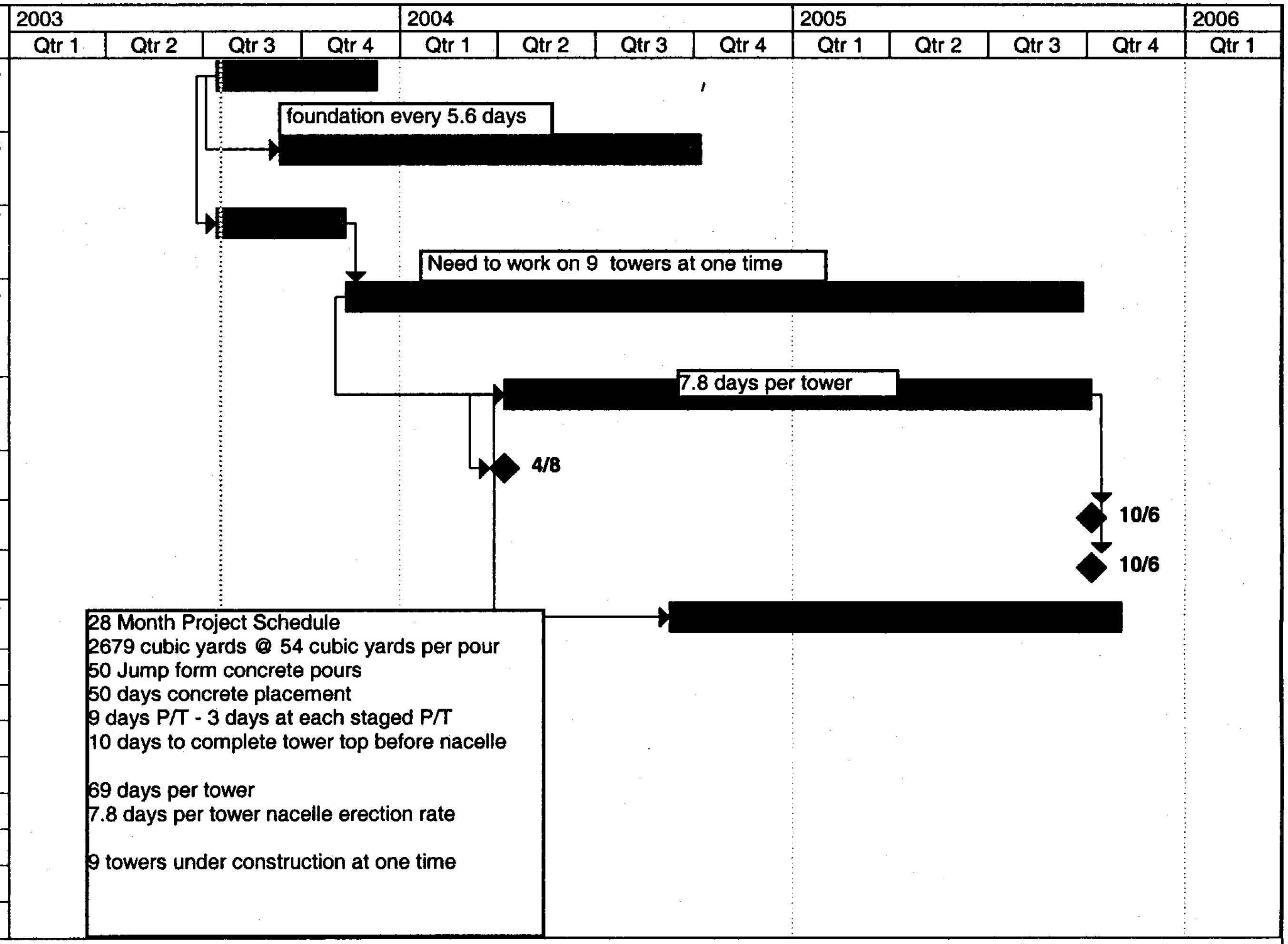


5.0 MW 100 m All Precast Concrete
Wind Turbine Tower Schedule
50 Turbines - Earthquake Design

Task	Milestone ◆	External Tasks
Split	Summary	External Milestone ◆
Progress	Project Summary	Deadline ⇩

 Tue 7/22/03

ID	Indicators	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Mobilize cast in place jump forming systems to site	87 days?
4		Construct 50 cast in place tower structures 2679 cubic yards per tower	490 days
5		Erect nacelle, hub & rotor at 100 m height - 50 towers	390 days?
6		Mobilize 1 LTL- 850 crane to site	1 day?
7		Need for 1 LTL- 850 crane complete	1 day?
8		Tower construction complete	1 day?
9		Install tower electrical and commission turbines	300 days?

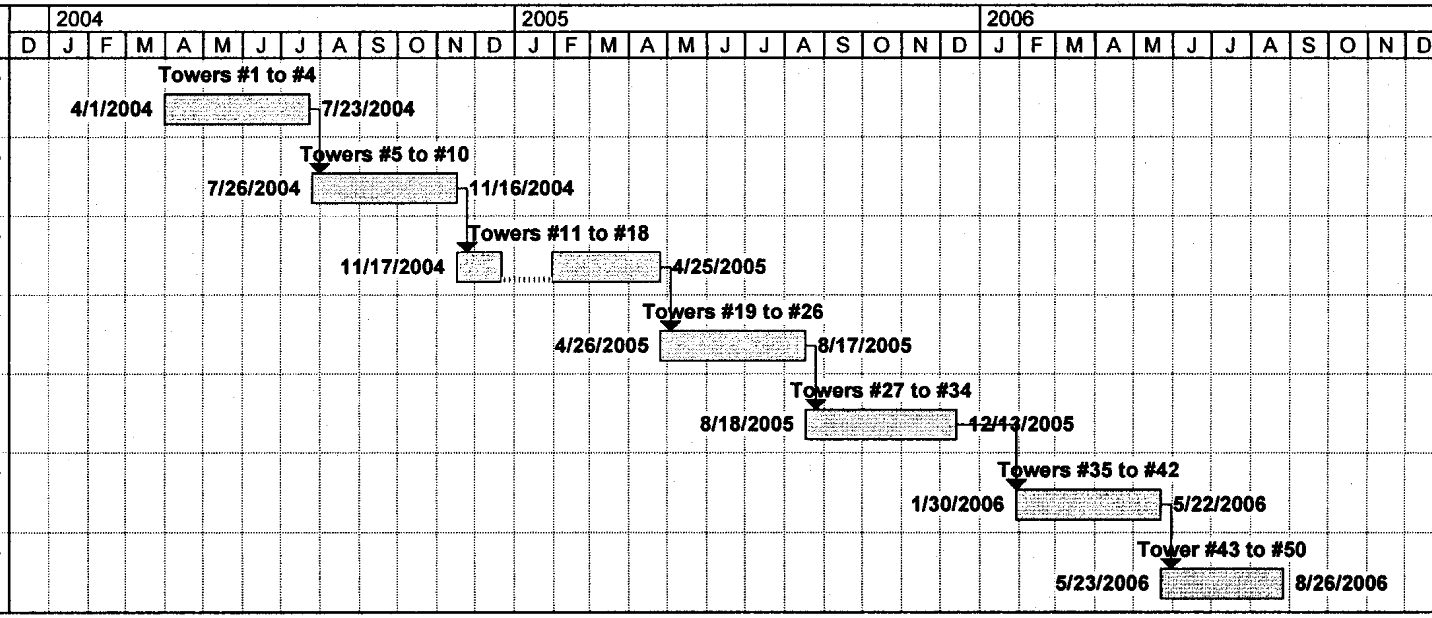


5.0 MW 100 m CIP Concrete
Wind Turbine Tower Schedule
50 Turbines -Earthquake Design

Task	Milestone	External Tasks
Split	Summary	External Milestone
Progress	Project Summary	Deadline

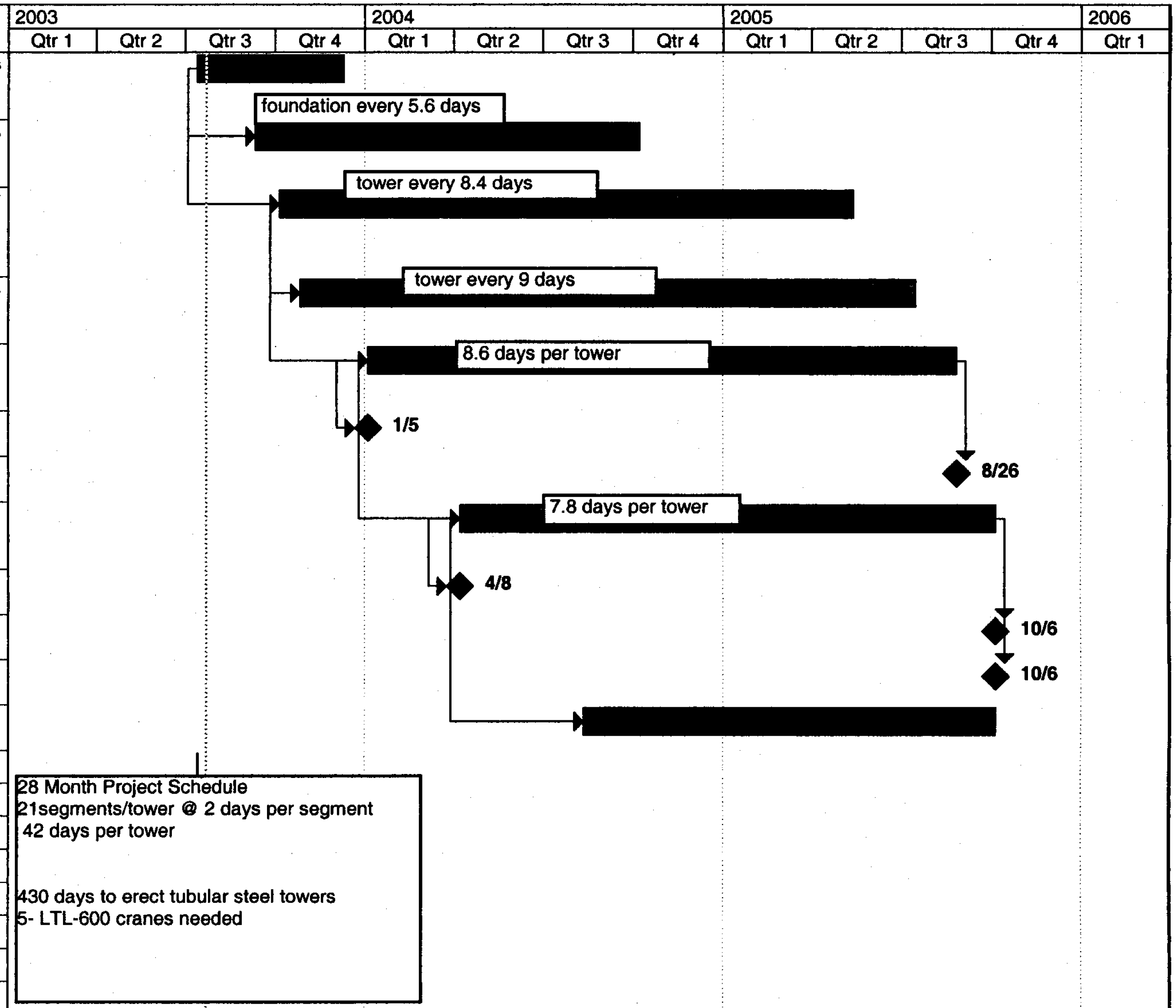
Thu 7/17/03

ID	Task Name	Duration
1	Towers #1 to #4	80 days
2	Towers #5 to #10	81 days
3	Towers #11 to #18	84 days
4	Towers #19 to #26	80 days
5	Towers #27 to #34	81 days
6	Towers #35 to #42	81 days
7	Tower #43 to #50	80 days



Cast-In-Place Concrete
Jump Formed Chimney Construction Technology

ID		Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 50 tower foundations	281 days
3		Fabricate 50 steel tubular towers 100 m tall and ship to site	420 days?
4		Weld quartered tower sectons into circular sections on-site	450 days
5		Erect and site weld 50 tubular towers 100 m tall (21 segments per tower)	430 days?
6		Mobilize (5) LTL-600 series cranes to site	1 day?
7		Need for (5) LTL-600 series cranes complete	0 days?
8		Erect nacelle, hub & rotor at 50 m height - 50 towers Using LTL-1100 crane	390 days
9		Mobilize (1) LTL- 1100 crane to site	1 day?
10		Need for (1) LTL- 1100 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	300 days?
13			1 day?
14			1 day?

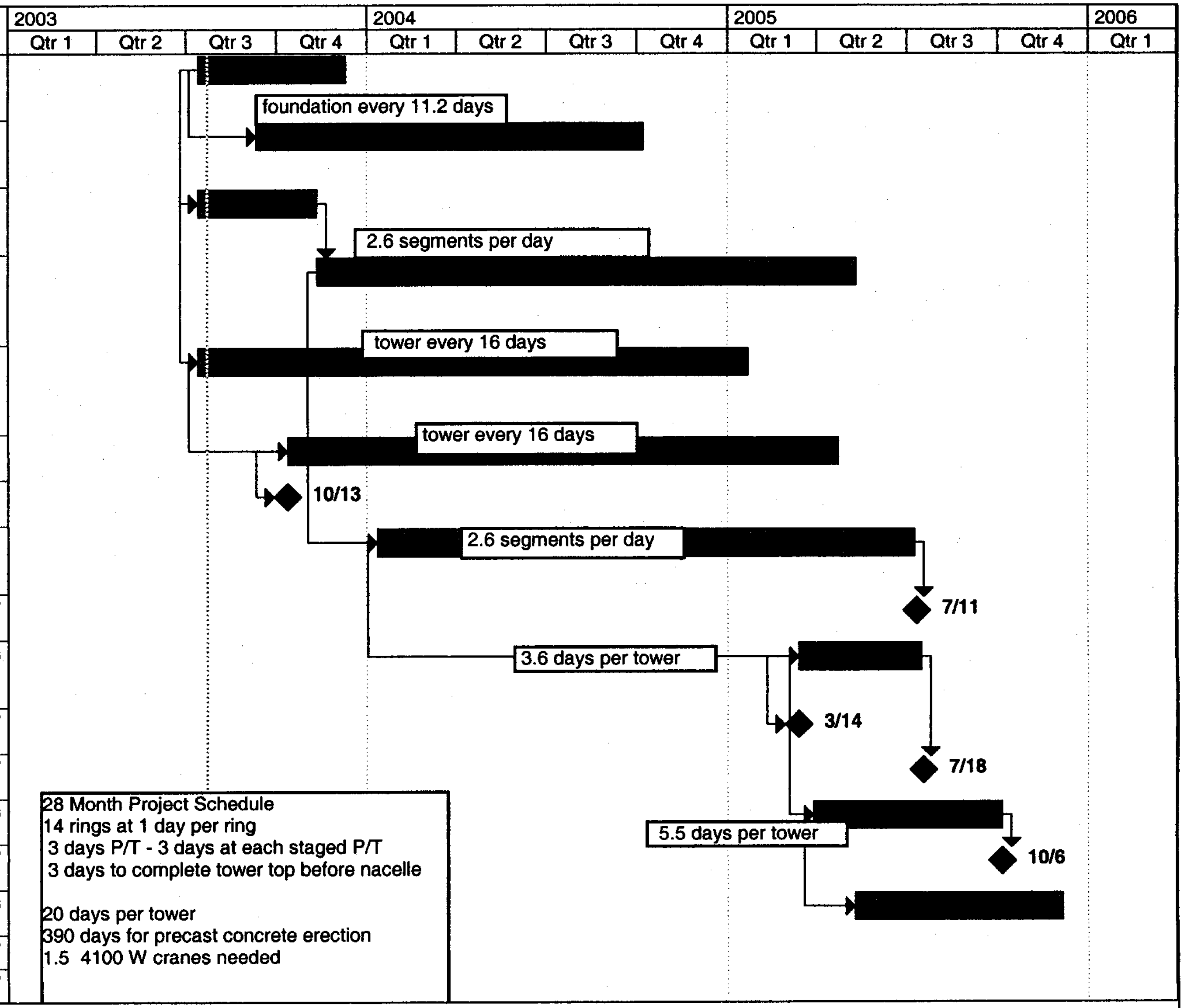


5.0 MW 100 m All Steel
Wind Turbine Tower Schedule
50 Turbines - Wind Design

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

Tue 7/22/03

ID	Task Name	Duration
1	Site development and mobilization	108 days
2	Construct 25 tower foundations	281 days
3	Construct forms for precast segments	87 days?
4	Produce 1050 precast tower segments	390 days?
5	Fabricate 25 steel tubular towers 50 m tall	400 days?
6	Erect and site weld 25 tubular towers 50 m tall	400 days?
7	Mobilize (3) 4100 W series crane to site	1 day?
8	Erect 1050 precast segments for 50 towers - with 4100W cranes	390 days?
9	Need for (3) 4100 W series crane complete	1 day?
10	Erect nacelle, hub & rotor at 50 m height - 25 towers - With LTL-600 crane	90 days
11	Mobilize LTL- 600 cranes to site	1 day?
12	Need for LTL- 600 cranes complete	1 day?
13	Jack-up tubular steel towers to full 100 m height	137 days
14	Tower construction complete	1 day?
15	Install tower electrical and commission turbines	150 days
16		1 day?
17		1 day?

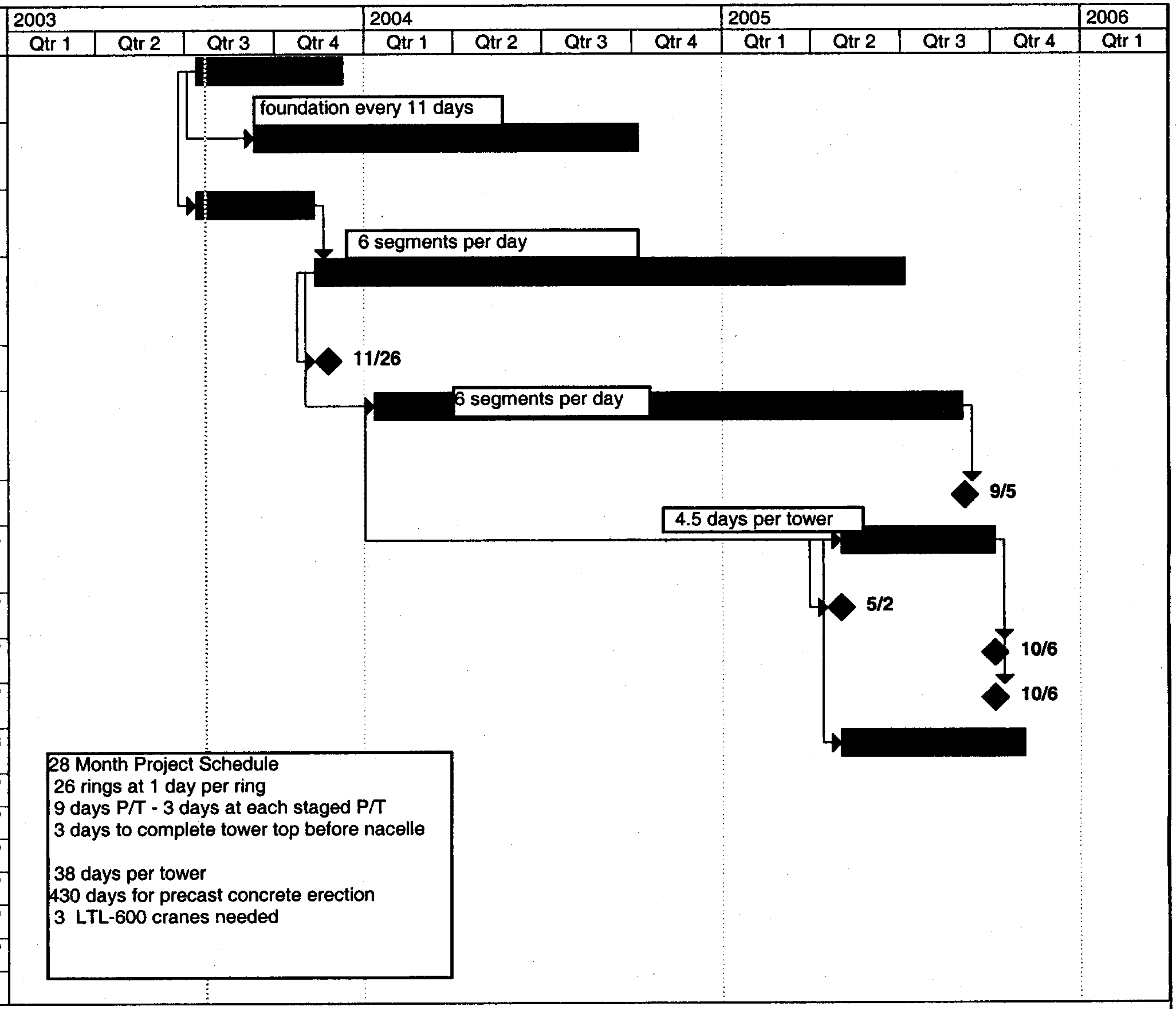


1.5 MW 100 m Hybrid
Wind Turbine Tower Schedule
25 Turbines - Earthquake Design

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

Tue 7/22/03

ID	Indicators	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 2550 precast tower segments	430 days?
5		Mobilize (3) LTL-600 series crane to site	1 day?
6		Erect 2550 precast segments for 50 towers - 26 rings per tower - using LTL-600 cranes	430 days
7		Need for (3) LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers using LTL-850 crane	113 days
9		Mobilize 1 LTL- 850 crane to site	1 day?
10		Need for 1 LTL- 850 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	135 days
13			1 day?
14			1 day?
15			1 day?
16			1 day?
17			1 day?
18			1 day?

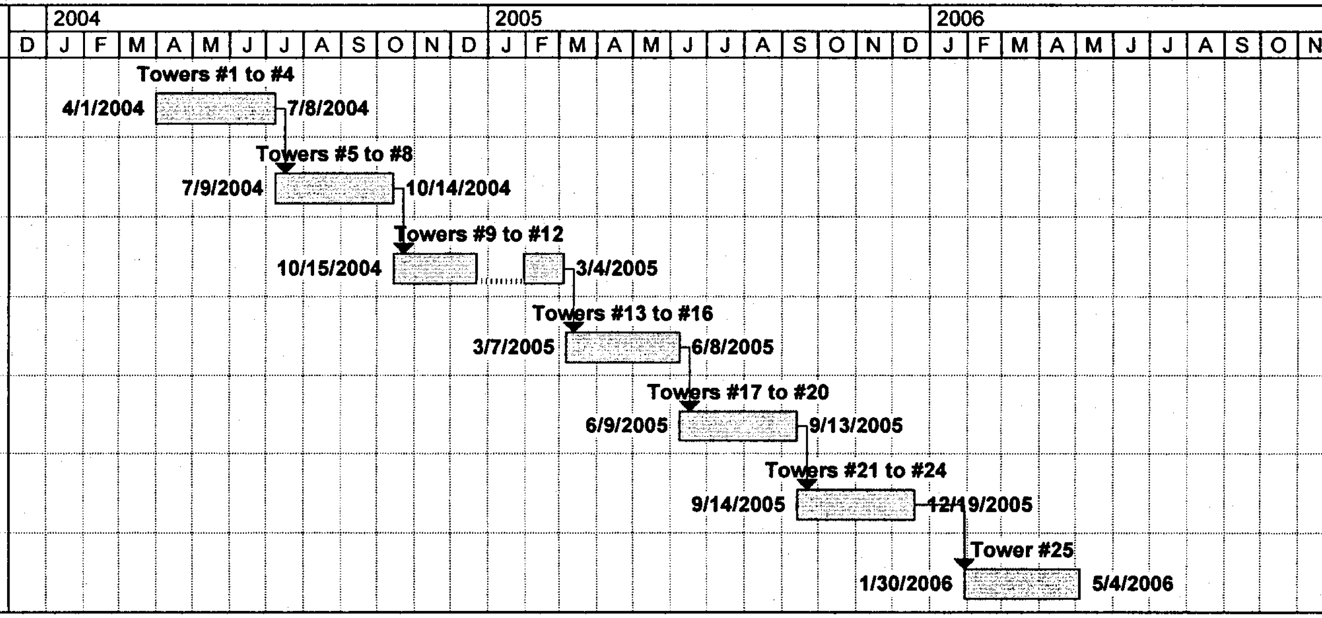


1.5 MW 100 m All Precast Concrete Wind Turbine Tower Schedule
25 Turbines (Wind Design)

Task	Milestone	External Tasks	
Split	Summary	External Milestone	
Progress	Project Summary	Deadline	

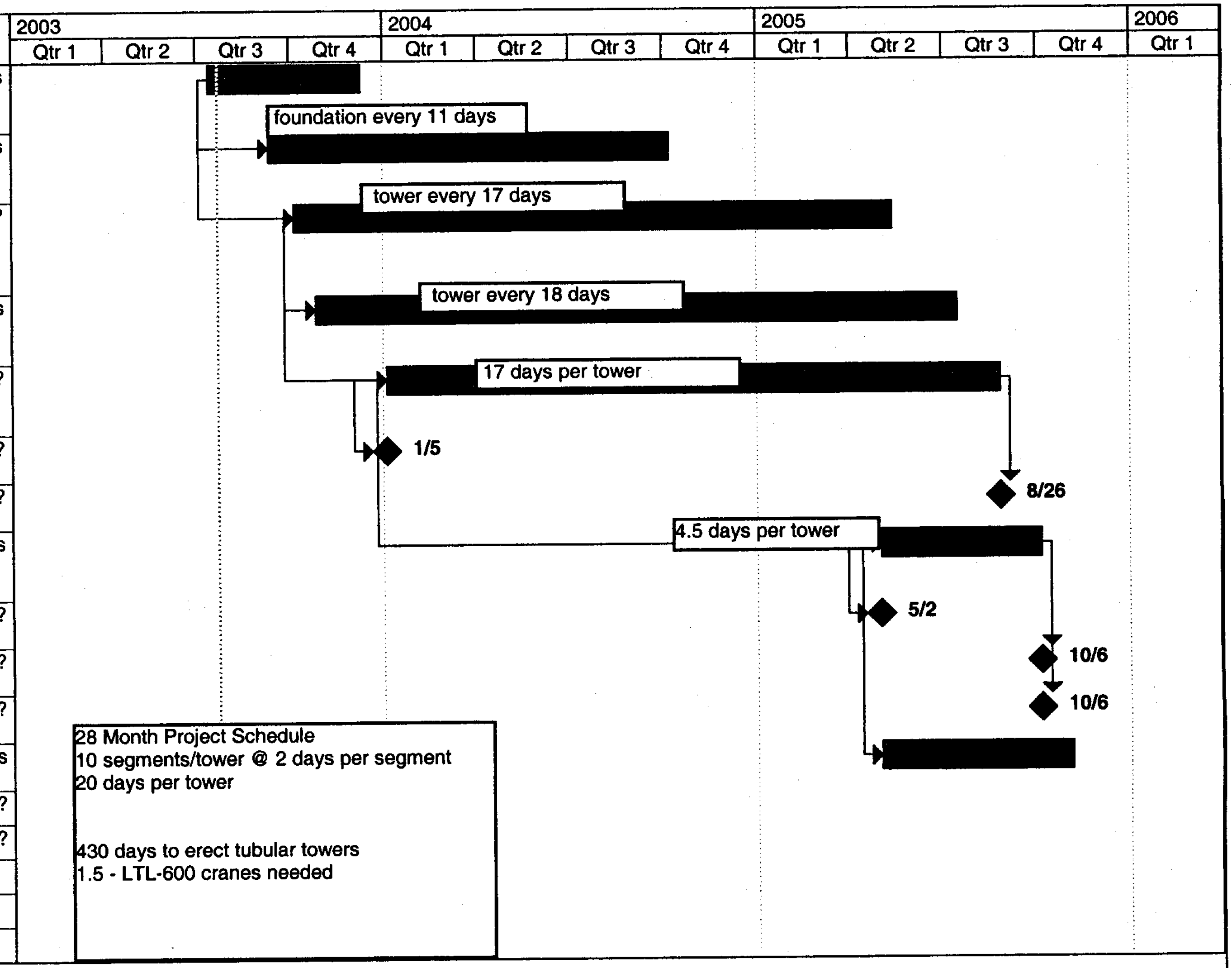
 Tue 7/22/03

ID	Task Name	Duration
1	Towers #1 to #4	69 days
2	Towers #5 to #8	69 days
3	Towers #9 to #12	72 days
4	Towers #13 to #16	67 days
5	Towers #17 to #20	67 days
6	Towers #21 to #24	67 days
7	Tower #25	69 days



