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7. Abstract

This report determines the proximity to which the Link-belt model LS-518 crane can approach Tank 241SY101 during Hydrogen Mitigation Pump installation and removal activities. This proximity is a function of the crane-imposed dome load and the weakest component in the crane load path. Furthermore, it provides an evaluation of the forces involved in the removal and insertion process.

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**DOMe LOAD CONTROL AND CRANE LOAD PATH EVALUATION FOR TANK 241SY101
DURING HYDROGEN MITIGATION PUMP REMOVAL AND INSTALLATION**

August 1994

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☒	☐	☐	Problem adequately defined.
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Duncan Lawler
Checker

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DOMES LOAD CONTROL AND CRANE LOAD PATH EVALUATION FOR TANK 241SY101 DURING HYDROGEN MITIGATION PUMP REMOVAL AND INSTALLATION

1.0 INTRODUCTION

The link-belt model LS-518 crawler-mounted crane will perform the critical lift of the hydrogen mitigation pump (HMP) in tank 241SY101 as defined in the critical lift procedure (Brewer 1994). There will be separate lifts to remove the hydrogen mitigation test (HMT) pump and then to install the second hydrogen mitigation test (HMT-2) pump. The HMT-2 pump is similar in design to the HMT pump. For both lifts the crane will be moved into the heavy equipment exclusion zone surrounding the tank. The *Tank 241-SY-101 Dome Loading Control Document* (Scott et al. 1994) defines the exclusion zone as a 20-ft annular region around the tank and recommends allowable dome loads that include a 40-lbf/ft² uniform load and a 50-ton concentrated load at the center of the tank. The dome-loading control document further recommends that requests for moving heavy equipment into the exclusion zone be evaluated by Westinghouse Hanford Company (WHC) Engineering on a case-by-case basis. The analysis presented here includes such an evaluation.

This report revisits and consolidates two analyses previously performed for the installation of the HMT pump. The first report (Weis 1993) determines, as a function of the crane-imposed dome load, the point to which the crane can encroach into the exclusion zone without exceeding the 50-ton limit. The second (Strehlow 1993a) performs a load evaluation for the crane and the components in the load path (crane lift accessories and pump). In doing so, it determines the weakest component in the load path and the effect of this component on the allowable encroachment distance. Furthermore, the second report sets operational limits on the allowable load decrease (unload) during installation in the event the pump sticks in the riser. The analysis presented here expands on the latter subject by setting an operational limit on the amount of allowable load increase (overload) during pump removal in the event the pump sticks in the riser.

The current 50-ton concentrated load limit may increase to 100 tons by the time the HMT-2 pump is installed. A recent revision (Blume 1994) to the original design analysis demonstrates the capability of the tanks in the SY tank farm to withstand additional load. WHC Engineering intends to present this revision as a basis for the future incorporation of new load limits into the operating specifications document (OSD) for the SY tank farm (Harris 1992). In that event, the 100-ton concentrated load likely will be shared between a 50-ton live load for moving equipment (e.g., vehicles) and 50-ton dead load for fixed equipment (e.g., concrete pads). The crane will not have to share the 50 tons with the fixed equipment as it currently does, and the LS-518 crane-imposed dome load will not be an issue for the loading expected in this pair of critical lifts. This report evaluates dome load for the current 50-ton limit and for the potential 100-ton limit separately.

2.0 BACKGROUND

In addition to the routine removal of the HMT pump, emergency removal may be required during the installation of the HMT-2 pump. During pump removal, additional loads on the pump from waste interaction and accumulation may cause the lifted loads to exceed the capacity of the crane when it is positioned outside the exclusion zone. To address this concern, the analysis presented here determines the maximum allowable distance into the exclusion zone that the LS-518 crane can encroach. Because the crane-imposed dome load increases as the crane approaches the tank, the allowable encroachment is a function of the dome load available to the crane. The allowable encroachment distance is also a separate function of the weakest component in the load path. The minimum of these two evaluations sets the allowable encroachment distance.

The available load for the crane is the difference between the dome's current 50-ton limit and the existing dome load from components already on the tank and in the exclusion zone. Although the full weight of existing components (Scott et al. 1994) is applied to the 50-ton limit, applying it to the crane would restrict crane encroachment into the exclusion zone. In reality, the crane-imposed dome load is some fraction of the crane's weight, because the crane applies load to the tank dome through the surrounding soil. The calculations supporting this analysis use the Boussinesq Equation (Sowers and Sowers 1970) to determine the crane-imposed dome load.

It is necessary to limit the load on the crane to the extent that lifting the pump through the waste does not exceed the capacity of the weakest component in the load path. This limiting crane load should equal crane capacity so that the crane has the freedom to lift its capacity without exceeding the capacity of the weakest component. Because the capacity of the crane increases as the crane approaches the tank, because of the crane's decreasing load radius, equating the limiting crane load to the capacity sets the allowable encroachment distance.

This analysis calculates operational limits on the allowable unload during pump installation and the allowable overload during pump removal in the event the pump sticks in the riser. These limits ensure enough margin of load to pull (during installation) or dislodge (during removal) the pump from the riser by overcoming the static friction between the pump and the riser.

The dome load analysis performed for the first pump installation (Weis 1993) includes the necessary structural evaluations to ensure that the tank's foundation footing can withstand the increased loading from the crane and that the soil around the tank will not fail under the bearing pressure of the LS-518's crawlers.

3.0 SUMMARY

The estimate used in this report for the current dome load on the tank, calculated in the most recent dome loading control document (Scott et al. 1994), is 72,232 lbf with the pump and 52,182 lbf without. Although this dome load inventory is the most recent available, it has not been updated since January 1994. Therefore, total load may not include all equipment on the tank. The dome load needs to be known before application of this analysis.

Given the current dome load and the current OSD limit of 50 tons, the maximum allowable encroachment distance into the exclusion zone is 17 ft if the central pump pit cover blocks remain above the tank or exclusion zone during either removal or installation. Once the cover blocks have been moved outside the exclusion zone, the maximum allowable encroachment distance into the exclusion zone is 18 ft. This value greatly depends on the current LS-518 crane configuration defined by the 180-ft boom length and the current dome loads on 241SY101 from equipment other than the crane. *It is likely to change if these data change.* If the crane configuration changes, crane-imposed dome loads will require re-calculation. However, if the only change in data is the current dome loads on the tank and the exclusion zone, there exist the means in this report to determine the allowable encroachment distance as its function of dome load (Section 4.2.3).

The 18-ft encroachment distance also is based on limiting the crane capacity so that the capacity of the weakest component in the load path cannot be exceeded. Even if dome load limits allow an encroachment greater than 18 ft, such an encroachment should not be attempted without first strengthening the weakest component in the load path (the lifting yoke).

If a revision to the OSD incorporates separate 50-ton live and dead load limits, the crane can encroach 18 ft into the exclusion zone and have adequate margins even with the cover blocks on the tank.

During HMT pump removal, the overload should not increase to more than 8,348 lbf above the load the crane is lifting when the pump first begins to lift off of the riser. This limit should apply until the hydraulic-actuated shim assembly (brake shoes) clears the riser. This procedure will ensure that, should the shim assembly become stuck in the riser, sufficient force from pump deadweight will be available to free the pump and allow it to settle back down onto the riser. To actually measure the overload the crane applies, a reading should be taken from the dynamometer at the point where the pump just begins to lift clear of the riser. More than 8,348 lbf of overload above the initial dynamometer reading may be required to pull the pump completely free. Care should be taken, however, to ensure that, if the 8348-lbf overload is exceeded, the pump appears to be moving continuously and freely. The movement would indicate that the added force is due to accumulated waste, viscous interaction, or decrease in buoyancy force, and not due to the pump sticking in the riser.

During pump removal, either as a routine procedure for the HMT pump or an emergency procedure for the HMT-2 pump, the viscous interaction force from the waste should be negligible compared to the weight of the pump. There may be

some waste accumulation on the pump's baffles and in its pipes; however, the crane has sufficient reserve capacity to lift the additional load.

During HMT-2 pump installation, the unload experienced at the dynamometer should be limited. A limit on the unload will ensure vertical stability of the pump and sufficient reserve crane capacity to free the pump in the event it becomes stuck in the riser. The allowable unload limits are 20 percent unload (5,094 lbf) before the pump enters the waste, 40 percent unload (10,188 lbf) until the midsection of the pump clears the riser, and 47.6 percent unload (12,124 lbf) for the remaining insertion distance. These values are percentages of the pump deadweight as read by the dynamometer (25,471 lbf). With these unload limits, the crane can free the pump when located at the 18-ft encroachment distance. The limits would be lower for a smaller encroachment distance.

If the HMT-2 pump is installed shortly after the HMT pump is removed, the shear resistance from the waste should be negligible. However, if it becomes necessary to install the HMT-2 pump after a sizable delay, a procedure similar to that for the HMT pump insertion could be used to ensure success.

Structural evaluation of the tank foundation footing in the vicinity of the crane reveals that the increased loading from the crane is negligible compared to the existing load. Furthermore, the maximum bearing pressure of the crane's crawlers on the ground remains within the calculated allowable for the soil around 241SY101. Both evaluations assume a conservative crane configuration and location: the crane lifting at its capacity and located at the edge of the tank (encroachment = 20 ft with front soil-contact line of crawlers tangent to outer radius of the tank).

4.0 ANALYSIS

4.1 ALLOWABLE ENCRoACHMENT DISTANCE AS A FUNCTION OF THE WEAKEST COMPONENT

4.1.1 Load Capacity of Each Component in the Crane Load Path

The components that will be used to lift the mixer pump into tank 241SY101, as specified in the critical lift procedure (Brewer 1994), are illustrated in Figure 1. The load capacity and weights for each of these components are listed in Table 1. The load capacity for the lifting lugs on the pump is the total capacity for both lifting lugs. The load capacity for the pump mid-level connection is the minimum value for any connection along the mid-length of the pump.

To provide a consistent baseline for comparison, the load capacity of each component is adjusted to an equivalent load at the dynamometer and a corresponding required crane capacity (Appendix A). These values are shown in Table 2. The equivalent load is the value that the dynamometer would measure when the load capacity of the component is reached. To attain these load limits, the pump is assumed to be stuck at a point below the component. The corresponding required crane capacity is the minimum capacity required to

achieve the equivalent load at the dynamometer. Because the weights of different components below the dynamometer are taken into account, the equivalent dynamometer load differs slightly from the component load capacity. Similarly, the required crane capacity differs from the equivalent dynamometer load.

Note that the component with the least capacity for load at the dynamometer and crane is the lifting yoke, with a rated capacity of 40,000 lbf. The corresponding loads at the dynamometer and crane are 41,921 and 46,271 lbf, respectively. For comparison, the estimated deadweight of the pump at the dynamometer is included in Table 2.

4.1.2 Crane Capacity as a Function of Encroachment Distance.

The crane capacity increases as the crane approaches the pump riser (riser 12A). With the crane facing the tank at the edge of the exclusion zone (encroachment distance = 0 ft), the load radius is approximately 75.6 ft. This radius is the sum of the offset of the pump riser from the tank center (3 ft), the tank's outer radius (41.5 ft), the exclusion zone annulus (20 ft), and half the ground bearing length of the LS-518 crawlers (11.1 ft). See Figure 2 for a plan view the tank, the exclusion zone, and the crane footprint. The pivot center of the crane is midway longitudinally between the crawlers. The load radius decreases to 55.6 ft at the edge of the tank (encroachment distance = 20 ft). The encroachment is the distance between the front, soil-contact line of the crawlers and a tangent to the outer edge of the exclusion zone parallel with this soil-contact line.

The load capacity chart for the crane lists capacity in increments of 10 ft in load radius. Interpolation of this chart between these increments provides the means for calculating the crane capacity at any load radius (see Appendix B.) The lifted load, including the weights of the lift accessories, the weight of the pump, and other removal forces, cannot exceed the crane capacity. The crane capacity varies from 31,200 to 48,200 lbf over the 20-ft exclusion zone. Table 3 summarizes the crane capacity and the equivalent dynamometer load as a function of encroachment distance (and corresponding load radius).

4.1.3 Recommendation for Crane Position Based on Weakest Component

Based on the data in Table 2, the required crane capacity to fully load the yoke, and Table 3, the range of crane capacity, the allowable encroachment distance for the crane is calculated at 18 ft into the exclusion zone. This encroachment distance corresponds to a load radius of 57.6 ft. The lift capacity for the crane at this load radius is 45,798 lbf. Therefore, the 18-ft encroachment distance provides the crane the freedom to lift its capacity without exceeding the capacity of the weakest component in the load path.

4.2 ALLOWABLE ENCROACHMENT DISTANCE AS A FUNCTION OF THE CRANE-IMPOSED DOME LOAD

4.2.1 Dome Load Available to the Crane.

The available load for the crane is the difference between the current 50-ton limit for the dome and the current dome loads. The current dome loads on tank 241SY101 have been compiled in the dome-loading control document (Scott et al. 1994). These dome loads currently are imposed by immobile structures totaling 72,232 lbf and include the weight of the pump, 20,050 lbf (Weis 1993); the weight of the pump pit cover blocks, 31,762 lbf (Strehlow 1993a); and the weight of other, miscellaneous components, 20,510 lbf. This load provides a margin available to the crane of 27,768 lbf before it lifts the pump from its supports. Once the pump is supported by the crane, its full weight is no longer on the dome; rather, a fraction of its weight contributes to the crane-imposed dome load through the soil. This situation increases the dome load available to the crane to 47,818 lbf. Available dome load will increase further if the cover blocks are moved outside the exclusion zone before HMT pump removal and then again before installation of the HMT-2 pump.

If the OSD sets separate 50-ton live and dead load limits, 50 tons will be available to the crane if there are no other live loads on the tank, and 50 tons will be available to fixed equipment. In this case, the full weight of the pump contributes to dead load when resting on the tank. When being lifted, it contributes to the live load through the crane and soil.

4.2.2 Crane-Imposed Dome Load

The crane-imposed dome load is a function of its own weight and the lifted load. This analysis assumes for conservatism that while lifting the pump the crane lifts its capacity, because the crane should never see a load larger than this value. Furthermore, this approach gives the crane the freedom to lift at its capacity without exceeding the dome load in the event the pump encounters waste interaction or accumulation forces.

4.2.2.1 Results. This analysis calculates the crane-imposed dome load for each foot of encroachment into the exclusion zone over the range of 10 to 20 ft. Two cases of crane loading are considered. In the first case, the crane supports the lift accessories, 9,771 lbf as the pump rests on the tank. (The lift accessories used to lift the pump are listed in Table 1.) In the second case, the crane supports its capacity at the given location. (The pump and the lift accessories are part of this load.) Table 4 lists the crane-imposed dome load as a function of the encroachment distance and the corresponding load radius for the two cases of crane loading.

4.2.2.2 Methodology. The analysis uses the Boussinesq Equation (Sowers and Sowers 1970) to calculate the LS-518 crane-imposed dome load through the soil. This equation gives the vertical soil stress field in the vicinity of a concentrated load applied to the soil surface.

The Mathcad¹ worksheet in Appendix C demonstrates a generic application of the Boussinesq Equation to tank 241SY101 in which a concentrated load of 1,000 lbf is applied to the soil in the vicinity of the tank. The calculation integrates the three-dimensional soil stress field over the dome's spherical surface to determine the percentage of the 1,000 lbf transmitted to the tank dome. Because the load transmitted to the dome is linearly proportional to the soil-applied load (see Appendix C), the percentage of transmitted load remains constant as the magnitude of the applied load changes. The calculation in Appendix C generates a table listing the percentage of transmitted load as a function of the distance of the 1,000 lbf from the edge of the tank.

The Mathcad worksheet in Appendix D determines the LS-518 crane-imposed dome load for the crane located near tank 241SY101. First, it determines the loads applied to the soil by the crane crawlers. Second, with these crawler loads, it applies the Boussinesq Equation to determine the load transmitted to the tank dome. The worksheet is versatile; it contains the crane geometry necessary to calculate the crawler loads for any load radius and angle of rotation of the crane body. Generation of the 22 data points in Table 4 required as many applications of the worksheet in Appendix D.

4.2.2.3 Validation of Crane Calculations. Appendix E contains the crane calculations that support the crane-imposed dome load calculations and a validation of these results. The validation is a comparison of WHC-generated results of sample crane calculations and the results of calculations from Link-belt for equivalent crane configurations. The data from Link-belt's calculation are the total weight of the crane and lifted load, and the crawlers' ground bearing-pressure profiles. The comparison is excellent. For example, the WHC- and Link-belt-calculated values for the total weight of the crane and the lifted load (approximately 150 tons) are equivalent when rounded to the nearest pound.

4.2.3 Recommendation Data for Crane Position Based on Crane-Imposed Dome Load

During the pump installation and removal activities, two heavy components in addition to the crane and pump, will likely be lifted and moved on and off the tank. These include the central pump pit cover blocks and the shield plug for the pump riser (riser 12A). This analysis investigates five separate load cases to demonstrate the allowable encroachment distance during the lifts. Table 5 summarizes these five load cases. Tables 6 and 7 apply these load cases against the single 50-ton limit and the separate 50-ton live and dead load limits, respectively. Given an allowable encroachment of 18 ft based on the weakest component (Section 4.1.3), crane-imposed dome load will affect this distance only if the crane-imposed dome load requires this distance to be less because the recommended crane position is the minimum encroachment of the two evaluations. The five load cases summarized in Table 5 are detailed below.

¹Mathcad is a copyrighted program of MathSoft Incorporated, Cambridge, Massachusetts.

- Loads case 1 applies to the beginning of the removal procedure before the HMT pump is lifted and at the end of the installation procedure after the HMT-2 pump is set on the riser while the crane is positioned 18 ft into the exclusion zone and lifting its accessories only.
- Load case 2 is similar to load case 3. In this case, however, the crane is positioned 17 ft into the exclusion zone.
- Load case 3 applies when the crane is lifting the pump during pump installation or removal. The crane is positioned 18 ft into the exclusion zone and lifting at capacity. Note that this case specifies that the cover blocks are outside the exclusion zone.
- Load case 4 is similar to load case 3. In this case, however, the cover blocks remain on the tank, and the crane, lifting at capacity, is 17 ft into the exclusion zone.
- Load case 5 applies after the test pump has been removed but before the permanent pump is installed. This case assumes that the riser shield plug and cover blocks have been installed temporarily between removal and installation.

The crane-imposed dome load estimates are based on the crane's being positioned 18 ft into the 20-ft load exclusion zone around the tank, except for load cases 2 and 4 where the crane is positioned 17 ft into the zone. At 18 ft into the exclusion zone, the load radius is 57.6 ft. The load estimates in Table 6 demonstrate that, throughout pump installation or emergency removal, there will be an adequate margin against the single 50-ton load limit that was established for the tank to meet safety requirements (Scott et al. 1994) if the cover blocks are removed with the crane less than or equal to 17 ft into the exclusion zone. Table 7 demonstrates that both the live and dead loads fall well below the respective 50-ton load limits in all load cases when they are accounted for separately. For the separate 50-ton load limits, only load cases 1, 3, and 5 apply; there is sufficient margin to allow the crane to encroach 18 ft. The order in which the load cases would likely occur during the actual procedure is 2, 3, 5, 3, 2 for the single 50-ton limit. For the separate 50-ton live and dead load limits, the order would be 1, 3, 5, 3, 1.

These results depend greatly on the current LS-518 crane configuration defined by the 180-ft boom length and the current dome loads on 241SY101 from equipment other than the crane. *They are likely to change if these data change.* The allowable encroachment distance is less sensitive to the weight of the lift accessories as this weight is small compared to the weight of the crane and is not likely to vary significantly. If the crane configuration changes or if the weight of the lift accessories increases significantly, crane-imposed dome loads will require re-calculation. However, if the only change in data is the current dome loads on the tank and the exclusion zone, the next paragraph discusses the means to determine the allowable encroachment distance.

Tables 6 and 7 tabulate the total dome load for a single 50-ton limit and separate 50-ton live and dead limits, respectively. Inserting the new values for the current dome loads into these tables and updating the totals will give

the available margins. In the event that the crane-imposed dome load exceeds the limit at the given encroachment distance, Table 4 is to be used to determine a new crane-imposed dome load based on a smaller encroachment distance, this value inserted into Tables 6 and 7, and the columns re-totaled. These tables should become part of the critical lift procedure in the event that the dome loads on the tank change before the installation of the pump. In addition, the 18-ft encroachment limit is based on limiting the crane capacity to the capacity of the weakest component in the load path. Even if dome load limits allow an encroachment of greater than 18 ft, such as encroachment should not be attempted without first strengthening the weakest component in the load path.

