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PRELIMINARY DESIGNS FOR OCEAN THERMAL ENERGY CONVERSION
(OTEC) STATIONKEEPING SUBSYSTEMS (SKSS)

Task II Conceptual Design, Final Report

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July 27, 1979

Work Performed Under Contract No. EG-77-A-29-1078

Lockheed Missiles & Space Company, Inc.
Ocean Systems
Sunnyvale, California

U.S. Department of Energy

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OCEAN THERMAL ENERGY CONVERSION (OTEC)
STATIONKEEPING SUBSYSTEMS (SKSS)

Task II Conceptual Design
Final Report

LMSC-D676379 27 July 1979

Prepared for

National Oceanographic and Atmospheric Administration
Office of Ocean Engineering
Under Contract NA-79-SAC-00635

Prepared by

Ocean Systems, Lockheed Missiles & Space Company, Inc.
with
IMODCO
Simplex Wire and Cable Company
Eager & Associates

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FOREWORD

Lockheed Ocean Systems is performing the Preliminary Design for OTEC Stationkeeping Subsystems (SKSS) study contract NA-79-SAC-00635 for NOAA, Office of Ocean Engineering, in support of the Department of Energy, Ocean Thermal Energy Conversion (OTEC) program. The SKSS design team includes IMODCO on design and analysis of mooring systems for the spar, Simplex Wire and Cable Company on SKSS interface with the Electrical Transmission System riser cable, and Eager & Associates on reliability assessment. The results of Task II - Conceptual Design - are presented in this report and in a presentation to NOAA/DOE personnel.

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Section 1

INTRODUCTION

Lockheed Ocean Systems is performing the Preliminary Designs for OTEC Stationkeeping Subsystems (SKSS) contract for NOAA, Office of Ocean Engineering, in support of the Department of Energy OTEC program. Lockheed is supported in this study by IMODCO, Simplex Wire and Cable Company, and Eager & Associates. The results of Task II, Conceptual Design, are presented in this report. The report consists of five sections: design loads, conceptual designs, trade studies, cost analysis and concept evaluation and ranking. Extensive appendixes provide back up calculations and data to support the results contained in this report.

Environmental forces and yaw moments acting on the barge and spar in the various design sea states are presented including wave, wind and current effects. A parametric analysis illustrates the impact on holding power requirement of varying the return periods for operational and extreme sea state (Section 2). The conceptual designs are presented for the barge followed by those for the spar, including configuration definition, performance characteristics, interfaces, areas for development and deployment scenarios for selected concepts (Section 3). The concept definition is followed by a set of trade studies that were performed to evaluate candidate anchor types and anchor leg materials. Parametric variations in anchor leg characteristics, wire-rope-to-chain length ratio for example, illustrate the influence of the significant design parameters on performance (Section 4). An extensive cost analysis of the candidate SKSS concepts is presented, including cost estimates, life cycle cost scenarios leading to expected value of life cycle cost, and cost equivalence of operational failures (Section 5). An evaluation of the eight SKSS concepts is presented, including assessment of performance and rankings based on risk versus cost and technology development (Section 6).

The appendixes include a report on the Electrical Transmission System interface, wave drift force, typical cost disbursement schedule and computer program listing, the IMODCO conceptual design report, and static configuration results.

Section 2

ENVIRONMENTAL LOADS

An assessment of the steady-state forces and yaw moment acting on the platforms is presented to provide holding power requirements for Stationkeeping Subsystem (SKSS) conceptual design. The approach and results presented in this section provide surge and sway force, as well as yaw moment on the barge and surge force on the spar in the horizontal plane. A range of sea states from Service to the Extreme sea states and beyond is examined to assess the sensitivity of loading to sea state return period. In the barge case, heading influence is evaluated. Finally, the effect of noncoincident wind, wave, and current is examined for most probable directions at Punta Tuna.

The summary of environmental conditions, presented in Task I Final Report (Table 2-1) is included for clarity.

2.1 WAVE DRIFT FORCE

The mean wave drift force and yaw moment on the barge is estimated using coefficients derived from potential theory and empirical studies of ships and barges in regular waves. Waves are assumed to be long crested and unidirectional.

The mean wave drift force in irregular seas is obtained as follows (Ref. 1):

$$F = 2 \int_0^{\infty} S(w) \bar{F}(w) dw \quad (2-1)$$

where

$S(w)$: Bretschneider wave spectral energy

$\bar{F}(w)$: Drift force coefficient

eg. $F_x = \bar{F}_x \rho g \alpha^2 B^2/L$

where

F_x : Mean Longitudinal Drift Force
 W : Wave Frequency
 ρ : Water Density
 g : Acceleration of Gravity
 B : Barge Beam
 L : Barge Length
 α : Wave Amplitude

Sway force and yaw moment in beam seas are calculated for the operational and extreme sea states using the coefficients published in Refs. 1 through 6. For completeness, the calculations are included in Appendix B, and results are compared in Table 2-2.