Cast-In-Place Concrete
Jump Formed Chimney Construction Technology

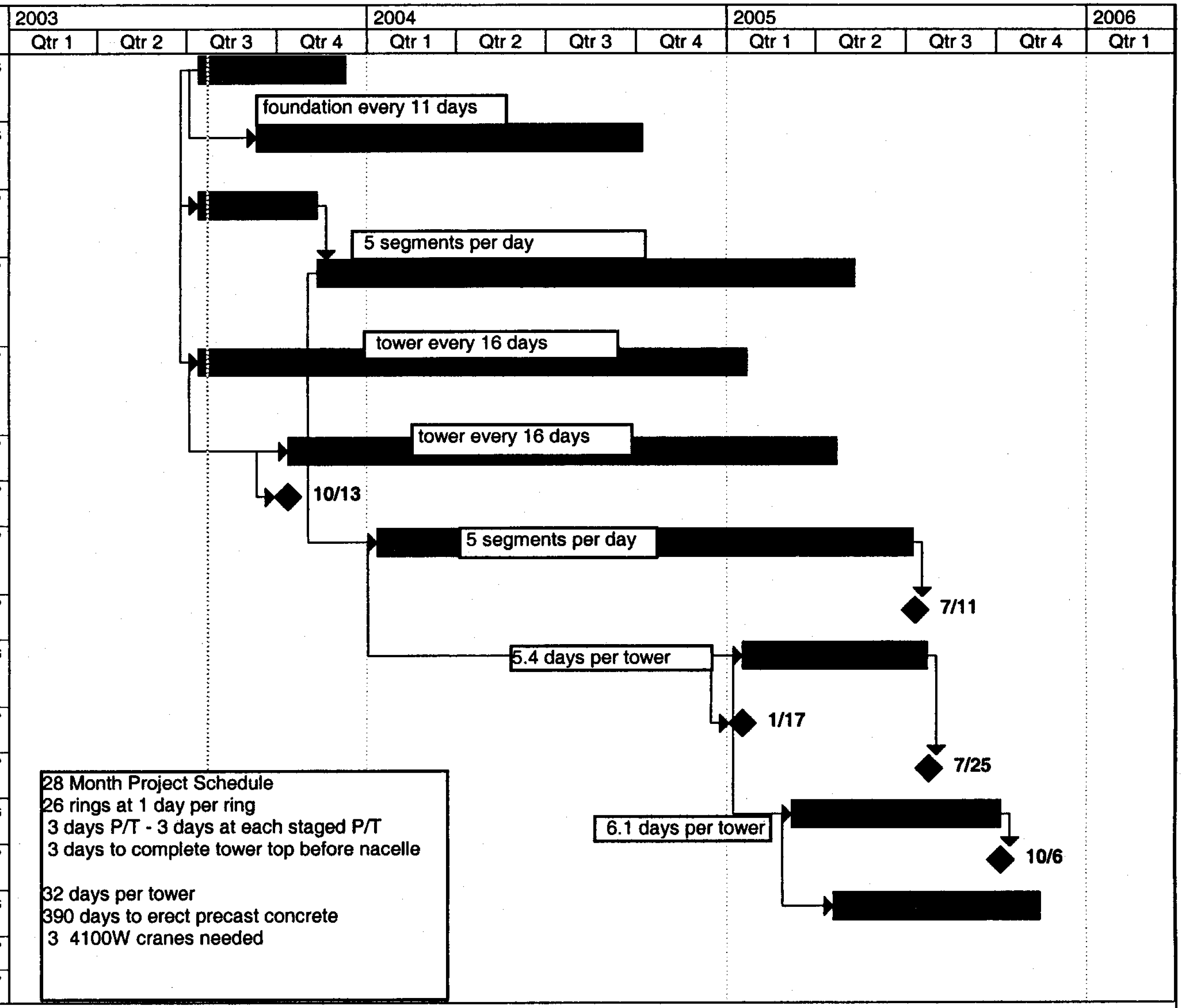
ID	ℹ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Fabricate 25 steel tubular towers 100 m tall and ship to site	420 days?
4		Weld quartered tower sectons into circular sections on-site	450 days
5		Erect and site weld 25 tubular towers 100 m tall (10 segments per tower)	430 days?
6		Mobilize (1.5) LTL-600 series crane to site	1 day?
7		Need for (1.5) LTL-600 series crane complete	0 days?
8		Erect nacelle, hub & rotor at 50 m height - 25 towers using LTL-850 crane	113 days
9		Mobilize (1) LTL- 850 cranes to site	1 day?
10		Need for (1) LTL- 850 cranes complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	135 days
13			1 day?
14			1 day?



1.5 MW 100 m All Steel
Wind Turbine Tower Schedule
25 Turbines - Wind Design

Task		Milestone	◆
Split		Summary	
Progress		Project Summary	
External Tasks		External Milestone	◆
Deadline	⇩		

ID	❶	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 1950 precast tower segments	390 days?
5		Fabricate 25 steel tubular towers 50 m tall	400 days?
6		Erect and site weld 25 tubular towers 50 m tall	400 days?
7		Mobilize (2.5) 4100 W series crane to site	1 day?
8		Erect 1950 precast segments for 50 towers - using 4100W crane	390 days?
9		Need for (4) 4100 W series crane complete	1 day?
10		Erect nacelle, hub & rotor at 50 m height - 25 towers - using LTL-850 crane	135 days
11		Mobilize LTL- 850 crane to site	1 day?
12		Need for LTL- 850 crane complete	1 day?
13		Jack-up tubular steel towers to full 100 m height	152 days
14		Tower construction complete	1 day?
15		Install tower electrical and commission turbines	150 days
16			1 day?
17			1 day?

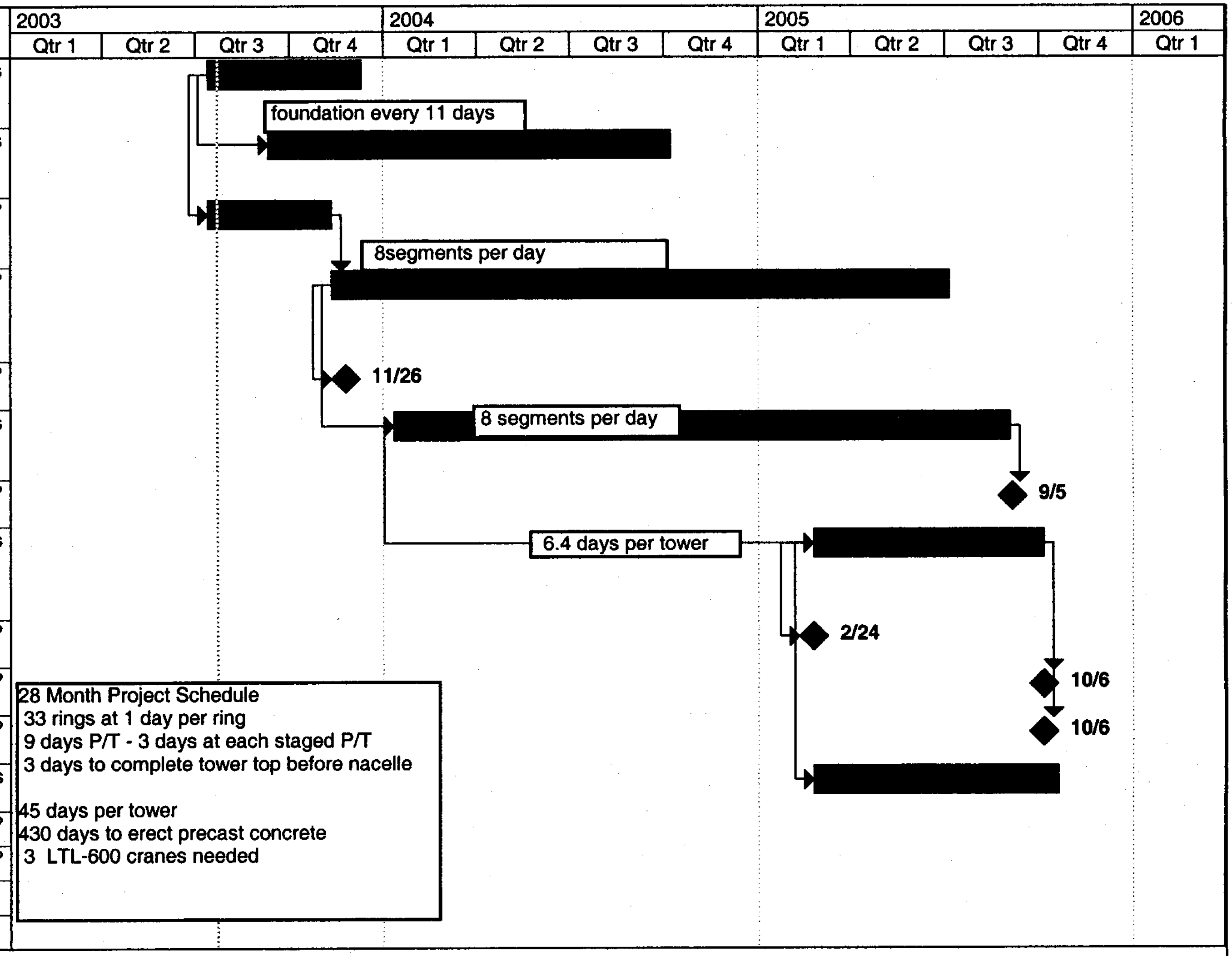


3.6 MW 100 m Hybrid
Wind Turbine Tower Schedule
25 Turbines - Earthquake Design

Task	Milestone	External Tasks
Split	Summary	External Milestone
Progress	Project Summary	Deadline

Tue 7/22/03

ID	ℹ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 3225 precast tower segments	430 days?
5		Mobilize (3) LTL-600 series crane to site	1 day?
6		Erect 3225 precast segments for 50 towers - using LTL-600 cranes	430 days
7		Need for(3) LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers - Using LTL 850 crane	160 days
9		Mobilize 1 LTL-850 crane to site	1 day?
10		Need for 1 LTL- 850 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	170 days
13			1 day?
14			1 day?

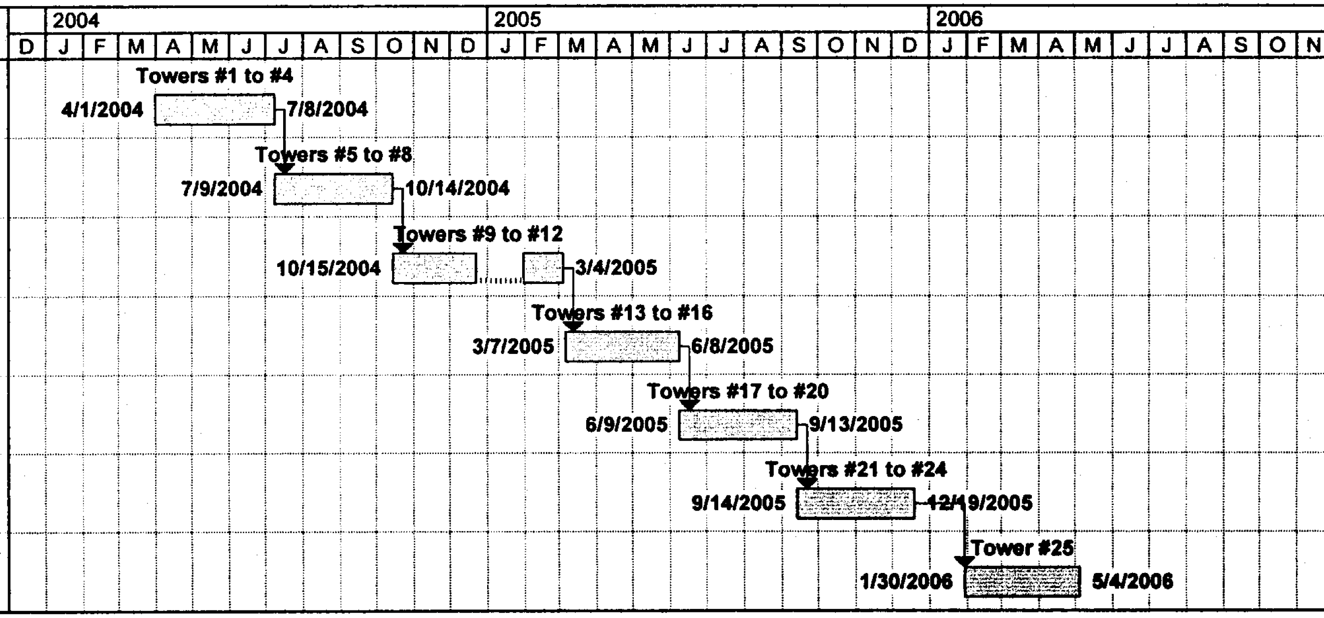


3.6 MW 100 m All Precast Concrete Wind Turbine Tower Schedule
25 Turbines - Wind Design

Task	Milestone	External Tasks	
Split	Summary	External Milestone	
Progress	Project Summary	Deadline	

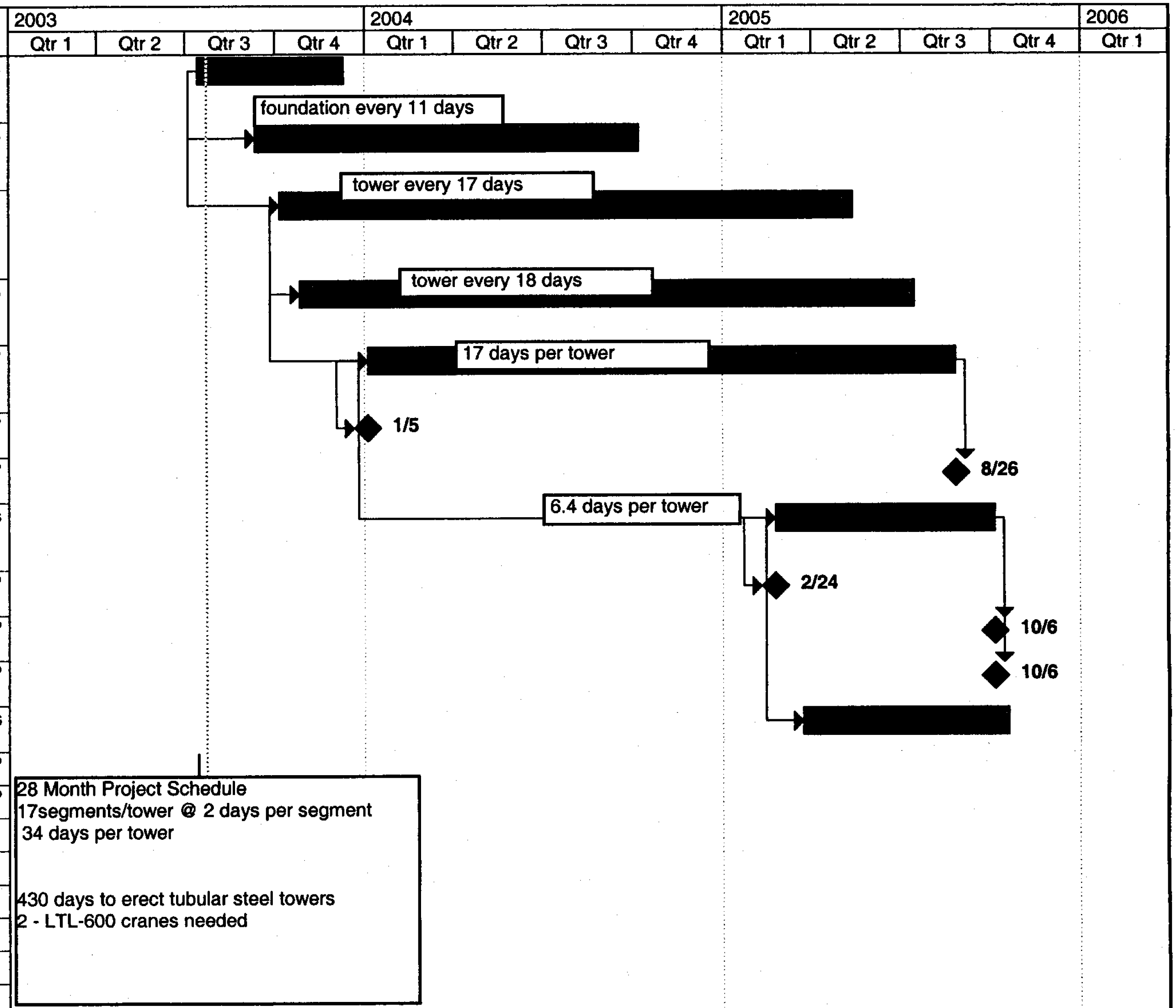
Tue 7/22/03

ID	Task Name	Duration
1	Towers #1 to #4	69 days
2	Towers #5 to #8	69 days
3	Towers #9 to #12	72 days
4	Towers #13 to #16	67 days
5	Towers #17 to #20	67 days
6	Towers #21 to #24	67 days
7	Tower #25	69 days



Cast-In-Place Concrete
Jump Formed Chimney Construction Technology

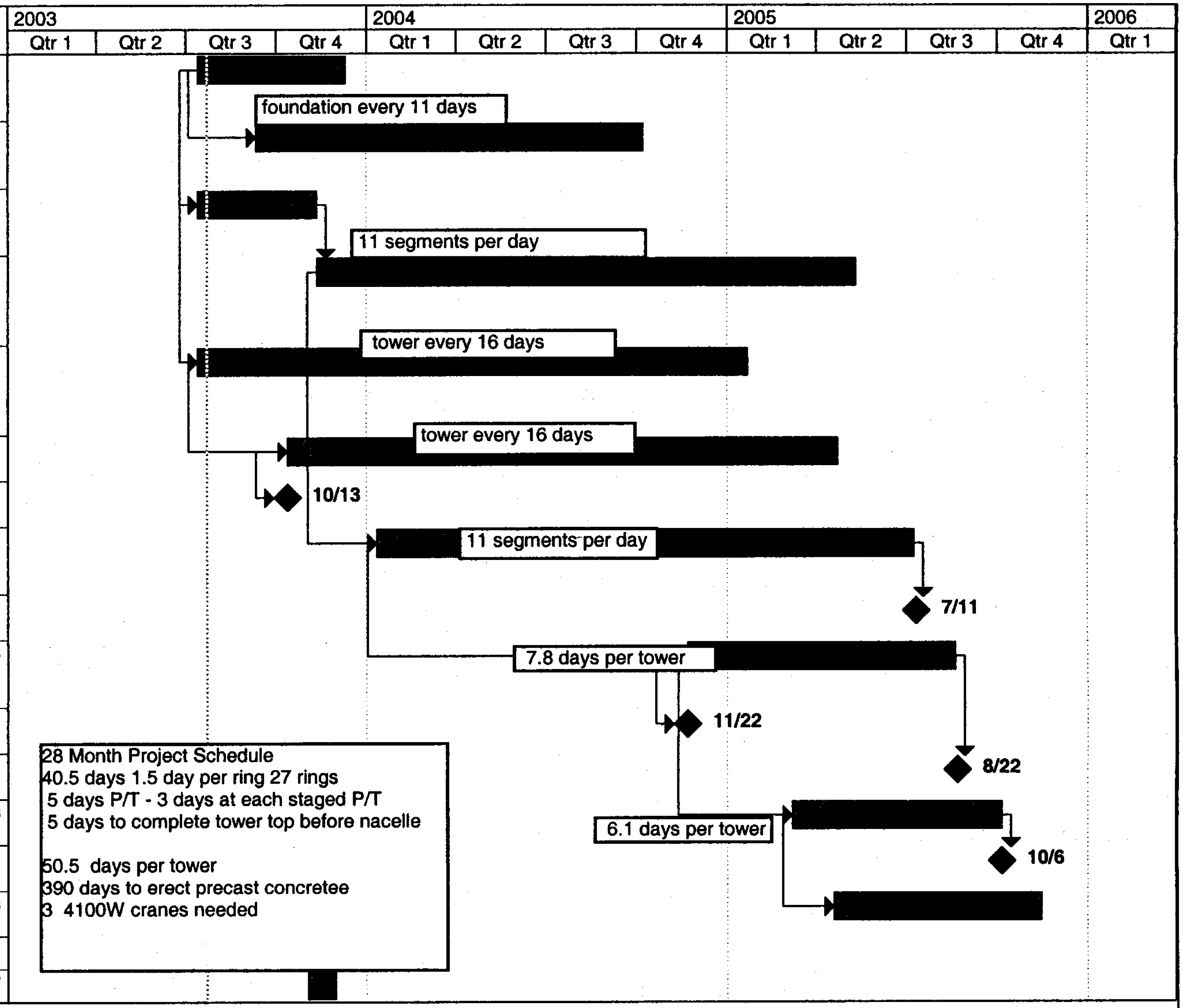
ID		Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Fabricate 25 steel tubular towers 100 m tall and ship to site	420 days?
4		Weld quartered tower sectons into circular sections on-site	450 days
5		Erect and site weld 25 tubular towers 100 m tall (17 segments per tower)	430 days?
6		Mobilize (4) LTL-600 series cranes to site	1 day?
7		Need for (4) LTL-600 series cranes complete	0 days?
8		Erect nacelle, hub & rotor at 25 m height - 50 towers using LTL-850 Crane	160 days
9		Mobilize (1) LTL- 850 cranes to site	1 day?
10		Need for (1) LTL- 850 cranes complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	150 days
13			1 day?
14			1 day?



3.6 MW 100 m All Steel
Wind Turbine Tower Schedule
25 Turbines - Wind Design

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

ID		Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 4050 precast tower segments	390 days?
5		Fabricate 25 steel tubular towers 50 m tall	400 days?
6		Erect and site weld 25 tubular towers 50 m tall	400 days?
7		Mobilize (3) 4100 W series crane to site	1 day?
8		Erect 4050 precast segments for 50 towers - Using 4100W Crane	390 days?
9		Need for (3) 4100 W series crane complete	1 day?
10		Erect nacelle, hub & rotor at 50 m height - 25 towers - Using LTL-1100 crane	195 days
11		Mobilize LTL- 1100 crane to site	1 day?
12		Need for LTL- 1100 crane complete	1 day?
13		Jack-up tubular steel towers to full 100 m height	152 days
14		Tower construction complete	1 day?
15		Install tower electrical and commission turbines	150 days
16			
17			20 days?

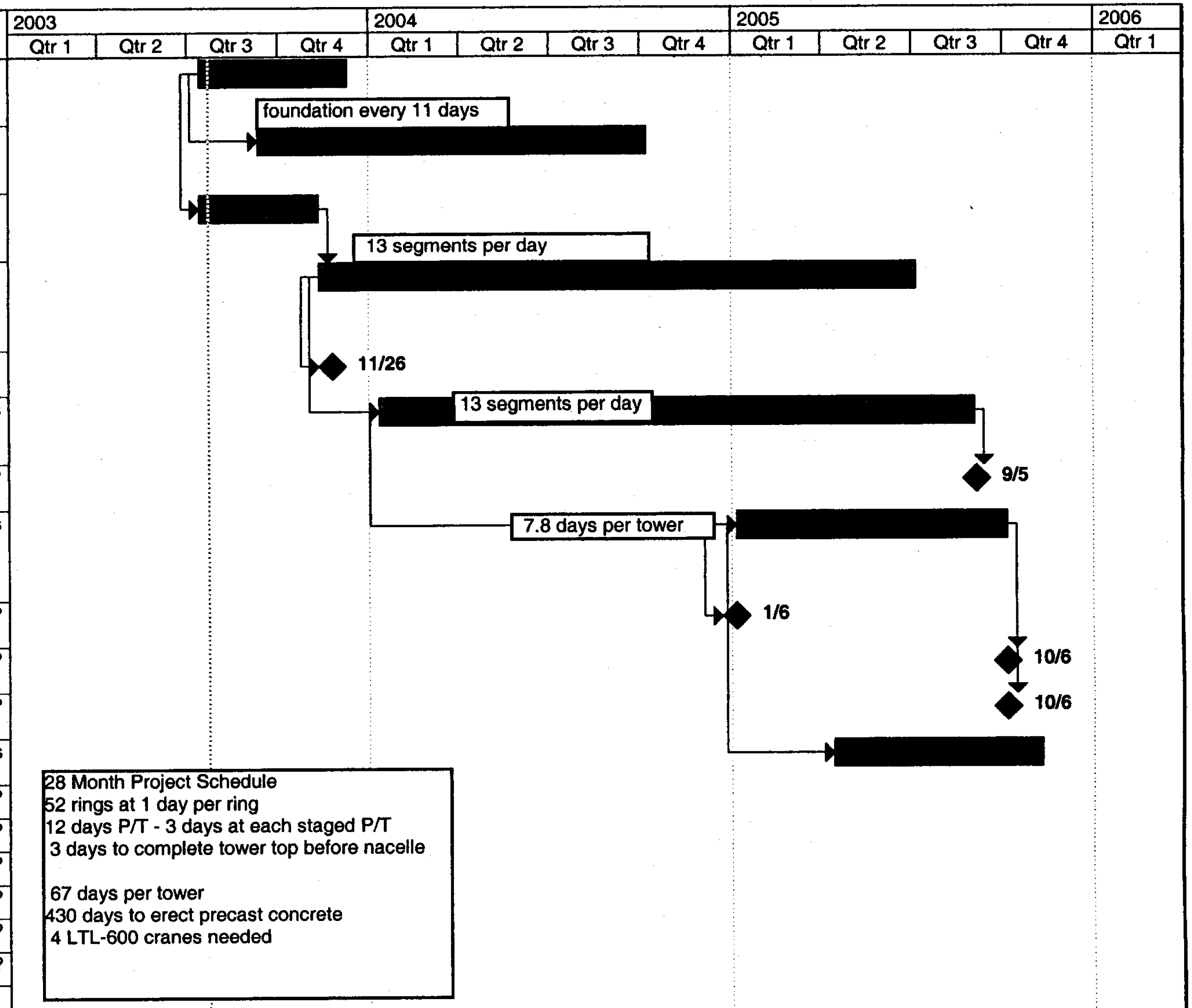


5.0 MW 100 m Hybrid
Wind Turbine Tower Schedule
25 Turbines- Earthquake Design

Task	Milestone	External Tasks
Split	Summary	External Milestone
Progress	Project Summary	Deadline

Tue 7/22/03

ID	Indicators	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Construct forms for precast segments	87 days?
4		Produce 5925 precast tower segments	430 days?
5		Mobilize (4) LTL-600 series crane to site	1 day?
6		Erect 5925 precast segments for 50 towers - Using LTL-600 cranes	430 days
7		Need for (4) LTL-600 series crane complete	1 day?
8		Erect nacelle, hub & rotor at 100 m height - 50 towers - Using LTL-850 crane	195 days
9		Mobilize 1 LTL- 1100 crane to site	1 day?
10		Need for 1 LTL- 1100 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	150 days
13			1 day?
14			1 day?
15			1 day?
16			1 day?
17			1 day?
18			1 day?