4.3 STRUCTURAL ANALYSIS OF TANK FOOTING

When positioned near the tank, the crane will apply load to the tank foundation footing through the soil. Calculations performed in the previous dome load analysis for the first pump installation (Weis 1993) revealed that the increased loading from the crane was negligible compared to the existing load. For the worst-possible crane configuration without encroaching into the area above the tank (lifting at its capacity at the tank edge), the crane in that analysis applied an additional load of 2,125 lbf/ft of circumferential wall. The total factored load (ACI 1982) of 85,000 lbf/ft remained within the footing's capacity of 91,825 lbf/ft. Using the worst-possible crane configuration for this analysis gives an additional load of approximately 2,180 lb/ft, based on the fact that the soil pressures for this analysis (Appendix D, p. D-21) have increased by approximately 3 percent over the previous analysis. Similarly, the total factored load increased slightly to 85,100 lb/ft, well within the footing's capacity.

4.4 CRAWLER GROUND BEARING PRESSURE

The Mathcad worksheet calculating the crane-imposed dome load (Appendix D) also calculates the ground bearing-pressure profiles of the crawlers. For the worst-possible crane configuration (lifting at its capacity at the tank edge) with the boom above the corner of one crawler, the maximum soil ground bearing pressure is approximately 6,457 lbf/ft². This applied pressure remains within the allowable bearing pressure of 9,179 lbf/ft² calculated in the previous dome load analysis for the first pump installation (Weis 1993).

4.5 EVALUATION OF REMOVAL FORCES

Based on the allowable encroachment distance of 18 ft presented in Sections 4.1 and 4.2, the maximum load at the dynamometer is 41,448 lbf for pump removal (Table 3). This load limit will ensure that the load capacity for the critical component in the load path, the lifting yoke, is not exceeded. The recommended load limit of 41,448 lbf provides a minimum pull-out force of 36,027 lbf at the pump lifting lugs for pump removal (Appendix F).

In establishing this load limit, the load reading from the dynamometer is assumed to be at or below the actual load, as indicated in the calibration records. However, if the calibration records indicate that the dynamometer reads a value higher than that of the actual load, the inaccuracy of the dynamometer will have to be factored into this load limit by subtracting the error value from the recommended load limit.

4.5.1 Waste Interaction and Accumulation Forces

During removal of the pump, forces in addition to the pump weight are likely to be encountered from the presence of the waste. Additional lifting force may be required first to break the pump free and start it moving, then to overcome shear resistance as the pump is pulled through the non-convective layer. Furthermore, waste accumulation on the pump will require additional lifting force.

Hudson (1994, attached in Appendix J) indicates that the forces required to break the pump free and move it through the waste will be negligible compared to the weight of the pump. Thus the only significant force is the weight of waste that has accumulated on and has been trapped in the pump. The magnitude of this force depends on conditions under which the pump is removed. The HMT pump will be removed as a normal procedure, and the HMT-2 pump may be removed as an emergency procedure during the pump installation. In each removal situation, waste is likely to settle on the pump baffles and become trapped in the pipes. During HMT pump removal, however, additional waste load is expected from solids that have precipitated on the pump column near the waste surface. (The precipitated solid is commonly called a "popsicle"). The load should be greater in the second scenario, the difference being the weight of the "popsicle."

Because the waste will likely be highly disturbed and fluid in the vicinity of the HMT pump, a conservative estimate for the additional load of accumulated waste due to settling and entrapment is 4,238 lbf (Strehlow 1993a, Appendix E.3). This calculation assumes a non-convective layer 200 in. in depth that was present before the first pump was installed. During final removal, the estimated load is 11,472 lbf (Strehlow 1993a, Appendix E.3). This number includes the 4,238 lbf and a 7,234 lbf "popsicle" in the shape of a circular disk. Each load is less than 15,977 lbf, a conservative estimate of the available pullout force for the pump without assistance from the buoyancy force (Appendix F). Therefore, accumulated waste will not pose a problem for pump removal.

4.5.2 Allowable Overload During the First Stage of Pump Removal

During initial removal of the HMT pump, the brake shoes might not retract properly and the pump may stick in the riser as the crane begins to lift it free. In such a case, it is important to limit the amount of overload applied to the pump. If the pump becomes stuck and the removal is aborted, the weight of the pump minus buoyancy forces must be able to free the pump to allow it to settle back onto the riser. Appendix G indicates that the deadweight of the pump will free it if it is stuck with less than 8,348 lbf of overload. It is difficult to calculate an allowable overload because waste may have accumulated on the pump. To actually measure the overload the crane is applying, a reading should be taken from the dynamometer at the point where

the pump just begins to lift clear of the riser. From this initial reading, the allowable overload should be restricted to 8348 lbf for the first few feet of the lift until the brake shoes clear the riser. The analysis in Appendix H shows that the brake shoe pivot bolts can withstand 16,830 lbf, well above the overload limit of 8,348 lbf. (The 16,830-lbf force, selected from the allowable unload forces in Section 4.6, is the force that the brake shoes may experience if the HMT-2 pump sticks in the riser upon installation.)

More than 8,348 lbf of overload above the initial dynamometer reading (as explained above) may be required to pull the pump completely free. Although Hudson (1994) indicates that the forces resulting from viscous interaction with the waste should be negligible, some resistance may be present. In addition, Strehlow (1993a, Appendix E.3) conservatively estimates an accumulated waste load of 11,472 lbf. Some of the accumulated waste load will be accounted for in the initial reading as the pump begins to lift off of the riser, but some of this load is canceled by the buoyancy force of the waste the pump is immersed in. Also, the buoyancy force initially supporting the pump will decrease as the pump rises. It may be necessary therefore to exceed the 8,348-lbf overload limit after the brake shoes clear the riser. This situation should be acceptable because as the pump moves farther out of the waste, there is less buoyancy force and therefore more deadweight available to dislodge the pump if it becomes stuck. Care should be taken, however, to ensure that, if the 8,348-lbf overload is exceeded, the pump appears to be moving continuously and freely. The movement would indicate that the added force is due to accumulated waste, viscous interaction, or decrease in buoyancy force, and not to the pump sticking in the riser.

4.6 EVALUATION OF INSERTION FORCES

4.6.1 Waste Interaction Forces

Hudson (1994) indicates that the forces resulting from the shear resistance will be negligible during pump extraction. As long as the HMT-2 pump is inserted into the tank shortly after the HMT pump removal, the insertion forces should also be negligible, as the non-convective layer will be highly disturbed and fluid in the region where the pump is to be inserted. In addition, during insertion of the HMT pump last year, no difficulties were encountered inserting the pump into the non-convective layer after it had been water lanced. If it became necessary to insert the HMT-2 pump after a sizeable delay, a procedure similar to that for the HMT pump insertion could be used to ensure success.

4.6.2 Allowable Unload During Insertion

The load reading at the dynamometer is expected to decrease because of buoyancy forces and the additional forces necessary to move the pump through the waste. However, such a load decrease could be the result of the pump's becoming stuck in the riser. The minimum unload limits recommended for pump insertion were established in Appendix I of this report. These limits represent the lowest load values allowed at the dynamometer during the pump installation that still allow sufficient reserve crane capacity to overcome the force of static friction binding the pump.

The capability of removing the pump if it does become stuck in the riser is the reason for calculating the allowable unload limits. In addition to this objective, goals were assumed to limit the load decrease at the pump lifting lugs to 25% (20% at the dynamometer) until the pump enters the waste and to 50% at the pump lifting lugs (40% at the dynamometer) until the critical midsection of the pump clears the riser. This limit is to ensure the vertical stability of the pump. The maximum decrease in load at the pump lifting lugs once vertical stability is no longer a concern is 60% (47.6% at the dynamometer). This unload is the maximum that can occur and still allow the crane enough reserve capacity to pull the pump free in the event this unload is due to the pump's becoming stuck.

If the pump becomes stuck in the riser during installation, it is most likely to stick as the widest point of the pump passes through the riser. The widest part of the pump is the hydraulic-actuated shim assembly. If the pump does become stuck, it is important that the pivot bolts on the brake shoes attached to the pump brake-holder assembly be capable of carrying the total amount of force required to pull the pump free (Appendix I). Appendix H calculate the stresses experienced by the pivot bolts with the maximum static friction force applied (Appendix I, Part 3, Force F_2). The results from the analysis demonstrate that the stresses in the pivot bolt(s) and clevis plates (attached to the pivot bolt and pump hydraulic brake holder) are acceptable, even when the load is carried by only one brake shoe.

5.0 RECOMMENDATIONS

The maximum allowable encroachment distance for the LS-518 crane depends on the dome load inventory above tank 241SY101. A complete inventory should be taken before installation and removal of the pump. This report used the dome-loading control document (Scott et al. 1994) as the basis for the dome loads on the tank for pump installation activities; however, any equipment added to and/or removed from the area above the tank and the exclusion zone since the release of that document will affect the maximum allowable encroachment distance. In any case, the load capacity of the yoke limits the encroachment distance to 18 ft.

As indicated in case 1 of Table 6, the 50-ton load limit for the tank is exceeded if the crane moves 18 ft into the exclusion zone while the cover blocks are still on the tank. For the sake of decreasing the tank dome load (i.e., increasing the available load to the crane), the cover blocks that are on the tank should be moved outside the exclusion zone before pump installation and removal. Removal of the cover blocks should be accomplished with the crane less than or equal to 17 ft into the exclusion zone. In addition conservative estimates of existing dome loads should be refined with supporting calculations. A small subset of the loads listed in the dome-loading control document are conservative estimates that are not supported by detailed calculations.

In calculating the crane-imposed dome load, this analysis assumes a load radius that positions the boom tip directly above the pump riser for the given encroachment distance. For example, as explained in Section 4.1.2, the load radius is 55.6 ft for the crane positioned at the tank edge. The load radius

corresponding to a given encroachment distance should not be exceeded. The greatest potential for a load radius larger than this occurs during final removal of the pump, when the crane, lifting the accessories, moves toward the tank. To minimize the load radius, the crane operator should move the boom to a lower radius (i.e., boom up) before driving the crane forward into the exclusion zone to lift the pump. If the boom extends beyond a load radius defined by the distance from the crane position to the pump riser, the actual crane-imposed dome load will be greater than those presented in Table 4 (crane lifting accessories only), because the resultant crawler loads will be closer to the tank. (When the crane is lifting its capacity, increasing the load radius decreases the capacity. The end effect is to decrease the crane-imposed dome load.)

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Figure 1. SY-101 Mixer Pump Critical Lift.

Figure 2. Plan View of Tank 241SY101, the 20-ft Exclusion Zone, and the LS-518 Crane Footprint (Not to Scale).

Table 1. Weights and Load Capacities of Components and Related Structures.

Item	Weight (lbf)	Load Capacity (lbf)	Reference
Load Block	4,000	----	Brewer 1994
Choker	150	64,000	Brewer 1994
Dynamometer	200	100,000	Brewer 1994
Shackle	46	70,000	Brewer 1994
Yoke	1,875 ¹	40,000 ²	Mackey 1993
Hose	500	N/A	communication w/ G. A. Ritter
Bag	3,000	N/A	Brewer 1994
Pump	20,050	N/A	Weis 1993
Lift Lug	N/A	105,000 ³	Strehlow 1993b
Mid Length Connection ⁴	N/A	55,654	Strehlow 1993a
Riser 12A (Vertical Lift)	N/A	233,300	Strehlow 1993a

¹Actual weight, painted on yoke.

²Rated capacity, painted on yoke.

³Total capacity of both lifting lugs.

⁴Conservative minimum value for any mid-length connection.

Table 2. Component Load Capacity, Equivalent Load at Dynamometer, and Required Crane Capacity to Achieve Component Load Capacity.

Item	Rated Load Capacity of Item (lbf)	Equivalent Load at Dynamometer (lbf)	Required Crane Capacity (lbf)
Choker	64,000	63,800	68,150
Dynamometer	100,000	100,000	104,350
Shackle	70,000	70,046	74,396
Lifting Yoke	40,000	<u>41,921</u>	46,271
Pump Lifting Lugs	105,000	110,421	114,771
Riser 12A (Vertical Lift) ¹	233,300	238,721	243,071
Pump Mid Level Connections ²	55,654	61,075	65,425
Pump Deadweight	----	25,471	----

¹Assume pump is stuck in riser.

²Assume pump is stuck in waste.

Table 3. Crane Lift Capacity and the Equivalent Load at the Dynamometer as a Function of Crane Encroachment.

Distance into Exclusion Zone (ft)	Crane Load Radius (ft)	Crane Lift Capacity (lbf)	Equivalent Load at Dynamometer (lbf)
16	59.6	43,357	39,007
17	58.6	44,578	40,228
18	57.6	45,798	<u>41,448</u>
19	56.6	47,018	42,668
20	55.6	48,238	43,888

Table 4. Crane-Imposed Dome Load as a Function of Crane Encroachment.

Distance into Exclusion Zone (ft)	Load Radius (ft)	Crane-Imposed Dome Load with Crane Lifting Accessories (lbf)	Crane-Imposed Dome Load with Crane Lifting Capacity (lbf)
10	65.6	15,297	24,407
11	64.6	16,407	26,600
12	63.6	17,635	29,073
13	62.6	18,983	31,804
14	61.6	20,477	34,887
15	60.6	22,121	38,293
16	59.6	23,942	42,215
17	58.6	25,945	46,724
18	57.6	28,157	51,766
19	56.6	30,583	57,319
20	55.6	33,244	63,439

Table 5. Definition of Load Cases for Dome Loading.

Equipment Description	Load Case					Comments
	1	2	3	4	5	
Total Dome Load, excluding pump, shield plug, and cover blocks	✓	✓	✓	✓	✓	Scott et al. 1994
Cover Blocks	✓	✓	---	✓	✓	Central Pump Pit Cover Blocks, Strehlow 1993a
Shield Plug	---	---	---	---	✓	Shield plug for riser 12A, Automation Industries 1976
Mixer Pump	✓	✓	---	---	---	Estimated to weigh 20,050 lbf, Weis 1993
Crane (lifting accessories at 18 ft into exclusion zone)	✓	---	---	---	✓	Crane-imposed dome load when crane is lifting accessories, Table 4
Crane (lifting accessories at 17 ft into exclusion zone)	---	✓	---	---	---	Crane-imposed dome load when crane is lifting accessories, Table 4
Crane (lifting capacity at 18 ft into exclusion zone)	---	---	✓	---	---	Crane-imposed dome load when crane is lifting at capacity, Table 4
Crane (lifting capacity at 17 ft into exclusion zone)	---	---	---	✓	---	Crane-imposed dome load when crane is lifting at capacity, Table 4

Table 6. Tank Dome Loading Summary by Load Case (Single 50-ton Limit).

Equipment Description	Load Case ¹					Comments
	1	2	3	4	5	
Total Dome Load, excluding pump, shield plug, and cover blocks	20,510	20,510	20,510	20,510	20,510	Scott et al. 1994
Cover Blocks	31,672	31,672	---	31,672	31,672	Strehlow 1993a
Shield Plug	---	---	---	---	5,286	Automation Industries 1976
Mixer Pump	20,050	20,050	---	---	---	Weis 1993
Crane Load on Tank Dome ² (lifting accessories)	28,157	25,945	---	---	28,157	Table 4
Crane Load on Tank Dome ² (lifting capacity)	---	---	51,766	46,724	---	Table 4
Dome Load	100,389	98,177	72,276	98,906	85,625	---
Margin	-389	1,823	27,724	1,094	14,375	---

¹See Table 5 for load case definition.

²With crane positioned 18 ft into exclusion zone except for cases 2 and 4 where crane is positioned 17 ft into exclusion zone.

Table 7. Tank Dome Loading Summary by Load Case (Separate Dead and Live Load 50-ton Limits).

Equipment Description	Load Case1						Comments
	1(dead)	1(live)	3(dead)	3(live)	5(dead)	5(live)	
Total Dome Load, excluding pump, shield plug, and cover blocks	20,510	---	20,510	---	20,510	---	Scott et al. 1994
Cover Blocks	31,672	---	---	---	31,672	---	Strehlow 1993a
Shield Plug	---	---	---	---	5,286	---	Automation Industries 1976
Mixer Pump	20,050	---	---	---	---	---	Weis 1993
Crane Load on Tank Dome ² (lifting accessories)	---	28,157	---	---	---	28,157	Table 4
Crane Load on Tank Dome ² (lifting capacity)	---	---	---	51,766	---	---	Table 4
Dome Load	72,232	28,157	20,510	51,766	57,468	28,157	---
Margin	27,768	71,843	79,490	48,234	42,532	71,843	---

¹See Table 5 for load case definition.

²With crane positioned 18 ft into exclusion zone.

APPENDIX A. EQUIVALENT DYNAMOMETER LOADS AND REQUIRED CRANE CAPACITY

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page ____ of ____
 (4) Building _____ (5) Rev. _____ (6) Job No. _____
 (7) Subject Equivalent Dynamometer Loads and Required Crane Capacity
 (8) Originator D. M. Lawler Queen Linda Date July 28, 1994
 (9) Checker W.D. Weiss M. J. Smith Date 8/2/94
 (10)

The load capacities and weights of the lift components and related structures are listed below.

Item	Weight (lbf)	Reference	Capacity (lbf)	Reference
Load Block	4,000	Brewer 1994	----	Brewer 1994
Choker	150	Brewer 1994	64,000	Brewer 1994
Dynamometer	200	Brewer 1994	100,000	Brewer 1994
Shackle	46	Brewer 1994	70,000	Brewer 1994
Lifting Yoke (H-2-83687, Rev. 0)	1,875 ¹	Brewer 1994	40,000 ²	Mackey 1994
Hose	500	G. A. Ritter	----	
Bag	3,000	Brewer 1994	----	
Pump Lifting Lugs	N/A	----	105,000	Strehlow 1993b
Pump Mid-level Connections (minimum)	N/A	----	55,654	Strehlow 1993a
Riser 12A (Vertical Lift)	N/A	----	233,300	Strehlow 1993a

¹Actual weight, painted on yoke.

²Actual capacity, painted on yoke.

The equivalent load at the dynamometer and the corresponding required crane capacity are determined for each of the components used in the pump lift (below the load block) and related structure (pump mid level connections and riser).

Choker

Equivalent load at dynamometer

64,000 load capacity
 - 200 Dynamometer
 63,800 lbf

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 3 of 7
(4) Building _____ (5) Rev. _____ (6) Job No. _____
(7) Subject Equivalent Dynamometer Loads and Required Crane Capacity
(8) Originator D. M. Lawler Duncan Semler Date July 28, 1994
(9) Checker M.P. Wers Michael Miller Date 8/2/94
(10)

Choker (cont)

Required Crane Capacity

64,000 load capacity
+ 150 choker weight
+4,000 load block weight
68,150 lbf

Dynamometer

Equivalent load at dynamometer

Same as load capacity

Required Crane Capacity

100,000 load capacity
+ 200 dynamometer weight
+ 150 choker weight
+ 4,000 load block weight
104,350 lbf

NOTE: The difference between dynamometer load and required crane capacity is 4,350 lbf.

Shackle

Equivalent load at dynamometer

70,000 load capacity
+ 46 shackle weight
70,046 lbf

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 4 of 7
 (4) Building _____ (5) Rev. _____ (6) Job No. _____
 (7) Subject Equivalent Dynamometer Loads and Required Crane Capacity
 (8) Originator D. M. Lawler Duncan Sanders Date July 28, 1994
 (9) Checker M.P. Weis Michael P. Weis Date 8/2/94
 (10)

Shackle (cont)

Required Crane Capacity

70,000	load capacity
+ 46	shackle weight
+ 200	dynamometer weight
+ 150	choker weight
+ 4,000	load block weight
<u>74,396</u>	lbf

Lifting Yoke

Equivalent load at dynamometer

40,000	load capacity
+ 1,875	lifting yoke weight
+ 46	shackle weight
<u>41,921</u>	lbf

Required Crane Capacity

40,000	load capacity
+ 1,875	lifting yoke weight
+ 46	shackle weight
+ 200	dynamometer weight
+ 150	choker weight
+ 4,000	load block weight
<u>46,271</u>	lbf

Pump Lifting Lugs

Equivalent load at dynamometer

105,000	load capacity
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
<u>110,421</u>	lbf

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 5 of 7
(4) Building _____ (5) Rev. _____ (6) Job No. _____
(7) Subject Equivalent Dynamometer Loads and Required Crane Capacity
(8) Originator D. M. Lawler [Signature] Date July 28, 1994
(9) Checker M.P. [Signature] [Signature] Date 8/2/94
(10)

Pump Lifting Lugs (cont)

Required Crane Capacity

105,000	load capacity
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
+ 200	dynamometer weight
+ 150	choker weight
+ 4,000	load block weight
<u>114,771</u>	lbf

Riser 12A

Equivalent load at dynamometer

233,300	load capacity (vertical lift)
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
<u>238,721</u>	lbf

Required Crane Capacity

233,300	load capacity
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
+ 200	dynamometer weight
+ 150	choker weight
+ 4,000	load block weight
<u>243,071</u>	lbf

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 6 of 7
(4) Building _____ (5) Rev. _____ (6) Job No. _____
(7) Subject Equivalent Dynamometer Loads and Required Crane Capacity
(8) Originator D. M. Lawler Duncan Simler Date July 28, 1994
(9) Checker R.P. Weir Michael Plun Date 8/2/94
(10)

Pump Mid Level Connections

Equivalent load at dynamometer
(conservatively neglecting pump weight)

55,654	minimum load capacity
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
<u>61,075</u>	lbf

Required Crane Capacity
(conservatively neglecting pump weight)

55,654	load capacity
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
+ 200	dynamometer weight
+ 150	choker weight
+ 4,000	load block weight
<u>65,425</u>	lbf

The estimated dead weight of the pump, as it would be read at the dynamometer is

20,050	estimated pump weight (Weis 1993)
+ 3,000	bag weight
+ 500	hose weight
+ 1,875	lifting yoke weight
+ 46	shackle weight
<u>25,471</u>	lbf

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 7 of 7
(4) Building _____ (5) Rev. _____ (6) Job No. _____
(7) Subject Equivalent Dynamometer Loads and Required Crane Capacity
(8) Originator D. M. Lawler Devin Smiles Date July 28, 1994
(9) Checker W.P. Lees Michael P. Lee Date 8/2/94
(10)

REFERENCES

Brewer, C. E., 1994, Test Pump Removal and Installation of the New Permanent Mixer Pump 101 SY Tank Critical Lift Procedure, Draft, (to be included in work packages 2W-94-00652 through 2W-94-00654), Westinghouse Hanford Company, Richland, Washington.