The agreement of sway force, F_y , in the lower sea state is good, considering the differences in characteristics of the platforms. In the higher sea state there is a larger variation among theories. The two results for yaw moment, N , differ greatly in both sea states, possibly because of the nonbeam condition of the Mariner. Based on these results and the recommendations found in Ref. 6, the 3-D theory of Faltinsen and Michelsen (Ref. 5) is selected for computing mean wave drift force in head and beam seas on the barge while the theory of Kim and Chou (Ref. 3) is selected for mean yaw moment. The results are given in Table 2-3.

The influence of wave heading is treated as follows (Ref. 7), where the wave drift force for relative wave heading is given as:

$$F = F_{\text{head}} \frac{2 \cos^2 \alpha}{1 + \cos^2 \alpha} + F_{\text{beam}} \frac{2 \sin^2 \alpha}{1 + \sin^2 \alpha} \quad (2-2)$$

where

F_{head} = drift force in head seas
 F_{beam} = drift force in beam seas
 α = angle of force off bow

Table 2-1
SUMMARY OF ENVIRONMENTAL CONDITIONS, PUNTA TUNA

Property	Condition
Climate	Marine Tropical
Latitude	17° 57' N
Longitude	65° 52' W
Approximate Depth (ft)	4,000
Distance to Shore (miles)	3
Distance along Shore (miles)	$\pm$ 5
Return Period of Design Operational Sea State (years)	3
Return Period of Design Extreme Sea State (years)	100
Surface Current (knots)	1.8 to 2.4
Current Profile	See Fig. 2-2
Bottom Quality	Silt, Clay, Mud, underlain by dense sand
Bottom Slope (deg)	10 to 18
Operational Sea State:	
Maximum Wave Height (ft)	34.0
Significant Wave Height (ft)	18.9
Period of Maximum Energy (sec)	10.1
Wind (knots)	29.5
Surface Current (knots)	1.8
Seafloor Current (knots)	0.18
Current Profile	See Fig. 2-2
Astronomical Tide (Diurnal Range) (ft)	1.0
Astronomical Tide (Annual Max. Range) (ft)	1.8
Extreme Sea State:	
Maximum Wave Height (ft)	63.2
Significant Wave Height (ft)	35.1
Period of Maximum Energy (sec)	13.0
Wind (knots)	79.1
Surface Current (knots)	2.4
Seafloor Current (knots)	0.24
Current Profile	See Fig. 2-2
Astronomical Tide-Storm Surge (ft)	5.5
Seismicity:	
Occurrence	Frequent
Epicenters (depth - ft)	230,000 to 984,000

Table 2-2 MEAN WAVE DRIFT FORCE AND MOMENT ON BARGE IN BEAM SEAS

Technique (Reference)	Platform	Beam/ Draft	Operational Sea State		Extreme Sea State	
			N(ft-lb)	F _y (lb)	N(ft-lb)	
Remery & Hermans (1)	Barge	2.5	205 700	-	827 600	-
Potash (2)	2-D	2.0	209 800	-	7.1 x 10 ⁶	-
Kim and Chou (3)	2-D, Series 60 Ship	2.5	168 700	950 000	283 296	1.35 x 10 ⁶
Salvesen (4)	2-D, Mariner Ship (120 deg)	-	234 908	8.9 x 10 ⁶	326 900	13 x 10 ⁶
Faltinsen & Michelsen (5)	3-D, Barge	2.2	283 096	-	777 761	-

The effect of wave heading on yaw moment is as follows (Ref. 3):

$$N = N_{\text{beam}} \sin 3\alpha \quad (2-3)$$

Table 2-3 MEAN WAVE DRIFT FORCES AND MOMENT

Heading	Operational Sea State			Extreme Sea State		
	Surge Force (lb)	Sway Force (lb)	Yaw Moment (ft-lb)	Surge Force (lb)	Sway Force (lb)	Yaw Moment (ft-lb)
Barge, Head	110 305	0	0	419 563	0	0
Barge, Beam	0	283 096	950 000	0	777 761 10 ⁶	1.35 x
Spar	137 229	0	0	416 818	0	0

To treat variation of wave height for sea states other than operational and extreme, the results in Table 2-2 provide the following approximate relationships:

$$\begin{aligned}
 F_{\text{head}} &= 419\,563 \left(\frac{H_{1/3}}{35} \right)^{2.17} \text{ lb} \\
 F_{\text{beam}} &= 777\,761 \left(\frac{H_{1/3}}{35} \right)^{1.64} \text{ lb} \\
 N_{\text{beam}} &= 1.35 \times 10^6 \left(\frac{H_{1/3}}{35} \right)^{0.57} \text{ ft-lb}
 \end{aligned}
 \tag{2-4}$$

Wave drift force is assumed to act only in the direction of wave travel on the spar while sway force and yaw moment are assumed to be zero. Mean wave drift force in surge on the spar is estimated by the following relationship applicable to wave drift force on semisubmersible platform cylinders in irregular waves (Ref. 7).

$$F = 2.28 \left(\frac{H_{1/3}}{T_{1/3}} \right)^2 D \exp \left[- \left(\frac{2\pi}{T_s} \right)^2 \frac{z}{g} \right]
 \tag{2-5}$$

where

$H_{1/3}$	= significant wave height (ft)
$T_{1/3}$	= significant wave period (sec)
D	= cylinder diameter (ft)
z	= depth of upper end of cylinder (ft)
g	= acceleration of gravity (ft/sec ²)

The exponential term is included to account for the submergence of the spar core below the wave surface. Assuming that the effective diameter of core and modules is 200 ft and the submergence depth is 80 ft, the drift force results are as given in Table 2-3. The wave drift force on the spar, as well as on the cold water pipe (CWP) and discharge pipes for spar and barge, will be investigated further at the beginning of Task III.