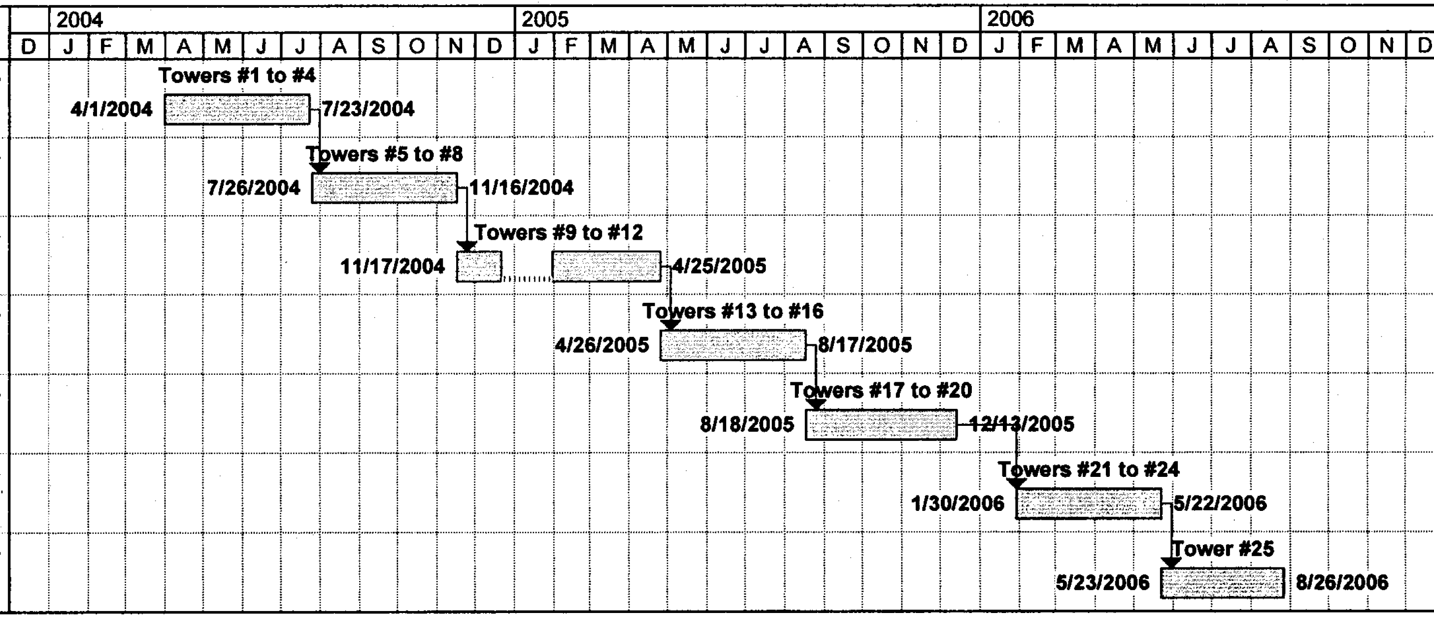


5.0 MW 100 m All Precast Concrete Wind Turbine Tower Schedule
25 Turbines - Earthquake Design

Task	Milestone	External Tasks
Split	Summary	External Milestone
Progress	Project Summary	Deadline

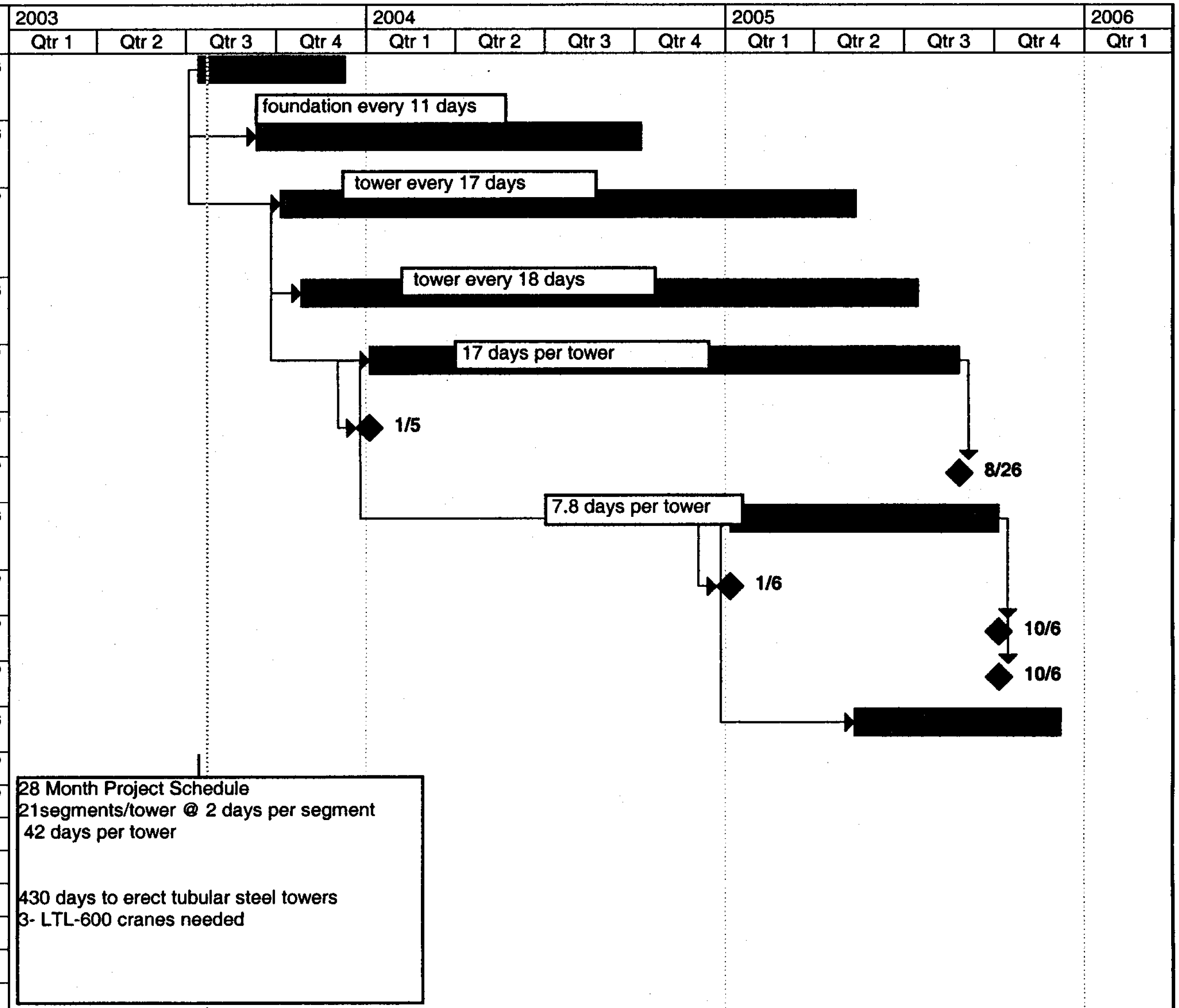
Tue 7/22/03

ID	Task Name	Duration
1	Towers #1 to #4	80 days
2	Towers #5 to #8	81 days
3	Towers #9 to #12	84 days
4	Towers #13 to #16	80 days
5	Towers #17 to #20	81 days
6	Towers #21 to #24	81 days
7	Tower #25	80 days



Cast-In-Place Concrete
Jump Formed Chimney Construction Technology

ID	ⓘ	Task Name	Duration
1		Site development and mobilization	108 days
2		Construct 25 tower foundations	281 days
3		Fabricate 25 steel tubular towers 100 m tall and ship to site	420 days?
4		Weld quartered tower sectons into circular sections on-site	450 days
5		Erect and site weld 25 tubular towers 100 m tall (21 segments per tower)	430 days?
6		Mobilize (3) LTL-600 series cranes to site	1 day?
7		Need for (3) LTL-600 series cranes complete	0 days?
8		Erect nacelle, hub & rotor at 50 m height - 25 towers Using LTL-1100 crane	195 days
9		Mobilize (1) LTL- 1100 crane to site	1 day?
10		Need for (1) LTL- 1100 crane complete	1 day?
11		Tower construction complete	1 day?
12		Install tower electrical and commission turbines	150 days
13			1 day?
14			1 day?



5.0 MW 100 m All Steel
Wind Turbine Tower Schedule
25 Turbines - Wind Design

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

APPENDIX H – Precast Concrete Segment Sizes and Weights

Segment Sizes and Weights 1.5 MW Hybrid Tower Designed for Earthquake And 1.5 MW All Concrete Tower Designed for Wind

Segment Sizes and Weights 1.5 MW Hybrid Tower Designed for Earthquake And 1.5 MW All Concrete Tower Designed for Earthquake

Segment Sizes and Weights 3.6 MW Hybrid Tower Designed for Wind And 3.6 MW All Concrete Tower Designed for Wind

Segment Sizes and Weights 3.6 MW Hybrid Tower Designed for Earthquake And 3.6 MW All Concrete Tower Designed for Earthquake

Segment Sizes and Weights 3.6 MW Hybrid Tower Designed for Earthquake And 3.6 MW All Concrete Tower Designed for Earthquake

Segment Sizes and Weights 5.0 MW Hybrid Tower Designed for Earthquake And 3.6 MW All Concrete Tower Designed for Earthquake

1.5 MW Segment Weights
All Concrete Tower Designed for Wind

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Area Sq. in	Height ft.	Weight Kips (each arc)	Weight (kg) (each arc)	Ciubic Yards (1 Arc)	Cubic yards full segment	Segment Number	Inside Diameter (in)	Outside Diameter (in)	Height ft.	Area Sq In	Weight Kips (each arc)	Weight (kg) (each arc)	Cubic Yards (1 Arc)	Cubic Yards Full Segment
									Full Height Concrete Tower			100m					
											Total Height	328	ft.				
	All concrete tower given here is designed for wind.								**26**	**78.00**	**114.00**	12.7	5429	23.9	10,859	5.91	17.7
									25	79.47	115.64	14.4	5543	27.7	12,573	6.84	20.5
	Each Horizontal segment has 3 arc segments								**24**	84.28	121.02	14.4	5924	29.6	13,436	7.31	21.9
									23	89.09	126.40	14.4	6314	31.6	14,320	7.79	23.4
									22	93.90	131.77	14.4	6713	33.6	15,225	8.29	24.9
									21	98.71	137.15	14.4	7121	35.6	16,150	8.79	26.4
	Full Height Concrete Tower								**20**	103.52	142.53	14.4	7538	37.7	17,095	9.31	27.9
			Horizontal	Arcs	50 Towers	Total Pieces			**19**	108.34	147.91	14.4	7964	39.8	18,061	9.83	29.5
	A Segments 10 ft		8	3	50	1200			**18**	113.15	153.28	14.4	8399	42.0	19,048	10.37	31.1
	B Segments 12.5 ft		5	3	50	750			**17**	117.96	158.66	14.4	8843	44.2	20,055	10.92	32.8
	C Segments 14.4 ft		12	3	50	1800			**16**	122.77	164.04	14.4	9296	46.5	21,083	11.48	34.4
	D Segments 12.7 ft		1	3	50	150			**15**	127.58	169.41	14.4	9758	48.8	22,131	12.05	36.1
									14	132.39	174.79	14.4	10229	51.1	23,200	12.63	37.9
									13	136.57	179.46	12.5	10646	46.2	20,959	11.41	34.2
									12	140.74	184.13	12.5	11069	48.0	21,792	11.86	35.6
					Total Pieces	3900			**11**	144.92	188.79	12.5	11499	49.9	22,639	12.32	37.0
									10	149.10	193.46	12.5	11936	51.8	23,499	12.79	38.4
									9	153.27	198.13	12.5	12380	53.7	24,373	13.27	39.8
									8	156.61	201.86	10	12740	44.2	20,065	10.92	32.8
									7	159.95	205.60	10	13104	45.5	20,639	11.23	33.7
									6	163.30	209.33	10	13473	46.8	21,219	11.55	34.7
									5	166.64	213.06	10	13846	48.1	21,807	11.87	35.6
									4	169.98	216.80	10	14223	49.4	22,401	12.19	36.6
									3	173.32	220.53	10	14605	50.7	23,002	12.52	37.6
									2	176.66	224.27	10	14991	52.1	23,611	12.85	38.6
									1	**180.00**	**228.00**	10	15381	53.4	24,226	13.19	39.6
									for all precast							Total yd3	838.5
												No. of segments / tower		78	10.75	av yd3 / segment	

1.5 MW Segment Weights
Tower Designed for Earthquake

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Area Sq. in	Height ft.	Weight Kips (each arc)	Weight (kg) (each arc)	Ciubic Yards (each arc)	Cubic Yards Full Segment	Segment Number	Inside Diameter (in)	Outside Diameter (in)	Height ft.	Area Sq In	Weight Kips (ea arc)	Weight (kg) (each arc)	Cubic Yards (each arc)	Cubic Yards Full Segment
											Full Height Concrete Tower			100m			
											Total Height	328	ft.				
									34	**78.00**	**114.00**	6	5429	11.3	5,161	2.79	8.38
	Towers designed for earthquake								**33**	80.87	116.54	14	5531	26.9	12,268	6.64	19.92
									32	86.19	122.55	14	5960	29.0	13,220	7.15	21.46
	Each horizontal segment has 3 arc segments								**31**	91.52	128.55	14	6401	31.1	14,199	7.68	23.05
									30	96.84	134.56	14	6855	33.3	15,205	8.23	24.68
	Concrete base tower of Hybrid tower is sized by interface with jack up steel tower.								**29**	102.16	140.68	14	7346	35.7	16,295	8.82	26.45
									28	107.49	146.81	14	7852	38.2	17,418	9.43	28.28
									27	112.81	152.93	14	8373	40.7	18,572	10.05	30.15
									26	118.14	159.05	14	8907	43.3	19,758	10.69	32.07
									25	122.51	165.18	11.5	9640	38.5	17,565	9.50	28.51
									24	126.88	170.21	11.5	10109	40.4	18,418	9.97	29.90
									23	131.26	175.24	11.5	10587	42.3	19,289	10.44	31.31
									22	135.63	180.27	11.5	11074	44.2	20,178	10.92	32.76
					Mid ht		164		**21**	**140.00**	**185.30**	11.5	11572	46.2	21,084	11.41	34.23
									20	143.62	189.45	9.5	11990	39.6	18,047	9.77	29.30
									19	147.23	193.61	9.5	12415	41.0	18,686	10.11	30.33
		Concrete Base for Hybrid Tower							**18**	150.84	197.76	9.5	12846	42.4	19,336	10.46	31.39
			Hybrid	Ft	m				**17**	154.46	201.92	9.5	13284	43.8	19,995	10.82	32.46
			Total Height	160.9	49				**16**	158.07	206.07	9.5	13729	45.3	20,664	11.18	33.55
									15	161.11	209.57	8	14109	39.2	17,883	9.68	29.03
14	**176**	**207**	9325	10	32.4	14,774	7.99	23.98	**14**	164.15	213.07	8	14493	40.3	18,370	9.94	29.82
13	176	208.62	9854	12.9	34.2	15,612	8.45	25.34	**13**	167.20	216.57	8	14882	41.3	18,863	10.21	30.62
12	176	210.24	10387	12.9	36.1	16,457	8.91	26.72	**12**	170.24	220.07	8	15276	42.4	19,362	10.48	31.43
11	176	211.85	10921	12.9	37.9	17,302	9.36	28.09	**11**	173.28	223.57	8	15674	43.5	19,867	10.75	32.25
10	176	213.47	11462	12.9	39.8	18,160	9.83	29.48	**10**	175.75	226.41	6.5	16001	36.1	16,479	8.92	26.75
9	176	215.08	12004	12.9	41.7	19,018	10.29	30.87	**9**	178.22	229.26	6.5	16332	36.9	16,819	9.10	27.30
8	176	216.7	12553	12.9	43.6	19,889	10.76	32.29	**8**	180.70	232.10	6.5	16665	37.6	17,162	9.29	27.86
7	176	218.31	13103	10.5	45.5	20,760	11.23	33.70	**7**	183.17	234.94	6.5	17001	38.4	17,509	9.47	28.42
6	176	219.92	13657	10.5	47.4	21,638	11.71	35.13	**6**	185.64	237.78	6.5	17341	39.1	17,858	9.66	28.99
5	176	221.54	14219	10.5	49.4	22,528	12.19	36.57	**5**	188.11	240.63	6.5	17684	39.9	18,211	9.85	29.56
4	176	223.15	14781	10.5	51.3	23,419	12.67	38.02	**4**	190.58	243.47	6.5	18029	40.7	18,567	10.05	30.14
3	176	224.77	15351	10.5	53.3	24,322	13.16	39.48	**3**	193.06	246.31	6.5	18378	41.5	18,927	10.24	30.72
2	176	226.38	15922	10.5	55.3	25,226	13.65	40.95	**2**	195.53	249.16	6.5	18730	42.3	19,289	10.44	31.31
1	**176**	**228**	16500	10.5	57.3	26,142	14.15	42.44	**1**	**198.00**	**252.00**	6.5	19085	43.1	19,655	10.64	31.91
												328					
							Total yd3	463.06	for all precast							Total yd3	974.31
					Total segments/ Tower		42	11.03	av yd3/segment			Total segments/ Tower		102	9.55	av yd3/segment	

1.5 MW Segment Weights
Tower Designed for Earthquake

Hybrid Tower	Horizontal	Arcs	50 Towers	Total Pieces
A Segments 10.5 ft	7	3	50	1050
B Segments 12.9 ft	6	3	50	900
C Segments 10.0 ft	1	3	50	150
			Total Pieces	2100

Full Height Concrete Tower	Horizontal	Arcs	50 Towers	Total Pieces
A Segments 6.5 ft	10	3	50	1500
B Segments 8 ft	5	3	50	750
C Segments 9.5 ft	5	3	50	750
D Segments 11.5 ft	5	3	50	750
E Segments 14 ft	8	3	50	1200
F Segments 6 ft	1	3	50	150
			Total Pieces	5100

3.6 MW Segment Weights
Tower Designed for Wind

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Area Sq.	Segment Height ft.	Weight (kips) (each arc)	Weight (kg) (each arc)	Cubic Yards (each arc)	Cubic Yards Full Segment	Segment Number	Inside Diameter (in)	Outside Diameter (in)	Segment Height ft.	Area in sq	Weight Kips (each arc)	Weight (kg) (each arc)	Cubic Yards (each arc)	Cubic Yards Full Segment
												Full Height Concrete Tower	100 m				
	These towers designed for wind										Total Height	328	ft				
	Each horizontal segment has 3 arcs								33	108.00	144.00	12	7464	31.1	14,108	7.68	23.04
									32	110.49	146.91	14	7364	35.8	16,237	8.84	26.52
									31	115.10	152.34	14	7822	38.0	17,248	9.39	28.17
									30	119.72	157.77	14	8293	40.3	18,287	9.95	29.86
									29	124.33	163.20	14	8777	42.7	19,354	10.54	31.61
									28	128.94	168.63	14	9274	45.1	20,450	11.13	33.40
									27	133.56	174.05	14	9784	47.6	21,574	11.74	35.23
									26	138.17	179.48	14	10307	50.1	22,726	12.37	37.11
									25	141.96	183.94	11.5	10746	42.9	19,463	10.59	31.78
									24	145.75	188.40	11.5	11193	44.7	20,274	11.04	33.11
									23	149.54	192.86	11.5	11650	46.5	21,100	11.49	34.46
									22	153.33	197.32	11.5	12114	48.4	21,942	11.94	35.83
									21	157.12	201.77	11.5	12588	50.3	22,800	12.41	37.23
									20	160.90	206.23	11.5	13070	52.2	23,674	12.89	38.66
									19	164.03	209.92	9.5	13475	44.4	20,162	10.98	32.93
	Full Height Concrete Tower								18	167.17	213.60	9.5	13886	45.8	20,777	11.31	33.93
			Horizontal	Arcs	50 Towers	Total Pieces			17	170.30	217.28	9.5	14303	47.2	21,401	11.65	34.95
	A Segments 6.5 ft		8	3	50	1200			16	173.43	220.97	9.5	14726	48.6	22,033	11.99	35.98
	B Segments 8 ft		5	3	50	750			15	176.56	224.65	9.5	15154	50.0	22,675	12.34	37.03
	C Segments 9.5 ft		6	3	50	900			14	179.69	228.33	9.5	15589	51.4	23,325	12.70	38.09
	D Segments 11.5 ft		6	3	50	900			13	182.32	231.43	8	15959	44.3	20,109	10.95	32.84
	E Segments 14 ft		7	3	50	1050			12	184.96	234.53	8	16334	45.4	20,581	11.20	33.61
	F Segments 12 ft		1	3	50	150			11	187.59	237.64	8	16713	46.4	21,058	11.46	34.39
									10	190.23	240.74	8	17096	47.5	21,541	11.73	35.18
					Total Pieces	4950			9	192.87	243.84	8	17483	48.6	22,029	11.99	35.97
									8	195.01	246.36	6.5	17801	40.2	18,224	9.92	29.76
									7	197.15	248.88	6.5	18122	40.9	18,552	10.10	30.30
									6	199.29	251.40	6.5	18445	41.6	18,883	10.28	30.84
									5	201.43	253.92	6.5	18771	42.4	19,217	10.46	31.38
									4	203.57	256.44	6.5	19100	43.1	19,554	10.64	31.93
									3	205.72	258.96	6.5	19432	43.9	19,893	10.83	32.49
									2	207.86	261.48	6.5	19766	44.6	20,235	11.01	33.04
									1	210.00	264.00	6.5	20103	45.4	20,581	11.20	33.61
																Total yd3	1094.23
													No. of segments / tower	99	11.05	av yd3 / segment	

3.6 MW Segment Weights
Tower Designed for Earthquake

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Area Sq.	Segment Height ft.	Weight (kips) (each arc)	Weight (kg) (each arc)	Cubic Yards (each arc)	Cubic Yards Full Segment	Segment Number	Inside Diameter (in)	Outside Diameter (in)	Segment Height ft.	Area in sq	Weight Kips (each arc)	Weight (kg) (each arc)	Cubic Yards (each arc)	Cubic Yards Full Segment
										Full Height Concrete Tower			100 m				
	These towers designed for earthquake										Total Height	328	ft				
	Each horizontal segment has 3 arcs								43	108.00	144.00	10	7125	24.7	11,222	6.11	18.33
									42	110.44	146.85	10	7357	25.5	11,587	6.31	18.92
									41	115.04	152.21	10	7803	27.1	12,289	6.69	20.07
									40	119.64	157.57	10	8260	28.7	13,010	7.08	21.25
									39	124.23	162.94	10	8730	30.3	13,749	7.48	22.45
									38	128.83	168.30	10	9211	32.0	14,507	7.90	23.69
									37	133.42	173.66	10	9705	33.7	15,285	8.32	24.96
									36	138.02	179.02	10	10210	35.5	16,081	8.75	26.26
									35	142.62	184.38	10	10727	37.2	16,896	9.20	27.59
									34	147.21	189.75	10	11257	39.1	17,729	9.65	28.95
									33	151.81	195.11	10	11798	41.0	18,582	10.12	30.35
									32	156.40	200.47	10	12352	42.9	19,454	10.59	31.77
			Concrete base for Hybrid Tower	Ft	m				31	161.00	205.83	10	12917	44.9	20,344	11.07	33.22
			Total Height	154	47				30	165.60	211.19	10	13494	46.9	21,253	11.57	34.71
									29	170.19	216.56	10	14084	48.9	22,182	12.07	36.22
									28	174.33	221.38	9	14624	45.7	20,730	11.28	33.85
									27	178.46	226.21	9	15174	47.4	21,510	11.71	35.13
26	258	306.00	21262	8	59.1	26,791	14.58	43.75	26	182.60	231.03	9	15734	49.2	22,304	12.14	36.42
25	258	306.26	21386	8	59.4	26,946	14.67	44.00	25	186.74	235.86	9	16304	51.0	23,111	12.58	37.74
24	258	306.85	21672	7	52.7	23,894	13.01	39.02	24	190.87	240.69	9	16884	52.8	23,933	13.03	39.08
23	258	307.45	21960	7	53.4	24,211	13.18	39.54	23	194.32	244.71	7.5	17374	45.2	20,523	11.17	33.51
22	258	308.04	22248	7	54.1	24,528	13.35	40.06	22	197.77	248.73	7.5	17871	46.5	21,110	11.49	34.47
21	258	308.64	22536	7	54.8	24,846	13.52	40.57	21	201.21	252.75	7.5	18375	47.9	21,705	11.82	35.45
20	258	309.23	22825	7	55.5	25,165	13.70	41.10	20	204.66	256.77	7.5	18885	49.2	22,308	12.14	36.43
19	258	309.75	23074	6	48.1	21,805	11.87	35.61	19	207.65	260.26	6.5	19333	43.6	19,792	10.77	32.32
18	258	310.26	23322	6	48.6	22,040	12.00	35.99	18	210.64	263.74	6.5	19786	44.7	20,256	11.03	33.08
17	258	310.77	23571	6	49.1	22,275	12.13	36.38	17	213.62	267.23	6.5	20244	45.7	20,725	11.28	33.84
16	258	311.28	23821	6	49.6	22,511	12.25	36.76	16	216.61	270.71	6.5	20707	46.7	21,199	11.54	34.62
15	258	311.79	24071	6	50.1	22,747	12.38	37.15	15	219.60	274.20	6.5	21175	47.8	21,678	11.80	35.40
14	258	312.30	24321	6	50.7	22,983	12.51	37.53	14	222.13	277.15	5.5	21575	41.2	18,690	10.17	30.52
13	258	312.81	24572	6	51.2	23,220	12.64	37.92	13	224.65	280.10	5.5	21979	42.0	19,039	10.36	31.09
12	258	313.32	24823	6	51.7	23,457	12.77	38.31	12	227.18	283.05	5.5	22386	42.8	19,392	10.56	31.67
11	258	313.75	25032	5	43.5	19,713	10.73	32.19	11	229.71	285.99	5.5	22797	43.5	19,748	10.75	32.25
10	258	314.17	25242	5	43.8	19,878	10.82	32.46	10	232.01	288.68	5	23174	40.2	18,250	9.93	29.80
9	258	314.60	25452	5	44.2	20,044	10.91	32.73	9	234.31	291.36	5	23554	40.9	18,549	10.10	30.29
8	258	315.02	25663	5	44.6	20,209	11.00	33.00	8	236.60	294.04	5	23936	41.6	18,850	10.26	30.78
7	258	315.45	25873	5	44.9	20,375	11.09	33.27	7	238.90	296.72	5	24322	42.2	19,154	10.43	31.28
6	258	315.87	26084	5	45.3	20,541	11.18	33.54	6	241.20	299.40	5	24711	42.9	19,460	10.59	31.78
5	258	316.30	26296	5	45.7	20,708	11.27	33.82	5	243.36	301.92	4.7	25079	40.9	18,565	10.11	30.32
4	258	316.72	26507	5	46.0	20,874	11.36	34.09	4	245.52	304.44	4.7	25450	41.5	18,839	10.25	30.76
3	258	317.15	26719	5	46.4	21,041	11.45	34.36	3	247.68	306.96	4.7	25823	42.1	19,116	10.41	31.22
2	258	317.57	26931	5	46.8	21,208	11.54	34.63	2	249.84	309.48	4.7	26199	42.8	19,394	10.56	31.67
1	258	318	27143	5	47.1	21,375	11.64	34.91	1	252.00	312.00	4.7	26578	43.4	19,674	10.71	32.13
							Total yd3	952.68								Total yd3	1325.65
			Total segments per tower		78	12.21	Av yd3 per segment					Total segments per tower		129	10.28	Av yd3 per segment	