Mackey, T. C., 1993, 101-SY Hydrogen Mitigation Test - Structural Analysis of the Lifting Beam, Lifting Yoke, and Transport Cradle for the Mixer Pump Assembly, WHC-SD-WM-DA-109, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

Strehlow, J. P., 1993b, Structural Analysis of Tank 241-SY-101 Mixing Pump, WHC-SD-WM-DA-111, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

APPENDIX B. LS-518 CRANE CAPACITY AND EQUIVALENT LOAD AT DYNAMOMETER WHEN
LIFTING CAPACITY

DESIGN CALCULATION

WHC-SD-WM-ER-373

Rev. 0

(1) Drawing _____ (2) Doc. No. _____ (3) Page 2 of 3
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject LS-518 Crane Capacity and Equivalent Load at Dynamometer when lifting Capacity
 (8) Originator M. P. Weis R.P. Item Date 7/30/94
 (9) Checker Duncan Fowler Date 8-2-94
 (10)

CRANE CAPACITY AS A FUNCTION OF ENCROACHMENT ON THE EXCLUSION ZONE AND THE EQUIVALENT LOAD AT THE DYNAMOMETER

LB := 180·ft

boom length associated with these capacities

m := 1..4

LoadRadius_m :=

Capacity_m :=

load radii and capacities at these radii
 (manufacturer's spec for LS-518)

50·ft
60·ft
70·ft
80·ft

55100·lbf
42900·lbf
34600·lbf
28600·lbf

r := 41.5·ft

outside radius of tank (Drawing H-2-37706)

t := 20·ft

thickness of exclusion zone (Scott et. al. 1992)

Ltrack := 22.25·ft

crawler ground bearing length (mfr spec)

offset := 3·ft

offset of pump riser from center of tank
 (Drawing H-2-37773)

n := 10..20

δ_n := n·ft

encroachment distance on exclusion zone

ExclusionZoneR := $\left[(r + t) + \frac{Ltrack}{2} \right] + offset$

radius of crane with crawlers lined radially and
 front contact line on edge of exclusion zone

LoadRadii_n := ExclusionZoneR - δ_n

Capacities_n := linterp LoadRadius, Capacity, LoadRadii_n

define load radii and capacities at foot intervals from
 midpoint of exclusion zone to edge of tank
 (linear interpolation OK'd by representative at Link-Belt)

Loadblock := 4000·lbf

Choker := 150·lbf

Dynamometer := 200·lbf

lift accessories above the dynamometer: load block, choker,
 and dynamometer

EquivLoadDyno_n := Capacities_n - (Loadblock + Choker + Dynamometer)

load measured by dynamometer, given
 the crane is lifting its capacity

Crane Capacity and Equivalent Load at Dynamometer Versus Encroachment on Exclusion Zone

δ _n ft	LoadRadii _n ft	Capacities _n lbf	EquivLoadDyno _n lbf
10	65.625	38231	33881
11	64.625	39061	34711
12	63.625	39891	35541
13	62.625	40721	36371
14	61.625	41551	37201
15	60.625	42381	38031
16	59.625	43357	39007
17	58.625	44578	40228
18	57.625	45798	41448
19	56.625	47018	42668
20	55.625	48238	43888

DESIGN CALCULATION

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Rev. 0

- (1) Drawing _____ (2) Doc. No. _____ (3) Page 3 of 3
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject LS-518 Crane Capacity and Equivalent Load of Dynamometer when Lifting Capacity
 (8) Originator M. P. Weis *M. P. Weis* Date 9/30/94
 (9) Checker D. Mason *D. Mason* Date 8-2-94
 (10)

MANUFACTURER'S INFORMATION - LS-518 CRANE CAPACITIES

FMC

LS-518 lifting crane capacities

Refer to Notes page 6.

Length	Boom					Ctwt. "A"		Ctwt. "AB"	
	Radius		Angle Degree	Boom Point Height [Ⓢ]		Pounds	Kilograms	Pounds	Kilograms
	Feet	Meters		Feet	Meters				
170' (51.82 m)	35	10.67	79.7	173' 8"	52.94	48,500	22,000	90,800	41,187
	40	12.19	78.0	172' 8"	52.63	39,700	18,008	75,300	34,156
	50	15.24	74.5	170' 3"	51.89	28,200	12,792	55,400	25,129
	60	18.29	71.0	167' 2"	50.95	21,300	9,662	43,200	19,596
	70	21.34	67.4	163' 4"	49.78	16,600	7,530	34,900	15,831
	80	24.38	63.7	158' 10"	48.41	13,100	5,942	28,900	13,109
	90	27.43	59.9	153' 5"	46.76	10,500	4,763	24,300	11,022
	100	30.48	55.9	147' 2"	44.86	8,500	3,856	20,900	9,480
	110	33.53	51.7	139' 10"	42.62	6,900	3,130	18,100	8,210
	120	36.58	47.3	131' 4"	40.03	5,500	2,495	15,700	7,122
	130	39.62	42.5	121' 3"	36.96	4,400	1,996	13,800	6,260
	140	42.67	37.2	109' 4"	33.32	3,400	1,542	12,100	5,490
	150	45.72	31.3	94' 7"	28.83	2,600	1,179	10,600	4,808
180' (54.86 m)	160	48.77	24.0	75' 6"	23.01	1,900	862	9,400	4,264
	170	51.82	13.5	46' 0"	14.02	1,200	544	8,300	3,765
	35	10.67	80.3	183' 10"	56.03	48,300	21,909	90,200	40,915
	40	12.19	78.7	182' 11"	55.75	39,500	17,917	75,000	34,020
	50	15.24	75.4	180' 7"	55.04	27,900	12,655	55,100	24,993
	60	18.29	72.1	177' 8"	54.15	21,100	9,571	42,900	19,459
	70	21.34	68.7	174' 2"	53.09	16,300	7,394	34,600	15,695
	80	24.38	65.3	169' 11"	51.79	12,900	5,851	28,600	12,973
	90	27.43	61.7	164' 11"	50.27	10,200	4,627	24,000	10,884
	100	30.48	58.0	159' 1"	48.49	8,200	3,720	20,600	9,344
	110	33.53	54.2	152' 5"	46.46	6,600	2,994	17,800	8,074
	120	36.58	50.2	144' 7"	44.07	5,200	2,359	15,400	6,985
	130	39.62	45.9	135' 7"	41.32	4,100	1,860	13,500	6,124
190' (57.91 m)	140	42.67	41.2	125' 1"	38.12	3,100	1,406	11,800	5,352
	150	45.72	36.2	112' 7"	34.31	2,300	1,043	10,400	4,717
	160	48.77	30.3	97' 4"	29.67	1,600	726	9,100	4,128
	170	51.82	23.3	77' 7"	23.65	—	—	8,000	3,629
	180	54.86	13.1	47' 2"	14.37	—	—	7,000	3,175
	40	12.19	79.3	192' 1"	58.55	39,200	17,781	74,800	33,929
	50	15.24	76.2	190' 11"	58.19	27,700	12,565	54,800	24,857
	60	18.29	73.1	188' 2"	57.35	20,800	9,435	42,600	19,323
	70	21.34	69.9	184' 10"	56.34	16,000	7,258	34,200	15,513
	80	24.38	66.6	180' 10"	55.12	12,500	5,670	28,200	12,792
	90	27.43	63.3	176' 2"	53.70	9,900	4,491	23,700	10,750
	100	30.48	59.9	170' 9"	52.04	7,900	3,583	20,300	9,208
	110	33.53	56.3	164' 7"	50.16	6,200	2,812	17,400	7,893
200' (60.96 m)	120	36.58	52.6	157' 5"	47.98	4,900	2,222	15,100	6,849
	130	39.62	48.7	149' 3"	45.49	3,800	1,724	13,100	5,942
	140	42.67	44.6	139' 3"	42.77	2,900	1,270	11,400	5,171
	150	45.72	40.1	128' 10"	39.27	2,000	907	10,000	4,536
	160	48.77	35.2	115' 10"	35.30	1,300	590	8,800	3,992
	170	51.82	29.5	100' 0"	30.48	—	—	7,700	3,493
	180	54.86	22.7	79' 7"	24.26	—	—	6,700	3,039
	190	57.91	12.7	48' 3"	14.71	—	—	5,800	2,631
	40	12.19	79.8	203' 3"	61.95	Not Applicable		69,300	31,434
	50	15.24	76.9	201' 3"	61.34			54,500	24,721
	60	18.29	73.9	198' 7"	60.53			42,300	19,187
	70	21.34	70.9	195' 5"	59.56			34,000	15,422
	80	24.38	67.9	191' 8"	58.42			27,900	12,655
	90	27.43	64.7	187' 4"	57.10			23,400	10,614
	100	30.48	61.5	182' 3"	55.55			20,000	9,072
	110	33.53	58.2	176' 5"	53.77			17,100	7,757
	120	36.58	54.8	169' 10"	51.76			14,800	6,713
	130	39.62	51.2	162' 3"	49.45			12,800	5,806
	140	42.67	47.4	153' 8"	46.84			11,100	5,035
	150	45.72	43.4	143' 10"	43.84			9,700	4,400
	160	48.77	39.0	132' 5"	40.36			8,500	3,856
	170	51.82	34.2	118' 11"	36.25			7,400	3,357
	180	54.86	28.8	102' 8"	31.29			6,400	2,903
	190	57.91	22.1	81' 7"	24.87			5,500	2,495
	200	60.96	12.4	49' 4"	15.04			4,800	2,177

Ⓢ Measured from center of boom head sheave to ground.

APPENDIX C. USE OF THE BOUSSINESQ EQUATION TO CALCULATE TANK DOME LOAD

DESIGN CALCULATION

WHC-SD-WM-ER-373

Rev. 0

(1) Drawing _____ (2) Doc. No. _____ (3) Page 2 of 6
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Application of the Boussinesq Equation to Calculate Tank Dome Load
 (8) Originator M. P. Weis Michael J. Weis Date 7/30/94
 (9) Checker Duncan Soule Date 8-2-94
 (10)

CALCULATION TO DETERMINE PERCENTAGE OF CONCENTRATED LOAD ON SOIL TRANSMITTED TO TANK DOME AS A FUNCTION OF DISTANCE FROM THE TANK EDGE

$$R_1 := \left(99 + \frac{10}{12} \right) \cdot \text{ft}$$

larger spherical radius of tank dome (Drwg H-2-37706)

$$r := 41.5 \cdot \text{ft}$$

cylindrical radius of tank (Drwg H-2-37706)

$$d := 6.5 \cdot \text{ft}$$

depth of tank below surface at the apex

$$\text{ORIGIN} := -10$$

sets default starting value for range variable

$$i := -10, -8..40$$

range variable to define distance

$$\Delta_i := i \cdot \text{ft}$$

distance of concentrated load from tank edge

$$Q := 1000 \cdot \text{lb} \cdot \text{ft}$$

concentrated load

Equation of spherical surface of tank dome (coordinate system explained below)

$$z(x, y) := -\sqrt{R_1^2 - \left[x - (r + \Delta_i) \right]^2 - y^2} + (d + R_1)$$

Vertical stress in soil as a function of the position on the dome and the concentrated load

The origin of the coordinate system is at the soil surface on the line of action of the concentrated load

The x-axis is arbitrarily chosen as containing the point of projection of the dome apex onto the soil surface. The relation is the Boussinesq Equation (Sowers and Sowers 1970) with the equation for the dome spherical surface substituted for z coordinate.

$$q(x, y) := \frac{Q}{\pi \cdot z(x, y)^2} \cdot \frac{1}{\left[1 + \frac{2}{z(x, y)^2} \cdot (x^2 + y^2) \right]^{\frac{3}{2}}}$$

Equation of dome's projection on xy-plane

$$f(x) := \sqrt{r^2 - \left[x - (r + \Delta_i) \right]^2}$$

Load on tank dome due to the vertical stress

Because the Boussinesq Equation and tank are symmetrical with respect to the x-axis, the limits of integration can be halved in the y direction

$$P_i := 2 \cdot \int_{\Delta_i}^{\Delta_i + 2 \cdot r} \int_{0 \cdot \text{ft}}^{f(x)} q(x, y) \, dy \, dx$$

$$P_i := \frac{P_i}{Q} \cdot 100$$

percentage of load transmitted to tank dome

DESIGN CALCULATION

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(1) Drawing _____ (2) Doc. No. _____ (3) Page 3 of 6
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Application of the Bousinesq Equation to Calculate Tank Dome Load
 (8) Originator M. P. Weis *Michael P. Weis* Date 8/1/94
 (9) Checker Duncan *Duncan* Sanborn *Sanborn* Date 8-2-94
 (10)

Tank dome load as a function of concentrated load's distance from tank

Δ_i ft	P_i lb _f	p_i (%)
-10	636.932	63.693
-8	584.02	58.402
-6	526.095	52.609
-4	464.154	46.415
-2	400.157	40.016
0	337.324	33.732
2	279.188	27.919
4	228.458	22.846
6	186.256	18.626
8	152.254	15.225
10	125.31	12.531
12	104.067	10.407
14	87.278	8.728
16	73.916	7.392
18	63.186	6.319
20	54.483	5.448
22	47.354	4.735
24	41.458	4.146
26	36.532	3.653
28	32.389	3.239
30	28.873	2.887
32	25.868	2.587
34	23.282	2.328
36	21.043	2.104
38	19.093	1.909
40	17.385	1.738

Percentage of concentrated load on soil transmitted to tank as a function of this load's distance from tank

DESIGN CALCULATION

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- (1) Drawing _____ (2) Doc. No. _____ (3) Page 4 of 6
(4) Building _____ (5) Rev. _____ (6) Job. No. _____
(7) Subject Application of the Boussinesq Equation to Calculate Tank Dome Load
(8) Originator M. P. Weis Unit Plan Date 7/30/94
(9) Checker Duncan Lowder Date 8-2-94
(10)

Graphic to illustrate the application of the Boussinesq Equation

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(1) Drawing _____ (2) Doc. No. _____ (3) Page 5 of 6
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Application of the Bousinesq Equation to Calculate Tank Dome Load
 (8) Originator M. P. Weis Date 7/30/94
 (9) Checker Duncan Lawler Date 8-2-94
 (10)

VALIDATION OF MATHCAD'S DOUBLE INTEGRAL CALCULATION WITH SUMMATION Checking the Case Where the Load Q is at the Tank Edge

Equation of spherical surface of tank dome for $\Delta_1=0$

$$z(x,y) := -\sqrt{R_1^2 - (x-r)^2 - y^2} + (d + R_1)$$

Vertical stress in soil as a function of the position on the dome and the concentrated load for $\Delta_1=0$

$$q(x,y) := \frac{Q}{\pi \cdot z(x,y)^2} \cdot \frac{1}{\left[1 + \frac{2}{z(x,y)^2} \cdot (x^2 + y^2)\right]^{\frac{3}{2}}}$$

Equation of dome's projection on xy-plane for $\Delta_1=0$

$$f(x) := \sqrt{r^2 - (x-r)^2}$$

Set up square grid enclosing tank for calculating vertical stress on tank surface at these grid points and for plotting this stress

ORIGIN := 0

reset start values for range variables

N := 85

number of increments per direction

j := 0..N k := 0..N

$$\Delta x := \frac{2 \cdot r}{N} \quad \Delta y := \frac{2 \cdot r}{N}$$

$x_j := \Delta x \cdot j$ $y_k := -r + \Delta y \cdot k$

x and y coordinates of square grid

Set it up so that those grid points that are not within the cylindrical radius of tank display as zero stress

$$\text{temp}_{(j,k)} := \text{if} \left(y_k \leq f(x_j), q(x_j, y_k), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right)$$

$$q'_{(j,k)} := \text{if} \left(y_k \geq -f(x_j), \text{temp}_{(j,k)}, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right)$$

matrix containing value of stress as a function of position on the dome

Calculate a rough estimate of the load on the dome

$$\text{Load} := \sum_j \sum_k q'_{(j,k)} \cdot \Delta x \cdot \Delta y$$

$$\text{Load} = 332.796 \cdot \text{lbf}$$

$$\text{PercentDiff} := \left| \frac{\text{Load} - 337.324 \cdot \text{lbf}}{337.324 \cdot \text{lbf}} \right| \cdot 100$$

percent difference with load calculated via double integral

$$\text{PercentDiff} = 1.342$$

DESIGN CALCULATION

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- (1) Drawing _____ (2) Doc. No. _____ (3) Page 6 of 6
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Application of the Bousinesq Equation to Calculate Tank Dome Load
 (8) Originator M. P. Weis *M. P. Weis* Date 7/30/44
 (9) Checker Duncan Lawler *Duncan Lawler* Date 8-2-44
 (10)

SURFACE PLOT OF VERTICAL STRESS ON TANK DOME for $\Delta_1=0$

(The plot peaks in from the edge of the tank, because the depth of the dome decreases from the edge towards the center of the tank; the decrease in depth of the tank dome is quickly overcome by the decrease in stress away from the load) (0, 0)

$$q(0\text{-ft}, 0\text{-ft}) = 1.319 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(2\text{-ft}, 0\text{-ft}) = 1.404 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(2\text{-r}, 0\text{-ft}) = 0.003 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(r, -r) = 0.008 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(r, r) = 0.008 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

APPENDIX D. CRANE-IMPOSED DOME LOADS AS A FUNCTION OF ENCROACHMENT ON
EXCLUSION ZONE

DESIGN CALCULATION

WHC-SD-WM-ER-373

Rev. 0

- (1) Drawing _____ (2) Doc. No. _____ (3) Page 2 of 35
(4) Building _____ (5) Rev. _____ (6) Job. No. _____
(7) Subject Crane-Imposed Dome Load as a Function of Encroachment into Exclusion Zone
(8) Originator M. P. Weis [Signature] Date 7/30/94
(9) Checker Duncan Lawler Date 8-2-94
(10)

DOMES LOADS IMPOSED ON TANK 241-SY-101 BY LINKBELT LS-518 CRANE

The purpose of this calculation is to determine the dome load on tank 241-SY-101 when the Linkbelt LS-518 crawler mounted crane installs or removes the hydrogen mitigation mixer pump. According to the *Tank 242-SY-101 Dome Loading Control Document* (Scott et al. 1994), a 50-ton load limit currently exists for this tank. The tank dome load from the crane will be applied to this limit. The margin available to the crane depends on the other loads on the tank being applied against this limit. This document also defines a heavy equipment exclusion zone, a 20-foot annular region outside the tank perimeter.

During pump removal, waste may adhere to the pump. Because of this additional load, the crane may have to move within the exclusion zone. This analysis will determine if it is feasible for the crane to do so as permitted by the dome loading control document. Pump removal may occur during installation of the pump and is certainly expected prior to final disposal of waste in 241-SY-101.

The crane-imposed dome load calculated here is used to determine the proximity with which the crane can approach the tank without exceeding the current 50-ton limit. To accomplish this, a sensitivity study was performed that determines the crane-imposed dome load as a function of the crane's encroachment onto the exclusion zone. (Each dome load result is a single application of this Mathcad worksheet.). To enter the exclusion zone, the crane must be positioned with the crawlers' direction of travel radial to the tank.