3.6 MW Segment Weights
Tower Designed for Earthquake

Hybrid Tower	Horizontal	Arcs	50 Towers	Total Pieces
A Segments 5 ft	11	3	50	1650
B Segments 6 ft	8	3	50	1200
C Segments 7 ft	5	3	50	750
D Segments 8 ft	2	3	50	300
			Total Pieces	3900

Full Height Concrete Tower	Horizontal	Arcs	50 Towers	Total Pieces
A Segments 4.7 ft	5	3	50	750
B Segments 5 ft	5	3	50	750
C Segments 5.5 ft	4	3	50	600
D Segments 6.5 ft	5	3	50	750
E Segments 7.5	4	3	50	600
F Segments 9 ft	5	3	50	750
G Segments 10 ft	15	3	50	2250
			Total Pieces	6450

5.0 MW Segment Weights
Tower Designed for Wind

Area Sq. in	Height ft.	Weight (kips) (each Arc)	Weight (kg) (each Arc)	Cubic Yards (each Arc)	Cubic Yards Full Segment	Segment Number	Inside Diameter (in)	Outside Diameter (in)	Height ft.	Area Sq In	Weight (kips) (each Arc)	Weight (kg) (each Arc)	Cubic Yards (each Arc)	Cubic Yards Full Segment
								Full Height Concrete Tower						
								Total Height	328	ft.	100		m	
							Each segment has 3 arc segments per level							
						38	**108.00**	**144.00**	12	7125	29.7	13,467	7.33	21.99
						37	112.20	148.97	12	7543	31.4	14,257	7.76	23.28
						36	117.24	154.93	12	8057	33.6	15,228	8.29	24.87
						35	122.29	160.90	12	8587	35.8	16,229	8.83	26.50
						34	127.33	166.86	12	9132	38.1	17,260	9.40	28.19
Horizontal	Arcs	50 Towers	Total Pieces			**33**	132.38	172.82	12	9694	40.4	18,321	9.97	29.92
9	3	50	1350			**32**	137.42	178.78	12	10271	42.8	19,413	10.57	31.70
6	3	50	900			**31**	142.47	184.74	12	10864	45.3	20,534	11.18	33.53
8	3	50	1200			**30**	147.51	190.70	12	11473	47.8	21,685	11.80	35.41
6	3	50	900			**29**	151.72	195.67	10	11993	41.6	18,889	10.28	30.85
9	3	50	1350			**28**	155.92	200.64	10	12523	43.5	19,724	10.74	32.21
						27	160.12	205.61	10	13065	45.4	20,578	11.20	33.60
						26	164.33	210.58	10	13618	47.3	21,448	11.67	35.02
		Total Pieces	5700			**25**	168.53	215.54	10	14181	49.2	22,336	12.16	36.47
						24	172.74	220.51	10	14756	51.2	23,241	12.65	37.95
						23	176.10	224.49	8	15224	42.3	19,182	10.44	31.32
						22	179.46	228.46	8	15698	43.6	19,780	10.77	32.30
						21	182.83	232.44	8	16180	44.9	20,387	11.10	33.29
						20	186.19	236.41	8	16669	46.3	21,003	11.43	34.30
						19	189.55	240.38	8	17165	47.7	21,627	11.77	35.32
						18	192.92	244.36	8	17667	49.1	22,261	12.12	36.35
						17	196.28	248.33	8	18177	50.5	22,903	12.47	37.40
						16	199.64	252.31	8	18694	51.9	23,555	12.82	38.47
						15	202.58	255.78	7	19152	46.6	21,115	11.49	34.48
						14	205.53	259.26	7	19616	47.7	21,626	11.77	35.32
						13	208.47	262.74	7	20085	48.8	22,143	12.05	36.16
						12	211.41	266.22	7	20559	50.0	22,666	12.34	37.01
						11	214.36	269.70	7	21039	51.1	23,195	12.63	37.88
						10	217.30	273.17	7	21524	52.3	23,730	12.92	38.75
						9	219.82	276.15	6	21944	45.7	20,737	11.29	33.86
						8	222.34	279.13	6	22368	46.6	21,138	11.51	34.52
						7	224.87	282.12	6	22796	47.5	21,542	11.73	35.18
						6	227.39	285.10	6	23228	48.4	21,950	11.95	35.85
						5	229.91	288.08	6	23664	49.3	22,362	12.17	36.52
						4	232.43	291.06	6	24104	50.2	22,778	12.40	37.20
						3	234.96	294.04	6	24547	51.1	23,197	12.63	37.88
						2	237.48	297.02	6	24995	52.1	23,620	12.86	38.57
						1	**240.00**	**300.00**	6	25447	53.0	24,047	13.09	39.27
													Total yd3	1288.71
						no. of segments per tower		114.00					Av yd^3/piece	11.30

5.0 MW Segment Weights
Tower Designed for Earthquake

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Area Sq. in	Height ft.	Weight (kips) (each Arc)	Weight (kg) (each Arc)	Cubic Yards (each Arc)	Cubic Yards Full Segment	Segment Number	Inside Diameter (in)	Outside Diameter (in)	Height ft.	Area Sq In	Weight (kips) (each Arc)	Weight (kg) (each Arc)	Cubic Yards (each Arc)	Cubic Yards Full Segment
											Full Height Concrete Tower						
											Total Height	328	ft.	100		m	
										Each segment has 3 arc segments per level							
									52	**102.00**	**144.00**	9	8115	25.4	11,503	6.26	18.78
									51	104.44	146.75	9	8348	26.1	11,834	6.44	19.32
									50	109.94	152.94	9	8879	27.7	12,586	6.85	20.55
									49	115.44	159.13	9	9422	29.4	13,356	7.27	21.81
									48	120.95	165.32	9	9978	31.2	14,144	7.70	23.10
									47	125.84	170.83	8	10483	29.1	13,208	7.19	21.57
									46	130.73	176.33	8	10997	30.5	13,857	7.54	22.63
									45	135.62	181.83	8	11522	32.0	14,518	7.90	23.71
									44	140.51	187.34	8	12057	33.5	15,192	8.27	24.81
									43	145.41	192.84	8	12601	35.0	15,878	8.64	25.93
									42	150.30	198.34	8	13156	36.5	16,577	9.02	27.07
									41	155.19	203.85	8	13721	38.1	17,288	9.41	28.23
									40	159.47	208.66	7	14223	34.6	15,681	8.54	25.61
									39	163.75	213.48	7	14733	35.8	16,243	8.84	26.53
									38	168.03	218.29	7	15250	37.1	16,813	9.15	27.46
									37	172.31	223.11	7	15775	38.3	17,392	9.47	28.40
									36	176.59	227.92	7	16308	39.6	17,980	9.79	29.36
		Concrete Base for Hybrid Tower							**35**	180.87	232.74	7	16849	41.0	18,576	10.11	30.33
			Hybrid	Ft	m				**34**	185.15	237.55	7	17397	42.3	19,180	10.44	31.32
			Total Height	154	49				**33**	189.43	242.37	7	17952	43.6	19,793	10.77	32.32
									32	193.71	247.18	7	18516	45.0	20,414	11.11	33.34
									31	197.38	251.31	6	19005	39.6	17,960	9.78	29.33
									30	201.05	255.44	6	19499	40.6	18,427	10.03	30.09
		Each segment has 3 arc segments							**29**	204.72	259.57	6	20000	41.7	18,900	10.29	30.86
									28	208.39	263.69	6	20505	42.7	19,378	10.55	31.64
28	**294**	**342.00**	23977	6	50.0	22,658	12.33	37.00	**27**	212.06	267.82	6	21017	43.8	19,861	10.81	32.43
27	294.0076	341.99	23970	6	49.9	22,652	12.33	36.99									0.00
26	294.2608	342.76	24262	6	50.5	22,928	12.48	37.44	**26**	215.73	271.95	6	21534	44.9	20,349	11.08	33.23
25	294.514	343.52	24555	6	51.2	23,205	12.63	37.89	**25**	219.40	276.08	6	22056	46.0	20,843	11.35	34.04
24	294.7672	344.28	24849	6	51.8	23,482	12.78	38.35	**24**	223.07	280.20	6	22585	47.1	21,343	11.62	34.85
23	295.0204	345.04	25144	6	52.4	23,761	12.93	38.80	**23**	226.74	284.33	6	23119	48.2	21,847	11.89	35.68
22	295.2736	345.80	25439	6	53.0	24,040	13.09	39.26	**22**	229.79	287.77	5	23568	40.9	18,560	10.10	30.31
21	295.5268	346.56	25735	6	53.6	24,320	13.24	39.72	**21**	232.85	291.21	5	24021	41.7	18,916	10.30	30.89
20	295.78	347.32	26032	6	54.2	24,601	13.39	40.17	**20**	235.91	294.65	5	24478	42.5	19,276	10.49	31.48
19	296.0121	348.02	26305	5.5	50.2	22,787	12.40	37.21	**19**	238.97	298.09	5	24939	43.3	19,639	10.69	32.07
18	296.2442	348.71	26579	5.5	50.8	23,024	12.53	37.60	**18**	242.02	301.53	5	25403	44.1	20,005	10.89	32.67
17	296.4763	349.41	26853	5.5	51.3	23,262	12.66	37.99	**17**	245.08	304.97	5	25872	44.9	20,374	11.09	33.27
16	296.7084	350.11	27128	5.5	51.8	23,500	12.79	38.38	**16**	248.14	308.41	5	26345	45.7	20,746	11.29	33.88

5.0 MW Segment Weights
Tower Designed for Earthquake

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Area Sq. in	Height ft.	Weight (kips) (each Arc)	Weight (kg) (each Arc)	Cubic Yards (each Arc)	Cubic Yards Full Segment
15	296.9405	350.81	27404	5.5	52.3	23,739	12.92	38.77
14	297.1726	351.50	27680	5.5	52.9	23,978	13.05	39.16
13	297.4047	352.20	27958	5.5	53.4	24,218	13.18	39.55
12	297.6368	352.90	28235	5.5	53.9	24,459	13.31	39.94
11	297.8689	353.60	28514	5.5	54.5	24,700	13.45	40.34
10	298.101	354.29	28793	5.5	55.0	24,942	13.58	40.73
9	298.312	354.93	29047	5	50.4	22,875	12.45	37.35
8	298.523	355.56	29302	5	50.9	23,075	12.56	37.68
7	298.734	356.20	29557	5	51.3	23,276	12.67	38.01
6	298.945	356.83	29813	5	51.8	23,478	12.78	38.34
5	299.156	357.46	30070	5	52.2	23,680	12.89	38.67
4	299.367	358.10	30327	5	52.7	23,883	13.00	39.00
3	299.578	358.73	30585	5	53.1	24,086	13.11	39.33
2	299.789	359.37	30843	5	53.5	24,289	13.22	39.66
1	**300**	**360.00**	31102	5	54.0	24,493	13.33	40.00
		Total segments per tower			84		Total yd3	1083.33
		Av yd^3 per segment			12.90			
Hybrid Tower								
			Horizontal	Arcs	50 Towers	Total Pieces		
A Segments 5 ft			9	3	50	1350		
B Segments 5.5 ft			10	3	50	1500		
C Segments 6 ft			9	3	50	1350		
					Total Pieces	4200		

Segment Number	Inside Diameter (in)	Outside Diameter (in)	Height ft.	Area Sq In	Weight (kips) (each Arc)	Weight (kg) (each Arc)	Cubic Yards (each Arc)	Cubic Yards Full Segment
15	251.20	311.85	5	26821	46.6	21,122	11.50	34.49
14	254.25	315.29	5	27301	47.4	21,500	11.70	35.11
13	257.31	318.73	5	27786	48.2	21,881	11.91	35.73
12	260.37	322.17	5	28274	49.1	22,266	12.12	36.36
11	263.43	325.61	5	28766	49.9	22,653	12.33	36.99
10	266.48	329.04	5	29262	50.8	23,044	12.54	37.63
9	269.54	332.48	5	29762	51.7	23,437	12.76	38.27
8	272.60	335.92	5	30266	52.5	23,834	12.97	38.92
7	275.66	339.36	5	30773	53.4	24,234	13.19	39.57
6	278.71	342.80	5	31285	54.3	24,637	13.41	40.23
5	281.77	346.24	5	31800	55.2	25,043	13.63	40.90
4	284.83	349.68	5	32320	56.1	25,452	13.85	41.56
3	287.89	353.12	5	32843	57.0	25,864	14.08	42.24
2	290.94	356.56	5	33370	57.9	26,279	14.30	42.91
1	**294.00**	**360.00**	5	33901	58.9	26,697	14.53	43.60
		Total segments per tower			156		Total yd3	1643.44
							Av Y^3/ piece	10.53
Full Height Concrete Tower								
			Horizontal	Arcs	50 Towers	Total Pieces		
A Segments 5 ft			22	3	50	3300		
B Segments 6 ft			9	3	50	1350		
C Segments 7 ft			9	3	50	1350		
D Segments 8 ft			7	3	50	1050		
E Segments 9 ft			5	3	50	750		
					Total Pieces	7800		

APPENDIX I – Cost of Energy Calculations

Input From BERGER/ABAM Estimates for COE Calculation

Table APP I-1 All tubular steel towers
Table APP I-2 Hybrid steel concrete towers
Table APP I-3 All precast concrete towers
Table APP I-4 All cast-in-place concrete towers

Table APP I-5 Tabulation of Estimated Tower, Nacelle, and Rotor Assembly and Installation Costs

Table APP I-6 Tabulation of Transportation Costs for Blade, Hub, Nacelle and Towers from WindPACT Technical Area 2 Study (Reference 17)

Table APP I – 7 COE- Comparison of BERGER/ABAM All Steel Towers with WindPACT Turbine Rotor Design Study (Reference 26)

Table APP I - 8 COE – 100 m Hub Height – All Steel Concrete Towers

Table APP I - 9 COE – 100 m Hub Height – Hybrid Steel Concrete Towers

Table APP I – 10 COE – 100 m Hub Height – All Precast Concrete Towers

Table APP I-11 COE – 100 m Hub Height – Cast-In-Place Concrete Towers

Input From BERGER/ABAM Estimates to COE Calculation									
All Tubular Steel Towers	1.5 MW (W) Estimate	OH and Profit	1.5 MW COE	3.6 MW (W) Estimate	OH and Profit	3.6 MW COE	5.0 MW (W) Estimate	OH and Profit	5.0 MW COE
Total Tower Cost Installed - 50 tower project	$1,363,156			$2,293,759			$2,956,356		
Minus Access road	$19,546	1.3	$25,410	$19,546	1.3	$25,410	$19,546	1.3	$25,410
Minus Site Offices	$4,000	1.3	$5,200	$4,000	1.3	$5,200	$4,000	1.3	$5,200
Minus Misc equip move in	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Mob & Site Dev.	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Other Equip Rental	$5,600	1.3	$7,280	$5,600	1.3	$7,280	$5,600	1.3	$7,280
Minus Foundation	$139,297	1.3	$181,086	$200,104	1.3	$260,135	$272,728	1.3	$354,546
Minus Assy & Installation	$219,728	1.3	$285,646	$420,954	1.3	$547,240	$564,413	1.3	$733,737
Minus Tower Transport to Site	$47,085	1.3	$61,211	$132,732	1.3	$172,552	$163,350	1.3	$212,355
Tower Cost for COE Calculation			**$792,123**			**$1,270,742**			**$1,612,628**

Table APP I -1
Input from BERGER/ABAM Estimates for COE Calculation – All Tubular Steel Towers

Input From BERGER/ABAM Estimates to COE Calculation									
Hybrid Steel Concrete Towers	1.5 MW (E) Estimate	OH and Profit	1.5 MW COE	3.6 MW (E) Estimate	OH and Profit	3.6 MW COE	5.0 MW (E) Estimate	OH and Profit	5.0 MW COE
Total Tower Cost Installed - 50 tower project	$1,402,721			$2,380,653			$3,242,075		
Minus Access road	$19,546	1.3	$25,410	$19,546	1.3	$25,410	$19,546	1.3	$25,410
Minus Site Offices	$4,000	1.3	$5,200	$4,000	1.3	$5,200	$4,000	1.3	$5,200
Minus Misc equip move in	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Mob & Site Dev.	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Other Equip Rental	$5,600	1.3	$7,280	$5,600	1.3	$7,280	$5,600	1.3	$7,280
Minus Foundation	$171,949	1.3	$223,534	$310,326	1.3	$403,424	$350,204	1.3	$455,265
Minus Assy & Installation	$135,931	1.3	$176,710	$211,718	1.3	$275,233	$385,564	1.3	$501,233
Minus Tower Transport to Site	$69,270	1.3	$90,051	$157,440	1.3	$204,672	$266,400	1.3	$346,320
Tower Cost for COE Calculation			**$869,336**			**$1,454,234**			**$1,896,167**

Table APP I -2
Input from BERGER/ABAM Estimates for COE Calculation –
Hybrid Steel Concrete Steel Towers

Input From BERGER/ABAM Estimates to COE Calculation									
All Precast Concrete Towers	1.5 MW (W) Estimate	OH and Profit	1.5 MW COE	3.6 MW (W) Estimate	OH and Profit	3.6 MW COE	5.0 MW (W) Estimate	OH and Profit	5.0 MW COE
Total Tower Cost Installed - 50 tower project	$1,581,707			$2,026,608			$2,402,928		
Minus Access road	$19,546	1.3	$25,410	$19,546	1.3	$25,410	$19,546	1.3	$25,410
Minus Site Offices	$4,000	1.3	$5,200	$4,000	1.3	$5,200	$4,000	1.3	$5,200
Minus Misc equip move in	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Mob & Site Dev.	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Other Equip Rental	$5,600	1.3	$7,280	$5,600	1.3	$7,280	$5,600	1.3	$7,280
Minus Foundation	$185,725	1.3	$241,443	$285,510	1.3	$371,163	$336,037	1.3	$436,848
Minus Assy & Installation	$275,282	1.3	$357,867	$338,303	1.3	$439,794	$373,204	1.3	$485,165
Minus Tower Transport to Site	$85,800	1.3	$111,540	$108,900	1.3	$141,570	$125,400	1.3	$163,020
Tower Cost for COE Calculation			**$827,768**			**$1,030,991**			**$1,274,805**

Table APP I -3
Input from BERGER/ABAM Estimates for COE Calculation –
All Precast Concrete Steel Towers

Input From BERGER/ABAM Estimates to COE Calculation									
All Cast In Place Concrete Towers	1.5 MW (W) Estimate	OH and Profit	1.5 MW COE	3.6 MW (W) Estimate	OH and Profit	3.6 MW COE	5.0 MW (W) Estimate	OH and Profit	5.0 MW COE
Total Tower Cost Installed - 50 tower project	$1,188,150			$1,550,472			$1,872,036		
Minus Access road	$19,546	1.3	$25,410	$19,546	1.3	$25,410	$19,546	1.3	$25,410
Minus Site Offices	$4,000	1.3	$5,200	$4,000	1.3	$5,200	$4,000	1.3	$5,200
Minus Misc equip move in	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Mob & Site Dev	$2,000	1.3	$2,600	$2,000	1.3	$2,600	$2,000	1.3	$2,600
Minus Other Equip Rental	$5,600	1.3	$7,280	$5,600	1.3	$7,280	$5,600	1.3	$7,280
Minus Foundation	$185,725	1.3	$241,443	$285,422	1.3	$371,049	$333,584	1.3	$433,659
Minus Assy & Installation	$58,991	1.3	$76,688	$69,311	1.3	$90,104	$108,009	1.3	$140,412
Minus Tower Transport to Site	$42,900	1.3	$55,770	$54,450	1.3	$70,785	$130,350	1.3	$169,455
Tower Cost for COE Calculation			**$771,159**			**$975,444**			**$1,085,420**

Table APP I -4
Input from BERGER/ABAM Estimates for COE Calculation –
All Cast In Place Concrete Steel Towers

Table APP I-5
Tabulation of Estimated Tower, Nacelle, and Rotor Assembly and Installation Costs

BERGERABAM Estimated Tower, Nacelle, and Rotor Assembly and Installation Costs

7/12/2004	1.5 hybrid	1.5 all precast	1.5 cast in place	1.5 all steel	3.6 hybrid	3.6 all precast	3.6 cast in place	3.6 all steel	5.0 hybrid	5.0 all precast	5.0 cast in place	5.0 all steel
Pedestal crane	$15,000	NA	NA	NA	$20,000	NA	NA	NA	$30,000	NA	NA	NA
Mob Demob tube and element erection cranes to site	$3.985	$41,509	NA	$24,905	$5,313	$49,811	NA	$33,207	$7,970	$49,811		$41,509
Rental for tube and element erection cranes	$16,380	$163,800	NA	$93,600	$21,840	$205,920	NA	$131,040	$32,760	$205,920		$163,800
Labor to assemble crane per turbine	$1,365	$3,685	NA	$3,685	$1,365	$3,685	NA	$3,685	$1,365	$3,685		$3,685
Labor to relocate crane per turbine	$780	$1,560	NA	$1,560	$780	$1,560	NA	$1,560	$780	$1,560		$1,560
Crane cribbing cost per turbine	$131	$538	NA	$538	$131	$538	NA	$538	$131	$538		$538
Meals and lodge crane crew per turbine	$248	$605	NA	$605	$248	$605	NA	$605	$248	$605		$605
Fule cost per month/turbine	$1,801	$8,866	NA	$5,066	$2,401	$11,146	NA	$7,093	$3,601	$8,866		$8,866
Mobe Demob turbine setting crane	$8,302	$9,695	$9,695	$9,695	$9,695	$9,695	$9,695	$9,695	$22,141	$22,141	$22,141	$22,141
Rental for turbine setting cranes	$14,040	$18,443	$22,521	$18,443	$22,533	$26,600	$30,679	$26,600	$43,680	$43,680	$49,261	$43,680
Labor cost to assemble crane per turbine	$3.685	$7,332	$7,332	$7,332	$7,332	$7,332	$7,332	$7,332	$10,296	$10,296	$10,296	$10,296
Labor cost to relocate crane per turbine	$1,560	$2,730	$2,730	$2,730	$2,730	$2,730	$2,730	$2,730	$4,875	$4,875	$4,875	$4,875
Crane cribbing cost per turbine	$538	$808	$808	$808	$808	$808	$808	$808	$943	$943	$943	$943
Meals and lodge crane crew per turbine	$605	$1,161	$1,161	$1,161	$1,161	$1,161	$1,161	$1,161	$1,751	$1,751	$1,751	$1,751
Fuel cost per month/turbine	$760	$878	$1,072	$878	$1,098	$1,267	$1,461	$1,267	$1,637	$1,637	$1,846	$1,637
Weld quarter joints	$0			$0	$17,039			$51,118	$23,577			$70,732
Erect and fit tube sections	$5.320	NA	NA	$16,523	$5,844	NA	NA	$30,144	$7,979	NA	NA	$37,237
Weld field joints	**$2,505**	NA	NA	$16,065	$22,500	NA	NA	$94.464	$97,700	NA	NA	$131,200
Grout and torque base - labor	$1,612	NA	NA	$1,612	$1,934	NA	NA	$1,612	$3,063	NA	NA	$1,612
Grout and torque base - material and equip	$850	NA	NA	$850	$986	NA	NA	$850	$1,615	NA	NA	$850
Erect pedestal crane on top of steel tube	$12,896	NA	NA	NA	$12,896	NA	NA	NA	$12,896	NA	NA	
Erection and assembly of precast concrete including post tensioning included in tower cost			NA	NA			NA					
Placement of cast in place concrete including post tensioning included in tower cost	NA	NA		NA	NA	NA		NA	NA	NA		NA
Jack up steel tube for hybrid concept	$43,568	NA			$53,084	NA	NA	NA	$76,556	NA	NA	NA
Erect transition section and turbine nacelle - labor	in jack up $	$4,836	$4,836	$4,836	in jack up $	$5,642	$5,642	$5,642	in jack up $	$6,448	$6,448	$6,448
Erect hub and blades - labor	in jack up $	$4,836	$4,836	$4,836	in jack up $	$5,803	$5,803	$5,803	in jack up $	$6,448	$6,448	$6,448
Erection equipment and small cranes	in jack up $	$4,000	$4,000	$4,000	in jack up $	$4,000	$4,000	$4,000	in jack up $	$4,000	$4,000	$4,000
Cost without Overhead and profit	$135,931	$275,282	$58,991	$219,728	$211,718	$338,303	$69,311	$420,954	$385,564	$373,204	$108,009	$564,413
Overhead and profit at 30%	$40,779	$82,585	$17,697	$65,918	$63,515	$101,491	$20,793	$126,286	$115,669	$111,961	$32,403	$169,324
Total Cost	**$176,710**	**$357,867**	**$76,688**	**$285,646**	**$275,233**	**$439,794**	**$90,104**	**$547,240**	**$501,233**	**$485,165**	**$140,412**	**$733,737**
WindPACT Tech Area 2 figure 4-14												
Assembly welding +crane range	$55,500	to	$87,000		$144,000	to	$432,000		$225,000	to	$790,000	
WindPACT tower heights	84 m				119 m				154 m			

Transport Costs for Rotors, Hub, Nacelle, and Towers													
7/19/2004													
	$/kW	Height ratio	1.5 MW	$/kW	Height ratio	3.0 MW	$/kW	Height ratio	3.6 MW	$/kW	Height ratio	5.0 MW	
Blade Transport													
Per Figure 3-4 (Grand Forks)	$3.00	NA	$4,500	$4.75		$14,250	5.50	NA	$19,800	$5.50	NA	$27,500	
Hub Transport													
Per Figure 3.5 Reference 17		NA	$3,800			$5,000		NA	$5,900		NA	$7,200	
Nacelle Transport													
Per Figure 3-6 Reference 17	$7.00	NA	$10,500	$13.00		$39,000	20.00	NA	$72,000	$57.00	NA	$285,000	
Tower Transport													
Per Scenario 2 Fig 3-7 Ref 17													
Hybrid WindPACT	$27.00	0.5952	$24,107				48.00	0.4202	$72,605	$51.00	0.3247	$82,792	
Hybrid B/A			$23,070	ok			ok		$71,640	ok		$88,200	ok
Precast Segment Transport			$46,200						$85,800			$178,200	
Total Transport Hybrid Towers			$69,270						$157,440			$266,400	
100m WindPACT	$27.00	1.1905	$48,214				48.00	0.8403	$145,210	$51.00	0.6494	$165,584	
100 m B/A			$47,085	ok					$132,732	ok		$163,350	ok

Table APP I-6
Tabulation of Transportation Costs for Blade, Hub, Nacelle and Towers from WindPACT Technical Area 2 Study (Reference 17)

COE - 100 m Hub Height - All Steel Towers Comparison with Reference 26								
Rating	kW	B/A 1.5 MW (100m)	Ref 26 - 1.5 MW (84 m)	Ref 26 - 3.0 MW (119 m) (Note 2)	3.6/3.0 factor	B/A 3.6 MW (100 m) (Note 1)	B/A 5.0 MW (100 m)	Ref 26 5.0 MW (154 m)
rotor dia		70.5	70	99		108.4	128	128
Rotor (Note 2)	$	**$247,530**	**$247,530**	**$727,931**	1.312	**$954,879**	**$1,484,426**	**$1,484,426**
blades (Note 2)	$	$147,791	$147,791	$437,464			$905,903	$905,903
hub (Note 2)	$	$64,191	$64,191	$213,027			$429,307	$429,307
pitch mechanism and bearings (Note 2)	$	$35,548	$35,548	$77,440			$149,216	$149,216
Drive train, nacelle (Note 2)	$	**$562,773**	**$562,773**	**$1,282,002**	1.279	**$1,639,679**	**$2,474,260**	**$2,474,260**
Low speed shaft (Note 2)	$	$19,857	$19,857	$56,263			$120,903	$120,903
Bearings (Note 2)	$	$12,317	$12,317	$41,436			$101,834	$101,834
gearbox (Note 2)	$	$150,880	$150,880	$357,224			$697,062	$697,062
mechanical brake, HS coupling (Note 2)	$	$2,984	$2,984	$5,968			$9,947	$9,947
generator (Note 2)	$	$97,500	$97,500	$195,000			$325,000	$325,000
variable speed electroincs (Note 2)	$	$100,500	$100,500	$201,000			$335,000	$335,000
yaw drive and bearing (Note 2)	$	$12,092	$12,092	$28,213			$109,705	$109,705
main frame (Note 2)	$	$63,992	$63,992	$192,115			$433,627	$433,627
electrical connections (Note 2)	$	$60,000	$60,000	$120,000			$200,000	$200,000
hydraulic system (Note 2)	$	$6,750	$6,750	$13,500			$22,500	$22,500
nacelle cover (Note 2)	$	$35,901	$35,901	$71,283			$118,682	$118,682
Control, safety system (Note 2)	$	**$10,200**	**$10,200**	**$10,490**	1.008	**$10,577**	**$10,780**	**$10,780**
Tower (Note 3)	$	**$792,123**	**$183,828**	**$551,415**		**$1,270,742**	**$1,612,628**	**$1,176,152**
Balance of Station	$	**$672,580**	**$388,411**	**$873,312**		**$1,410,765**	**$2,187,096**	**$2,458,244**
Foundations (Note 5)	$	$68,742	$48,513	$76,765		$76,765	$108,094	$108,094
Tower Transportation (Note 3)(Note 6)	$	$61,211	$32,204	$195,160		$172,552	$212,355	$992,450
Blade Transportation (Note 4)	$	$4,500	$4,500	$14,250		$19,800	$27,500	$27,500
Hub Transportation (Note 4)	$	$3,800	$3,800	$5,000		$5,900	$7,200	$7,200
Nacelle Transportation (Note 4)	$	$10,500	$10,500	$39,000		$72,000	$285,000	$285,000
Roads, civil works (Note 2)	$	$78,931	$78,931	$136,359	1.200	$163,631	$255,325	$255,325
Assembly and installation (Note 3)	$	$285,646	$50,713	$112,714		$547,240	$733,737	$224,790
Electrical interface/connections (Note 2)	$	$126,552	$126,552	$224,196	1.200	$269,035	$431,500	$431,500
Permits, engineering (Note 2)	$	$32,698	$32,698	$69,868	1.200	$83,842	$126,385	$126,385
Initial capital cost (ICC)	$	**$2,285,206**	**$1,392,742**	**$3,445,150**		**$5,286,642**	**$7,769,190**	**$7,603,862**
Initial capital cost (ICC)	$/kw	$1,523	$928	$1,148		$1,469	$1,554	$1,521
Net annual energy production	kWh	**5,002,400**	**4,816,715**	**10,371,945**	1.158	**12,006,000**	**16,703,000**	**18,132,994**
Rotor	¢/kWh	0.586	0.582	0.741		0.942	1.053	0.864
Drive train, nacelle	¢/kWh	1.333	1.258	1.305		1.618	1.755	1.441
Controls	¢/kWh	0.024	0.022	0.011		0.010	0.008	0.006
Tower	¢/kWh	1.876	0.415	0.561		1.254	1.144	0.685
Balance of Station	¢/kWh	1.593	0.851	0.889		1.392	1.552	1.432
Replacement Costs	¢/kWh	0.467	0.467	0.434		0.428	0.414	0.414
O and M	¢/kWh	0.800	0.800	0.800		0.800	0.800	0.800
Total COE (10.6% charge rate Ref 26)	¢/kWh	**6.680**	**4.395**	**4.741**		**6.446**	**6.726**	**5.642**
Using 11.85% fixed charge rate for Ref 26 COE calculation			4.933	5.321				6.333
Fixed Charge Rate = 11.85% (this revised fixed charge rate increases cost of energy by 12.24% over fixed charge rate of 10.6% used in Reference 26)								
This table is taken from reference 26 " WindPACT Rotor Design Study" with the addition of								
costs from this study for TOWER, and TOWER TRANSPORTATION and ASSEMBLY AND INSTALLATION.								
Note 1. Values ratioed from 3.0 MW values.								
Note 2. All cost values from reference 26								
Note 3. Values developed form this study.								
Note 4. Cost values from reference 17 - values not broken down in Reference 26.								
Note 5. Foundation cost values used from reference 26 except 1.5 MW ratioed up by square of tower height = 1.417								
Note 6. For Ref 26 values blade, hub and nacelle transport costs from Ref 17. Remainder of Ref 26 transport cost assigned to tower.								

Table APP I – 7
COE- Comparison of BERGER/ABAM All Steel Towers with WindPACT Turbine Rotor Design Study (Reference 26)

COE - 100 m Hub Height - All Steel Towers					
Rating	kW	B/A 1.5 MW	3.0 MW Steel Ref 26 (Note 2)	B/A 3.6 MW (Note 1)	B/A 5.0 MW
Rotor (Note 2)	$	**$247,530**	**$727,931**	**$954,880**	**$1,484,426**
blades (Note 2)	$	$147,791	$437,464		$905,903
hub (Note 2)	$	$64,191	$213,027		$429,307
pitch mechanism and bearings (Note 2)	$	$35,548	$777,440		$149,216
Drive train, nacelle (Note 2)	$	**$562,773**	**$1,282,002**	**$1,639,679**	**$2,474,260**
Low speed shaft (Note 2)	$	$19,857	$56,263		$120,903
Bearings (Note 2)	$	$12,317	$41,436		$101,834
gearbox (Note 2)	$	$150,880	$357,224		$697,062
mechanical brake, HS coupling (Note 2)	$	$2,984	$5,968		$9,947
generator (Note 2)	$	$97,500	$195,000		$325,000
variable speed electroincs (Note 2)	$	$100,500	$201,000		$335,000
yaw drive and bearing (Note 2)	$	$12,092	$28,213		$109,705
main frame (Note 2)	$	$63,992	$192,115		$433,627
electrical connections (Note 2)	$	$60,000	$120,000		$200,000
hydraulic system (Note 2)	$	$6,750	$13,500		$22,500
nacelle cover (Note 2)	$	$35,901	$71,283		$118,682
Control, safety system (Note 2)	$	**$10,200**	**$10,490**	**$10,577**	**$10,780**
Tower (Note 3)	$	**$792,123**	**$551,415**	**$1,270,742**	**$1,612,628**
Balance of Station	$	**$672,580**	**$873,312**	**$1,410,765**	**$2,187,096**
Foundations (Note 5)	$	$68,742	$76,765	$76,765	$108,094
Tower Transportation (Note 3) (Note 6)	$	$61,211	$195,160	$172,552	$212,355
Blade Transportation (Note 4)	$	$4,500	$14,250	$19,800	$27,500
Hub Transportation (Note 4)	$	$3,800	$5,000	$5,900	$7,200
Nacelle Transportation (Note 4)	$	$10,500	$39,000	$72,000	$285,000
Roads, civil works (Note 2)	$	$78,931	$136,359	$163,631	$255,325
Assembly and installation (Note 2)	$	$285,646	$112,714	$547,240	$733,737
Electrical interface/connections (Note 2)	$	$126,552	$224,196	$269,035	$431,500
Permits, engineering (Note 2)	$	$32,698	$69,868	$83,842	$126,385
Initial capital cost (ICC)	$	**$2,285,206**	**$3,445,150**	**$5,286,643**	**$7,769,190**
Initial capital cost (ICC)	$/kW	$1,523	$1,148	$1,469	$1,554
Net annual energy production	kWh	**5,002,400**	**10,371,945**	**12,006,000**	**16,703,000**
Rotor	¢/kWh	0.586		0.942	1.053
Drive train, nacelle	¢/kWh	1.333		1.618	1.755
Controls	¢/kWh	0.024		0.010	0.008
Tower	¢/kWh	1.876		1.254	1.144
Balance of Station	¢/kWh	1.593		1.392	1.552
Replacement Costs	¢/kWh	0.467		0.124	0.414
O and M	¢/kWh	0.800		0.800	0.800
Total COE	¢/kWh	**6.681**		**6.486**	**6.780**

Fixed Charge Rate = 11.85%

This table is taken from reference 26 " WindPACT Rotor Design Study" with the addition of costs from this study for TOWER, TOWER TRANSPORTATION and ASSEMBLY AND INSTALLATION.

Note 1. Values ratioed from 3.0 MW values.

Note 2. All cost values from reference 26

Note 3. Values developed form this study.

Note 4. Cost values from reference 17 - values not broken down in reference 26

Note 5. Foundation cost values used from Reference 26 except 1.5 MW ratioed up by square of tower height = 1.417

Note 6. For Ref 26 values blade, hub and nacelle transport costs from Ref 17. Remainder of Ref 26 transport cost asigned to tower.

Table APP I - 8
COE – 100 m Hub Height – All Steel Concrete Towers

COE - 100 m Hub Height - Hybrid Steel Concrete Towers					
Rating	**kW**	**B/A 1.5 MW**	**3.0 MW Steel Ref 26 (Note 2)**	**B/A 3.6 MW (Note 1)**	**B/A 5.0 MW**
Rotor (Note 2)	$	**$247,530**	**$727,931**	**$954,880**	**$1,484,426**
blades (Note 2)	$	$147,791	$437,464		$905,903
hub (Note 2)	$	$64,191	$213,027		$429,307
pitch mechanism and bearings (Note 2)	$	$35,548	$77,440		$149,216
Drive train, nacelle (Note 2)	$	**$562,773**	**$1,282,002**	**$1,639,679**	**$2,474,260**
Low speed shaft (Note 2)	$	$19,857	$56,263		$120,903
Bearings (Note 2)	$	$12,317	$41,436		$101,834
gearbox (Note 2)	$	$150,880	$357,224		$697,062
mechanical brake, HS coupling (Note 2)	$	$2,984	$5,968		$9,947
generator (Note 2)	$	$97,500	$195,000		$325,000
variable speed electroincs (Note 2)	$	$100,500	$201,000		$335,000
yaw drive and bearing (Note 2)	$	$12,092	$28,213		$109,705
main frame (Note 2)	$	$63,992	$192,115		$433,627
electrical connections (Note 2)	$	$60,000	$120,000		$200,000
hydraulic system (Note 2)	$	$6,750	$13,500		$22,500
nacelle cover (Note 2)	$	$35,901	$71,283		$118,682
Control, safety system (Note 2)	$	**$10,200**	**$10,490**	**$10,577**	**$10,780**
Tower (Note 3)	$	**$869,336**	**$551,415**	**$1,454,234**	**$1,896,167**
Balance of Station	$	**$592,484**	**$873,312**	**$1,170,878**	**$2,088,557**
Foundations (Note 5)	$	$68,742	$76,765	$76,765	$108,094
Tower Transportation (Note 3)	$	$90,051	$195,160	$204,672	$346,320
Blade Transportation (Note 4)	$	$4,500	$14,250	$19,800	$27,500
Hub Transportation (Note 4)	$	$3,800	$5,000	$5,900	$7,200
Nacelle Transportation (Note 4)	$	$10,500	$39,000	$72,000	$285,000
Roads, civil works (Note 2)	$	$78,931	$136,359	$163,631	$255,325
Assembly and installation (Note 2)	$	$176,710	$112,714	$275,233	$501,233
Electrical interface/connections (Note 2)	$	$126,552	$224,196	$269,035	$431,500
Permits, engineering (Note 2)	$	$32,698	$69,868	$83,842	$126,385
Initial capital cost (ICC)	$	**$2,282,323**	**$3,445,150**	**$5,230,248**	**$7,954,190**
Initial capital cost (ICC)	$/kW	$1,522	$1,148	$1,453	$1,591
Net annual energy production	kWh	**5,002,400**	**10,371,945**	**12,006,000**	**16,703,000**
Rotor	¢/kWh	0.586		0.942	1.053
Drive train, nacelle	¢/kWh	1.333		1.618	1.755
Controls	¢/kWh	0.024		0.010	0.008
Tower	¢/kWh	2.059		1.435	1.345
Balance of Station	¢/kWh	1.404		1.156	1.482
Replacement Costs	¢/kWh	0.467		0.124	0.414
O and M	¢/kWh	0.800		0.800	0.800
Total COE	¢/kWh	**6.675**		**6.430**	**6.911**
Fixed Charge Rate = 11.85%					
This table is taken from reference 24 "Results from the WindPACT Rotor Design Study" with the addition of					
costs from this study for TOWER, FOUNDATIONS, and TOWER TRANSPORTATION.					
Note 1. Values ratioed from 3.0 MW values..					
Note 2. All cost values from reference 26					
Note 3. Values developed form this study.					
Note 4. Cost values from reference 17 - values not broken down in reference 26.					
Note 5. Foundation cost values used from reference 26, except 1.5 MW ratioed up by square of tower height = 1.417					
Note 6. For Ref 26 values blade, hub and nacelle transport costs from Ref 17. Remainder of Ref 26 transport cost asigned to tower.					

Table APP I - 9
COE – 100 m Hub Height – Hybrid Steel Concrete Towers

COE - 100 m Hub Height - All Precast Concrete Towers					
Rating	kW	B/A 1.5 MW	3.0 MW Steel Rf 26 (Note 2)	B/A 3.6 MW (Note 1)	B/A 5.0 MW
Rotor (Note 2)	$	**$247,530**	**$727,931**	**$954,879**	**$1,484,426**
blades (Note 2)	$	$147,791	$437,464		$905,903
hub (Note 2)	$	$64,191	$213,027		$429,307
pitch mechanism and bearings (Note 2)	$	$35,548	$77,040		$149,216
Drive train, nacelle (Note 2)	$	**$562,773**	**$1,282,002**	**$1,639,679**	**$2,474,260**
Low speed shaft (Note 2)	$	$19,857	$56,263		$120,903
Bearings (Note 2)	$	$12,317	$41,436		$101,834
gearbox (Note 2)	$	$150,880	$357,224		$697,062
mechanical brake, HS coupling (Note 2)	$	$2,984	$5,968		$9,947
generator (Note 2)	$	$97,500	$195,000		$325,000
variable speed electroincs (Note 2)	$	$100,500	$201,000		$335,000
yaw drive and bearing (Note 2)	$	$12,092	$28,213		$109,705
main frame (Note 2)	$	$63,992	$192,115		$433,627
electrical connections (Note 2)	$	$60,000	$120,000		$200,000
hydraulic system (Note 2)	$	$6,750	$13,500		$22,500
nacelle cover (Note 2)	$	$35,901	$71,283		$118,682
Control, safety system (Note 2)	$	**$10,200**	**$10,490**	**$10,577**	**$10,780**
Tower (Note 3)	$	**$827,768**	**$551,415**	**$1,030,991**	**$1,274,805**
Balance of Station	$	**$795,130**	**$873,312**	**$1,272,337**	**$1,889,189**
Foundations (Note 3)	$	$68,742	$76,765	$76,765	$108,094
Tower Transportation (Note 3)	$	$111,540	$195,160	$141,570	$163,020
Blade Transportation (Note 4)	$	$4,500	$14,250	$19,800	$27,500
Hub Transportation (Note 4)	$	$3,800	$5,000	$5,900	$7,200
Nacelle Transportation (Note 4)	$	$10,500	$39,000	$72,000	$285,000
Roads, civil works (Note 2)	$	$78,931	$136,359	$163,631	$255,325
Assembly and installation (Note 2)	$	$357,867	$112,714	$439,794	$485,165
Electrical interface/connections (Note 2)	$	$126,552	$224,196	$269,035	$431,500
Permits, engineering (Note 2)	$	$32,698	$69,868	$83,842	$126,385
Initial capital cost (ICC)	$	**$2,443,401**	**$3,445,150**	**$4,908,463**	**$7,133,460**
Initial capital cost (ICC)	$/kW	**$1,629**	**$1,148**	**$1,363**	**$1,427**
Net annual energy production	kWh	5,002,400	10,371,945	12,006,000	16,703,000
Rotor	¢/kWh	0.586		0.942	1.053
Drive train, nacelle	¢/kWh	1.333		1.618	1.755
Controls	¢/kWh	0.024		0.010	0.008
Tower	¢/kWh	1.961		1.018	0.904
Balance of Station	¢/kWh	1.884		1.256	1.340
Replacement Costs	¢/kWh	0.467		0.124	0.414
O and M	¢/kWh	0.800		0.800	0.800
Total COE	¢/kWh	7.056		6.113	6.329

Fixed Charge Rate = 11.85%

This table is taken from reference 26 " WindPACT Rotor Design Study" with the addition of costs from this study for TOWER, TOWER TRANSPORTATION, and ASSEMBLY AND INSTALLATION.

Note 1. Values ratioed from 3.0 MW values.

Note 2. All cost values from reference 26

Note 3. Values developed form this study.

Note 4. Cost values from reference 17 - values not broken down in reference 26.

Note 5. Foundation cost values used from reference 26, except 1.5 MW ratioed up by square of tower height = 1.417

Note 6. For Ref 26 values blade, hub and nacelle transport costs from Ref 17. Remainder of Ref 26 transport cost asigned to tower.

Table APP I – 10
COE – 100 m Hub Height – All Precast Concrete Towers

COE - 100 m Hub Height - All Cast in Place Concrete Towers					
Rating	kW	B/A 1.5 MW	3.0 MW Steel Ref 26 (Note 2)	B/A 3.6 MW (Note 1)	B/A 5.0 MW
Rotor (Note 2)	$	**$247,530**	**$727,931**	**$954,879**	**$1,484,426**
blades (Note 2)	$	$147,791	$437,464		$905,903
hub (Note 2)	$	$64,191	$213,027		$429,307
pitch mechanism and bearings (Note 2)	$	$35,548	$77,440		$149,216
Drive train, nacelle (Note 2)	$	**$562,773**	**$1,282,002**	**$1,639,679**	**$2,474,260**
Low speed shaft (Note 2)	$	$19,857	$56,263		$120,903
Bearings (Note 2)	$	$12,317	$41,436		$101,834
gearbox (Note 2)	$	$150,880	$357,224		$697,062
mechanical brake, HS coupling (Note 2)	$	$2,984	$5,968		$9,947
generator (Note 2)	$	$97,500	$195,000		$325,000
variable speed electroincs (Note 2)	$	$100,500	$201,000		$335,000
yaw drive and bearing (Note 2)	$	$12,092	$28,213		$109,705
main frame (Note 2)	$	$63,992	$192,115		$433,627
electrical connections (Note 2)	$	$60,000	$120,000		$200,000
hydraulic system (Note 2)	$	$6,750	$13,500		$22,500
nacelle cover (Note 2)	$	$35,901	$71,283		$118,682
Control, safety system (Note 2)	$	**$10,200**	**$10,490**	**$10,577**	**$10,780**
Tower (Note 3)	$	**$771,159**	**$551,415**	**$975,444**	**$1,085,420**
Balance of Station	$	**$458,181**	**$873,312**	**$851,862**	**$1,550,871**
Foundations (Note 3)	$	$68,742	$76,765	$76,765	$108,094
Tower Transportation (Note 3)	$	$55,770	$195,160	$70,785	$169,455
Blade Transportation (Note 4)	$	$4,500	$14,250	$19,800	$27,500
Hub Transportation (Note 4)	$	$3,800	$5,000	$5,900	$7,200
Nacelle Transportation (Note 4)	$	$10,500	$39,000	$72,000	$285,000
Roads, civil works (Note 2)	$	$78,931	$136,359	$163,631	$255,325
Assembly and installation (Note 2)	$	$76,688	$112,714	$90,104	$140,412
Electrical interface/connections (Note 2)	$	$126,552	$224,196	$269,035	$431,500
Permits, engineering (Note 2)	$	$32,698	$69,868	$83,842	$126,385
Initial capital cost (ICC)	$	**$2,049,843**	**$3,445,150**	**$4,432,441**	**$6,605,757**
Initial capital cost (ICC)	$/kW	**$1,367**	**$1,148**	**$1,231**	**$1,321**
Net annual energy production	kWh	**5,002,400**	**10,371,945**	**12,006,000**	**16,703,000**
Rotor	¢/kWh	0.586		0.942	1.053
Drive train, nacelle	¢/kWh	1.333		1.618	1.755
Controls	¢/kWh	0.024		0.010	0.008
Tower	¢/kWh	1.827		0.963	0.770
Balance of Station	¢/kWh	1.085		0.841	1.100
Replacement Costs	¢/kWh	0.467		0.124	0.414
O and M	¢/kWh	0.800		0.800	0.800
Total COE	¢/kWh	**6.124**		**5.643**	**5.954**

Fixed Charge Rate = 11.85%

This table is taken from reference 26 " WindPACT Rotor Design Study" with the addition of costs from this study for TOWER, TOWER TRANSPORTATION and ASSSEMBLY AND INSTALLATION.

Note 1. Values ratioed from 3.0 MW values.

Note 2. All cost values from reference 26

Note 3. Values developed form this study.

Note 4. Cost values from reference 17 - values not broken down in reference 26.

Note 5. Foundation cost values used from Reference 26, except 1.5 MW ratioed up by square of tower heights = 1.417

Note 6. For Ref 26 values blade, hub and nacelle transport costs from Ref 17. Remainder of Ref 26 transport cost asigned to tower.

Table APP I-11
COE – 100 m Hub Height – Cast-In-Place Concrete Towers

Appendix J – WindPACT Design Loads

The attached tower design loads were provided by representatives of Global Energy Concepts (GEC). The loads were developed from computer simulations used as input to the WindPACT Turbine Rotor Design Study (Reference 26). Scaling of the loads for rotor diameter and hub height was also done with input from GEC.

BERGER/ABAM used the attached fatigue data for the fatigue design of the all concrete and the concrete portions of the hybrid steel concrete towers. Fatigue evaluation of the tubular steel tower designs was accomplished using the Damage Equivalent Load concept as described in the text.

The contents of this Appendix are:

Coordinate directions					
	x = downwind				
	z= upwards				
	y = lateral (right hand triad)				
Extreme characteristic loads (non-factored)			at yaw bearing	at 100m tower base	
	Non-operating loads (EWM50)				
		extreme 3-sec wind speed	59.5		m/s
		Fx min		NA	kN
		Fx max	190	NA	kN
		Fy min	-308	NA	kN
		Fy max	334	NA	kN
		Fz min	-832	NA	kN
		Mx min	-1,237	-38,036	kN m
		Mx max	3,398	36,508	kN m
		My min	-1,713	-11,729	kN m
		My max	-341	11,270	kN m
		Mz min	-1,009	-922	kN m
		Mz max	1,966	1,756	kN m
	Operating loads (EOG50)				
		extreme 3-sec wind speed	35		m/s
		Fx min	52	NA	kN
		Fx max	401	NA	kN
		Fy min	-39	NA	kN
		Fy max	29	NA	kN
		Fz min	-832	NA	kN
		Mx min	574	-2,767	kN m
		Mx max	889	5,428	kN m
		My min	-1,168	-3,976	kN m
		My max	-592	32,607	kN m
		Mz min	-232	-298	kN m
		Mz max	94	32	kN m
Operating fatigue loads (full range, non factored)					
	Equivalent fatigue damage loads (m=4, Ni=5.29E8)				
		Fx	57		kN
		Mx	121	3,171	kN m
		My	554	8,311	kN m
		Mz	551		kN m

Bending moment values at 100m tower base have been obtained by linear extrapolation of the 84m hub ht WindPACT resultsusing 1.5A08C01V07cAdm

1). while the peak 3-second wind speed at the rotor hub height is 59.5 m/s, this occurrence does not necessarily coincide with any of the peak loads. Such as combination will be conservative.

2). For the EWM50 load, the IEC code specifies a wind shear exponent of 0.10 whereas an exponent of 0.2 is specified for all operating conditions.

Safety Factors:
The loads presented in this spreadsheet are characteristic values and do not contain any load factors.

The partial safety factor for the extreme loads is 1.35 (as specified by the IEC code), for both the operating and the stationary conditions.

The partial safety factor for fatigue loads, as specified by the IE C code is 1.0. However, the same code also specifies a "consequences of failure" factor of 1.15 for all critical loads plus a minimum material safety factor of 1.10.

Unfactored Loads for 1.5 MW Wind Turbine Tower
100 M Hub Height
(from Reference 26)
Table J-1

Coordinate directions		**these values are directly from WindPACT Design….3.0A09C02V01 Adm with no adjustments**			
	x = downwind	**for different rotor diameter or hub heights**			
	z= upwards				
	y = lateral (right hand triad)				
Extreme characteristic loads (non-factored)			at yaw bearing	at 119m tower base	
	Non-operating loads (EWM50)				
		extreme 3-sec wind speed	59.5		m/s
		Fx min	-114	NA	kN
		Fx max	529.8	NA	kN
		Fy min	-734	NA	kN
		Fy max	657	NA	kN
		Fz min	-2400	NA	kN
		Mx min	-2971	-84940	kN m
		Mx max	10786	101040	kN m
		My min	-6356	-46647	kN m
		My max	-3120	43903	kN m
		Mz min	-2614	-2623	kN m
		Mz max	4535	4093	kN m
	Operating loads (EOG50)				
		extreme 3-sec wind speed	35		m/s
		Fx min	-198	NA	kN
		Fx max	997	NA	kN
		Fy min	-67.9	NA	kN
		Fy max	42.9	NA	kN
		Fz min	-2380	NA	kN
		Mx min	1338	-4111	kN m
		Mx max	3242	11015	kN m
		My min	-5866	-57698	kN m
		My max	-2821	90538	kN m
		Mz min	-1215	-1449	kN m
		Mz max	273	93	kN m
Operating fatigue loads (full range, non factored)					
	Equivalent fatigue damage loads (m=4, Ni=5.29E8)				
		Fx	119		kN
		Mx	329	9015	kN m
		My	1651	19615	kN m
		Mz	1689		kN m

1). while the peak 3-second wind speed at the rotor hub height is 59.5 m/s, this occurrence does not necessarily coincide with any of the peak loads. Such as combination will be conservative.