The sensitivity study was performed for the two load cases:

- 1) The crane lifts the pump accessories only. At some time during installation or removal the crane will be in position with the pump setting on the riser. With the pump on the riser, the full weight of the pump is applied against the 50-ton limit. When lifted by the crane, a percentage of the pump's weight will be imposed on the dome through the soil.
- 2) The crane lifts its capacity. This case is run to determine if the crane can lift its capacity in the event the additional loads from waste are greater than estimated. Bearing pressure is calculated also.

Assuming the crane does not encroach upon the tank, the absolute worst case for the load on the tank dome is the crane lifting its capacity at the tank edge (20 feet into the exclusion zone). This case has been chosen to illustrate the application of the Mathcad worksheet.

This calculation first determines the resultant crawler loads on the soil (magnitude and location relative to the crawlers) for the load radius such that when the boom is parallel with the direction crawler travel, the boom tip positioned over the pump riser. The calculation is versatile in that it can calculate crawler loads and the dome load for a rotation of the crane body. By integrating the Boussinesq Equation (Sowers & Sowers 1970), this calculation then determines the vertical load imposed on the dome of the tank as a function of these loads, specifically their magnitude and distance from the tank. The Boussinesq Equation gives the 3-d vertical soil stress field in the vicinity of a concentrated load on the soil surface.

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 (8) Originator M. P. Weis [Signature] Date 7/30/94
 (9) Checker Duncan Sauter Date 8-2-94
 (10)

DOME LOADS IMPOSED ON TANK 241-SY-101 BY LINKBELT LS-518 CRANE (continued)

On the next page is a plan view of the tank, the exclusion zone, and the "footprint" of the LS-518 crane located in the exclusion zone. The crane's approximate position on the east side of the tank has been derived from sketch 3A in the critical lift procedure for the installation of the mixer pump assembly (C. Brewer 1994). A free body diagram of the crane is on the following page. Note that the ground bearing length of the crawlers (22.25 feet) defines the length of this "footprint" as opposed to the overall length of the crawlers (24.33 feet). Therefore, when the crane is at the edge of the exclusion zone, it follows that there is crawler overhang into this zone. The encroachment distance is the distance between the front, soil-contact line of the crawlers and a tangent to the outer edge of the exclusion zone parallel with this soil-contact line.

The variables used in this graphic correspond to variables in the Mathcad worksheet. They are defined here also:

r = cylindrical radius of the tank
 t = thickness of the exclusion zone
 d = the distance from the crane center of rotation to the line of action of a crawler resultant load
 A = the distance from a resultant crawler load to the tank center
 δ = the encroachment distance of the crane onto the exclusion zone
 R_C = distance from the crane axis of rotation to the centerline of the tank

The xyz rectangular coordinate system with the origin at the line of action of the resultant crawler load is the coordinate system for application of the Boussinesq Equation.

The following assumptions apply to this analysis:

- o The axis of symmetry of the crawlers passes through the center of the tank
- o The load radius, the distance from the crane's axis of rotation to the pump riser is 3 feet greater than R_C , defined above.
- o The parts of rope hanging from the boom tip are included in the overall weight of the crane for each load case, but they are not subtracted from the load (the crane's capacity) lifted by the crane in load case 2. This is conservative for load case 2.
- o The weight of the new permanent mixer pump is the same as the weight of the currently installed pump.

The variables that describe the crane configuration and its lifting capacities were obtained from the manufacturer's specification for the LS-518 and from the manufacturer via facsimile. The pertinent information is attached to the end of this calculation.

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 (9) Checker Doreen Lemley Date 8-2-94
 (10) SCHEMATIC OF TANK, EXCLUSION ZONE, AND LS-518 CRANE "FOOTPRINT"

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FREE BODY DIAGRAM OF LS-518 CRANE

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LSI-518 CRANE: ILLUSTRATION OF VARIABLES DEFINING CRANE CONFIGURATION

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RESULTS OF SENSITIVITY STUDY: DOME LOAD AS A FUNCTION OF CRANE ENCROACHMENT ON THE 20-FOOT EXCLUSION ZONE OF TANK 241-SY-101

Two different load cases have been analyzed. The results are tabulated below.

$n := 10..20$

define range variable for encroachment distance (10 to 20 ft)

$\delta_n := n \cdot \text{ft}$

encroachment distance on exclusion zone

encroachment distance on exclusion zone

1) crane lifting accessories only (pump setting on riser)

$\frac{\delta_n}{\text{ft}}$

DomeLoadAcc_n :=

10	15297·lbf
11	16407·lbf
12	17635·lbf
13	18983·lbf
14	20477·lbf
15	22121·lbf
16	23942·lbf
17	25945·lbf
18	28157·lbf
19	30583·lbf
20	33244·lbf

2) crane lifting its capacity

$\frac{\delta_n}{\text{ft}}$

DomeLoadCapcty_n :=

10	24407·lbf
11	26600·lbf
12	29073·lbf
13	31804·lbf
14	34887·lbf
15	38293·lbf
16	42215·lbf
17	46724·lbf
18	51766·lbf
19	57319·lbf
20	63439·lbf

$\text{psf} := \frac{\text{lbf}}{\text{ft}^2}$

equivalent units

maximum bearing pressure:

$\frac{\delta_n}{\text{ft}}$

MaxBrgPres_n :=

10	6286·psf
11	6296·psf
12	6299·psf
13	6296·psf
14	6287·psf
15	6272·psf
16	6283·psf
17	6340·psf
18	6389·psf
19	6427·psf
20	6457·psf

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CRANE CONFIGURATION

The encroachment distance of the crane into the exclusion zone defines the load radius for the crane. This in turn defines the crane's configuration during the lift, from which the resultant crawler loads are calculated. The crane-imposed dome load is a function of the resultant crawler loads.

NumInserts := 12

number of inserts to extend boom

Linsert := 10·ft

length of boom insert

The particular crane used for the mixer pump lift will use three 40-foot sections. Twelve 10-foot sections are used in the analysis, because they weigh more per foot (LS-518 operator's manual). This is conservative. The excellent agreement between this calculation and the manufacturer's analysis (Appendix: Verification of Crane Calculations) verifies the conservatism in this approach.

DefaultLB := 60·ft

standard boom length for crane

LB := DefaultLB + NumInserts·Linsert

boom length

LB = 180·ft

Ltrack := 22.25·ft

crawler ground bearing length

Lwtrack := $3 + \frac{8}{12}$ ·ft

crawler ground bearing width

Lbtk := 8·ft

half the distance between centers of crawlers

r := 41.5·ft

outside radius of tank

t := 20·ft

exclusion zone around tank

→ δ := 20·ft

encroachment distance on exclusion zone

$R_c := \left[(r + t) + \frac{Ltrack}{2} \right] - \delta$

distance from crane center of rotation to center of tank

$R_c = 52.6$ ·ft

R := $R_c + 3$ ·ft

load radius, approximate - accounts for 3-foot offset of pump riser from center of tank

R = 55.6·ft

RF := $4 + \frac{8}{12}$ ·ft

offset of boom pivot from center of rotation

RB := 84.48·ft

location of CG of boom from pivot point towards tip (this is a function of NumInserts)

LM := 30·ft

length of live mast

CGLMT := 10.33·ft

offset of CG of live mast from upper end of live mast

HMF := 0.88·ft

horizontal offset of live mast pivot to boom pivot

VMF := 1.17·ft

vertical offset of live mast pivot to boom pivot

E := 40.25·ft

default pendant length

E1 := E + NumInserts·Linsert

pendant length

E1 = 160.3·ft

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CRANE CONFIGURATION (continued)

$$DU := 9.78 \cdot \text{ft}$$

offset of upper (counterweight) from center of rotation

$$Y := 6 + \frac{7}{12} \cdot \text{ft}$$

height of boom pivot off ground

$$HLMAX := 37100 \cdot \text{lbf}$$

allowable load for 1 part of 1 1/8" wire rope

$$\theta_b := \pi - \arccos \frac{R - RF}{LB}$$

boom angle with horizontal (CCW positive)

$$\theta_b = 106.4 \cdot \text{deg}$$

$$\theta_o := \arctan \frac{VMF}{HMF}$$

angular offset of live mast lower pivot and

boom lower pivot (CCW positive)

$$\theta_o = 53.1 \cdot \text{deg}$$

$$LO := \sqrt{VMF^2 + HMF^2}$$

length of offset of the lower pivots of live
mast and boom

$$LO = 1.5 \cdot \text{ft}$$

Calculation of Live Mast's and Pendants' Angles with Horizontal

Set of 2 simultaneous equations to solve for the live mast and pendants angular offset with horizontal. Graphically, the boom, live mast, pendants, and displacement between lower pivots of boom and live mast are treated as vectors. The direction of the vectors is set such that the vector for the boom is the summation of the vectors for the other three displacements. The horizontal components are equated for the 1st equation and the vertical ones for the 2nd equation. Note that angles are measured counterclockwise from the horizontal. The two unknowns are the live mast angle and the pendants angle.

$$LB \cdot \cos(\theta_b) = LO \cdot \cos(\theta_o) + LM \cdot \cos(\theta_{lm}) + E1 \cdot \cos(\theta_p) \quad (1)$$

$$LB \cdot \sin(\theta_b) = LO \cdot \sin(\theta_o) + LM \cdot \sin(\theta_{lm}) + E1 \cdot \sin(\theta_p) \quad (2)$$

Solving for the live mast angle in (1)

$$\theta_{lm} = \arccos \frac{B - E1 \cdot \cos(\theta_p)}{LM}$$

where

$$B := LB \cdot \cos(\theta_b) - LO \cdot \cos(\theta_o)$$

Substituting this expression into (2) yields an equation in one unknown, the pendants angle

$$A = E1 \cdot \sin(\theta_p) + \sqrt{LM^2 - (B - E1 \cdot \cos(\theta_p))^2}$$

where

$$A := LB \cdot \sin(\theta_b) - LO \cdot \sin(\theta_o)$$

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CRANE CONFIGURATION (continued)

Solving (2) in the Mathcad symbolic processor yields

$$\theta_p := 2 \cdot \text{atan} \left[\frac{2 \cdot A \cdot E1 \dots + \sqrt{2 \cdot A^2 \cdot E1^2 - B^4 - A^4 - 2 \cdot B^2 \cdot A^2 - LM^4 - E1^4 + 2 \cdot LM^2 \cdot E1^2 + 2 \cdot LM^2 \cdot B^2 + 2 \cdot LM^2 \cdot A^2 + 2 \cdot B^2 \cdot E1^2}}{-LM^2 + B^2 + 2 \cdot B \cdot E1 + A^2 + E1^2} \right]$$

Solving for the live mast angle

$$\theta_p = 114.7 \cdot \text{deg}$$

$$\theta_{lm} := \text{acos} \frac{B - E1 \cdot \cos(\theta_p)}{LM}$$

$$\theta_{lm} = 59.7 \cdot \text{deg}$$

CRANE AND PICKED-LOAD WEIGHT

Weights Per Foot

one boom insert

1 1/8" wire rope

pendants

$$w := 77.5 \cdot \frac{\text{lbf}}{\text{ft}}$$

$$w2 := 2.34 \cdot \frac{\text{lbf}}{\text{ft}}$$

$$w3 := 12.39 \cdot \frac{\text{lbf}}{\text{ft}}$$

Weight of Crane

Boom

$$W_{top} := 2780 \cdot \text{lbf}$$

$$W_{base} := 3780 \cdot \text{lbf}$$

$$W_{mid} := (\text{NumInserts} \cdot \text{Linsert}) \cdot w$$

$$W_{rope} := LB \cdot w2$$

$$W_b := W_{top} + W_{base} + W_{mid} + W_{rope}$$

$$W_{mid} = 9300 \cdot \text{lbf}$$

$$W_{rope} = 421.2 \cdot \text{lbf}$$

$$W_b = 16281.2 \cdot \text{lbf}$$

Upper

Carrier

Live Mast

$$W_u := 153700 \cdot \text{lbf}$$

$$W_c := 88775 \cdot \text{lbf}$$

$$W_{lm} := 4970 \cdot \text{lbf}$$

Head machinery

Pendants

$$W_{hm} := 1663 \cdot \text{lbf}$$

$$W_p := E1 \cdot w3$$

$$W_p = 1985.5 \cdot \text{lbf}$$

Rope from boom tip to picked load at elevation equal to ground

4 parts are being used; however, if a load is picked requiring more than 4 parts, min req'd is used
 (min number of parts required = next integer greater than (picked load/allowable load per part))

$$\text{NumParts} := \text{if } \text{ceil} \frac{W_l}{HLMAX} > 4, \text{ceil} \frac{W_l}{HLMAX}, 4$$

$$\text{NumParts} = 4$$

$$W_r := \text{NumParts} \cdot (LB \cdot \sin(\theta_b) + Y) \cdot w2$$

$$W_r = 1677.5 \cdot \text{lbf}$$

Weight of Crane

$$W_{crane} := W_b + W_u + W_c + W_{lm} + W_{hm} + W_p + W_r$$

$$W_{crane} = 269052.2 \cdot \text{lbf}$$

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CRANE AND PICKED-LOAD WEIGHT (continued)

Weight of Accessories (defined globally for calculation of NumParts above)

$$W_{block} = 4000 \cdot \text{lb} \cdot \text{f}$$

$$W_{dyno} = 200 \cdot \text{lb} \cdot \text{f}$$

$$W_{hose} = 500 \cdot \text{lb} \cdot \text{f}$$

$$W_{yoke} = 1875 \cdot \text{lb} \cdot \text{f}$$

$$W_{chkr} = 150 \cdot \text{lb} \cdot \text{f}$$

$$W_{bag} = 3000 \cdot \text{lb} \cdot \text{f}$$

$$W_{shkl} = 45.75 \cdot \text{lb} \cdot \text{f}$$

$$W_{acc} = W_{block} + W_{yoke} + W_{bag} + W_{dyno} + W_{chkr} + W_{shkl} + W_{hose}$$

$$W_{acc} = 9770.7 \cdot \text{lb} \cdot \text{f}$$

Weight of Pump

$$W_{pump} = 20050 \cdot \text{lb} \cdot \text{f}$$

Weight of Picked Load (defined globally for calculation of NumParts above)

$$W_l = 48238 \cdot \text{lb} \cdot \text{f}$$

$$W_l = 48238 \cdot \text{lb} \cdot \text{f}$$

Total Load (crane and picked load)

$$W_t = W_{crane} + W_l$$

$$W_t = 317290 \cdot \text{lb} \cdot \text{f}$$

CENTERS OF GRAVITY OF CRANE COMPONENTS AND PICKED LOAD

$$L_b = -RF + RB \cdot \cos(\theta_b)$$

boom

$$L_b = -28.6 \cdot \text{ft}$$

$$L_u = DU$$

upper

$$L_u = 9.78 \cdot \text{ft}$$

$$L_c = 0 \cdot \text{ft}$$

carrier

$$L_{lm} = -(RF - HMF) + (LM - CGLMT) \cdot \cos(\theta_{lm})$$

live mast

$$L_{lm} = 6.1 \cdot \text{ft}$$

$$L_{hm} = -R$$

head machinery

$$L_{hm} = -55.6 \cdot \text{ft}$$

$$L_p = -(RF - HMF) + LM \cdot \cos(\theta_{lm}) + \frac{El}{2} \cdot \cos(\theta_p)$$

pendants

$$L_p = -22.1 \cdot \text{ft}$$

$$L_r = -R$$

rope

$$L_r = -55.6 \cdot \text{ft}$$

$$L_l = -R$$

picked load

$$L_l = -55.6 \cdot \text{ft}$$

Center of gravity of entire crane (excluding picked load)

(positive/negative result indicates CG is on the same side of center of rotation as counterweight/boom, respectively)

$$L_{crane} = \frac{L_b \cdot W_b + L_u \cdot W_u + L_c \cdot W_c + L_{lm} \cdot W_{lm} + L_{hm} \cdot W_{hm} + L_p \cdot W_p + L_r \cdot W_r}{W_b + W_u + W_c + W_{lm} + W_{hm} + W_p + W_r}$$

$$L_{crane} = 3.1 \cdot \text{ft}$$

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Load case 2, encroachment distance = 20 feet, crane rotation angle = 0°

Illustration of maximum crane-imposed tank dome load with crane lifting at capacity

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CALCULATION OF REACTION FORCES (See crane free body diagram)

Summing the moments about the centerline to locate the line of action of the resultant of the crawler reaction forces: (positive/negative result indicates resultant is on the same side of center of rotation as boom/counterweight, respectively)

$$d := \frac{W_{\text{crane}} \cdot L_{\text{crane}} + W_1 \cdot L_1}{-(W_t)}$$

$$d = 5.8 \cdot \text{ft}$$

The reaction forces on the tracks depend on the upper angle, the angle between the boom's projection on the horizontal plane and the crane centerline parallel with the crawlers (see sketch). Sensitivity study reveals max bearing pressure is at 30 degrees with crane at capacity & 20' encroachment.

$$\theta := 0 \cdot \text{deg}$$

$$\Delta w := d \cdot \cos(90 \cdot \text{deg} - \theta)$$

offset of reaction from centerline of crane parallel to crawlers (sketch)

$$\Delta w = -2.2 \cdot 10^{-15} \cdot \text{ft}$$

$$\Delta l := d \cdot \sin(90 \cdot \text{deg} - \theta)$$

offset of reaction from centerline of crane perpendicular to crawlers (sketch)

$$\Delta l = 5.8 \cdot \text{ft}$$

Reaction from left crawler (sketch)

$$R_L := \frac{L_{\text{btk}} - \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_L = 158645 \cdot \text{lb}_f$$

Reaction from right crawler (sketch)

$$R_R := \frac{L_{\text{btk}} + \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_R = 158645 \cdot \text{lb}_f$$

Note that the reaction forces and their offset from front of crawler (next pg) are correct for negative value of d (location of resultant of reaction forces) above

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CALCULATION OF GROUND BEARING PRESSURE ON SOIL

offset of reaction force from front of crawler (same for each crawler)

$$e := \frac{1}{2} \cdot L_{track} - \Delta l$$

$$e = 5.311 \cdot ft$$

overall length of pressure profile (same for each crawler)

$$L_{track} = 22.3 \cdot ft$$

$$b := \text{if} \left[e > \frac{L_{track}}{2}, 3 \cdot (L_{track} - e), 3 \cdot e \right]$$

$$b = 15.93 \cdot ft$$

Triangular pressure profile: maximum ground bearing pressure at front of crawler (if zero, see trapezoidal)

$$p_{fnt L} := \text{if} \left[b < L_{track}, \frac{2 \cdot RL}{b \cdot L_{wtrack}}, 0 \cdot \frac{lbf}{ft^2} \right]$$

$$p_{fnt L} = 5430.7 \cdot \frac{lbf}{ft^2}$$

$$p_{fnt L} = 37.71 \cdot \frac{lbf}{in^2}$$

$$p_{fnt R} := \text{if} \left[b < L_{track}, \frac{2 \cdot RR}{b \cdot L_{wtrack}}, 0 \cdot \frac{lbf}{ft^2} \right]$$

$$p_{fnt R} = 5430.7 \cdot \frac{lbf}{ft^2}$$

$$p_{fnt R} = 37.71 \cdot \frac{lbf}{in^2}$$

$$Resultant L := \text{if} \left[b < L_{track}, \frac{p_{fnt L}}{2} \cdot (b \cdot L_{wtrack}), 0 \cdot lbf \right]$$

$$Resultant L = 158645 \cdot lbf$$

$$Resultant R := \text{if} \left[b < L_{track}, \frac{p_{fnt R}}{2} \cdot (b \cdot L_{wtrack}), 0 \cdot lbf \right]$$

$$Resultant R = 158645 \cdot lbf$$

Trapezoidal pressure profile: ground bearing pressure at front and rear of crawler (if zero, see triangular)

Left crawler

$$p_{fnt2 L} := \text{if} \left[b > L_{track}, \frac{2 \cdot RL}{L_{track} \cdot L_{wtrack}} \cdot 2 - \frac{3 \cdot e}{L_{track}}, 0 \cdot \frac{lbf}{ft^2} \right]$$

$$p_{fnt2 L} = 0 \cdot \frac{lbf}{ft^2}$$

$$p_{fnt2 L} = 0 \cdot \frac{lbf}{in^2}$$

$$p_{bk L} := \text{if} \left[b > L_{track}, \frac{2 \cdot RL}{L_{track} \cdot L_{wtrack}} \cdot \frac{3 \cdot e}{L_{track}} - 1, 0 \cdot \frac{lbf}{ft^2} \right]$$

$$p_{bk L} = 0 \cdot \frac{lbf}{ft^2}$$

$$p_{bk L} = 0 \cdot \frac{lbf}{in^2}$$

$$Resultant L := \text{if} \left[b > L_{track}, \frac{p_{fnt2 L} + p_{bk L}}{2} \cdot (L_{track} \cdot L_{wtrack}), 0 \cdot lbf \right]$$

$$Resultant L = 0 \cdot lbf$$

Right crawler

$$p_{fnt2 R} := \text{if} \left[b > L_{track}, \frac{2 \cdot RR}{L_{track} \cdot L_{wtrack}} \cdot 2 - \frac{3 \cdot e}{L_{track}}, 0 \cdot \frac{lbf}{ft^2} \right]$$

$$p_{fnt2 R} = 0 \cdot \frac{lbf}{ft^2}$$

$$p_{fnt2 R} = 0 \cdot \frac{lbf}{in^2}$$

$$p_{bk R} := \text{if} \left[b > L_{track}, \frac{2 \cdot RR}{L_{track} \cdot L_{wtrack}} \cdot \frac{3 \cdot e}{L_{track}} - 1, 0 \cdot \frac{lbf}{ft^2} \right]$$

$$p_{bk R} = 0 \cdot \frac{lbf}{ft^2}$$

$$p_{bk R} = 0 \cdot \frac{lbf}{in^2}$$

$$Resultant R := \text{if} \left[b > L_{track}, \frac{p_{fnt2 R} + p_{bk R}}{2} \cdot (L_{track} \cdot L_{wtrack}), 0 \cdot lbf \right]$$

$$Resultant R = 0 \cdot lbf$$

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(8) Originator M. P. Weis Michael P. Weis Date 7/30/94
(9) Checker Duncan Lawler Date 8-2-94
(10)