2). For the EWM50 load, the IEC code specifies a wind shear exponent of 0.10 whereas an exponent of 0.2 is specified for all operating conditions.

Safety Factors:
The loads presented in this spreadsheet are characteristic values and do not contain any load factors.

The partial safety factor for the extreme loads is 1.35 (as specified by the IEC code), for both the operating and the stationary conditions.

The partial safety factor for fatigue loads, as specified by the IE C code is 1.0. However, the same code also specifies a "consequences of failure" factor of 1.15 for all critical loads plus a minimum material safety factor of 1.10.

Unfactored Loads for 3.0 MW Wind Turbine Tower
119 m Hub Height
(from Reference 26)
Table J-2

Coordinate directions			**these values are are obtained from page 3.0MW_WP by linear inter/extrapolating**				
	x = downwind		**on the rotor area and hub height where appropriate**				
	z= upwards		ratio of swept areas =		1.2		
	y = lateral (right hand triad)		ratio of hub heights =		0.84		
Extreme characteristic loads (non-factored)				at yaw bearing		at 100m tower base	
	Non-operating loads (EWM50)						
		extreme 3-sec wind speed		60			m/s
		Fx min		-137		NA	kN
		Fx max		636		NA	kN
		Fy min		-881		NA	kN
		Fy max		788		NA	kN
		Fz min		-3,155		NA	kN
		Mx min		-3,905		-93,791	kN m
		Mx max		14,179		111,569	kN m
		My min		-8,950		-51,508	kN m
		My max		-4,696		48,478	kN m
		Mz min		-3,436		-3,448	kN m
		Mz max		5,961		5,380	kN m
	Operating loads (EOG50)						
		extreme 3-sec wind speed		35			m/s
		Fx min		-238		NA	kN
		Fx max		1,196		NA	kN
		Fy min		-81		NA	kN
		Fy max		51		NA	kN
		Fz min		-3,129		NA	kN
		Mx min		1,759		-4,539	kN m
		Mx max		4,262		12,163	kN m
		My min		-8,950		-63,711	kN m
		My max		-4,696		99,973	kN m
		Mz min		-1,597		-1,905	kN m
		Mz max		359		122	kN m
Operating fatigue loads (full range, non factored)							
	Equivalent fatigue damage loads (m=4, Ni=5.29E8)						
		Fx		143			kN
		Mx		432		9,087	kN m
		My		2,170		19,772	kN m
		Mz		2,220			kN m

1). while the peak 3-second wind speed at the rotor hub height is 59.5 m/s, this occurrence does not necessarily coincide with any of the peak loads. Such as combination will be conservative.

2). For the EWM50 load, the IEC code specifies a wind shear exponent of 0.10 whereas an exponent of 0.2 is specified for all operating conditions.

Safety Factors:
The loads presented in this spreadsheet are characteristic values and do not contain any load factors.

The partial safety factor for the extreme loads is 1.35 (as specified by the IEC code), for both the operating and the stationary conditions.

The partial safety factor for fatigue loads, as specified by the IE C code is 1.0. However, the same code also specifies a "consequences of failure" factor of 1.15 for all critical loads plus a minimum material safety factor of 1.10.

Unfactored Loads for 3.6 MW Wind Turbine Tower
100 m Hub Height
(from Reference 26)
Table J-3

Coordinate directions		**these values are directly from WindPACT Design….5.0A04C01V00c with no adjustments**			
	x = downwind	**for different rotor diameter or hub heights**			
	z= upwards				
	y = lateral (right hand triad)				
Extreme characteristic loads (non-factored)			at yaw bearing	at 154m tower base	
	Non-operating loads (EWM50)				
		extreme 3-sec wind speed	59.5		m/s
		Fx min	-106	NA	kN
		Fx max	199	NA	kN
		Fy min	-543	NA	kN
		Fy max	527	NA	kN
		Fz min	-4998	NA	kN
		Mx min	-7445	-183900	kN m
		Mx max	21820	206300	kN m
		My min	-18440	-42960	kN m
		My max	-7272	64550	kN m
		Mz min	-5834	-5510	kN m
		Mz max	5624	5603	kN m
	Operating loads (EOG50)				
		extreme 3-sec wind speed	35		m/s
		Fx min	-358	NA	kN
		Fx max	1057	NA	kN
		Fy min	-128	NA	kN
		Fy max	83	NA	kN
		Fz min	-4879	NA	kN
		Mx min	2946	-76300	kN m
		Mx max	5822	83730	kN m
		My min	-13810	-165200	kN m
		My max	-9457	207900	kN m
		Mz min	-3714	-3966	kN m
		Mz max	767	805	kN m
Operating fatigue loads (full range, non factored)					
	Equivalent fatigue damage loads (m=4, Ni=5.29E8)				
		Fx	**197**		kN
		Mx	**722**	**21792**	kN m
		My	**3616**	**46037**	kN m
		Mz	**3483**		kN m

1). while the peak 3-second wind speed at the rotor hub height is 59.5 m/s, this occurrence does not necessarily coincide with any of the peak loads. Such as combination will be conservative.

2). For the EWM50 load, the IEC code specifies a wind shear exponent of 0.10 whereas an exponent of 0.2 is specified for all operating conditions.

Safety Factors:
The loads presented in this spreadsheet are characteristic values and do not contain any load factors.

The partial safety factor for the extreme loads is 1.35 (as specified by the IEC code), for both the operating and the stationary conditions.

The partial safety factor for fatigue loads, as specified by the IE C code is 1.0. However, the same code also specifies a "consequences of failure" factor of 1.15 for all critical loads plus a minimum material safety factor of 1.10.

Unfactored Loads for 5.0 MW Wind Turbine Tower
154 m Hub Height
(from Reference 26)
Table J-4

Coordinate directions

x = downwind

z= upwards

y = lateral (right hand triad)

these values are are obtained from page 5.0MW_WP by linear inter/extrapolating
on the rotor area and hub height where appropriate

ratio of swept areas = 1

ratio of hub heights = 0.649351

Extreme characteristic loads (non-factored)		at yaw bearing	at 100m tower base	
Non-operating loads (EWM50)				
	extreme 3-sec wind speed	60		m/s
	Fx min	-106	NA	kN
	Fx max	199	NA	kN
	Fy min	-543	NA	kN
	Fy max	527	NA	kN
	Fz min	-4,998	NA	kN
	Mx min	-7,445	-119,416	kN m
	Mx max	21,820	133,961	kN m
	My min	-18,440	-27,896	kN m
	My max	-7,272	41,916	kN m
	Mz min	-5,834	-5,510	kN m
	Mz max	5,624	5,603	kN m
Operating loads (EOG50)				
	extreme 3-sec wind speed	35		m/s
	Fx min	-358	NA	kN
	Fx max	1,057	NA	kN
	Fy min	-128	NA	kN
	Fy max	83	NA	kN
	Fz min	-4,879	NA	kN
	Mx min	2,946	-49,545	kN m
	Mx max	5,822	54,370	kN m
	My min	-18,440	-107,273	kN m
	My max	-7,272	135,000	kN m
	Mz min	-3,714	-3,966	kN m
	Mz max	767	805	kN m
Operating fatigue loads (full range, non factored)				
Equivalent fatigue damage loads (m=4, Ni=5.29E8)				
	Fx	197		kN
	Mx	722	14,151	kN m
	My	3,616	29,894	kN m
	Mz	3,483		kN m

1). while the peak 3-second wind speed at the rotor hub height is 59.5 m/s, this occurrence does not necessarily coincide with any of the peak loads. Such as combination will be conservative.

2). For the EWM50 load, the IEC code specifies a wind shear exponent of 0.10 whereas an exponent of 0.2 is specified for all operating conditions.

Safety Factors:
The loads presented in this spreadsheet are characteristic values and do not contain any load factors.

The partial safety factor for the extreme loads is 1.35 (as specified by the IEC code), for both the operating and the stationary conditions.

The partial safety factor for fatigue loads, as specified by the IE C code is 1.0. However, the same code also specifies a "consequences of failure" factor of 1.15 for all critical loads plus a minimum material safety factor of 1.10.

Unfactored Loads for 5.0 MW Wind Turbine Tower
100 m Hub Height
(from Reference 26)
Table J-5

The Envelope Force for Wind Turbine Loads at 100m Hub Height					
		No SafetyFactor			
		Thrust	Moment	Vertical	Torsion
		Fh(kN)	Mh(kNm)	Fz(kN)	Mz(kN)
1.5 MW	EWM50	384	3,805	832	1,966
	EOG50	403	1,468	832	232
	Fat. Load	57	567		551
3.6 MW	EWM50	1,086	16,767	3,155	5,961
	EOG50	1,199	9,913	3,129	1,597
	Fat. Load	143	2,213		2,220
5.0 MW	EWM50	578	28,568	4,998	5,834
	EOG50	1,065	19,337	4,879	3,714
	Fat. Load	197	3,687		3,483
	Including	SafetyFactor	1.35		
		Thrust	Moment	Vertical	Torsion
		Fh(kN)	Mh(kNm)	Fz(kN)	Mz(kN)
1.5 MW	EWM50	518	5,137	1,123	2,654
	EOG50	544	1,982	1,123	313
3.6 MW	EWM50	1,466	22,635	4,259	8,048
	EOG50	1,619	13,382	4,224	2,156
5.0 MW	EWM50	781	38,567	6,747	7,876
	EOG50	1,437	26,105	6,587	5,014
	GE Load	SafetyFactor	1.35		
		Thrust	Moment	Vertical	Torsion
		Fh(kN)	Mh(kNm)	Fz(kN)	Mz(kN)
1.5 MW	EWM50	514	4,358	1320	3,310
	Diff.(%)	-0.84%	-15.17%	17.52%	24.71%
	Fat. Load	52	550		
	Diff.(%)	-8.77%	-3.01%		
3.6 MW	EWM50	1,245	14,413	3,406	13,879
	Diff.(%)	-15.13%	-36.32%	-20.03%	72.46%
	Fat. Load	148	2355		
	Diff.(%)	3.85%	6.40%		
5.0 MW	EWM50	1,693	22,244	4,685	22,110
	Diff.(%)	116.85%	-42.32%	-30.56%	180.73%
	Fat. Load	207	3760		
	Diff.(%)	5.08%	1.97%		

Envelope Forces for Wind Turbine Loads
100 m Hub Height
(after Reference 26)

Table J-6

		source: Design…..1.5A08C01V07cAdm.xls									
shaft Fx		shaft Mx		yaw bearing My		yaw bearing Mz		tower base (84m) Mx		tower base (84m) My	
range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr
kN		kN m		kN m		kN m		kN m		kN m	
2.41	1.14E+09	6.53	2.06E+09	28.085	3.77E+08	27.5	3.48E+08	170.91	3.44E+08	364.98	3.74E+08
7.23	1.96E+08	19.59	2.63E+08	84.255	1.08E+08	82.5	1.08E+08	512.73	24146438	1094.94	28965583
12.05	93514324	32.65	73526196	140.425	93746704	137.5	80618819	854.55	34639084	1824.9	29391732
16.87	51435838	45.71	30762200	196.595	84966412	192.5	75616509	1196.37	36025442	2554.86	25170414
21.69	28025755	58.77	14006684	252.765	76415879	247.5	69929530	1538.19	28532723	3284.82	20590049
26.51	16475983	71.83	7431032	308.935	60553101	302.5	62975126	1880.01	19283320	4014.78	17595962
31.33	11391410	84.89	5021933	365.105	49398792	357.5	52435869	2221.83	14295876	4744.74	11746408
36.15	9400521	97.95	4517031	421.275	35180278	412.5	45411784	2563.65	9532734	5474.7	11753601
40.97	7371806	111.01	3473038	477.445	26329398	467.5	28941829	2905.47	7604252	6204.66	9693792
45.79	4887148	124.07	2129250	533.615	17875476	522.5	23824684	3247.29	6313088	6934.62	6688330
50.61	4820123	137.13	2318025	589.785	13293724	577.5	15949899	3589.11	5593309	7664.58	6801521
55.43	4948421	150.19	1531036	645.955	9376072	632.5	11836717	3930.93	3955794	8394.54	4848324
60.25	4424909	163.25	1637124	702.125	7177889	687.5	9576364	4272.75	2703168	9124.5	4690229
65.07	3877198	176.31	1381835	758.295	6088895	742.5	7398549	4614.57	2472757	9854.46	4058788
69.89	2673562	189.37	1360888	814.465	4502470	797.5	5213957	4956.39	1756321	10584.42	2924812
74.71	2382562	202.43	448314.3	870.6349	4187170	852.5	4126234	5298.21	1427485	11314.38	2870143
79.53	2391833	215.49	908327.5	926.805	2442610	907.5	2709474	5640.03	1106620	12044.34	1948244
84.35	2117561	228.55	490808.7	982.975	2371953	962.5	2278864	5981.85	920935.8	12774.3	2112592
89.17	1285822	241.61	595012.8	1039.145	1741536	1017.5	1819478	6323.67	904318	13504.26	2147659
93.99	1887277	254.67	576909.8	1095.315	1356695	1072.5	1973874	6665.49	444104.3	14234.22	1433763
98.81	954487.2	267.73	416496.4	1151.485	812039.3	1127.5	1286326	7007.31	348734.2	14964.18	1017136
103.63	1421933	280.79	87451.99	1207.655	1137348	1182.5	519423.4	7349.13	335960.2	15694.14	897270.7
108.45	1260726	293.85	311282.3	1263.825	981112.5	1237.5	629460.8	7690.95	456372.7	16424.1	846078.5
113.27	486185.3	306.91	326920.6	1319.995	285543.2	1292.5	612840.4	8032.77	198463.7	17154.06	595520.8
118.09	806948.5	319.97	206748.1	1376.165	508499.2	1347.5	425167.8	8374.59	154991.5	17884.02	764957.1
122.91	564409.9	333.03	133650.8	1432.335	591810.9	1402.5	465165.3	8716.41	154855.7	18613.98	356178.4
127.73	958291.3	346.09	137863.5	1488.505	210593.7	1457.5	399417.6	9058.231	117076.8	19343.94	327393.6
132.55	396278.2	359.15	131798.6	1544.675	291609	1512.5	243788.3	9400.05	127218.9	20073.9	152495.2
137.37	439413.1	372.21	134798.8	1600.845	237351	1567.5	112864.1	9741.87	33701.95	20803.86	282070
142.19	380942.2	385.27	139011.5	1657.015	95877.38	1622.5	244155.4	10083.69	27128.6	21533.82	81386.87
147.01	325169.8	398.33	22915.91	1713.185	64671.66	1677.5	85599.56	10425.51	35554.19	22263.78	71108.38
151.83	404230.6	411.39	0	1769.355	43979.58	1732.5	39766.89	10767.33	54257.4	22993.74	175175.3
156.65	547926	424.45	134798.8	1825.525	141845.8	1787.5	143698.3	11109.15	39766.89	23723.7	180630.8
161.47	225451.3	437.51	110734.9	1881.695	77174.17	1842.5	54257.4	11450.97	39766.89	24453.66	21063.67
166.29	229895.3	450.57	134798.8	1937.865	31341.49	1897.5	8425.392	11792.79	4212.696	25183.62	12638.28
171.11	422562.4	463.63	0	1994.035	8425.392	1952.5	64671.66	12134.61	8425.392	25913.58	48192.28
175.93	217025.9	476.69	130586.1	2050.205	87587.76	2007.5	18703.21	12476.43	8425.392	26643.54	83374.87
180.75	120917.9	489.75	0	2106.375	21063.67	2062.5	18703.21	12818.25	31341.49	27373.5	12638.28
185.57	110734.9	502.81	0	2162.545	22915.91	2117.5	35554.19	13160.07	0	28103.46	12638.28
190.39	194109.8	515.87	0	2218.715	8425.392	2172.5	4212.696	13501.89	4212.696	28833.42	64671.66
195.21	161927.6	528.93	0	2274.885	4212.696	2227.5	4212.696	13843.71	4212.696	29563.38	22915.91
200.03	0	541.99	0	2331.055	4212.696	2282.5	8425.392	14185.53	0	30293.34	0
204.85	130586.1	555.05	130586.1	2387.225	18703.21	2337.5	27128.6	14527.35	8425.392	31023.3	8425.392
209.67	4212.696	568.11	0	2443.395	0	2392.5	0	14869.17	4212.696	31753.26	0
214.49	0	581.17	0	2499.565	8425.392	2447.5	0	15210.99	4212.696	32483.22	0

Unfactored Tower Fatigue Loads
1.5 MW Turbine at 84 m Hub Height
(Reference 26)
Table J-7.1

shaft Fx			shaft Mx			yaw bearing My			yaw bearing Mz			tower base (84m) Mx			tower base (84m) My	
range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr
kN			kN m			kN m			kN m			kN m			kN m	
219.31	56246.27		594.23	0		2555.735	0		2502.5	0		15552.81	0		33213.18	0
224.13	74949.48		607.29	0		2611.905	0		2557.5	0		15894.63	0		33943.14	0
228.95	0		620.35	130586.1		2668.075	0		2612.5	0		16236.45	0		34673.1	0
233.77	0		633.41	0		2724.245	0		2667.5	0		16578.27	0		35403.06	0
238.59	134798.8		646.47	0		2780.415	4212.696		2722.5	0		16920.09	4212.696		36133.02	4212.696
243.41	0		659.53	130586.1		2836.585	0		2777.5	4212.696		17261.91	0		36862.98	0
248.23	0		672.59	0		2892.755	0		2832.5	0		17603.73	0		37592.94	0
253.05	0		685.65	0		2948.925	0		2887.5	0		17945.55	0		38322.9	0
257.87	0		698.71	0		3005.095	0		2942.5	0		18287.37	0		39052.86	0
262.69	0		711.77	0		3061.265	0		2997.5	0		18629.19	0		39782.82	0
267.51	0		724.83	0		3117.435	0		3052.5	0		18971.01	0		40512.78	0
272.33	0		737.89	0		3173.605	0		3107.5	0		19312.83	0		41242.74	0
277.15	0		750.95	0		3229.775	0		3162.5	0		19654.65	0		41972.7	0
281.97	0		764.01	0		3285.945	0		3217.5	0		19996.47	0		42702.66	0
286.79	0		777.07	0		3342.115	0		3272.5	0		20338.29	0		43432.62	0
291.61	0		790.13	0		3398.285	0		3327.5	0		20680.11	0		44162.58	0
296.43	0		803.19	0		3454.455	0		3382.5	0		21021.93	0		44892.54	0
301.25	0		816.25	0		3510.625	0		3437.5	0		21363.75	0		45622.5	0
306.07	0		829.31	0		3566.795	0		3492.5	0		21705.57	0		46352.46	0
310.89	0		842.37	0		3622.965	0		3547.5	0		22047.39	0		47082.42	0
315.71	0		855.43	0		3679.135	0		3602.5	0		22389.21	0		47812.38	0
320.53	0		868.49	0		3735.305	0		3657.5	0		22731.03	0		48542.34	0
325.35	0		881.55	0		3791.475	0		3712.5	0		23072.85	0		49272.3	0
330.17	0		894.61	0		3847.645	0		3767.5	0		23414.67	0		50002.26	0
334.99	0		907.67	0		3903.815	0		3822.5	0		23756.49	0		50732.22	0
339.81	0		920.73	0		3959.985	0		3877.5	0		24098.31	0		51462.18	0
344.63	0		933.79	0		4016.155	0		3932.5	0		24440.13	0		52192.14	0
349.45	0		946.85	0		4072.325	0		3987.5	0		24781.95	0		52922.1	0
354.27	0		959.91	0		4128.495	0		4042.5	0		25123.77	0		53652.06	0
359.09	0		972.97	0		4184.665	0		4097.5	0		25465.59	0		54382.02	0
363.91	0		986.03	0		4240.835	0		4152.5	0		25807.41	0		55111.98	0
368.73	0		999.09	0		4297.005	0		4207.5	0		26149.23	0		55841.94	0
373.55	0		1012.15	0		4353.175	0		4262.5	0		26491.05	0		56571.9	0
378.37	0		1025.21	0		4409.345	0		4317.5	0		26832.87	0		57301.86	0
383.19	0		1038.27	0		4465.515	0		4372.5	0		27174.69	0		58031.82	0
388.01	0		1051.33	0		4521.685	0		4427.5	0		27516.51	0		58761.78	0
392.83	0		1064.39	0		4577.855	0		4482.5	0		27858.33	0		59491.74	0
397.65	0		1077.45	0		4634.025	0		4537.5	0		28200.15	0		60221.7	0
402.47	0		1090.51	0		4690.195	0		4592.5	0		28541.97	0		60951.66	0
407.29	0		1103.57	0		4746.365	0		4647.5	0		28883.79	0		61681.62	0
412.11	0		1116.63	0		4802.535	0		4702.5	0		29225.61	0		62411.58	0
416.93	0		1129.69	0		4858.705	0		4757.5	0		29567.43	0		63141.54	0
421.75	0		1142.75	0		4914.875	0		4812.5	0		29909.25	0		63871.5	0
426.57	0		1155.81	0		4971.045	0		4867.5	0		30251.07	0		64601.46	0
431.39	0		1168.87	0		5027.215	0		4922.5	0		30592.89	0		65331.42	0
436.21	0		1181.93	0		5083.385	0		4977.5	0		30934.71	0		66061.38	0
441.03	0		1194.99	0		5139.555	0		5032.5	0		31276.53	0		66791.34	0
445.85	0		1208.05	0		5195.725	0		5087.5	0		31618.35	0		67521.3	0
450.67	0		1221.11	0		5251.895	0		5142.5	0		31960.17	0		68251.27	0
455.49	0		1234.17	0		5308.065	0		5197.5	0		32301.99	0		68981.22	0
460.31	0		1247.23	0		5364.235	0		5252.5	0		32643.81	0		69711.18	0
465.13	0		1260.29	0		5420.405	0		5307.5	0		32985.63	0		70441.14	0
469.95	0		1273.35	0		5476.575	0		5362.5	0		33327.45	0		71171.1	0
474.77	0		1286.41	0		5532.745	0		5417.5	0		33669.27	0		71901.06	0
479.59	0		1299.47	0		5588.915	0		5472.5	0		34011.09	0		72631.02	0

Unfactored Tower Fatigue Loads
1.5 MW Turbine at 84 m Hub Height
(Reference 26)
Table J-7.2

		obtained from page 1.5MW_WP with scaling factors applied to the range values									
			scaling factor for swept area		1						
			scaling factor for hub height		1.190476						
shaft Fx		shaft Mx		yaw bearing My		yaw bearing Mz		tower base (84m) Mx		tower base (84m)	
range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr
kN		kN m		kN m		kN m		kN m		kN m	
2.41	1141088237	6.53	2063945921	28.085	3.77E+08	27.5	3.48E+08	203.4643	3.44E+08	434.5	3.74E+08
7.23	196032387	19.59	263274538	84.255	1.08E+08	82.5	1.08E+08	610.3929	24146438	1303.5	28965583
12.05	93514324.3	32.65	73526195.6	140.425	93746704	137.5	80618819	1017.321	34639084	2172.5	29391732
16.87	51435837.9	45.71	30762200.1	196.595	84966412	192.5	75616509	1424.25	36025442	3041.5	25170414
21.69	28025754.6	58.77	14006684	252.765	76415879	247.5	69929530	1831.179	28532723	3910.5	20590049
26.51	16475983.1	71.83	7431031.97	308.935	60553101	302.5	62975126	2238.107	19283320	4779.5	17595962
31.33	11391409.9	84.89	5021932.62	365.105	49398792	357.5	52435869	2645.036	14295876	5648.5	11746408
36.15	9400520.53	97.95	4517030.6	421.275	35180278	412.5	45411784	3051.964	9532734	6517.5	11753601
40.97	7371805.64	111.01	3473037.66	477.445	26329398	467.5	28941829	3458.893	7604252	7386.5	9693792
45.79	4887148.36	124.07	2129250.41	533.615	17875476	522.5	23824684	3865.821	6313088	8255.5	6688330
50.61	4820123.16	137.13	2318025.3	589.785	13293724	577.5	15949899	4272.75	5593309	9124.5	6801521
55.43	4948420.9	150.19	1531036.48	645.955	9376072	632.5	11836717	4679.679	3955794	9993.5	4848324
60.25	4424909.24	163.25	1637124.01	702.125	7177889	687.5	9576364	5086.607	2703168	10862.5	4690229
65.07	3877197.79	176.31	1381834.65	758.295	6088895	742.5	7398549	5493.536	2472757	11731.5	4058788
69.89	2673562.32	189.37	1360888	814.465	4502470	797.5	5213957	5900.464	1756321	12600.5	2924812
74.71	2382561.9	202.43	448314.314	870.6349	4187170	852.5	4126234	6307.393	1427485	13469.5	2870143
79.53	2391832.75	215.49	908327.474	926.805	2442610	907.5	2709474	6714.322	1106620	14338.5	1948244
84.35	2117560.55	228.55	490808.697	982.975	2371953	962.5	2278864	7121.25	920935.8	15207.5	2112592
89.17	1285821.5	241.61	595012.77	1039.145	1741536	1017.5	1819478	7528.178	904318	16076.5	2147659
93.99	1887276.64	254.67	576909.841	1095.315	1356695	1072.5	1973874	7935.107	444104.3	16945.5	1433763
98.81	954487.178	267.73	416496.378	1151.485	812039.3	1127.5	1286326	8342.036	348734.2	17814.5	1017136
103.63	1421932.71	280.79	87451.9902	1207.655	1137348	1182.5	519423.4	8748.965	335960.2	18683.5	897270.7
108.45	1260725.77	293.85	311282.324	1263.825	981112.5	1237.5	629460.8	9155.893	456372.7	19552.5	846078.5
113.27	486185.254	306.91	326920.61	1319.995	285543.2	1292.5	612840.4	9562.821	198463.7	20421.5	595520.8
118.09	806948.531	319.97	206748.09	1376.165	508499.2	1347.5	425167.8	9969.75	154991.5	21290.5	764957.1
122.91	564409.909	333.03	133650.846	1432.335	591810.9	1402.5	465165.3	10376.68	154855.7	22159.5	356178.4
127.73	958291.256	346.09	137863.542	1488.505	210593.7	1457.5	399417.6	10783.61	117076.8	23028.5	327393.6
132.55	396278.165	359.15	131798.61	1544.675	291609	1512.5	243788.3	11190.54	127218.9	23897.5	152495.2
137.37	439413.144	372.21	134798.808	1600.845	237351	1567.5	112864.1	11597.46	33701.95	24766.5	282070
142.19	380942.188	385.27	139011.504	1657.015	95877.38	1622.5	244155.4	12004.39	27128.6	25635.5	81386.87
147.01	325169.785	398.33	22915.909	1713.185	64671.66	1677.5	85599.56	12411.32	35554.19	26504.5	71108.38
151.83	404230.55	411.39	0	1769.355	43979.58	1732.5	39766.89	12818.25	54257.4	27373.5	175175.3
156.65	547925.97	424.45	134798.808	1825.525	141845.8	1787.5	143698.3	13225.18	39766.89	28242.5	180630.8
161.47	225451.303	437.51	110734.937	1881.695	77174.17	1842.5	54257.4	13632.11	39766.89	29111.5	21063.67
166.29	229895.266	450.57	134798.808	1937.865	31341.49	1897.5	8425.392	14039.04	4212.696	29980.5	12638.28
171.11	422562.36	463.63	0	1994.035	8425.392	1952.5	64671.66	14445.96	8425.392	30849.5	48192.28
175.93	217025.911	476.69	130586.112	2050.205	87587.76	2007.5	18703.21	14852.89	8425.392	31718.5	83374.87
180.75	120917.926	489.75	0	2106.375	21063.67	2062.5	18703.21	15259.82	31341.49	32587.5	12638.28
185.57	110734.937	502.81	0	2162.545	22915.91	2117.5	35554.19	15666.75	0	33456.5	12638.28
190.39	194109.809	515.87	0	2218.715	8425.392	2172.5	4212.696	16073.68	4212.696	34325.5	64671.66
195.21	161927.606	528.93	0	2274.885	4212.696	2227.5	4212.696	16480.61	4212.696	35194.5	22915.91
200.03	0	541.99	0	2331.055	4212.696	2282.5	8425.392	16887.54	0	36063.5	0
204.85	130586.112	555.05	130586.112	2387.225	18703.21	2337.5	27128.6	17294.47	8425.392	36932.5	8425.392
209.67	4212.69596	568.11	0	2443.395	0	2392.5	0	17701.39	4212.696	37801.5	0
214.49	0	581.17	0	2499.565	8425.392	2447.5	0	18108.32	4212.696	38670.5	0
219.31	56246.2669	594.23	0	2555.735	0	2502.5	0	18515.25	0	39539.5	0
224.13	74949.4799	607.29	0	2611.905	0	2557.5	0	18922.18	0	40408.5	0
228.95	0	620.35	130586.112	2668.075	0	2612.5	0	19329.11	0	41277.5	0

Unfactored Tower Fatigue Loads
1.5 MW Turbine at 100 m Hub Height
(Reference 26)
Table J-8.1

shaft Fx		shaft Mx		yaw bearing My		yaw bearing Mz		tower base (84m) Mx		tower base (84m)	
range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr
kN		kN m		kN m		kN m		kN m		kN m	
233.77	0	633.41	0	2724.245	0	2667.5	0	19736.04	0	42146.5	0
238.59	134798.808	646.47	0	2780.415	4212.696	2722.5	0	20142.96	4212.696	43015.5	4212.696
243.41	0	659.53	130586.112	2836.585	0	2777.5	4212.696	20549.89	0	43884.5	0
248.23	0	672.59	0	2892.755	0	2832.5	0	20956.82	0	44753.5	0
253.05	0	685.65	0	2948.925	0	2887.5	0	21363.75	0	45622.5	0
257.87	0	698.71	0	3005.095	0	2942.5	0	21770.68	0	46491.5	0
262.69	0	711.77	0	3061.265	0	2997.5	0	22177.61	0	47360.5	0
267.51	0	724.83	0	3117.435	0	3052.5	0	22584.54	0	48229.5	0
272.33	0	737.89	0	3173.605	0	3107.5	0	22991.46	0	49098.5	0
277.15	0	750.95	0	3229.775	0	3162.5	0	23398.39	0	49967.5	0
281.97	0	764.01	0	3285.945	0	3217.5	0	23805.32	0	50836.5	0
286.79	0	777.07	0	3342.115	0	3272.5	0	24212.25	0	51705.5	0
291.61	0	790.13	0	3398.285	0	3327.5	0	24619.18	0	52574.5	0
296.43	0	803.19	0	3454.455	0	3382.5	0	25026.11	0	53443.5	0
301.25	0	816.25	0	3510.625	0	3437.5	0	25433.04	0	54312.5	0
306.07	0	829.31	0	3566.795	0	3492.5	0	25839.96	0	55181.5	0
310.89	0	842.37	0	3622.965	0	3547.5	0	26246.89	0	56050.5	0
315.71	0	855.43	0	3679.135	0	3602.5	0	26653.82	0	56919.5	0
320.53	0	868.49	0	3735.305	0	3657.5	0	27060.75	0	57788.5	0
325.35	0	881.55	0	3791.475	0	3712.5	0	27467.68	0	58657.5	0
330.17	0	894.61	0	3847.645	0	3767.5	0	27874.61	0	59526.5	0
334.99	0	907.67	0	3903.815	0	3822.5	0	28281.54	0	60395.5	0
339.81	0	920.73	0	3959.985	0	3877.5	0	28688.46	0	61264.5	0
344.63	0	933.79	0	4016.155	0	3932.5	0	29095.39	0	62133.5	0
349.45	0	946.85	0	4072.325	0	3987.5	0	29502.32	0	63002.5	0
354.27	0	959.91	0	4128.495	0	4042.5	0	29909.25	0	63871.5	0
359.09	0	972.97	0	4184.665	0	4097.5	0	30316.18	0	64740.5	0
363.91	0	986.03	0	4240.835	0	4152.5	0	30723.11	0	65609.5	0
368.73	0	999.09	0	4297.005	0	4207.5	0	31130.04	0	66478.5	0
373.55	0	1012.2	0	4353.175	0	4262.5	0	31536.97	0	67347.5	0
378.37	0	1025.2	0	4409.345	0	4317.5	0	31943.89	0	68216.5	0
383.19	0	1038.3	0	4465.515	0	4372.5	0	32350.82	0	69085.5	0
388.01	0	1051.3	0	4521.685	0	4427.5	0	32757.75	0	69954.5	0
392.83	0	1064.4	0	4577.855	0	4482.5	0	33164.68	0	70823.5	0
397.65	0	1077.5	0	4634.025	0	4537.5	0	33571.61	0	71692.5	0
402.47	0	1090.5	0	4690.195	0	4592.5	0	33978.54	0	72561.5	0
407.29	0	1103.6	0	4746.365	0	4647.5	0	34385.47	0	73430.5	0
412.11	0	1116.6	0	4802.535	0	4702.5	0	34792.39	0	74299.5	0
416.93	0	1129.7	0	4858.705	0	4757.5	0	35199.32	0	75168.5	0
421.75	0	1142.8	0	4914.875	0	4812.5	0	35606.25	0	76037.5	0
426.57	0	1155.8	0	4971.045	0	4867.5	0	36013.18	0	76906.5	0
431.39	0	1168.9	0	5027.215	0	4922.5	0	36420.11	0	77775.5	0
436.21	0	1181.9	0	5083.385	0	4977.5	0	36827.04	0	78644.5	0
441.03	0	1195	0	5139.555	0	5032.5	0	37233.97	0	79513.5	0
445.85	0	1208.1	0	5195.725	0	5087.5	0	37640.89	0	80382.5	0
450.67	0	1221.1	0	5251.895	0	5142.5	0	38047.82	0	81251.5	0
455.49	0	1234.2	0	5308.065	0	5197.5	0	38454.75	0	82120.5	0
460.31	0	1247.2	0	5364.235	0	5252.5	0	38861.68	0	82989.5	0
465.13	0	1260.3	0	5420.405	0	5307.5	0	39268.61	0	83858.5	0
469.95	0	1273.4	0	5476.575	0	5362.5	0	39675.53	0	84727.5	0
474.77	0	1286.4	0	5532.745	0	5417.5	0	40082.46	0	85596.5	0
479.59	0	1299.5	0	5588.915	0	5472.5	0	40489.39	0	86465.5	0

Unfactored Tower Fatigue Loads
1.5 MW Turbine at 100 m Hub Height
(Reference 26)
Table J-8.2

			source: Design…..3.0A09C02V01Adm.xls															
shaft Fx			shaft Mx			yaw bearing My			yaw bearing Mz			base (119m) Mx			base (119m) My			Fx range *
range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		119
kN			kN m			kN m			kN m			kN m			kN m			
3.75	1.23E+09		30	2.25E+09		230	5.18E+08		210	4.07E+08		555	4E+08		935	4.05E+08		446.25
11.25	2.03E+08		90	2.24E+08		690	1.56E+08		630	1.31E+08		1665	11181145		2805	37208797		1338.75
18.75	92718348		150	58978292		1150	98666524		1050	1.03E+08		2775	16545445		4675	17166413		2231.25
26.25	61177395		210	20540038		1610	50903770		1470	64475136		3885	16794972		6545	17633322		3123.75
33.75	36007968		270	8421670		2070	22365126		1890	32847225		4995	20441688		8415	14847083		4016.25
41.25	23124330		330	4497755		2530	11275418		2310	16106953		6105	16062985		10285	13407438		4908.75
48.75	15279107		390	3148678		2990	5359548		2730	7287158		7215	12875476		12155	9537479		5801.25
56.25	10070634		450	2665140		3450	2981990		3150	5262913		8325	11502045		14025	10150972		6693.75
63.75	7860175		510	2214517		3910	1848049		3570	2134667		9435	7610400		15895	6403889		7586.25
71.25	6492465		570	1526081		4370	987586.3		3990	1355022		10545	6646446		17765	5341399		8478.75
78.75	3872546		630	781814.9		4830	527110.3		4410	1047905		11655	5742092		19635	4772289		9371.25
86.25	3363756		690	704779.9		5290	327301.6		4830	585947.4		12765	4248585		21505	4316845		10263.75
93.75	3736480		750	750704.8		5750	102450.5		5250	237859		13875	2905741		23375	4319589		11156.25
101.25	2510661		810	1204003		6210	39766.89		5670	156336.3		14985	2881952		25245	3061705		12048.75
108.75	2659302		870	383779.1		6670	21063.67		6090	141845.8		16095	2215964		27115	3105984		12941.25
116.25	1792598		930	420437.5		7130	27128.6		6510	27128.6		17205	1731592		28985	1948502		13833.75
123.75	2147061		990	439276.5		7590	0		6930	21063.67		18315	1360123		30855	1867834		14726.25
131.25	1104999		1050	117076.8		8050	4212.696		7350	0		19425	889730.2		32725	1852907		15618.75
138.75	1791331		1110	155862.5		8510	0		7770	4212.696		20535	993661.4		34595	1599132		16511.25
146.25	2504568		1170	281087.9		8970	4212.696		8190	0		21645	435817.2		36465	1782742		17403.75
153.75	1657684		1230	41619.12		9430	0		8610	0		22755	651968.5		38335	1447337		18296.25
161.25	1207747		1290	18703.21		9890	0		9030	0		23865	296056.7		40205	1585241		19188.75
168.75	1177487		1350	143224.4		10350	0		9450	0		24975	306471.1		42075	932553		20081.25
176.25	1062768		1410	0		10810	0		9870	0		26085	465031.3		43945	994767.3		20973.75
183.75	897677.4		1470	4212.696		11270	0		10290	0		27195	192262.1		45815	570477.7		21866.25
191.25	1170230		1530	130586.1		11730	0		10710	0		28305	98237.84		47685	454380.1		22758.75
198.75	302394.2		1590	4212.696		12190	0		11130	0		29415	166985.8		49555	636894.9		23651.25
206.25	699913.8		1650	0		12650	0		11550	0		30525	116941.1		51425	416742.4		24543.75
213.75	852782.9		1710	0		13110	0		11970	0		31635	79533.77		53295	509373.6		25436.25
221.25	304477.7		1770	130586.1		13570	0		12390	0		32745	106663.2		55165	605114.8		26328.75
228.75	882738.9		1830	0		14030	0		12810	0		33855	89812.45		57035	229433.6		27221.25
236.25	915459.6		1890	0		14490	0		13230	0		34965	54765.63		58905	295348		28113.75
243.75	595068.5		1950	0		14950	0		13650	0		36075	35554.19		60775	346371.8		29006.25
251.25	578900.4		2010	0		15410	0		14070	0		37185	29489.06		62645	127218.9		29898.75
258.75	862278.1		2070	0		15870	0		14490	0		38295	35554.19		64515	110503.7		30791.25
266.25	879810		2130	0		16330	0		14910	0		39405	0		66385	75321.08		31683.75
273.75	204157.2		2190	0		16790	0		15330	0		40515	12638.28		68255	77309.94		32576.25
281.25	509238.3		2250	0		17250	0		15750	0		41625	8425.392		70125	22915.91		33468.75
288.75	601571.2		2310	0		17710	0		16170	0		42735	16850.98		71995	79162.18		34361.25
296.25	124995		2370	0		18170	0		16590	0		43845	12638.28		73865	0		35253.75
303.75	192257.6		2430	0		18630	0		17010	0		44955	0		75735	27128.6		36146.25
311.25	241563.6		2490	0		19090	0		17430	0		46065	8425.392		77605	8425.392		37038.75
318.75	123006		2550	0		19550	0		17850	0		47175	4212.696		79475	22915.91		37931.25
326.25	333121.5		2610	0		20010	0		18270	0		48285	4212.696		81345	4212.696		38823.75
333.75	237490.2		2670	0		20470	0		18690	0		49395	0		83215	12638.28		39716.25
341.25	287763.4		2730	0		20930	0		19110	0		50505	4212.696		85085	4212.696		40608.75
348.75	22915.91		2790	0		21390	0		19530	0		51615	4212.696		86955	8425.392		41501.25
356.25	146289.1		2850	0		21850	0		19950	0		52725	0		88825	0		42393.75

Unfactored Tower Fatigue Loads
3.0 MW Turbine at 119 m Hub Height
(Reference 26)
Table J-9.1

shaft Fx			shaft Mx			yaw bearing My			yaw bearing Mz			tower base (119m)			tower base (119m)			Fx range *
range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		range	cycles/20 yr		119
kN			kN m			kN m			kN m			kN m			kN m			
363.75	12638.28		2910	0		22310	0		20370	0		53835	0		90695	0		43286.25
371.25	519042.3		2970	0		22770	0		20790	0		54945	0		92565	4212.696		44178.75
378.75	79162.18		3030	0		23230	0		21210	0		56055	0		94435	0		45071.25
386.25	247291.3		3090	0		23690	0		21630	0		57165	0		96305	0		45963.75
393.75	179483.7		3150	0		24150	0		22050	0		58275	0		98175	0		46856.25
401.25	83374.87		3210	0		24610	0		22470	0		59385	0		100045	0		47748.75
408.75	60458.96		3270	0		25070	0		22890	0		60495	0		101915	4212.696		48641.25
416.25	189897.1		3330	0		25530	0		23310	0		61605	0		103785	0		49533.75
423.75	27128.6		3390	0		25990	0		23730	0		62715	0		105655	0		50426.25
431.25	4212.696		3450	0		26450	0		24150	0		63825	0		107525	0		51318.75
438.75	153502		3510	0		26910	0		24570	0		64935	0		109395	0		52211.25
446.25	60458.96		3570	0		27370	0		24990	0		66045	0		111265	0		53103.75
453.75	0		3630	0		27830	0		25410	0		67155	0		113135	0		53996.25
461.25	22915.91		3690	0		28290	0		25830	0		68265	0		115005	0		54888.75
468.75	4212.696		3750	0		28750	0		26250	0		69375	0		116875	0		55781.25
476.25	56246.27		3810	0		29210	0		26670	0		70485	0		118745	0		56673.75
483.75	18703.21		3870	0		29670	0		27090	0		71595	0		120615	0		57566.25
491.25	0		3930	0		30130	0		27510	0		72705	0		122485	0		58458.75
498.75	0		3990	0		30590	0		27930	0		73815	0		124355	0		59351.25
506.25	4212.696		4050	0		31050	0		28350	0		74925	0		126225	0		60243.75
513.75	0		4110	0		31510	0		28770	0		76035	0		128095	0		61136.25
521.25	0		4170	0		31970	0		29190	0		77145	0		129965	0		62028.75
528.75	0		4230	0		32430	0		29610	0		78255	0		131835	0		62921.25
536.25	0		4290	0		32890	0		30030	0		79365	0		133705	0		63813.75
543.75	4212.696		4350	0		33350	0		30450	0		80475	0		135575	0		64706.25
551.25	0		4410	0		33810	0		30870	0		81585	0		137445	0		65598.75
558.75	0		4470	0		34270	0		31290	0		82695	0		139315	0		66491.25
566.25	0		4530	0		34730	0		31710	0		83805	0		141185	0		67383.75
573.75	0		4590	0		35190	0		32130	0		84915	0		143055	0		68276.25
581.25	0		4650	0		35650	0		32550	0		86025	0		144925	0		69168.75
588.75	0		4710	0		36110	0		32970	0		87135	0		146795	0		70061.25
596.25	0		4770	0		36570	0		33390	0		88245	0		148665	0		70953.75
603.75	0		4830	0		37030	0		33810	0		89355	0		150535	0		71846.25
611.25	0		4890	0		37490	0		34230	0		90465	0		152405	0		72738.75
618.75	0		4950	0		37950	0		34650	0		91575	0		154275	0		73631.25
626.25	0		5010	0		38410	0		35070	0		92685	0		156145	0		74523.75
633.75	0		5070	0		38870	0		35490	0		93795	0		158015	0		75416.25
641.25	0		5130	0		39330	0		35910	0		94905	0		159885	0		76308.75
648.75	0		5190	0		39790	0		36330	0		96015	0		161755	0		77201.25
656.25	0		5250	0		40250	0		36750	0		97125	0		163625	0		78093.75
663.75	0		5310	0		40710	0		37170	0		98235	0		165495	0		78986.25
671.25	0		5370	0		41170	0		37590	0		99345	0		167365	0		79878.75
678.75	0		5430	0		41630	0		38010	0		100455	0		169235	0		80771.25
686.25	0		5490	0		42090	0		38430	0		101565	0		171105	0		81663.75
693.75	0		5550	0		42550	0		38850	0		102675	0		172975	0		82556.25
701.25	0		5610	0		43010	0		39270	0		103785	0		174845	0		83448.75
708.75	0		5670	0		43470	0		39690	0		104895	0		176715	0		84341.25
716.25	0		5730	0		43930	0		40110	0		106005	0		178585	0		85233.75
723.75	0		5790	0		44390	0		40530	0		107115	0		180455	0		86126.25
731.25	0		5850	0		44850	0		40950	0		108225	0		182325	0		87018.75
738.75	0		5910	0		45310	0		41370	0		109335	0		184195	0		87911.25
746.25	0		5970	0		45770	0		41790	0		110445	0		186065	0		88803.75

Unfactored Tower Fatigue Loads
3.0 MW Turbine at 119 m Hub Height
(Reference 26)
Table J-9.2

obtained from page 3.0MW_WP with scaling factors applied to the range values

scaling factor for swept area 1.2

scaling factor for hub height 0.84

shaft Fx range	cycles/20 yr	shaft Mx range	cycles/20 yr	yaw bearing My range	cycles/20 yr	yaw bearing Mz range	cycles/20 yr	tower base (100m) Mx range	cycles/20 yr	tower base (100m) My range	cycles/20 yr	Fx range * 100
kN		kN m		kN m		kN m		kN m		kN m		
4.5	1226374366	39.43602	2245361583	302.3429	518132697	252	407359675	559.44	399628326	942.48	405384246	450
13.5	202843556	118.3081	223634936	907.0286	156250368	756	130993513	1678.32	11181145	2827.44	37208797	1350
22.5	92718347.7	197.1801	58978292.5	1511.714	98666524	1260	103285892	2797.2	16545445	4712.4	17166413	2250
31.5	61177395.3	276.0522	20540038.2	2116.4	50903770	1764	64475136	3916.08	16794972	6597.36	17633322	3150
40.5	36007968.2	354.9242	8421669.53	2721.086	22365126	2268	32847225	5034.96	20441688	8482.32	14847083	4050
49.5	23124330	433.7963	4497754.53	3325.771	11275418	2772	16106953	6153.84	16062985	10367.28	13407438	4950
58.5	15279107.5	512.6683	3148677.91	3930.457	5359548.2	3276	7287157.7	7272.72	12875476	12252.24	9537479.5	5850
67.5	10070633.9	591.5404	2665140.29	4535.143	2981990.3	3780	5262912.7	8391.6	11502045	14137.2	10150972	6750
76.5	7860174.82	670.4124	2214516.87	5139.828	1848049	4284	2134667.2	9510.48	7610399.7	16022.16	6403888.7	7650
85.5	6492464.92	749.2845	1526080.59	5744.514	987586.27	4788	1355021.7	10629.36	6646446.4	17907.12	5341399.4	8550
94.5	3872545.59	828.1565	781814.852	6349.2	527110.31	5292	1047905.1	11748.24	5742091.8	19792.08	4772289.1	9450
103.5	3363755.92	907.0286	704779.889	6953.886	327301.56	5796	585947.45	12867.12	4248585.2	21677.04	4316844.5	10350
112.5	3736480.29	985.9006	750704.818	7558.571	102450.54	6300	237858.98	13986	2905741	23562	4319588.9	11250
121.5	2510660.83	1064.773	1204003.06	8163.257	39766.886	6804	156336.35	15104.88	2881951.8	25446.96	3061705.2	12150
130.5	2659302.13	1143.645	383779.09	8767.943	21063.673	7308	141845.83	16223.76	2215964.2	27331.92	3105983.8	13050
139.5	1792598.15	1222.517	420437.532	9372.628	27128.605	7812	27128.605	17342.64	1731591.5	29216.88	1948501.8	13950
148.5	2147060.8	1301.389	439276.516	9977.314	0	8316	21063.673	18461.52	1360122.6	31101.84	1867833.9	14850
157.5	1104999.06	1380.261	117076.826	10582	4212.696	8820	0	19580.4	889730.23	32986.8	1852906.8	15750
166.5	1791330.5	1459.133	155862.481	11186.69	0	9324	4212.696	20699.28	993661.41	34871.76	1599132.3	16650
175.5	2504567.86	1538.005	281087.935	11791.37	4212.696	9828	0	21818.16	435817.22	36756.72	1782742.4	17550
184.5	1657683.88	1616.877	41619.122	12396.06	0	10332	0	22937.04	651968.53	38641.68	1447336.6	18450
193.5	1207747.03	1695.749	18703.213	13000.74	0	10836	0	24055.92	296056.68	40526.64	1585241.2	19350
202.5	1177486.67	1774.621	143224.393	13605.43	0	11340	0	25174.8	306471.13	42411.6	932553.02	20250
211.5	1062767.73	1853.493	0	14210.11	0	11844	0	26293.68	465031.31	44296.56	994767.27	21150
220.5	897677.393	1932.365	4212.69596	14814.8	0	12348	0	27412.56	192262.13	46181.52	570477.68	22050
229.5	1170230.07	2011.237	130586.112	15419.49	0	12852	0	28531.44	98237.842	48066.48	454380.1	22950
238.5	302394.205	2090.109	4212.69596	16024.17	0	13356	0	29650.32	166985.76	49951.44	636894.94	23850
247.5	699913.848	2168.981	0	16628.86	0	13860	0	30769.2	116941.06	51836.4	416742.41	24750
256.5	852782.903	2247.853	0	17233.54	0	14364	0	31888.08	79533.772	53721.36	509373.56	25650
265.5	304477.708	2326.725	130586.112	17838.23	0	14868	0	33006.96	106663.23	55606.32	605114.83	26550
274.5	882738.913	2405.597	0	18442.91	0	15372	0	34125.84	89812.45	57491.28	229433.59	27450
283.5	915459.636	2484.47	0	19047.6	0	15876	0	35244.72	54765.627	59376.24	295348.04	28350
292.5	595068.472	2563.342	0	19652.29	0	16380	0	36363.6	35554.19	61261.2	346371.81	29250
301.5	578900.426	2642.214	0	20256.97	0	16884	0	37482.48	29489.065	63146.16	127218.88	30150
310.5	862278.103	2721.086	0	20861.66	0	17388	0	38601.36	35554.19	65031.12	110503.67	31050
319.5	879809.95	2799.958	0	21466.34	0	17892	0	39720.24	0	66916.08	75321.076	31950
328.5	204157.22	2878.83	0	22071.03	0	18396	0	40839.12	12638.281	68801.04	77309.94	32850
337.5	509238.308	2957.702	0	22675.71	0	18900	0	41958	8425.3919	70686	22915.909	33750
346.5	601571.16	3036.574	0	23280.4	0	19404	0	43076.88	16850.977	72570.96	79162.176	34650
355.5	124995.044	3115.446	0	23885.09	0	19908	0	44195.76	12638.281	74455.92	0	35550
364.5	192257.573	3194.318	0	24489.77	0	20412	0	45314.64	0	76340.88	27128.605	36450
373.5	241563.646	3273.19	0	25094.46	0	20916	0	46433.52	8425.3919	78225.84	8425.3919	37350
382.5	123005.987	3352.062	0	25699.14	0	21420	0	47552.4	4212.696	80110.8	22915.909	38250
391.5	333121.506	3430.934	0	26303.83	0	21924	0	48671.28	4212.696	81995.76	4212.696	39150
400.5	237490.156	3509.806	0	26908.51	0	22428	0	49790.16	0	83880.72	12638.281	40050
409.5	287763.359	3588.678	0	27513.2	0	22932	0	50909.04	4212.696	85765.68	4212.696	40950
418.5	22915.909	3667.55	0	28117.89	0	23436	0	52027.92	4212.696	87650.64	8425.3919	41850
427.5	146289.127	3746.422	0	28722.57	0	23940	0	53146.8	0	89535.6	0	42750
436.5	12638.281	3825.294	0	29327.26	0	24444	0	54265.68	0	91420.56	0	43650