CALCULATION OF THE LOAD ON TANK DUE TO BOTH CRAWLERS - Using Resultant Crawler Load
This calculation utilizes the table developed for the Boussinesq Equation which gives the percentage of concentrated load transmitted to the tank dome as function of distance from the tank edge. The calculation here interpolates from the table to calculate the crane-imposed load. This interpolation is possible since the dome load is proportional to the concentrated load according to the calculation that developed this table. Note that from the plot below the interpolation is conservative for load applied at distances beyond the tank edge, because for abscissa greater than zero the curve is concave up.

$$A := \sqrt{R_c - \Delta l^2 + Lbtk^2} \quad A = 47.5 \cdot \text{ft} \quad \text{distance of concentrated load from center of tank}$$

$$Q := RL + RR \quad \text{concentrated load due to both crawlers} \\ \text{(crawler loads are equidistant from tank center)}$$

PERCENT OF CONCENTRATED LOAD TRANSMITTED TO DOME AS A FUNCTION OF THE LOAD'S DISTANCE FROM THE CENTER OF THE TANK

$$i := 0..25 \quad \text{range variable for table}$$

$$\Delta_i := -10 \cdot \text{ft} + (2 \cdot \text{ft}) \cdot i \quad \text{distance of load from tank edge}$$

P_i := --percentage of load transmitted to dome as a function of this distance

$\frac{\Delta_i}{\text{ft}}$	P_i
-10	63.693
-8	58.402
-6	52.609
-4	46.415
-2	40.016
0	33.732
2	27.919
4	22.846
6	18.626
8	15.225
10	12.531
12	10.407
14	8.728
16	7.392
18	6.319
20	5.448
22	4.735
24	4.146
26	3.653
28	3.239
30	2.887
32	2.587
34	2.328
36	2.104
38	1.909
40	1.738

% of load transmitted vs distance of load from tank edge

Calculate crane-imposed dome load by interpolation from table (graph)

$$P := \frac{\text{interp}(\Delta, p, A - r)}{100} \cdot Q \quad P = 59165 \cdot \text{lbf}$$

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(8) Originator M. P. Weis *Mental Plan* Date 7/30/94
(9) Checker Duncan Sander Date 8-2-94
(10)

CALCULATION OF LOAD ON TANK DUE TO BOTH CRAWLERS - Using Several Loads Equivalent to Resultant Crawler Load. This method calculates a set of forces equivalent to the crawlers' bearing pressure profile (instead of a single force as done above). This is a more accurate method. See sketch for variable descriptions.

ORIGIN = 0

$$\text{psf} := \frac{\text{lbf}}{\text{ft}^2}$$

n := 20

i := 1..n

L := if(b < Ltrack, b, Ltrack)

$$\Delta L := \frac{L}{n}$$

check start value of range; should be zero

shorten lbf/ft²

number of loads

define range variables for data associated with each incremental load

length of bearing pressure profile L = 15.9·ft

incremental length of bearing profile for each incremental load

$$\Delta L = 0.8 \cdot \text{ft}$$

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CALCULATION OF LOAD ON TANK DUE TO BOTH CRAWLERS (continued)

Left crawler pressure profile

$pres_{L_0} := \text{if } b < L_{track}, 0 \cdot \text{psf}, pbk_L$

start pressure of profile (rear of crawler)

$pres_{L_n} := \text{if } b < L_{track}, pfnt_L, pfnt2_L$

end pressure of profile (front of crawler)

$\delta pres_L := pres_{L_n} - pres_{L_0}$

margin between max and min pressures

$\Delta pres_L := \frac{\delta pres_L}{n}$

incremental pressure for calculating pressures at next increment
 $\Delta pres_L = 271.5 \cdot \text{psf}$

$pres_{L_i} := pres_{L_0} + \Delta pres_L \cdot i$

pressure at next increment

Right crawler pressure profile

$pres_{R_0} := \text{if } b < L_{track}, 0 \cdot \text{psf}, pbk_R$

start pressure of profile (rear of crawler)

$pres_{R_n} := \text{if } b < L_{track}, pfnt_R, pfnt2_R$

end pressure of profile (front of crawler)

$\delta pres_R := pres_{R_n} - pres_{R_0}$

margin between max and min pressures

$\Delta pres_R := \frac{\delta pres_R}{n}$

incremental pressure for calculating pressures at next increment
 $\Delta pres_R = 271.5 \cdot \text{psf}$

$pres_{R_i} := pres_{R_0} + \Delta pres_R \cdot i$

pressure at next increment

Plotting generated pressure profile; zero starts at beginning of profile

$j := 0..n$

$x_j := j \cdot \Delta L$

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(8) Originator M. P. Weis *M. P. Weis* Date 7/30/94
(9) Checker *Dennis Leach* Date 8-2-94
(10)

CALCULATION OF LOAD ON TANK DUE TO BOTH CRAWLERS (continued)

Variables with subscripts L and R are values for the left and right crawlers, respectively

$$\bar{x}_{L_i} := \frac{1}{3} \cdot \frac{2 \cdot \text{pres}_{L_{i-1}} + \text{pres}_{L_i}}{\text{pres}_{L_{i-1}} + \text{pres}_{L_i}} \cdot \Delta L$$

distance of line of action of incremental load from the front of its own incremental bearing profile

$$\bar{x}_{R_i} := \frac{1}{3} \cdot \frac{2 \cdot \text{pres}_{R_{i-1}} + \text{pres}_{R_i}}{\text{pres}_{R_{i-1}} + \text{pres}_{R_i}} \cdot \Delta L$$

$$f_{L_i} := \bar{x}_{L_i} + (n - i) \cdot \Delta L$$

offset of incremental load from front of crawler

$$f_{R_i} := \bar{x}_{R_i} + (n - i) \cdot \Delta L$$

$$F_{L_i} := \frac{1}{2} \left[\text{pres}_{L_{(i-1)}} + \text{pres}_{L_i} \right] \cdot L_{\text{track}} \cdot \Delta L$$

incremental load over incremental bearing profile

$$F_{R_i} := \frac{1}{2} \left[\text{pres}_{R_{(i-1)}} + \text{pres}_{R_i} \right] \cdot L_{\text{track}} \cdot \Delta L$$

$$A_{L_i} := \sqrt{\left[R_c - \frac{L_{\text{track}}}{2} + f_{L_i} \right]^2 + L_{\text{btk}}^2}$$

distance of incremental load from center of tank

$$A_{R_i} := \sqrt{\left[R_c - \frac{L_{\text{track}}}{2} + f_{R_i} \right]^2 + L_{\text{btk}}^2}$$

$$P_{L_i} := \frac{\text{linterp } \Delta, p, A_{L_i} - r}{100} \cdot F_{L_i}$$

portion of incremental load transmitted to the tank

$$P_{R_i} := \frac{\text{linterp } \Delta, p, A_{R_i} - r}{100} \cdot F_{R_i}$$

$$P_{\text{tot}} := \sum_i P_{L_i} + P_{R_i}$$

total load transmitted to tank from both crawlers

$$P_{\text{tot}} = 63439 \cdot \text{lbf}$$

using single load per crawler: $P = 59165 \cdot \text{lbf}$
(calculated above)

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 (9) Checker A. M. G. G. G. *A. M. G. G. G.* Date 8-2-94
 (10)

DISPLAY OF APPROXIMATE PRESSURE PROFILE ON TANK DOME

The two crawler loads are lumped into one load for this plot - in actuality the plot should display two humps, each of lesser magnitude than the one hump shown on the next page.

$$R1 := \left(99 + \frac{10}{12}\right) \cdot \text{ft}$$

larger spherical radius of tank dome

$$\text{depth} := 6.5 \cdot \text{ft}$$

depth of tank below surface

Equation of spherical surface of tank dome

$$z(x,y) := -\sqrt{R1^2 - (x - A)^2 - y^2} + (\text{depth} + R1)$$

Vertical stress in soil as a function of the position on the dome and the concentrated load
(form of Boussinesq Equation with tank surface equation substituted for z coordinate)

$$q(x,y) := \frac{Q}{\pi \cdot z(x,y)^2} \cdot \frac{1}{\left[1 + \frac{2}{z(x,y)^2} \cdot (x^2 + y^2)\right]^{\frac{3}{2}}}$$

Equation of dome's projection on xy-plane

$$f(x) := \sqrt{r^2 - (x - A)^2}$$

Set up square grid enclosing tank for surface plot of vertical stress on tank surface and calculate vertical stress on tank surface as at these grid points

$$N := 40$$

$$i := 0..N \quad j := 0..N$$

$$\Delta x := \frac{2 \cdot r}{N} \quad \Delta y := \frac{2 \cdot r}{N} \quad x_i := (A - r) + (\Delta x) \cdot i \quad y_j := -r + \Delta y \cdot j$$

Set it up so that those grid points that are not within the cylindrical radius of tank display as zero stress

$$\text{temp}_{(i,j)} := \text{if} \left(y_j \leq f(x_i), q(x_i, y_j), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right)$$

$$q'_{(i,j)} := \text{if} \left[y_j \geq -f(x_i), \text{temp}_{(i,j)}, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

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(9) Checker Deanne Louie *Deanne Louie* Date 8-2-94
(10)

Surface plot of vertical stress on tank surface (assumption that the two crawler loads are lumped at one point)

$$q(0\text{-ft}, 0\text{-ft}) = 294.5 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(A - r, 0\text{-ft}) = 283.2 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(A + r, 0\text{-ft}) = 0.8 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$q(A, r) = 2.1 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

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(8) Originator M. P. Weis [Signature] Date 7/30/94
(9) Checker [Signature] [Signature] Date 8-2-94
(10)

CALCULATE PRESSURES ON DOME AT LOCATIONS GIVEN IN SKETCH FOR STRUCTURAL EVALUATION OF THE TANK FOOTING IN THE VICINITY OF THE PEAK SOIL PRESSURE

$$k := 0..16$$

range variable to define points on x-axis

$$x_k := (A - r) + (5 \cdot \text{ft}) \cdot k$$

x coordinates of points on tank at intervals of 5 feet starting at point 5 feet off tank in line with load and ending near the other end of the tank on a line thru center of tank,

$$A - r = 6 \cdot \text{ft}$$

distance of load from edge of tank

$$q_{\text{on_tank}_k} := q(x_k, 0 \cdot \text{ft})$$

pressures on dome at these locations

show first 9 points

Soil pressure of points on dome with y coordinate zero

$$m := 0..8$$

x_m ft	$q_{\text{on_tank}_m}$ $\left(\frac{\text{lbf}}{\text{ft}^2}\right)$
6	283.2
11	156.6
16	71.4
21	33
26	16.5
31	9
36	5.3
41	3.4
46	2.4

z axis into soil

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Load case 2, encroachment distance = 20 feet, crane rotation angle = 30°

Illustration of maximum ground bearing pressure with crane lifting at capacity

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CALCULATION OF REACTION FORCES (See crane free body diagram)

Summing the moments about the centerline to locate the line of action of the resultant of the crawler reaction forces: (positive/negative result indicates resultant is on the same side of center of rotation as boom/counterweight, respectively)

$$d := \frac{W_{\text{crane}} \cdot L_{\text{crane}} + W_1 \cdot L_1}{-(W_t)}$$

$$d = 5.8 \cdot \text{ft}$$

The reaction forces on the tracks depend on the upper angle, the angle between the boom's projection on the horizontal plane and the crane centerline parallel with the crawlers (see sketch). Sensitivity study reveals max bearing pressure is at 30 degrees with crane at capacity & 20' encroachment.

$$\theta := 30 \cdot \text{deg}$$

Reaction from left crawler (sketch)

$$R_L := \left(\frac{L_{\text{btk}} - \Delta w}{2 \cdot L_{\text{btk}}} \right) \cdot W_t$$

$$R_L = 101001 \cdot \text{lbf}$$

Reaction from right crawler (sketch)

$$R_R := \left(\frac{L_{\text{btk}} + \Delta w}{2 \cdot L_{\text{btk}}} \right) \cdot W_t$$

$$R_R = 216289 \cdot \text{lbf}$$

Note that the reaction forces and their offset from front of crawler (next pg) are correct for negative value of d (location of resultant of reaction forces) above

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(9) Checker Ducan Sander *Ducan Sander* Date 8-2-94
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CALCULATION OF GROUND BEARING PRESSURE ON SOIL

offset of reaction force from front of crawler (same for each crawler)

$$e := \frac{1}{2} \cdot L_{\text{track}} - \Delta l$$

$$e = 6.09 \cdot \text{ft}$$

overall length of pressure profile (same for each crawler)

$$L_{\text{track}} = 22.3 \cdot \text{ft}$$

$$b := \text{if} \left[e > \frac{L_{\text{track}}}{2}, 3 \cdot (L_{\text{track}} - e), 3 \cdot e \right]$$

$$b = 18.27 \cdot \text{ft}$$

Triangular pressure profile: maximum ground bearing pressure at front of crawler (if zero, see trapezoidal)

$$p_{\text{fnt}} L := \text{if} \left[b < L_{\text{track}}, \left(\frac{2 \cdot RL}{b \cdot L_{\text{wtrack}}} \right), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt}} L = 3015.3 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt}} L = 20.94 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{fnt}} R := \text{if} \left[b < L_{\text{track}}, \left(\frac{2 \cdot RR}{b \cdot L_{\text{wtrack}}} \right), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt}} R = 6457.1 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt}} R = 44.84 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant } L := \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt}} L}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant } L = 101001 \cdot \text{lbf}$$

$$\text{Resultant } R := \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt}} R}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant } R = 216289 \cdot \text{lbf}$$

Trapezoidal pressure profile: ground bearing pressure at front and rear of crawler (if zero, see triangular)

Left crawler

$$p_{\text{fnt}2} L := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \left(2 - \frac{3 \cdot e}{L_{\text{track}}} \right), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt}2} L = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt}2} L = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk}} L := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \left(\frac{3 \cdot e}{L_{\text{track}}} - 1 \right), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk}} L = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk}} L = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant } L := \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt}2} L + p_{\text{bk}} L}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant } L = 0 \cdot \text{lbf}$$

Right crawler

$$p_{\text{fnt}2} R := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \left(2 - \frac{3 \cdot e}{L_{\text{track}}} \right), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt}2} R = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt}2} R = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk}} R := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \left(\frac{3 \cdot e}{L_{\text{track}}} - 1 \right), 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk}} R = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk}} R = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant } R := \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt}2} R + p_{\text{bk}} R}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant } R = 0 \cdot \text{lbf}$$

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 (8) Originator M. P. Weis Michael P. Weis Date 7/30/94
 (9) Checker Duncan Sander Date 8-2-94
 (10)

CALCULATION OF THE LOAD ON TANK DUE TO BOTH CRAWLERS - Using Resultant Crawler Load
 This calculation utilizes the table developed for the Boussinesq Equation which gives the percentage of concentrated load transmitted to the tank dome as function of distance from the tank edge. The calculation here interpolates from the table to calculate the crane-imposed load. This interpolation is possible since the dome load is proportional to the concentrated load according to the calculation that developed this table. Note that from the plot below the interpolation is conservative for load applied at distances beyond the tank edge, because for abscissa greater than zero the curve is concave up.

$$A := \sqrt{(R_c - \Delta l)^2 + L b t k^2} \quad A = 48.3 \cdot \text{ft} \quad \text{distance of concentrated load from center of tank}$$

$$Q := RL + RR \quad \text{concentrated load due to both crawlers} \\ \text{(crawler loads are equidistant from tank center)}$$

PERCENT OF CONCENTRATED LOAD TRANSMITTED TO DOME AS A FUNCTION OF THE LOAD'S DISTANCE FROM THE CENTER OF THE TANK

$$i := 0..25 \quad \text{range variable for table} \\ \Delta_i := -10 \cdot \text{ft} + (2 \cdot \text{ft}) \cdot i \quad \text{distance of load from tank edge}$$

$\frac{\Delta_i}{\text{ft}}$	p_i
-10	63.693
-8	58.402
-6	52.609
-4	46.415
-2	40.016
0	33.732
2	27.919
4	22.846
6	18.626
8	15.225
10	12.531
12	10.407
14	8.728
16	7.392
18	6.319
20	5.448
22	4.735
24	4.146
26	3.653
28	3.239
30	2.887
32	2.587
34	2.328
36	2.104
38	1.909
40	1.738

<--percentage of load transmitted to dome as a function of this distance

% of load transmitted vs distance of load from tank edge

Calculate crane-imposed dome load by interpolation from table (graph)

$$P := \left(\frac{\text{interp}(\Delta, p, A - r)}{100} \right) \cdot Q \quad P = 55009 \cdot \text{lbf}$$

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 (9) Checker _____ _____ Date 8-2-94
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CALCULATION OF LOAD ON TANK DUE TO BOTH CRAWLERS - Using Several Loads Equivalent to Resultant Crawler Load. This method calculates a set of forces equivalent to the crawlers' bearing pressure profile (instead of a single force as done above). This is a more accurate method. See sketch for variable descriptions.