Unfactored Tower Fatigue Loads
3.6 MW Turbine at 100 m Hub Height
(Reference 26)
Table J-10.1

shaft Fx range kN	cycles/20 yr	shaft Mx range kN m	cycles/20 yr	yaw bearing My range kN m	cycles/20 yr	yaw bearing Mz range kN m	cycles/20 yr	tower base (100m) Mx range kN m	cycles/20 yr	tower base (100m) My range kN m	cycles/20 yr	Fx range * 100
445.5	519042.265	3904.166	0	29931.94	0	24948	0	55384.56	0	93305.52	4212.696	44550
454.5	79162.1759	3983.038	0	30536.63	0	25452	0	56503.44	0	95190.48	0	45450
463.5	247291.342	4061.91	0	31141.31	0	25956	0	57622.32	0	97075.44	0	46350
472.5	179483.714	4140.783	0	31746	0	26460	0	58741.2	0	98960.4	0	47250
481.5	83374.8719	4219.655	0	32350.69	0	26964	0	59860.08	0	100845.4	0	48150
490.5	60458.9629	4298.527	0	32955.37	0	27468	0	60978.96	0	102730.3	4212.696	49050
499.5	189897.113	4377.399	0	33560.06	0	27972	0	62097.84	0	104615.3	0	49950
508.5	27128.6049	4456.271	0	34164.74	0	28476	0	63216.72	0	106500.2	0	50850
517.5	4212.69596	4535.143	0	34769.43	0	28980	0	64335.6	0	108385.2	0	51750
526.5	153502.021	4614.015	0	35374.11	0	29484	0	65454.48	0	110270.2	0	52650
535.5	60458.9629	4692.887	0	35978.8	0	29988	0	66573.36	0	112155.1	0	53550
544.5	0	4771.759	0	36583.49	0	30492	0	67692.24	0	114040.1	0	54450
553.5	22915.909	4850.631	0	37188.17	0	30996	0	68811.12	0	115925	0	55350
562.5	4212.69596	4929.503	0	37792.86	0	31500	0	69930	0	117810	0	56250
571.5	56246.2669	5008.375	0	38397.54	0	32004	0	71048.88	0	119695	0	57150
580.5	18703.213	5087.247	0	39002.23	0	32508	0	72167.76	0	121579.9	0	58050
589.5	0	5166.119	0	39606.91	0	33012	0	73286.64	0	123464.9	0	58950
598.5	0	5244.991	0	40211.6	0	33516	0	74405.52	0	125349.8	0	59850
607.5	4212.69596	5323.863	0	40816.28	0	34020	0	75524.4	0	127234.8	0	60750
616.5	0	5402.735	0	41420.97	0	34524	0	76643.28	0	129119.8	0	61650
625.5	0	5481.607	0	42025.66	0	35028	0	77762.16	0	131004.7	0	62550
634.5	0	5560.479	0	42630.34	0	35532	0	78881.04	0	132889.7	0	63450
643.5	0	5639.351	0	43235.03	0	36036	0	79999.92	0	134774.6	0	64350
652.5	4212.69596	5718.224	0	43839.71	0	36540	0	81118.8	0	136659.6	0	65250
661.5	0	5797.096	0	44444.4	0	37044	0	82237.68	0	138544.6	0	66150
670.5	0	5875.968	0	45049.08	0	37548	0	83356.56	0	140429.5	0	67050
679.5	0	5954.84	0	45653.77	0	38052	0	84475.44	0	142314.5	0	67950
688.5	0	6033.712	0	46258.46	0	38556	0	85594.32	0	144199.4	0	68850
697.5	0	6112.584	0	46863.14	0	39060	0	86713.2	0	146084.4	0	69750
706.5	0	6191.456	0	47467.83	0	39564	0	87832.08	0	147969.4	0	70650
715.5	0	6270.328	0	48072.51	0	40068	0	88950.96	0	149854.3	0	71550
724.5	0	6349.2	0	48677.2	0	40572	0	90069.84	0	151739.3	0	72450
733.5	0	6428.072	0	49281.88	0	41076	0	91188.72	0	153624.2	0	73350
742.5	0	6506.944	0	49886.57	0	41580	0	92307.6	0	155509.2	0	74250
751.5	0	6585.816	0	50491.26	0	42084	0	93426.48	0	157394.2	0	75150
760.5	0	6664.688	0	51095.94	0	42588	0	94545.36	0	159279.1	0	76050
769.5	0	6743.56	0	51700.63	0	43092	0	95664.24	0	161164.1	0	76950
778.5	0	6822.432	0	52305.31	0	43596	0	96783.12	0	163049	0	77850
787.5	0	6901.304	0	52910	0	44100	0	97902	0	164934	0	78750
796.5	0	6980.176	0	53514.68	0	44604	0	99020.88	0	166819	0	79650
805.5	0	7059.048	0	54119.37	0	45108	0	100139.8	0	168703.9	0	80550
814.5	0	7137.92	0	54724.06	0	45612	0	101258.6	0	170588.9	0	81450
823.5	0	7216.792	0	55328.74	0	46116	0	102377.5	0	172473.8	0	82350
832.5	0	7295.664	0	55933.43	0	46620	0	103496.4	0	174358.8	0	83250
841.5	0	7374.537	0	56538.11	0	47124	0	104615.3	0	176243.8	0	84150
850.5	0	7453.409	0	57142.8	0	47628	0	105734.2	0	178128.7	0	85050
859.5	0	7532.281	0	57747.48	0	48132	0	106853	0	180013.7	0	85950
868.5	0	7611.153	0	58352.17	0	48636	0	107971.9	0	181898.6	0	86850
877.5	0	7690.025	0	58956.86	0	49140	0	109090.8	0	183783.6	0	87750
886.5	0	7768.897	0	59561.54	0	49644	0	110209.7	0	185668.6	0	88650
895.5	0	7847.769	0	60166.23	0	50148	0	111328.6	0	187553.5	0	89550

Unfactored Tower Fatigue Loads
3.6 MW Turbine at 100 m Hub Height
(Reference 26)
Table J-10.2

		source: Design…..5.0A04C01V00c.xls									
shaft Fx		shaft Mx		yaw bearing My		yaw bearing Mz		tower base (154m) Mx		tower base (154m)	
range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr
kN		kN m		kN m		kN m		kN m		kN m	
8	1434349999	37.5	1085287143	180	457455845	200	704721098	1900	187624907	2750	387193564
24	147975063	112.5	328451324	540	65738468	600	70316661	5700	13792445	8250	84382273
40	78753259.7	187.5	164758441	900	43852068	1000	49815243	9500	21811040	13750	30687943
56	43849964.1	262.5	108056651	1260	39913776	1400	42771593	13300	20882604	19250	16977870
72	29437645.1	337.5	68801540.6	1620	37766392	1800	40649988	17100	16187118	24750	10869141
88	13146060.2	412.5	42890499.9	1980	33008139	2200	32523309	20900	10780337	30250	7191169.3
104	11971566.4	487.5	33328098.5	2340	29457286	2600	29355414	24700	6538492.1	35750	5646634.2
120	9534338	562.5	21901889	2700	22107372	3000	20946401	28500	5314368.6	41250	5704810.5
136	5168956.54	637.5	13990184.2	3060	18569227	3400	16942505	32300	3494743.7	46750	4063771.4
152	3765130.82	712.5	10727784	3420	14158553	3800	13603712	36100	2512483.3	52250	3971226.7
168	3626056	787.5	6658198.99	3780	11211839	4200	9463215	39900	2044947.2	57750	3589670.5
184	3061408.05	862.5	5595683.36	4140	8225625.8	4600	6241453.9	43700	1060321.3	63250	2856074.1
200	2384531.97	937.5	4437766.31	4500	6892873.5	5000	4615137	47500	1160506	68750	2189892.4
216	2131638.23	1012.5	2428136.33	4860	5874291.8	5400	4523437.4	51300	1037641.2	74250	2955399.6
232	1424692.01	1087.5	2986014.51	5220	3861230.9	5800	3277467.9	55100	723116.06	79750	2333221.7
248	1807868.43	1162.5	1778443.27	5580	3286658.2	6200	1963061.2	58900	458361.53	85250	2203219.3
264	2100995.03	1237.5	1439055.38	5940	2251236.6	6600	2261246.6	62700	664506.76	90750	1230596.8
280	1327481.13	1312.5	1300225.78	6300	2156978.2	7000	1755100.6	66500	252721.09	96250	1465344.7
296	1352903.47	1387.5	873855.499	6660	1761809.7	7400	986905.92	70300	229296.96	101750	844729.11
312	1144858.87	1462.5	715758.979	7020	1154672.3	7800	627703.2	74100	168974.63	107250	700992.22
328	615065.108	1537.5	471267.227	7380	1535986.8	8200	737606.58	77900	72961.473	112750	850556.52
344	725326.181	1612.5	550152.639	7740	859455.97	8600	623490.5	81700	35554.19	118250	419058.3
360	682191.866	1687.5	483869.361	8100	763442.81	9000	415256.35	85500	48192.278	123750	474830.71
376	471231.08	1762.5	221243.829	8460	417114.01	9400	433823.8	89300	79026.405	129250	513122.6
392	708339.433	1837.5	342623.625	8820	1140080.2	9800	369149.56	93100	64535.888	134750	440025.36
408	1017537.72	1912.5	627929.331	9180	381787.65	10200	123141.76	96900	68748.777	140250	193879.4
424	580346.688	1987.5	252952.361	9540	229433.59	10600	360723.97	100700	27128.605	145750	327393.62
440	744493.568	2062.5	233172.421	9900	360723.97	11000	39766.886	104500	45831.818	151250	215173.48
456	963008.113	2137.5	160779.644	10260	268831.46	11400	110503.67	108300	18703.213	156750	137633.13
472	507152.308	2212.5	56617.8629	10620	227073.13	11800	110503.67	112100	12638.281	162250	58470.099
488	449921.375	2287.5	155862.481	10980	62682.795	12200	22915.909	115900	4212.696	167750	81386.865
504	378041.704	2362.5	25276.3689	11340	194109.81	12600	68748.777	119700	4212.696	173250	21063.673
520	257024.064	2437.5	262384.722	11700	81522.636	13000	16850.977	123500	8425.3919	178750	73097.244
536	527844.385	2512.5	22915.909	12060	39766.886	13400	18703.213	127300	0	184250	39766.886
552	72961.4732	2587.5	0	12420	133420.44	13800	83374.872	131100	0	189750	31341.494
568	314418.293	2662.5	16850.9769	12780	27128.605	14200	27128.605	134900	0	195250	21063.673
584	268449.654	2737.5	16850.9769	13140	87587.761	14600	0	138700	4212.696	200750	8425.3919
600	344012.204	2812.5	130586.112	13500	41619.122	15000	0	142500	0	206250	0
616	227440.167	2887.5	0	13860	27128.605	15400	4212.696	146300	0	211750	27128.605
632	300632.05	2962.5	4212.69596	14220	18703.213	15800	4212.696	150100	0	217250	4212.696
648	227440.167	3037.5	130586.112	14580	8425.3919	16200	0	153900	0	222750	4212.696
664	93652.6929	3112.5	4212.69596	14940	8425.3919	16600	4212.696	157700	0	228250	0
680	134798.808	3187.5	0	15300	8425.3919	17000	0	161500	0	233750	0
696	110734.937	3262.5	0	15660	4212.696	17400	0	165300	0	239250	0
712	60458.9629	3337.5	0	16020	4212.696	17800	0	169100	0	244750	0
728	41619.122	3412.5	0	16380	0	18200	4212.696	172900	0	250250	0
744	56246.2669	3487.5	0	16740	0	18600	0	176700	0	255750	4212.696
760	56246.2669	3562.5	0	17100	18703.213	19000	0	180500	0	261250	0
776	0	3637.5	0	17460	0	19400	0	184300	0	266750	0
792	56246.2669	3712.5	130586.112	17820	0	19800	0	188100	0	272250	0
808	4212.69596	3787.5	0	18180	4212.696	20200	0	191900	0	277750	0
824	0	3862.5	0	18540	0	20600	0	195700	0	283250	0

Unfactored Tower Fatigue Loads
5.0 MW Turbine at 154 m Hub Height
(Reference 26)
Table J-11.1

shaft Fx		shaft Mx		yaw bearing My		yaw bearing Mz		tower base (154m) Mx		tower base (154m)	
range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr	range	cycles/20 yr
kN		kN m		kN m		kN m		kN m		kN m	
840	18703.213	3937.5	0	18900	0	21000	0	199500	0	288750	0
856	0	4012.5	0	19260	0	21400	0	203300	0	294250	0
872	0	4087.5	0	19620	0	21800	0	207100	0	299750	0
888	0	4162.5	0	19980	4212.696	22200	0	210900	0	305250	0
904	0	4237.5	0	20340	0	22600	0	214700	0	310750	0
920	0	4312.5	0	20700	0	23000	0	218500	0	316250	0
936	0	4387.5	0	21060	0	23400	0	222300	0	321750	0
952	0	4462.5	0	21420	0	23800	0	226100	0	327250	0
968	0	4537.5	0	21780	0	24200	0	229900	0	332750	0
984	0	4612.5	0	22140	0	24600	0	233700	0	338250	0
1000	0	4687.5	0	22500	0	25000	0	237500	0	343750	0
1016	0	4762.5	0	22860	0	25400	0	241300	0	349250	0
1032	0	4837.5	0	23220	0	25800	0	245100	0	354750	0
1048	0	4912.5	0	23580	0	26200	0	248900	0	360250	0
1064	0	4987.5	0	23940	0	26600	0	252700	0	365750	0
1080	0	5062.5	0	24300	0	27000	0	256500	0	371250	0
1096	0	5137.5	0	24660	0	27400	0	260300	0	376750	0
1112	0	5212.5	0	25020	0	27800	0	264100	0	382250	0
1128	0	5287.5	0	25380	0	28200	0	267900	0	387750	0
1144	0	5362.5	0	25740	0	28600	0	271700	0	393250	0
1160	0	5437.5	0	26100	0	29000	0	275500	0	398750	0
1176	0	5512.5	0	26460	0	29400	0	279300	0	404250	0
1192	0	5587.5	0	26820	0	29800	0	283100	0	409750	0
1208	0	5662.5	0	27180	0	30200	0	286900	0	415250	0
1224	0	5737.5	0	27540	0	30600	0	290700	0	420750	0
1240	0	5812.5	0	27900	0	31000	0	294500	0	426250	0
1256	0	5887.5	0	28260	0	31400	0	298300	0	431750	0
1272	0	5962.5	0	28620	0	31800	0	302100	0	437250	0
1288	0	6037.5	0	28980	0	32200	0	305900	0	442750	0
1304	0	6112.5	0	29340	0	32600	0	309700	0	448250	0
1320	0	6187.5	0	29700	0	33000	0	313500	0	453750	0
1336	0	6262.5	0	30060	0	33400	0	317300	0	459250	0
1352	0	6337.5	0	30420	0	33800	0	321100	0	464750	0
1368	0	6412.5	0	30780	0	34200	0	324900	0	470250	0
1384	0	6487.5	0	31140	0	34600	0	328700	0	475750	0
1400	0	6562.5	0	31500	0	35000	0	332500	0	481250	0
1416	0	6637.5	0	31860	0	35400	0	336300	0	486750	0
1432	0	6712.5	0	32220	0	35800	0	340100	0	492250	0
1448	0	6787.5	0	32580	0	36200	0	343900	0	497750	0
1464	0	6862.5	0	32940	0	36600	0	347700	0	503250	0
1480	0	6937.5	0	33300	0	37000	0	351500	0	508750	0
1496	0	7012.5	0	33660	0	37400	0	355300	0	514250	0
1512	0	7087.5	0	34020	0	37800	0	359100	0	519750	0
1528	0	7162.5	0	34380	0	38200	0	362900	0	525250	0
1544	0	7237.5	0	34740	0	38600	0	366700	0	530750	0
1560	0	7312.5	0	35100	0	39000	0	370500	0	536250	0
1576	0	7387.5	0	35460	0	39400	0	374300	0	541750	0
1592	0	7462.5	0	35820	0	39800	0	378100	0	547250	0
1592	0	7462.5	0	35820	0	39800	0	378100	0	547250	0

Unfactored Tower Fatigue Loads
5.0 MW Turbine at 154 m Hub Height
(Reference 26)
Table J-11.2

		obtained from page 5.0MW_WP with scaling factors applied to the range values										
			scaling factor for swept ar		1							
			scaling factor for hub heig		0.649							
shaft Fx range	cycles/20 yr	shaft Mx range	cycles/20 yr	yaw bearing My range	cycles/20 yr	yaw bearing Mz range	cycles/20 yr	tower base (100m) Mx range	cycles/20 yr	tower base (100m) My range	cycles/20 yr	Fx range * 100
kN		kN m		kN m		kN m		kN m		kN m		
8	1434349999	37.5	1085287143	180	457455845	200	704721098	1233.1	187624907	1784.75	387193564	800
24	147975063	112.5	328451324	540	65738468	600	70316661	3699.3	13792445	5354.25	84382273	2400
40	78753259.7	187.5	164758441	900	43852068	1000	49815243	6165.5	21811040	8923.75	30687943	4000
56	43849964.1	262.5	108056651	1260	39913776	1400	42771593	8631.7	20882604	12493.25	16977870	5600
72	29437645.1	337.5	68801540.6	1620	37766392	1800	40649988	11097.9	16187118	16062.75	10869141	7200
88	13146060.2	412.5	42890499.9	1980	33008139	2200	32523309	13564.1	10780337	19632.25	7191169.3	8800
104	11971566.4	487.5	33328098.5	2340	29457286	2600	29355414	16030.3	6538492.1	23201.75	5646634.2	10400
120	9534338	562.5	21901889	2700	22107372	3000	20946401	18496.5	5314368.6	26771.25	5704810.5	12000
136	5168956.54	637.5	13990184.2	3060	18569227	3400	16942505	20962.7	3494743.7	30340.75	4063771.4	13600
152	3765130.82	712.5	10727784	3420	14158553	3800	13603712	23428.9	2512483.3	33910.25	3971226.7	15200
168	3626056	787.5	6658198.99	3780	11211839	4200	9463215	25895.1	2044947.2	37479.75	3589670.5	16800
184	3061408.05	862.5	5595683.36	4140	8225625.8	4600	6241453.9	28361.3	1060321.3	41049.25	2856074.1	18400
200	2384531.97	937.5	4437766.31	4500	6892873.5	5000	4615137	30827.5	1160506	44618.75	2189892.4	20000
216	2131638.23	1012.5	2428136.33	4860	5874291.8	5400	4523437.4	33293.7	1037641.2	48188.25	2955399.6	21600
232	1424692.01	1087.5	2986014.51	5220	3861230.9	5800	3277467.9	35759.9	723116.06	51757.75	2333221.7	23200
248	1807868.43	1162.5	1778443.27	5580	3286658.2	6200	1963061.2	38226.1	458361.53	55327.25	2203219.3	24800
264	2100995.03	1237.5	1439055.38	5940	2251236.6	6600	2261246.6	40692.3	664506.76	58896.75	1230596.8	26400
280	1327481.13	1312.5	1300225.78	6300	2156978.2	7000	1755100.6	43158.5	252721.09	62466.25	1465344.7	28000
296	1352903.47	1387.5	873855.499	6660	1761809.7	7400	986905.92	45624.7	229296.96	66035.75	844729.11	29600
312	1144858.87	1462.5	715758.979	7020	1154672.3	7800	627703.2	48090.9	168974.63	69605.25	700992.22	31200
328	615065.108	1537.5	471267.227	7380	1535986.8	8200	737606.58	50557.1	72961.473	73174.75	850556.52	32800
344	725326.181	1612.5	550152.639	7740	859455.97	8600	623490.5	53023.3	35554.19	76744.25	419058.3	34400
360	682191.866	1687.5	483869.361	8100	763442.81	9000	415256.35	55489.5	48192.278	80313.75	474830.71	36000
376	471231.08	1762.5	221243.829	8460	417114.01	9400	433823.8	57955.7	79026.405	83883.25	513122.6	37600
392	708339.433	1837.5	342623.625	8820	1140080.2	9800	369149.56	60421.9	64535.888	87452.75	440025.36	39200
408	1017537.72	1912.5	627929.331	9180	381787.65	10200	123141.76	62888.1	68748.777	91022.25	193879.4	40800
424	580346.688	1987.5	252952.361	9540	229433.59	10600	360723.97	65354.3	27128.605	94591.75	327393.62	42400
440	744493.568	2062.5	233172.421	9900	360723.97	11000	39766.886	67820.5	45831.818	98161.25	215173.48	44000
456	963008.113	2137.5	160779.644	10260	268831.46	11400	110503.67	70286.7	18703.213	101730.8	137633.13	45600
472	507152.308	2212.5	56617.8629	10620	227073.13	11800	110503.67	72752.9	12638.281	105300.3	58470.099	47200
488	449921.375	2287.5	155862.481	10980	62682.795	12200	22915.909	75219.1	4212.696	108869.8	81386.865	48800
504	378041.704	2362.5	25276.3689	11340	194109.81	12600	68748.777	77685.3	4212.696	112439.3	21063.673	50400
520	257024.064	2437.5	262384.722	11700	81522.636	13000	16850.977	80151.5	8425.3919	116008.8	73097.244	52000
536	527844.385	2512.5	22915.909	12060	39766.886	13400	18703.213	82617.7	0	119578.3	39766.886	53600
552	72961.4732	2587.5	0	12420	133420.44	13800	83374.872	85083.9	0	123147.8	31341.494	55200
568	314418.293	2662.5	16850.9769	12780	27128.605	14200	27128.605	87550.1	0	126717.3	21063.673	56800
584	268449.654	2737.5	16850.9769	13140	87587.761	14600	0	90016.3	4212.696	130286.8	8425.3919	58400
600	344012.204	2812.5	130586.112	13500	41619.122	15000	0	92482.5	0	133856.3	0	60000
616	227440.167	2887.5	0	13860	27128.605	15400	4212.696	94948.7	0	137425.8	27128.605	61600
632	300632.05	2962.5	4212.69596	14220	18703.213	15800	4212.696	97414.9	0	140995.3	4212.696	63200
648	227440.167	3037.5	130586.112	14580	8425.3919	16200	0	99881.1	0	144564.8	4212.696	64800
664	93652.6929	3112.5	4212.69596	14940	8425.3919	16600	4212.696	102347.3	0	148134.3	0	66400
680	134798.808	3187.5	0	15300	8425.3919	17000	0	104813.5	0	151703.8	0	68000
696	110734.937	3262.5	0	15660	4212.696	17400	0	107279.7	0	155273.3	0	69600
712	60458.9629	3337.5	0	16020	4212.696	17800	0	109745.9	0	158842.8	0	71200

Unfactored Tower Fatigue Loads
5.0 MW Turbine at 100 m Hub Height
(Reference 26)
Table J-12.1

shaft Fx range kN	cycles/20 yr	shaft Mx range kN m	cycles/20 yr	yaw bearing My range kN m	cycles/20 yr	yaw bearing Mz range kN m	cycles/20 yr	tower base (100m) Mx range kN m	cycles/20 yr	tower base (100m) My range kN m	cycles/20 yr	Fx range * 100
728	41619.122	3412.5	0	16380	0	18200	4212.696	112212.1	0	162412.3	0	72800
744	56246.2669	3487.5	0	16740	0	18600	0	114678.3	0	165981.8	4212.696	74400
760	56246.2669	3562.5	0	17100	18703.213	19000	0	117144.5	0	169551.3	0	76000
776	0	3637.5	0	17460	0	19400	0	119610.7	0	173120.8	0	77600
792	56246.2669	3712.5	130586.112	17820	0	19800	0	122076.9	0	176690.3	0	79200
808	4212.69596	3787.5	0	18180	4212.696	20200	0	124543.1	0	180259.8	0	80800
824	0	3862.5	0	18540	0	20600	0	127009.3	0	183829.3	0	82400
840	18703.213	3937.5	0	18900	0	21000	0	129475.5	0	187398.8	0	84000
856	0	4012.5	0	19260	0	21400	0	131941.7	0	190968.3	0	85600
872	0	4087.5	0	19620	0	21800	0	134407.9	0	194537.8	0	87200
888	0	4162.5	0	19980	4212.696	22200	0	136874.1	0	198107.3	0	88800
904	0	4237.5	0	20340	0	22600	0	139340.3	0	201676.8	0	90400
920	0	4312.5	0	20700	0	23000	0	141806.5	0	205246.3	0	92000
936	0	4387.5	0	21060	0	23400	0	144272.7	0	208815.8	0	93600
952	0	4462.5	0	21420	0	23800	0	146738.9	0	212385.3	0	95200
968	0	4537.5	0	21780	0	24200	0	149205.1	0	215954.8	0	96800
984	0	4612.5	0	22140	0	24600	0	151671.3	0	219524.3	0	98400
1000	0	4687.5	0	22500	0	25000	0	154137.5	0	223093.8	0	100000
1016	0	4762.5	0	22860	0	25400	0	156603.7	0	226663.3	0	101600
1032	0	4837.5	0	23220	0	25800	0	159069.9	0	230232.8	0	103200
1048	0	4912.5	0	23580	0	26200	0	161536.1	0	233802.3	0	104800
1064	0	4987.5	0	23940	0	26600	0	164002.3	0	237371.8	0	106400
1080	0	5062.5	0	24300	0	27000	0	166468.5	0	240941.3	0	108000
1096	0	5137.5	0	24660	0	27400	0	168934.7	0	244510.8	0	109600
1112	0	5212.5	0	25020	0	27800	0	171400.9	0	248080.3	0	111200
1128	0	5287.5	0	25380	0	28200	0	173867.1	0	251649.8	0	112800
1144	0	5362.5	0	25740	0	28600	0	176333.3	0	255219.3	0	114400
1160	0	5437.5	0	26100	0	29000	0	178799.5	0	258788.8	0	116000
1176	0	5512.5	0	26460	0	29400	0	181265.7	0	262358.3	0	117600
1192	0	5587.5	0	26820	0	29800	0	183731.9	0	265927.8	0	119200
1208	0	5662.5	0	27180	0	30200	0	186198.1	0	269497.3	0	120800
1224	0	5737.5	0	27540	0	30600	0	188664.3	0	273066.8	0	122400
1240	0	5812.5	0	27900	0	31000	0	191130.5	0	276636.3	0	124000
1256	0	5887.5	0	28260	0	31400	0	193596.7	0	280205.8	0	125600
1272	0	5962.5	0	28620	0	31800	0	196062.9	0	283775.3	0	127200
1288	0	6037.5	0	28980	0	32200	0	198529.1	0	287344.8	0	128800
1304	0	6112.5	0	29340	0	32600	0	200995.3	0	290914.3	0	130400
1320	0	6187.5	0	29700	0	33000	0	203461.5	0	294483.8	0	132000
1336	0	6262.5	0	30060	0	33400	0	205927.7	0	298053.3	0	133600
1352	0	6337.5	0	30420	0	33800	0	208393.9	0	301622.8	0	135200
1368	0	6412.5	0	30780	0	34200	0	210860.1	0	305192.3	0	136800
1384	0	6487.5	0	31140	0	34600	0	213326.3	0	308761.8	0	138400
1400	0	6562.5	0	31500	0	35000	0	215792.5	0	312331.3	0	140000
1416	0	6637.5	0	31860	0	35400	0	218258.7	0	315900.8	0	141600
1432	0	6712.5	0	32220	0	35800	0	220724.9	0	319470.3	0	143200
1448	0	6787.5	0	32580	0	36200	0	223191.1	0	323039.8	0	144800
1464	0	6862.5	0	32940	0	36600	0	225657.3	0	326609.3	0	146400
1480	0	6937.5	0	33300	0	37000	0	228123.5	0	330178.8	0	148000
1496	0	7012.5	0	33660	0	37400	0	230589.7	0	333748.3	0	149600
1512	0	7087.5	0	34020	0	37800	0	233055.9	0	337317.8	0	151200
1528	0	7162.5	0	34380	0	38200	0	235522.1	0	340887.3	0	152800
1544	0	7237.5	0	34740	0	38600	0	237988.3	0	344456.8	0	154400
1560	0	7312.5	0	35100	0	39000	0	240454.5	0	348026.3	0	156000
1576	0	7387.5	0	35460	0	39400	0	242920.7	0	351595.8	0	157600
1592	0	7462.5	0	35820	0	39800	0	245386.9	0	355165.3	0	159200

Unfactored Tower Fatigue Loads
5.0 MW Turbine at 100 m Hub Height
(Reference 26)
Table J-12.2

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M. W. LaNier, PE

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Michael W. LaNier, PE
BERGER/ABAM Engineers Inc.
33301 Ninth Avenue South Suite 300
Federal Way, Washington 98003-2600

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14. ABSTRACT *(Maximum 200 Words)*
The United States Department of Energy (DOE) Wind Energy Research Program has begun a new effort to partner with U.S. industry to develop wind technolgy that will allow wind systems to compete in regions of low wind speed. The Class 4 and 5 sites targeted by this effort have annual average wind speeds of 5.8 m/s (13 mph), measured at 10 m (33 ft) height. Such sites are abundant in the United States and would increase the land area available for wind energy production twenty-fold. The new program is targeting a levelized cost of energy of 3 cents/kWh at these sites by 2010. A three-element approach has been initiated. These efforts are concept design, component development, and system development. This work builds on previous activties under the WindPACT program and the Next Generation Turbine program. If successful, DOE estimates that his new technology could result in 35 to 45 gigawatts of additional wind capacity being installed by 2020.

15. SUBJECT TERMS
wind energy; low wind speed; wind speed; cost of energy; windPACT; wind turbine; technology

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