ORIGIN = 0

$$psf := \frac{lbf}{ft^2}$$

n := 20

i := 1..n

L := if(b < Ltrack, b, Ltrack)

$$\Delta L := \frac{L}{n}$$

check start value of range; should be zero

shorten lbf/ft²

number of loads

define range variables for data associated with each incremental load

length of bearing pressure profile L = 18.3 · ft

incremental length of bearing profile for each incremental load

$$\Delta L = 0.9 \cdot ft$$

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 (9) Checker Dennis Sander Date 8-2-94
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CALCULATION OF LOAD ON TANK DUE TO BOTH CRAWLERS (continued)

Left crawler pressure profile

$$\text{pres}_{L_0} := \text{if}(b < L_{\text{track}}, 0 \cdot \text{psf}, \text{pbk}_L)$$

start pressure of profile (rear of crawler)

$$\text{pres}_{L_n} := \text{if}(b < L_{\text{track}}, \text{pfint}_L, \text{pfint2}_L)$$

end pressure of profile (front of crawler)

$$\delta \text{pres}_L := \text{pres}_{L_n} - \text{pres}_{L_0}$$

margin between max and min pressures

$$\Delta \text{pres}_L := \frac{\delta \text{pres}_L}{n}$$

incremental pressure for calculating pressures at next increment
 $\Delta \text{pres}_L = 150.8 \cdot \text{psf}$

$$\text{pres}_{L_i} := \text{pres}_{L_0} + \Delta \text{pres}_L \cdot i$$

pressure at next increment

Right crawler pressure profile

$$\text{pres}_{R_0} := \text{if}(b < L_{\text{track}}, 0 \cdot \text{psf}, \text{pbk}_R)$$

start pressure of profile (rear of crawler)

$$\text{pres}_{R_n} := \text{if}(b < L_{\text{track}}, \text{pfint}_R, \text{pfint2}_R)$$

end pressure of profile (front of crawler)

$$\delta \text{pres}_R := \text{pres}_{R_n} - \text{pres}_{R_0}$$

margin between max and min pressures

$$\Delta \text{pres}_R := \frac{\delta \text{pres}_R}{n}$$

incremental pressure for calculating pressures at next increment
 $\Delta \text{pres}_R = 322.9 \cdot \text{psf}$

$$\text{pres}_{R_i} := \text{pres}_{R_0} + \Delta \text{pres}_R \cdot i$$

pressure at next increment

Plotting generated pressure profile; zero starts at beginning of profile

$$j := 0..n$$

$$x_j := j \cdot \Delta L$$

DESIGN CALCULATION

WHC-SD-WM-ER-373

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 (7) Subject Crane-Imposed Dome Load as a Function of Encroachment into Exclusion Zone
 (8) Originator M. P. Weis *Michael P. Weis* Date 7/30/94
 (9) Checker Dennis Semler *Dennis Semler* Date 8-2-94
 (10)

CALCULATION OF LOAD ON TANK DUE TO BOTH CRAWLERS (continued)

Variables with subscripts L and R are values for the left and right crawlers, respectively

$$\bar{x}_{L_i} := \frac{1}{3} \cdot \left(\frac{2 \cdot \text{pres}_{L_{i-1}} + \text{pres}_{L_i}}{\text{pres}_{L_{i-1}} + \text{pres}_{L_i}} \right) \cdot \Delta L$$

distance of line of action of incremental load from the front of its own incremental bearing profile

$$\bar{x}_{R_i} := \frac{1}{3} \cdot \left(\frac{2 \cdot \text{pres}_{R_{i-1}} + \text{pres}_{R_i}}{\text{pres}_{R_{i-1}} + \text{pres}_{R_i}} \right) \cdot \Delta L$$

$$f_{L_i} := \bar{x}_{L_i} + (n - i) \cdot \Delta L$$

offset of incremental load from front of crawler

$$f_{R_i} := \bar{x}_{R_i} + (n - i) \cdot \Delta L$$

$$F_{L_i} := \frac{1}{2} \cdot [\text{pres}_{L_{(i-1)}} + \text{pres}_{L_i}] \cdot L_{\text{wtrack}} \cdot \Delta L$$

incremental load over incremental bearing profile

$$F_{R_i} := \frac{1}{2} \cdot [\text{pres}_{R_{(i-1)}} + \text{pres}_{R_i}] \cdot L_{\text{wtrack}} \cdot \Delta L$$

$$A_{L_i} := \sqrt{\left[\left(R_c - \frac{L_{\text{track}}}{2} \right) + f_{L_i} \right]^2 + L_{\text{btk}}^2}$$

distance of incremental load from center of tank

$$A_{R_i} := \sqrt{\left[\left(R_c - \frac{L_{\text{track}}}{2} \right) + f_{R_i} \right]^2 + L_{\text{btk}}^2}$$

$$P_{L_i} := \left(\frac{\text{interp}(\Delta, p, A_{L_i} - r)}{100} \right) \cdot F_{L_i}$$

portion of incremental load transmitted to the tank

$$P_{R_i} := \left(\frac{\text{interp}(\Delta, p, A_{R_i} - r)}{100} \right) \cdot F_{R_i}$$

$$P_{\text{tot}} := \sum_i (P_{L_i} + P_{R_i})$$

total load transmitted to tank from both crawlers

$$P_{\text{tot}} = 59957 \cdot \text{lbf}$$

using single load per crawler: $P = 55009 \cdot \text{lbf}$
 (calculated above)

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MANUFACTURER'S INFORMATION FROM SPECIFICATION

Link-Belt Speeder

DIVISION OF FMC CORPORATION

LS-518 FLYSHEET CRAWLER MOUNTED CRANE

Dimensions — Working ranges

Specifications — Lifting capacities

DIMENSIONS AND WORKING RANGES

Crawler — 16' 0" Gauge, 24' 4" Long Overall

Load block 4000 lbs.
 Load line 2500 lbs.
 Gross Wt. with 70' Boom 258,000 lbs.
 Ctl. Wt. A 20,500 lbs.
 Ctl. Wt. AB 90,000 lbs.

Basic boom length	A	60' 0"
Boom angle	B	—
Height of boom hinge pin	Y	6' 7"
Radius of boom hinge pin	X	4' 8"
Height over boomhoist unit	P ₁	13' 4"
Height over vertical live boom mast	P ₂	39' 3"
Overall height, live boom mast with 60' boom horizontal	P ₃	25' 6"
Tail swing of counterweight "A" or "AB"	U	15' 10"
Ground clearance under counterweight "A" or "AB"	N	4' 3"
Crawler ground bearing length	O	22' 3"
Center to center of track drive sprocket and idler roller	R	21' 1"
Overall crawler length	S	24' 4"
Overall width, with 44" wide track shoes		19' 8"
Overall width, less side frames		17' 7"
Overall shipping width, less side frames and catwalks (axles in line with upper)		11' 0"
Overall cab width (less catwalks and railings)		11' 0"
Overall height, side frames removed		11' 11"
Minimum ground clearance		1' 5"

Miscellaneous:

Swing speed 3.0 r.p.m.

Travel speed 1.0 m.p.m.

Approximate lifting crane working weight, 60' "Hi-Lite" tubular boom with heavy lattice, live boom mast, catwalks and railings, 44" wide track shoes, no hook block:

with cwt. "A" 183,500 lbs.

with cwt. "AB" 263,000 lbs.

* Optional planetary drive for higher speed (one direction) available.

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(8) Originator M. P. Weis *Michael P. Weis* Date 7/30/91
(9) Checker *Dennis Sander* Date 8-2-94
(10)

MANUFACTURER'S INFORMATION OBTAINED VIA FASCIMILE

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 (9) Checker Duncan Lander Date 8-2-94
 (10)

MANUFACTURER'S INFORMATION OBTAINED VIA FASCIMILE

CRANE WEIGHTS AND C.G.'S

DESCRIPTION OF VARIABLES

LB = Boom Length (Ft.)
 WB = Boom Wt. Incl. M/H and A/H Rope Running Up Boom (Lbs.)
 CGB = Boom C.G. Incl. M/H and A/H Rope Running Up Boom (Ft.)
 WHMAC = Weight of all head machinery, including sheaves, guards, hammerhead, etc. (Lbs.)
 WU = Weight of Upper (Lbs.)
 DU = C.G. of upper from centerline rotation (negative if to rear of upper) (Ft.)
 WC = Weight of carrier, (includes lower counterweight) (Lbs.)
 DC = C.G. of carrier (negative if toward rear of lower) (Ft.)
 LM = Length of live mast (Ft.) set = 0 when no live mast is required.
 WLMT = Weight of live mast (Lbs.)
 CGLMT = C.G. of live mast from point of mast (+ number) (Ft.)
 WCWT = Weight of upper counterweight. (Lbs.)
 If WCWT = 0, then the weight of the counterweight is included in WL.
 DCWT = C.G. of the upper counterweight (Ft.)
 LJ = Length of jib (Ft.)
 WJ = Weight of jib or tip extension (Lbs.)
 MU = Angle of jib with respect to boom centerline (Degrees)
 XJ = Center of gravity of jib from jib foot (Ft.)

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 (9) Checker [Signature] Date 8-2-94
 (10)

MANUFACTURER'S INFORMATION OBTAINED VIA FASCIMILE

08/31/92

18:51

1 606 263 5260

LINK-BELT LEX,KY

003/005

PP = Parts of line in boom hoist reeving.
 WBR = Weight of boom hoist rope per foot (Lbs./Ft.)
 WBLK = Weight of hook block (Lbs.)
 WBALL = Weight of headache ball or block on auxiliary hoist (Lbs.)
 WBRI = Weight of boom hoist bridle or spreader bar (Lbs.)
 BLMPT = Boom length where midpoint suspension is initially employed with suspension system (Ft.)
 EM = Length of midpoint pendants (Ft.)
 BLM = Distance from boom foot to the pin connecting the midpoint pendants. (Ft.)
 VXM = Midpoint pendant weight per foot (Lbs./Ft.)
 VX = Boom main pendant weight per foot (Incl. end sockets and links) (Lbs./Ft.)

DESIGN CALCULATION

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(8) Originator M. P. Weis *M. P. Weis* Date 7/30/14
(9) Checker D. J. Sander *D. J. Sander* Date 8-2-94
(10)

MANUFACTURER'S INFORMATION OBTAINED VIA FASCIMILE

08/31/92 18:52 31 606 263 5260 LINK-BELT LEX.KY

Link-Belt Construction Equipment Co. 08-31-1992
Crane weights and c.g. program (run # basereac.025)
Model LS-518 - std 44 inch shoes - incl wt of shoes on ground
AB (90000#) ctwt - open throat tube boom (62 x 70) w/ 45 ft jib @ 15 deg offset

OUTPUT DATA FOR DATA SET # BASEREAC.025

LB	LEXT1	LEXT2	WB	CSB	WMAC
60	0	0	6700	25.81	1663
70	0	10	7498	30.57	1663
80	0	20	8297	35.38	1663
90	0	30	9095	40.22	1663
100	0	40	9894	45.08	1663
110	0	50	10692	49.97	1663
120	0	60	11490	54.87	1663
130	0	70	12289	59.79	1663
140	0	80	13087	64.71	1663
150	0	90	13886	69.64	1663
160	0	100	14684	74.58	1663
170	0	110	15482	79.53	1663
180	0	120	16281	84.48	1663
190	0	130	17079	89.44	1663
200	0	140	17878	94.4	1663
210	0	150	18676	99.36	1663
220	0	160	19474	104.33	1663
230	0	170	20273	109.3	1663
240	0	180	21071	114.27	1663
250	0	190	21870	119.24	1663

LEB = center of gravity of boom relative to base pivot point

DESIGN CALCULATION

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(8) Originator M. P. Weis *M. P. Weis* Date 7-30-94
(9) Checker Duncan Sunde Date 8-2-94
(10)

MANUFACTURER'S INFORMATION OBTAINED VIA FASCIMILE

07/22/04 00:51 FAX 1 606 263 5260

LINK BELT LEX.KY ... ETC2

004/006

Link-Belt Construction Equipment Co. 07-21-1994
Crane base reactions program (run # hasareac.025)
Model LS-518 - std 44 inch shoes - incl wt of shoes on ground
AB (90000#) ctwt - open throat tube boom (62 x 70) w/o jib

INPUT DATA FOR DATA SET # : 025

CARD # 1	TOOTP 1	DES1\$ Model LS-518 - std 44 inch shoes - incl wt of shoes on ground							
CARD # 2	DEBUG 0	DES2\$ AB (90000#) ctwt - open throat tube boom (62 x 70) w/o jib							
CARD # 3	RF 4.67	X3 12.82	U 6.54	LM 30	PP 9	VY 12.39	WU 153700	LEMIN 60	CHGR 0
CARD # 4	DO -9.78	WC RR775	XO 0	WLMT 4970	CGINT 10.33	VHF 1.17	EMF .88	VEXT1 0	BLCPT 0
CARD # 5	CABWT 2.34	WEMAC 1663	VEXT2 77.5	TOP 30	RSE 30	WTTOP 2780	WTBASE 3780	LEXT1 0	VZH 2.91
CARD # 6	CCTOP 12.51	CGRASE 9.88	WJ 0	MU 0	XJ 0	LJ 0	W 3.67	BLMPT 190	EM 92.11
CARD # 7	DL 22.25	DT 16	WBLK 0	WBALL 0	WAR 0	HLMAX 37100	WBR 0	BLM 110	WCWT 0
CARD # 8	Y1 6.17	DC 0	E1 10.25	YFR 10.54	YRR 8.333	D6 0	YRF 10.52	YRF 8.333	SPREAD 0
CARD # 9	SCAV 0	SCAN 0	L1 0	DIA 0	SCDV 0	SCDH 0	RCWTAN 0	TRMN 0	RCWTX 0
CARD # 10	PREL 0	WBRI 0	U .75	YLF 10.52	YLP 8.333	YLR 10.54	YLR 9.333	PETHA 0	BUMTA 0

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(8) Originator M. P. Weis [Signature] Date 7/30/94
(9) Checker [Signature] Date 8-2-94
(10)

References:

- 1) Scott, M. A. et al., 1994, *Tank 241-SY-101 Dome Loading Control Document*, WHC-SD-WM-TA-141, Rev 0A., Westinghouse Hanford Company, Richland, Washington.
- 2) Sowers, G. B., and G. F. Sowers, 1970, *Introductory Soil Mechanics and Foundations*, McMillen Publishing Company, Inc., New York, New York.
- 3) Brewer C., 1994, *Test Pump Removal and Installation of the New Permanent Mixer Pump 101 SY Tank Critical Lift Procedure*, Draft, to be included in Westinghouse work packages 2W-94-00652 through 2W-94-00654,
- 4) Link-Belt Construction Equipment Company, *LS-518 Flysheet, Crawler Mounted Crane, Dimensions - Working Ranges - Specifications - Lifting Capacities*, Lexington Kentucky.
- 5) Link-Belt Construction Equipment Company, crane details provided via fascimile.

APPENDIX E. VALIDATION OF CRANE CALCULATIONS

DESIGN CALCULATION

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(8) Originator M. P. Weis *[Signature]* Date 7/31/94
(9) Checker Dusan Semler *[Signature]* Date 8-2-94
(10)

COMPARISON OF LS-518 CRANE CALCULATIONS (crawler resultant loads and bearing pressures) WITH CALCULATIONS PERFORMED BY LINKBELT CONSTRUCTION EQUIPMENT COMPANY

To verify that the calculations developed here were correct, Linkbelt Construction Equipment Company was requested to perform calculations to which results could be compared. A copy of these results, sent by fax, is attached to this calculation.

Each entry in the table of this fax is for a given lift. The three boxed entries are used for verification of these calculations. These are for a lift of 30,000 lbf at crane rotation angles of 0, 45, and 90 degrees. 0 degrees corresponds to the boom lifting over the front, while 90 degrees corresponds to the boom lifting over the side (see figure included with fax).

The full calculation sheet is given for the rotation angle of 45 degrees; just the results are provided for the other two angles.

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 (10) _____

FREE BODY DIAGRAM OF LS-518 CRANE

- LSI-518 CRANE: ILLUSTRATION OF VARIABLES DEFINING CRANE CONFIGURATION

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RESULTS FOR 45 DEGREE CRANE ROTATION ANGLE

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 (10)

CRANE CONFIGURATION

NumInserts := 12

number of inserts to extend boom

Linsert := 10·ft

length of boom insert

DefaultLB := 60·ft

standard boom length for crane

LB := DefaultLB + NumInserts·Linsert

boom length

LB = 180·ft

Ltrack := 22.25·ft

crawler ground bearing length

Lwtrack := $3 + \frac{8}{12}$ ·ft

crawler ground bearing width

Lbtk := 8·ft

half the distance between centers of crawlers

R := 56·ft

load radius

R = 56·ft

RF := $4 + \frac{8}{12}$ ·ft

offset of boom pivot from center of rotation

RB := 84.48·ft

location of CG of boom from pivot point towards tip
(this is a function of NumInserts)

LM := 30·ft

length of live mast

CGLMT := 10.33·ft

offset of CG of live mast from upper end of live mast

HMF := 0.88·ft

horizontal offset of live mast pivot to boom pivot

VMF := 1.17·ft

vertical offset of live mast pivot to boom pivot

E := 40.25·ft

default pendant length

E1 := E + NumInserts·Linsert

pendant length

E1 = 160.3·ft

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CRANE CONFIGURATION (continued)

$$DU := 9.78 \cdot \text{ft}$$

offset of upper (counterweight) from center of rotation

$$Y := 6 + \frac{7}{12} \cdot \text{ft}$$

height of boom pivot off ground

$$HLMAX := 37100 \cdot \text{lbf}$$

allowable load for 1 part of 1 1/8" wire rope

$$\theta_b := \pi - \arccos \frac{R - RF}{LB}$$

boom angle with horizontal (CCW positive)

$$\theta_b = 106.6 \cdot \text{deg}$$

$$\theta_o := \arctan \frac{VMF}{HMF}$$

angular offset of live mast lower pivot and

boom lower pivot (CCW positive)

$$\theta_o = 53.1 \cdot \text{deg}$$

$$LO := \sqrt{VMF^2 + HMF^2}$$

length of offset of the lower pivots of live
mast and boom

$$LO = 1.5 \cdot \text{ft}$$

Calculation of Live Mast's and Pendants' Angles with Horizontal

Set of 2 simultaneous equations to solve for the live mast and pendants angular offset with horizontal. Graphically, the boom, live mast, pendants, and displacement between lower pivots of boom and live mast are treated as vectors. The direction of the vectors is set such that the vector for the boom is the summation of the vectors for the other three displacements. The horizontal components are equated for the 1st equation and the vertical ones for the 2nd equation. Note that angles are measured counterclockwise from the horizontal. The two unknowns are the live mast angle and the pendants angle.

$$LB \cdot \cos(\theta_b) = LO \cdot \cos(\theta_o) + LM \cdot \cos(\theta_{lm}) + E1 \cdot \cos(\theta_p) \quad (1)$$

$$LB \cdot \sin(\theta_b) = LO \cdot \sin(\theta_o) + LM \cdot \sin(\theta_{lm}) + E1 \cdot \sin(\theta_p) \quad (2)$$

Solving for the live mast angle in (1)

$$\theta_{lm} = \arccos \frac{B - E1 \cdot \cos(\theta_p)}{LM}$$

where

$$B := LB \cdot \cos(\theta_b) - LO \cdot \cos(\theta_o)$$

Substituting this expression into (2) yields an equation in one unknown, the pendants angle

$$A = E1 \cdot \sin(\theta_p) + \sqrt{LM^2 - (B - E1 \cdot \cos(\theta_p))^2}$$

where

$$A := LB \cdot \sin(\theta_b) - LO \cdot \sin(\theta_o)$$

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CRANE CONFIGURATION (continued)

Solving (2) in the Mathcad symbolic processor yields

$$\theta_p := 2 \cdot \text{atan} \left[\frac{2 \cdot A \cdot E1 \dots + \sqrt{2 \cdot A^2 \cdot E1^2 - B^4 - A^4 - 2 \cdot B^2 \cdot A^2 - LM^4 - E1^4 + 2 \cdot LM^2 \cdot E1^2 + 2 \cdot LM^2 \cdot B^2 + 2 \cdot LM^2 \cdot A^2 + 2 \cdot B^2 \cdot E1^2}}{-LM^2 + B^2 + 2 \cdot B \cdot E1 + A^2 + E1^2} \right]$$

$$\theta_p = 114.8 \cdot \text{deg}$$

Solving for the live mast angle

$$\theta_{lm} := \text{acos} \frac{B - E1 \cdot \cos(\theta_p)}{LM}$$

$$\theta_{lm} = 59.8 \cdot \text{deg}$$

CRANE AND PICKED-LOAD WEIGHT

Weights Per Foot

one boom insert

1 1/8" wire rope

pendants

$$w := 77.5 \cdot \frac{\text{lbf}}{\text{ft}}$$

$$w2 := 2.34 \cdot \frac{\text{lbf}}{\text{ft}}$$

$$w3 := 12.39 \cdot \frac{\text{lbf}}{\text{ft}}$$

Weight of Crane

Boom

$$W_{top} := 2780 \cdot \text{lbf}$$

$$W_{base} := 3780 \cdot \text{lbf}$$

$$W_{mid} := (\text{NumInserts} \cdot \text{Linsert}) \cdot w$$

$$W_{rope} := LB \cdot w2$$

$$W_b := W_{top} + W_{base} + W_{mid} + W_{rope}$$

$$W_{mid} = 9300 \cdot \text{lbf}$$

$$W_{rope} = 421.2 \cdot \text{lbf}$$

$$W_b = 16281.2 \cdot \text{lbf}$$

Upper

Carrier

Live Mast

$$W_u := 153700 \cdot \text{lbf}$$

$$W_c := 88775 \cdot \text{lbf}$$

$$W_{lm} := 4970 \cdot \text{lbf}$$

Head machinery

Pendants

$$W_{hm} := 1663 \cdot \text{lbf}$$

$$W_p := E1 \cdot w3$$

$$W_p = 1985.5 \cdot \text{lbf}$$

Rope from boom tip to picked load at elevation equal to ground

(min number of parts required = next integer greater than (picked load/allowable load per part))

$$\text{NumParts} := \text{ceil} \frac{W_l}{HLMAX}$$

$$\text{NumParts} = 1$$

$$W_r := \text{NumParts} \cdot (LB \cdot \sin(\theta_b) + Y) \cdot w2$$

$$W_r = 419.1 \cdot \text{lbf}$$

Weight of Crane

$$W_{crane} := W_b + W_u + W_c + W_{lm} + W_{hm} + W_p + W_r$$

$$W_{crane} = 267793.8 \cdot \text{lbf}$$

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(10)

Weight of Picked Load (defined globally for calculation of NumParts above)

$$W1 = 30000 \cdot \text{lbf}$$

$$W1 = 30000 \cdot \text{lbf}$$

Total Load (crane and picked load)

$$Wt = Wb + Wu + Wc + Wlm + Whm + Wp + Wr + Wl$$

$$Wt = 297794 \cdot \text{lbf}$$

CENTERS OF GRAVITY OF CRANE COMPONENTS AND PICKED LOAD

$Lb := -RF + RB \cdot \cos(\theta b)$	boom	$Lb = -28.8 \cdot \text{ft}$
$Lu := DU$	upper	$Lu = 9.78 \cdot \text{ft}$
$Lc := 0 \cdot \text{ft}$	carrier	
$Llm := -(RF - HMF) + (LM - CGLMT) \cdot \cos(\theta lm)$	live mast	$Llm = 6.1 \cdot \text{ft}$
$Lhm := -R$	head machinery	$Lhm = -56 \cdot \text{ft}$
$Lp := -(RF - HMF) + LM \cdot \cos(\theta lm) + \frac{E1}{2} \cdot \cos(\theta p)$	pendants	$Lp = -22.3 \cdot \text{ft}$
$Lr := -R$	rope	$Lr = -56 \cdot \text{ft}$
$Ll := -R$	picked load	$Ll = -56 \cdot \text{ft}$

Center of gravity of entire crane

(positive/negative result indicates CG is on the same side of center of rotation as counterweight/boom, respectively)

$$L_{\text{crane}} := \frac{Lb \cdot Wb + Lu \cdot Wu + Lc \cdot Wc + Llm \cdot Wlm + Lhm \cdot Whm + Lp \cdot Wp + Lr \cdot Wr}{Wb + Wu + Wc + Wlm + Whm + Wp + Wr}$$

$$L_{\text{crane}} = 3.4 \cdot \text{ft}$$

DESIGN CALCULATION

W:HC-SD-WM-ER-373

Rev. 0

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 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Validation of Crane Calculations
 (8) Originator M. P. Weis Date 7/31/14
 (9) Checker Dustin Lumber Date 8-2-94
 (10)

CALCULATION OF REACTION FORCES (See crane free body diagram)

Summing the moments about the centerline to locate the line of action of the resultant of the crawler reaction forces: (positive/negative result indicates resultant is on the same side of center of rotation as boom/counterweight, respectively)

$$d := \frac{W_{\text{crane}} \cdot L_{\text{crane}} + W_t \cdot L_t}{-(W_t)}$$

$$d = 2.6 \cdot \text{ft}$$

The reaction forces on the tracks depend on the upper angle, the angle between the boom's projection on the horizontal plane and the crane centerline parallel with the crawlers (see sketch).

$$\Delta w := d \cdot \cos(90 \cdot \text{deg} - \theta)$$

offset of reaction from centerline of crane parallel to crawlers (sketch)

$$\Delta w = 1.8 \cdot \text{ft}$$

$$\Delta l := d \cdot \sin(90 \cdot \text{deg} - \theta)$$

offset of reaction from centerline of crane perpendicular to crawlers (sketch)

$$\Delta l = 1.8 \cdot \text{ft}$$

Reaction from left crawler (sketch)

$$R_L := \frac{L_{\text{btk}} - \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_L = 114618 \cdot \text{lbf}$$

Reaction from right crawler (sketch)

$$R_R := \frac{L_{\text{btk}} + \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_R = 183176 \cdot \text{lbf}$$

DESIGN CALCULATION

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 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Validation of Crane Calculations
 (8) Originator M. P. Weis Date 7/31/14
 (9) Checker Duncan Sander Date 8-2-14
 (10)

CALCULATION OF GROUND BEARING PRESSURE ON SOIL

offset of reaction force from front of crawler (same for each crawler)

$$e := \frac{1}{2} \cdot L_{\text{track}} - \Delta l$$

$$e = 9.283 \cdot \text{ft}$$

overall length of pressure profile (same for each crawler)

$$L_{\text{track}} = 22.3 \cdot \text{ft}$$

$$b := \text{if} \left[e > \frac{L_{\text{track}}}{2}, 3 \cdot (L_{\text{track}} - e), 3 \cdot e \right]$$

$$b = 27.85 \cdot \text{ft}$$

Triangular pressure profile: maximum ground bearing pressure at front of crawler (if zero, see trapezoidal)

$$p_{\text{fnt L}} := \text{if} \left[b < L_{\text{track}}, \frac{2 \cdot RL}{b \cdot L_{\text{wtrack}}} \cdot 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt L}} = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt L}} = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{fnt R}} := \text{if} \left[b < L_{\text{track}}, \frac{2 \cdot RR}{b \cdot L_{\text{wtrack}}} \cdot 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt R}} = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt R}} = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant L} := \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt L}}}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant L} = 0 \cdot \text{lbf}$$

$$\text{Resultant R} := \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt R}}}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant R} = 0 \cdot \text{lbf}$$

Trapezoidal pressure profile: ground bearing pressure at front and rear of crawler (if zero, see triangular)

Left crawler

$$p_{\text{fnt L}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot 2 - \frac{3 \cdot e}{L_{\text{track}}} \cdot 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt L}} = 2102.7 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt L}} = 14.6 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk L}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \frac{3 \cdot e}{L_{\text{track}}} - 1 \cdot 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk L}} = 707.2 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk L}} = 4.91 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant L} := \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt L}} + p_{\text{bk L}}}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant L} = 114618 \cdot \text{lbf}$$

Right crawler

$$p_{\text{fnt R}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot 2 - \frac{3 \cdot e}{L_{\text{track}}} \cdot 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt R}} = 3360.4 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt R}} = 23.34 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk R}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \frac{3 \cdot e}{L_{\text{track}}} - 1 \cdot 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk R}} = 1130.1 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk R}} = 7.85 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant R} := \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt R}} + p_{\text{bk R}}}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant R} = 183176 \cdot \text{lbf}$$

DESIGN CALCULATION

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(4) Building _____ (5) Rev. _____ (6) Job. No. _____
(7) Subject Validation of Crane Calculations
(8) Originator M. P. Weis [Signature] Date 7/31/11
(9) Checker [Signature] Date 8-2-94
(10)

RESULTS FOR 0 DEGREE CRANE ROTATION ANGLE

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 13 of 19
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Validation of Crane Calculations
 (8) Originator M. P. Weis Michael P. Weis Date 7/31/11
 (9) Checker Duncan Sander Date 8-2-11
 (10)

CALCULATION OF REACTION FORCES (See crane free body diagram)

Summing the moments about the centerline to locate the line of action of the resultant of the crawler reaction forces: (positive/negative result indicates resultant is on the same side of center of rotation as boom/counterweight, respectively)

$$d := \frac{W_{\text{crane}} \cdot L_{\text{crane}} + W_1 \cdot L_1}{-(W_t)}$$

$$d = 2.6 \cdot \text{ft}$$

The reaction forces on the tracks depend on the upper angle, the angle between the boom's projection on the horizontal plane and the crane centerline parallel with the crawlers (see sketch).

$$\Delta w := d \cdot \cos(90 \cdot \text{deg} - \theta)$$

offset of reaction from centerline of crane parallel to crawlers (sketch)

$$\Delta w = 0 \cdot \text{ft}$$

$$\Delta l := d \cdot \sin(90 \cdot \text{deg} - \theta)$$

offset of reaction from centerline of crane perpendicular to crawlers (sketch)

$$\Delta l = 2.6 \cdot \text{ft}$$

Reaction from left crawler (sketch)

$$R_L := \frac{L_{\text{btk}} - \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_L = 148897 \cdot \text{lbf}$$

Reaction from right crawler (sketch)

$$R_R := \frac{L_{\text{btk}} + \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_R = 148897 \cdot \text{lbf}$$

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 14 of 19
 (4) Building _____ (5) Rev. _____ (6) Job. No. _____
 (7) Subject Validation of Crane Calculations
 (8) Originator M. P. Weis Assistant Date 7/31/14
 (9) Checker Duncan Sumler Date 8-2-14
 (10)

CALCULATION OF GROUND BEARING PRESSURE ON SOIL

offset of reaction force from front of crawler (same for each crawler)

$$e = \frac{1}{2} \cdot L_{\text{track}} - \Delta l$$

$$e = 8.52 \cdot \text{ft}$$

overall length of pressure profile (same for each crawler)

$$L_{\text{track}} = 22.3 \cdot \text{ft}$$

$$b := \text{if} \left[e > \frac{L_{\text{track}}}{2}, 3 \cdot (L_{\text{track}} - e), 3 \cdot e \right]$$

$$b = 25.56 \cdot \text{ft}$$

Triangular pressure profile: maximum ground bearing pressure at front of crawler (if zero, see trapezoidal)

$$p_{\text{fnt L}} := \text{if} \left[b < L_{\text{track}}, \frac{2 \cdot RL}{b \cdot L_{\text{wtrack}}}, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt L}} = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt L}} = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{fnt R}} := \text{if} \left[b < L_{\text{track}}, \frac{2 \cdot RR}{b \cdot L_{\text{wtrack}}}, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt R}} = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt R}} = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant L} := \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt L}}}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant L} = 0 \cdot \text{lbf}$$

$$\text{Resultant R} := \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt R}}}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant R} = 0 \cdot \text{lbf}$$

Trapezoidal pressure profile: ground bearing pressure at front and rear of crawler (if zero, see triangular)

Left crawler

$$p_{\text{fnt L}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot 2 - \frac{3 \cdot e}{L_{\text{track}}}, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt L}} = 3107 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt L}} = 21.58 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk L}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \frac{3 \cdot e}{L_{\text{track}}} - 1, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk L}} = 543.2 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk L}} = 3.77 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant L} := \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt L}} + p_{\text{bk L}}}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant L} = 148897 \cdot \text{lbf}$$

Right crawler

$$p_{\text{fnt R}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot 2 - \frac{3 \cdot e}{L_{\text{track}}}, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt R}} = 3107 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt R}} = 21.58 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk R}} := \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \frac{3 \cdot e}{L_{\text{track}}} - 1, 0 \cdot \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk R}} = 543.2 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk R}} = 3.77 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant R} := \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt R}} + p_{\text{bk R}}}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant R} = 148897 \cdot \text{lbf}$$

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(7) Subject Validation of Crane Calculations
(8) Originator M. P. Weis *[Signature]* Date 7/31/94
(9) Checker Duncan Lawler *[Signature]* Date 8-2-94
(10)

RESULTS FOR 90 DEGREE CRANE ROTATION ANGLE

DESIGN CALCULATION

WHC-SD-WM-ER-373
Rev. 0

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(7) Subject Validation of Crane Calculations
(8) Originator M. P. Weis Date 7/31/11
(9) Checker Duncan Sawyer Date 8-2-94
(10)

CALCULATION OF REACTION FORCES (See crane free body diagram)

Summing the moments about the centerline to locate the line of action of the resultant of the crawler reaction forces: (positive/negative result indicates resultant is on the same side of center of rotation as boom/counterweight, respectively)

$$d := \frac{W_{\text{crane}} \cdot L_{\text{crane}} + W_t \cdot L_t}{-(W_t)}$$

$$d = 2.6 \cdot \text{ft}$$

The reaction forces on the tracks depend on the upper angle, the angle between the boom's projection on the horizontal plane and the crane centerline parallel with the crawlers (see sketch).

$$\Delta w := d \cdot \cos(90\text{-deg} - \theta)$$

offset of reaction from centerline of crane parallel to crawlers (sketch)

$$\Delta w = 2.6 \cdot \text{ft}$$

$$\Delta l := d \cdot \sin(90\text{-deg} - \theta)$$

offset of reaction from centerline of crane perpendicular to crawlers (sketch)

$$\Delta l = 0 \cdot \text{ft}$$

Reaction from left crawler (sketch)

$$R_L := \frac{L_{\text{btk}} - \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_L = 100419 \cdot \text{lbf}$$

Reaction from right crawler (sketch)

$$R_R := \frac{L_{\text{btk}} + \Delta w}{2 \cdot L_{\text{btk}}} \cdot W_t$$

$$R_R = 197375 \cdot \text{lbf}$$

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 (8) Originator M. P. Weis [Signature] Date 7/31/14
 (9) Checker Duncan Lawler Date 8-2-94
 (10)

CALCULATION OF GROUND BEARING PRESSURE ON SOIL

offset of reaction force from front of crawler (same for each crawler)

$$e = \frac{1}{2} \cdot L_{\text{track}} - \Delta l$$

$$e = 11.125 \cdot \text{ft}$$

overall length of pressure profile (same for each crawler)

$$L_{\text{track}} = 22.3 \cdot \text{ft}$$

$$b = \text{if} \left[e > \frac{L_{\text{track}}}{2}, 3 \cdot (L_{\text{track}} - e), 3 \cdot e \right]$$

$$b = 33.38 \cdot \text{ft}$$

Triangular pressure profile: maximum ground bearing pressure at front of crawler (if zero, see trapezoidal)

$$p_{\text{fnt L}} = \text{if} \left[b < L_{\text{track}}, \frac{2 \cdot RL}{b \cdot L_{\text{wtrack}}}, 0, \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt L}} = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt L}} = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{fnt R}} = \text{if} \left[b < L_{\text{track}}, \frac{2 \cdot RR}{b \cdot L_{\text{wtrack}}}, 0, \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt R}} = 0 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt R}} = 0 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant L} = \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt L}}}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant L} = 0 \cdot \text{lbf}$$

$$\text{Resultant R} = \text{if} \left[b < L_{\text{track}}, \frac{p_{\text{fnt R}}}{2} \cdot (b \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant R} = 0 \cdot \text{lbf}$$

Trapezoidal pressure profile: ground bearing pressure at front and rear of crawler (if zero, see triangular)

Left crawler

$$p_{\text{fnt L}} = \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot 2 - \frac{3 \cdot e}{L_{\text{track}}}, 0, \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt L}} = 1230.9 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt L}} = 8.55 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk L}} = \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RL}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \frac{3 \cdot e}{L_{\text{track}}} - 1, 0, \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk L}} = 1230.9 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk L}} = 8.55 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant L} = \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt L}} + p_{\text{bk L}}}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant L} = 100419 \cdot \text{lbf}$$

Right crawler

$$p_{\text{fnt R}} = \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot 2 - \frac{3 \cdot e}{L_{\text{track}}}, 0, \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{fnt R}} = 2419.3 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{fnt R}} = 16.8 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$p_{\text{bk R}} = \text{if} \left[b > L_{\text{track}}, \frac{2 \cdot RR}{L_{\text{track}} \cdot L_{\text{wtrack}}} \cdot \frac{3 \cdot e}{L_{\text{track}}} - 1, 0, \frac{\text{lbf}}{\text{ft}^2} \right]$$

$$p_{\text{bk R}} = 2419.3 \cdot \frac{\text{lbf}}{\text{ft}^2}$$

$$p_{\text{bk R}} = 16.8 \cdot \frac{\text{lbf}}{\text{in}^2}$$

$$\text{Resultant R} = \text{if} \left[b > L_{\text{track}}, \frac{p_{\text{fnt R}} + p_{\text{bk R}}}{2} \cdot (L_{\text{track}} \cdot L_{\text{wtrack}}), 0 \cdot \text{lbf} \right]$$

$$\text{Resultant R} = 197375 \cdot \text{lbf}$$

DESIGN CALCULATION

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 (7) Subject Validation of Crane Calculations
 (8) Originator M. P. Weis Date 7/31/94
 (9) Checker Duncan Lumbler Date 8-2-94
 (10)

FASCIMILE OF CRANE CALCULATIONS FROM LINKBELT

07/22/94 09:51 FAX 1 606 263 5260

LINK-BELT LEX.KY --- ETC2

005/005

Link-Belt Construction Equipment Co. 07-21-1994
 Crane base reactions program (run # basereac.025)
 Model LS-518 - std 44 inch shoes - incl wt of shoes on ground
 AB (90000#) ctwt - open throat tube boom (62 x 70) w/o jib

GROUND BEARING PRESSURE
 SAMPLE TRAPEZOIDAL PATTERN

GROUND BEARING PRESSURE
 SAMPLE TRIANGULAR PATTERN

BOOM LENGTH (FT.)	LOAD RADIUS (FT.)	BOOM ANGLE (DEG.)	MAIN LOAD (LBS.)	AUX LOAD (LBS.)	UPPER ANGLE (DEG.)	LEFT FRT PRESSURE (PSI)	LEFT REAR PRESSURE (PSI)	RIGHT FRT PRESSURE (PSI)	RIGHT REAR PRESSURE (PSI)	LEFT SIDE PATTERN LTH (FT.)	RIGHT SIDE PATTERN LTH (FT.)	TOTAL WEIGHT (LBS.)
180.	56.0	73.4	30000.	0.	0.0	21.6	3.8	21.6	3.8	22.25	22.25	297794.
180.	56.0	73.4	30000.	0.	45.0	23.3	7.8	14.6	4.9	22.25	22.25	297794.
	56.0	73.4	30000.	0.	90.0	16.8	16.8	8.5	8.5	22.25	22.25	297794.

NOTES: 1. IF A PRESSURE OF 0 IS SHOWN ABOVE, THE PRESSURE PATTERN IS TRIANGULAR. OTHERWISE IT IS TRAPEZOIDAL.

DESIGN CALCULATION

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 (7) Subject Validation of Crane Calculations
 (8) Originator M. P. Weis Washburn Date 7/31/94
 (9) Checker Duncan Semler Date 8-2-94
 (10) _____

FASCIMILE FROM LINKBELT (ILLUSTRATE CRANE ROTATION ANGLE)

08/28/92 17:01

1 606 263 5260

LINK-BELT LEX.KY

003/004

Drive Motors
Towards Rear

The distance between the centerline of the axis of rotation and the centerline of the bearing (see plan view) for the LS-518 crane is zero (see info from Manufacturer attached to appendix a Crane - Imposed Down Load and Crawler Bearing Pressure Profiles

Trapezoidal Pattern

Triangular Pattern

APPENDIX F. MAXIMUM PUMP REMOVAL LOAD LIMITS AND NET AVAILABLE PULLOUT FORCES

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 2 of 3
(4) Building _____ (5) Rev. _____ (6) Job No. _____
(7) Subject Maximum Pump Removal Load Limits and Net Available Pullout Forces
(8) Originator D. M. Lawler Duncan Lawler Date July 28 1994
(9) Checker W.P. Weis Michael P. Weis Date 8/2/94
(10)

The recommended load radius for the lift, based on data in Tables 2 and 3 is 57.6. At this position, the crane is capable of lifting 41,448 lbf at the dynamometer. This is approximately equal to the equivalent load at the dynamometer for the critical component in the lifting load path, 41,921 lbf for the lifting yoke.

With the crane lifting 41,448 lbf at the dynamometer, the available lifting force at the pump lifting lugs is

41,448	
- 46	shackle weight (Brewer 1994)
- 1,875	lifting yoke weight (Mackey 1993)
- 500	hose
- 3,000	bag weight (Brewer 1994)
<u>36,027</u>	<u>lbf</u>

The net pullout force available to overcome any resistance encountered during pump removal, without the assistance of the buoyancy force, is

36,027	
- 20,050	estimated pump weight (Weis 1993)
<u>15,977</u>	<u>lbf</u>

And with the pump fully inserted and the buoyancy force for the unmixed waste present, the net available pullout force is

36,027	
- 20,050	estimated pump weight (Weis 1993)
+ 6,786	buoyancy force (Strehlow 1993a, Appendix E.1)
<u>22,763</u>	<u>lbf</u>

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. _____ (3) Page 3 of 3
(4) Building _____ (5) Rev. _____ (6) Job No. _____
(7) Subject Maximum Pump Removal Load Limits and Net Available Pullout Forces
(8) Originator D. M. Lawler [Signature] Date July 28 1994
(9) Checker M. P. Weis [Signature] Date 8/2/94
(10)

REFERENCES

Brewer, C. E., 1994, Test Pump Removal and Installation of the New Permanent Mixer Pump 101 SY Tank Critical Lift Procedure, Draft, (to be included in work packages 2W-94-00652 through 2W-94-00654), Westinghouse Hanford Company, Richland, Washington.

Mackey, T. C., 1993, 101-SY Hydrogen Mitigation Test - Structural Analysis of the Lifting Beam, Lifting Yoke, and Transport Cradle for the Mixer Pump Assembly, WHC-SD-WM-DA-109, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

Strehlow, J. P., 1993b, Structural Analysis of Tank 241-SY-101 Mixing Pump, WHC-SD-WM-DA-111, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

APPENDIX G. MAXIMUM OVERLOAD LIMITS DURING PUMP INSERTION

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 2 of 2
 (4) Building _____ (5) Rev. 0 (6) Job. No. _____
 (7) Subject Maximum Overload Limits During Pump Extraction
 (8) Originator D.M. Lawler *D.M. Lawler* Date 7/28/94
 (9) Checker M.P. Wiers *M.P. Wiers* Date 8/2/94
 (10)

1.0 INTRODUCTION

The objective of this analysis is to establish the allowable overload limits for pump removal. These limits are based on the assumption that the pump could become stuck in the riser during removal. The overload limits are necessary to insure that force required to free the pump is below the force available due to the weight of the pump minus buoyancy forces. This ensures that if the pump becomes stuck during extraction, relaxing the tension in the crane will cause the pump to break free again and settle back into place.

2.0 EVALUATION OF ALLOWABLE OVERLOAD LIMITS

$Wt_{\text{pump}} := 20050$

Pump weight

$DLF := 1.15$

Assumed dynamic load factor for pump installation

$\mu := 1.3$

Friction factor - ratio of static to dynamic coefficients of friction for metal to metal contact (Marks' Handbook for Mechanical Engineers).

$F_{\text{buoyancy}} := 7569$

Maximum buoyancy force with pump all the way inserted into mixed waste will give the minimum force available to dislodge a stuck pump back down into the tank (Strehlow 1993a, Appendix E.1).

$F_{\text{deadweight}} := Wt_{\text{pump}} - F_{\text{buoyancy}}$

$F_{\text{deadweight}} = 12481$

This is the force available to dislodge a stuck pump back down into the tank. In order to dislodge the stuck pump the static frictional force (between pump and riser) cannot exceed this deadweight load.

$F_{\text{kinetic}} := \frac{F_{\text{deadweight}}}{\mu}$

$F_{\text{kinetic}} = 9601$

This was the kinetic frictional force between the pump and the riser assuming the crane pulled the pump into its stuck position resulting in a static frictional force as calculated above.

$F_{\text{overload}} := \frac{F_{\text{kinetic}}}{DLF}$

$F_{\text{overload}} = 8348$

The kinetic frictional force between the pump and the riser includes the force required to decelerate and lodge the moving pump. Therefore, the additional (additional to deadweight) pulling force applied by the crane is less than the kinetic force by the factor DLF.

APPENDIX H. BREAK SHOE CONNECTION BOLTS AND CLEVIS PLATES STRESS ANALYSIS

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 2 of 3
 (4) Building _____ (5) Rev. 0 (6) Job. No. _____
 (7) Subject 241-SY-101 Hydrogen Mitigation Pump Brake Shoe Connection Bolts Maximum Load
 (8) Originator D.M. Lawler *Duncan Sumler* Date 7/28/94
 (9) Checker W.P. Weis *Michael P. Weis* Date 8/2/94
 (10) _____

Introduction

The following calculations are to qualify the connection bolts of the brake shoe hinge joint (ECN-188484). As the brake shoes are the largest diameter component on the pump, if the pump becomes stuck, it will most likely be on this component. Given the load limits developed in the appendix Minimum Pump Insertion Load Limits, the maximum force that a stuck component would experience during pullout would be 16,830 lbf, the force required to overcome the initial sticking force due to the static coefficient of friction. This force is detailed in Part 3 of the appendix and is the largest sticking force possible given the maximum unload limit of 47.6%.

Allowable stresses for shear in connection bolts and shear and tension in clevis plates
 (From AISC) :

A193 Grade B7 (ASTM, 1989)

$$F_u = 125,000 \text{ psi}$$

$$\text{Shear stress : } F_s = 0.22 F_u = 27,500 \text{ psi} \quad (\text{For bolts})$$

ASTM A-36

$$F_y = 36,000 \text{ psi}$$

$$\text{Tensile stress : } F_t = 0.6 F_y = 21,600 \text{ psi} \quad (\text{For clevis plate})$$

$$\text{Shear stress : } F_s = 0.4 F_y = 14,400 \text{ psi} \quad (\text{For clevis plate})$$

Analysis

Shear stress in 1/2 in. bolt (There are two bolts with double shear):

$$F = 16830 \text{ lbf}$$

$$A_1 = 4 \cdot \pi \cdot (0.25 \text{ in})^2 \quad \text{The 4 is for 2 bolts each having double shear}$$

$$\sigma_1 = \frac{F}{A_1}$$

$$\sigma_1 = 21429 \cdot \frac{\text{lbf}}{\text{in}^2} \quad \text{Less than allowable (Fs Bolts)}$$

Shear stress in 5/8 in. bolt (Only one bolt with double shear):

$$A_2 = 2 \cdot \pi \cdot (0.3125 \text{ in})^2 \quad \text{The 2 is for double shear}$$

$$\sigma_2 = \frac{F}{A_2}$$

$$\sigma_2 = 27429 \cdot \frac{\text{lbf}}{\text{in}^2} \quad \text{Less than allowable (Fs Bolts)}$$

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 3 of 3
 (4) Building _____ (5) Rev. 0 (6) Job. No. _____
 (7) Subject 241-SY-101 Hydrogen Mitigation Pump Brake Shoe Connection Bolts Maximum Load
 (8) Originator D.M. Lawler Duncan Sumler Date 7/28/94
 (9) Checker H.P. Wiers Michael Miller Date 8/2/94
 (10)

Tensile and shear stresses of clevis plate

For 1/2 in. clevis plate :

$$A_3 := \left[\left[2 - \frac{21}{32} \right] \cdot \text{in} \cdot 0.5 \cdot \text{in} \right] \cdot 2 \quad \text{The 2 is for number of clevises}$$

$$A_3 = 1.344 \cdot \text{in}^2$$

$$\sigma_3 := \frac{F}{A_3}$$

$$\sigma_3 = 12525 \cdot \frac{\text{lbf}}{\text{in}^2}$$

Less than allowable for both shear and tensile stresses (Fs and Ft Plate)

For 1/4 in. clevis plate:

$$A_4 := \left[\left[2 - \frac{17}{32} \right] \cdot \text{in} \cdot 0.25 \cdot \text{in} \right] \cdot 4 \quad \text{The 4 is for the number of clevises}$$

$$A_4 = 1.469 \cdot \text{in}^2$$

$$\sigma_4 := \frac{F}{A_4}$$

$$\sigma_4 = 11459 \cdot \frac{\text{lbf}}{\text{in}^2}$$

Less than allowable for both shear and tensile stresses (Fs and Ft Plate)

References

AISC, 1989, AISC Manual of Steel Construction, 9th ed., American Institute of Steel Construction, Inc., Chicago, Illinois

H-2-89962, HMT Hydraulic Brake Holder Assembly, H-2-89962, Rev. 0, ECN No. 188484, Westinghouse Hanford Company, Richland, Washington, October 3, 1992

ASTM, 1989, Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania.

APPENDIX I. MINIMUM PUMP INSERTION LOAD LIMITS

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 2 of 7
 (4) Building _____ (5) Rev. 0 (6) Job. No. _____
 (7) Subject Minimum Pump Insertion Load Limits
 (8) Originator D.M. Lawler *D.M. Lawler* Date 7/28/94
 (9) Checker W.T. Weis *W.T. Weis* Date 8/2/94
 (10)

1.0 INTRODUCTION

The objective of this analysis is to establish the allowable unload limits for pump installation. These limits are based on the assumption that the pump could become stuck in the riser during installation. The unload limits are necessary to insure that force required to free the pump is below the available crane lift capacity. The maximum available lift capacity at the pump lifting lugs from appendix Maximum Pump Removal Load Limits and Net Available Pullout Forces is 36,027 lbf. The load decrease at the pump lifting lugs is limited to 25% until the pump is in the waste, 50% after the pump is in the waste but before the critical mid section has cleared the riser, and 60% once the mid section has cleared the riser. The 25% load limit is assumed, but the 50% load limit is necessary to ensure vertical stability in the event the pump encounters resistance during insertion, especially at or near the surface of the waste. The 60% limit is the maximum unload that can occur if the crane is to have sufficient reserve capacity to pull the pump free. The 25%, 50%, and 60 % load limits correspond to 20%, 40%, and 47.6% load decrease limits at the dynamometer.

2.0 EVALUATION OF ALLOWABLE UNLOAD LIMITS

$Wt_{pump} := 20050$

Pump weight

$F_{crane} := 36027$

Available crane lift capacity at pump bails (41,448 lbf - 3000 - 1875 - 500 - 46 for the bag, yoke, hose and shackle respectively)

$DLF := 1.15$

Assumed dynamic load factor for pump installation

$\mu := 1.3$

Friction factor - ratio of static to dynamic coefficients of friction for metal to metal contact (Marks' Standard Handbook for Mechanical Engineers).

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 3 of 7
(4) Building _____ (5) Rev. 0 (6) Job. No. _____
(7) Subject Minimum Pump Insertion Load Limits
(8) Originator D.M. Lawler *Duncan Lawler* Date 7/28/94
(9) Checker W.P. Weeks *W.P. Weeks* Date 8/2/94
(10)

PART 1 - pump not inserted into waste

Bouancy force

$$F_{\text{bouancy}} := 0$$

Unload force based on a 20% reduction of the load at the dynamometer (part of which is used by bouancy)

$$F_{\text{unload}} := 0.20 \cdot [Wt_{\text{pump}} + (5421)] - F_{\text{bouancy}}$$

$$F_{\text{unload}} = 5094$$

The 5421 weight accounts for the weight of the following items located below the dynamometer :

1875 lbf	Yoke
+3000 lbf	Bag
+ 500 lbf	Hose
+ 46 lbf	Schackle

5421 lbf Total

Percent reduction of pump weight on pump bails

$$\frac{F_{\text{unload}} + F_{\text{bouancy}}}{Wt_{\text{pump}}} = 0.2541$$

OK approximately 25%

Initial sticking force assuming pump seizes in riser (kinetic force of friction)

$$F_1 := F_{\text{unload}} \cdot DLF$$

$$F_1 = 5858$$

Force required to overcome initial sticking force (static force of friction)

$$F_2 := \mu \cdot F_1$$

$$F_2 = 7616$$

Net force required to free pump

$$F_2 := Wt_{\text{pump}} + F_2 - F_{\text{bouancy}}$$

$$F_2 = 27666$$

OK less than 36,027, crane capacity at pump bails

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 4 of 7
(4) Building _____ (5) Rev. 0 (6) Job. No. _____
(7) Subject Minimum Pump Insertion Load Limits
(8) Originator D.M. Lawler Duncan Lumber Date 7/28/94
(9) Checker W.P. Wells Michael P. Wells Date 8/2/94
(10) _____

PART 2 - pump has just entered waste (no significant bouancy force developed).

Bouancy force

$$F_{\text{bouancy}} = 0$$

Unload force based on a 40% reduction of the load at the dynamometer (part of which is used by bouancy)

$$F_{\text{unload}} = 0.40 \cdot [Wt_{\text{pump}} + (5421)] - F_{\text{bouancy}}$$

$$F_{\text{unload}} = 10188$$

Percent reduction of pump weight on pump bails

$$\frac{F_{\text{unload}} + F_{\text{bouancy}}}{Wt_{\text{pump}}} = 0.5081 \quad \text{OK approximately 50\%}$$

Initial sticking force assuming pump seizes in riser (kinetic force of friction)

$$F_1 = F_{\text{unload}} \cdot DLF$$

$$F_1 = 11717$$

Force required to overcome initial sticking force (static force of friction)

$$F_2 = \mu \cdot F_1$$

$$F_2 = 15232$$

Net force required to free pump

$$F_2 = Wt_{\text{pump}} + F_2 - F_{\text{bouancy}}$$

$$F_2 = 35282 \quad \text{OK less than 36,027, crane capacity at pump bails}$$

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 5 of 7
(4) Building _____ (5) Rev. 0 (6) Job. No. _____
(7) Subject Minimum Pump Insertion Load Limits
(8) Originator D.M. Lawler *Duncan Lawler* Date 7/28/94
(9) Checker W.P. Weis *Michael Weis* Date 8/2/94
(10)

PART 3 - pump in waste and critical mid section clear of riser

Bouancy force, used value for 200 inches into waste (Strehlow 1993a, Appendix E.1)

$$F_{\text{bouancy}} := 867$$

Unload force based on a 47.6% reduction of the load at the dynamometer (part of which is used by bouancy)

$$F_{\text{unload}} := 0.476 \cdot [Wt_{\text{pump}} + (5421)] - F_{\text{bouancy}}$$

$$F_{\text{unload}} = 11257$$

Percent reduction of pump weight on pump bails

$$\frac{F_{\text{unload}} + F_{\text{bouancy}}}{Wt_{\text{pump}}} = 0.6047 \quad \text{OK approximately 60\%}$$

Initial sticking force assuming pump seizes in riser (kinetic force of friction)

$$F_1 := F_{\text{unload}} \cdot DLF$$

$$F_1 = 12946$$

Force required to overcome initial sticking force (static force of friction)

$$F_2 := \mu \cdot F_1$$

$$F_2 = 16830$$

Net force required to free pump

$$F_2 := Wt_{\text{pump}} + F_2 - F_{\text{bouancy}}$$

$$F_2 = 36013$$

OK less than 36,027, crane capacity at pump bails

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 6 of 7
(4) Building _____ (5) Rev. 0 (6) Job. No. _____
(7) Subject Minimum Pump Insertion Load Limits
(8) Originator D.M. Lawler *Dyanese Lawler* Date 7/28/94
(9) Checker W.P. Wells *W.P. Wells* Date 8/2/94
(10) _____

PART 4 - pump in waste and near final installation position.

Bouancy force, used value for unmixed condition in waste (Strehlow 1993a, Appendix E.1)

$$F_{\text{bouancy}} := 6786$$

Unload force based on a 47.6% reduction of the load at the dynamometer (part of which is used by bouancy)

$$F_{\text{unload}} := 0.476 \cdot [Wt_{\text{pump}} + (5421)] - F_{\text{bouancy}}$$

$$F_{\text{unload}} = 5338$$

Percent reduction of pump weight on pump bails

$$\frac{F_{\text{unload}} + F_{\text{bouancy}}}{Wt_{\text{pump}}} = 0.6047$$

OK approximately 60%

Initial sticking force assuming pump seizes in riser (kinetic force of friction)

$$F_1 := F_{\text{unload}} \cdot DLF$$

$$F_1 = 6139$$

Force required to overcome initial sticking force (static force of friction)

$$F_2 := \mu \cdot F_1$$

$$F_2 = 7981$$

Net force required to free pump

$$F_2 := Wt_{\text{pump}} + F_2 - F_{\text{bouancy}}$$

$$F_2 = 21245$$

OK less than 36,027, crane capacity at pump bails

DESIGN CALCULATION

(1) Drawing _____ (2) Doc. No. WHC-SD-WM-ER-373 (3) Page 7 of 7
(4) Building _____ (5) Rev. 0 (6) Job. No. _____
(7) Subject Minimum Pump Insertion Load Limits
(8) Originator D.M. Lawler D. Mason Lemley Date 7/28/94
(9) Checker W.P. Myers N. H. Miller Date 8/2/94
(10)

PART 5 - pump in waste and near final installation position

Bouancy force for mixed condition in waste from Appendix (Strehlow 1993a, Appendix E.1)

$$F_{\text{bouancy}} = 7569$$

Unload force based on a 47.6% reduction of the load at the dynamometer (part of which is used by bouancy)

$$F_{\text{unload}} = 0.476 [Wt_{\text{pump}} + (5421)] - F_{\text{bouancy}}$$

$$F_{\text{unload}} = 4555$$

Percent reduction of pump weight on pump bails

$$\frac{F_{\text{unload}} + F_{\text{bouancy}}}{Wt_{\text{pump}}} = 0.6047$$

OK approximately 60%

Initial sticking force assuming pump seizes in riser (kinetic force of friction)

$$F_1 = F_{\text{unload}} \cdot DLF$$

$$F_1 = 5238$$

Force required to overcome initial sticking force (static force of friction)

$$F_2 = \mu \cdot F_1$$

$$F_2 = 6810$$

Net force required to free pump

$$F_2 = Wt_{\text{pump}} + F_2 - F_{\text{bouancy}}$$

$$F_2 = 19291$$

OK less than 36,027, crane capacity at pump bails

APPENDIX J. BATELLE EVALUATIONS OF REMOVAL FORCES

Battelle

Pacific Northwest Division
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)

372-4678

July 11, 1994

Mike Ostrom
Westinghouse Hanford Company
MS H5-68
Richland, WA 99352

SUBJECT: Pump Removal Loads

Dear Mike:

The attached memo from John Hudson gives a revised analysis with our best current estimates of the condition of SY-101 waste. The conclusion is that the removal force is negligible compared to the weight of the pump as long as the pressure (suction) force is small.

The suction can be broken easily by letting fluid (air or water) in through the sparger jets. Also, the suction force will be insignificant if the waste has been yielded around the pump. This has almost certainly been accomplished by rotation of the pump column to position the jets. Note that John's shear force calculation assumes a high viscosity only over the lower 30 inches of the pump. However, the shear force remains negligible even if the 500 cp viscosity were applied over the full submerged length of 400 inches.

If you need more information, give me a call.

Sincerely,

C.W. Stewart, Manager
Hydrogen Mitigation Project

CWS:kah

Distribution:

Steve Shaw
Tony Benegas
Jack Lentsch
Larry Efferding
Bob White
John Hudson
Frank Panisko

Project Number _____

Internal Distribution

Date July 6, 1994

To Chuck Stewart

From J. D. Hudson *John D. Hudson*

Subject Revised Calculation of Additional Resistance to Pump Pullout Due to the
Tank Waste

Summary

This letter gives a revised¹ calculation of the forces resisting pullout of the mixer pump in 241-SY-101 due to the viscous shearing of the waste. This calculation provides a significantly lower value for this resistance due to recent changes in waste rheology which have resulted from pump activity. Even with what is thought to be a very conservative value for the viscosity, the resulting force is small compared to the pump weight.

Discussion

The total force, F , resisting the pump pullout is the sum of F_p , the pressure force on the pump bottom which results from the creation of void beneath the pump, F_s , the shear force resisting motion tangential to the pump pullout and F_w , the weight of the pump, housing and instrumentation

$$F = F_p + F_s + F_w. \quad 1$$

This estimate will focus on the that part of the force caused by the waste.

$$F_a = F - F_w = F_p + F_s \quad 2$$

These two forces are illustrated in Figure 1.

¹Hudson, J.D. and R. T. Allemann "Additional Resistance to Pump Pullout Due to the Tank Waste," Memo to Max Krieter, Mitigation Program (Tank Waste Safety), Pacific Northwest Laboratory, Richland, Washington, April 13, 1993.

Chuck Stewart
July 11, 1994
Page 2

Figure 1: Control volume about which the forces are calculated. Inset shows the idealized velocity distribution for the flow near the control volume (liquid slurry assumption, shear force calculation).

For waste with a significant yield strength, the pressure force is given by

$$F_p = (P_{h=0} - P_v)A_{bottom} \quad 3$$

where $P_{h=0}$ is the pressure at the bottom of the tank, P_v is the vapor pressure of the liquid waste and $A_{bottom} = \pi r^2 = \pi(20 \text{ in})^2 = 1260 \text{ in}^2$ is the area of the pump bottom. (P_v is very small and may be neglected.) The pressure force, therefore, is

$$F_p = (38.5 \text{ lbs / in}^2)(1260 \text{ in}^2) = 48,000 \text{ lbs.} \quad 4$$

However, in practice this force may be virtually eliminated by introducing air or water through the sparger jets located on the pump bottom. In addition, if the waste near the pump no longer has significant yield strength, this force should be small compared to the weight of the pump (even without the use of the sparger jets).

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July 11, 1994
Page 3

Since the waste above the bottom sludge (the bottom sludge is assumed to be less than 30 inches beneath the pump) is now assumed to be a liquid slurry, the shear force may be defined by

$$F_s = \mu \frac{dU}{dy} A_c, \quad 5$$

with

$$A_c = 2\pi rh = 2\pi(20\text{ in})(275\text{ in}) = 34,560\text{ in}^2. \quad 6$$

For a pullout rate of 0.25 inches per second and an effective shear length of 0.5 inches, the velocity gradient $\frac{dU}{dy} = 0.5\text{ sec}^{-1}$. According to Allemann², the viscosity of the non-convective slurry (prior to pump installation) may be estimated according to

$$\mu = \mu_0 / \dot{\epsilon} \quad 7$$

where $\mu_0 = 5 \times 10^6\text{ cP}$ and $\dot{\epsilon}$ is the velocity gradient (in the range from 0.1 to 1500 sec^{-1}) used in the measurements of core samples. For this estimate, a viscosity of the form of Equation 7 is used, but with a much lower reference viscosity of 500 cP, a value which is quite conservative based on recent pump operations³. With this lower reference value, Equation 7 gives $\mu = 10^3\text{ cP} = 1.5 \times 10^{-4} \frac{\text{lb} \cdot \text{s}}{\text{in}^2}$. Using these values the shear of the liquid slurry resisting the pump pullout is

$$F_s = (1.5 \times 10^{-4} \frac{\text{lb} \cdot \text{s}}{\text{in}^2})(0.5\text{ s}^{-1})(34,560\text{ in}^2) = 2.6\text{ lbs.} \quad 8$$

Since both terms in Equation 2 are small compared to the weight of the pump, the total force due to viscous shearing of the waste may be neglected.

²Allemann, R. T. "Viscosity and Shear Strength of 241-SY-101 Slurry," Memo to Max Kreiter, Mitigation Program (Tank Waste Safety), Pacific Northwest Laboratory, Richland, Washington, October 28, 1992.

³This is also conservative based on the laboratory results of Tingey (1994). Tingey, J. M. *Rheological Properties of Waste from Tank 101-SY*, Pacific Northwest Laboratory, Richland, Washington, In progress.