Another approach to determining wave drift force based on empirical data from tests of moored tank models, is used by IMODCO (Ref. 8). The applicability of this approach to wave drift force on the spar is not established.

2.2 WIND FORCE AND MOMENT

The wind load on the barge is given by the following expression applicable to ship profiles (Ref. 9):

$$F_W = C_D \frac{1}{2} \rho V_W^2 \frac{A \sin^2 \theta_W + B' \cos^2 \theta_W}{\cos(\alpha - \theta_W)} \quad (2-6)$$

where

- θ_W = $B_2 - B_1$ (see Fig. 2-1).
- α = relative direction of wind force off bow, = (θ_W)
- C_D = drag coefficient (0.8)
- V_W = free stream wind speed
- A = broadside projected area of hull above waterline (13,434 ft²)
- B^1 = $B_s + 0.3 B_h$
- B_s = ahead projected area of superstructure (7,460 ft²)
- B_h = ahead projected area of hull above waterline (3,816 ft²)
- ρ = density of air (0.002378 slugs/ft³)

The (x,y) coordinate frame is fixed in the barge and (X,Y) is the inertial frame. (See Fig. 2-1.) Barge frame wind force components are:

$$F_x = - F_W \cos \alpha \quad (2-7)$$

$$F_y = - F_W \sin \alpha$$

while in the inertial frame:

$$F_x = - F_W \cos (\alpha + B_1) \quad (2-8)$$

$$F_y = - F_W \sin (\alpha + B_1)$$

Yaw moment about amidships due to wind is given by

$$N = - F_y \cos \alpha \left(\frac{L}{2} - \bar{L} \right) \quad (2-9)$$

where

L = Barge length

$\bar{L}$ = Distance aft of bow to center of wind force, $\bar{L} = \bar{L}(\theta_W)$

Spar wind side force and yaw moment are assumed to be zero, while wind drag is given by:

$$F_W = - \frac{1}{2} \rho V_W^2 (A_S C_{DS} + A_C C_{DC}) \quad (2-10)$$

where

A_S = projected area of superstructure (2,750 ft²)

A_C = projected area of column (1,675 ft²)

C_{DS} = drag coefficient of superstructure (1.0)

C_{DC} = drag coefficient of column (0.55)

β_1 : PLATFORM HEADING FROM EAST

β_2 : WIND DIRECTION

β_3 : CURRENT DIRECTION

β_4 : WAVE DIRECTION NORMAL TO CRESTS

FIG. 2-1
COORDINATES FOR PLATFORM ENVIRONMENTAL
LOADING

2.3 CURRENT FORCE AND MOMENT

The wetted surfaces of hull, discharge pipes, and CWP contribute to platform loading in a current. The drag force on the barge hull is given by the following expressions for the surge and sway components:

$$F_x = -\frac{1}{2} \rho C_D B_C V_C^2 \cos^2 \theta_W \quad (2-11)$$

$$F_y = -\frac{1}{2} \rho C_D A_C V_C^2 \sin^2 \theta_W$$

where

- C_D = drag coefficient (0.6)
- A_C = broadside projected wetted area (24,770 ft²)
- V_C = speed of surface current
- B_C = frontal projected wetted area (7,865 ft²)
- θ_W = $B_1 - B_3$

The net force is then:

$$F_C = \left(F_x^2 + F_y^2 \right)^{1/2}$$

with direction

$$\alpha = \tan^{-1} (F_y/F_x)$$

The yaw moment is (Ref. 9)

$$N_C = - F_y \cos \lambda \left(\frac{L}{2} - \bar{L} \right) \quad (2-12)$$

with the current center $\hat{L}(\hat{e}_w)$ assumed to be equal to wind force center (see Eq. 2-9).

Drag on the discharge pipes is

$$F_{cp} = \frac{1}{2} \rho C_D A (0.9 v_C)^2 \quad (2-13)$$

where

C_D = drag coefficient (0.5)

A = total projected area of two pipes, no blockage (22,040 ft²)

The factor 0.9 accounts for the current shear at the pipe depth. The CWP drag is

$$F_{CWP} = \frac{1}{2} \rho A v_C^2 \bar{C}_D \quad (2-14)$$

where $A = 88\,050 \text{ ft}^2$ and the equivalent drag coefficient, C_D , accounts for the current shear and drag coefficient dependence on Reynolds number. A planar current distribution is assumed. This is a conservative assumption as current measurements indicate flow reversal at 200-ft depth. Dynamic loads such as Vortex shedding loads are not included in this static loads analysis. The following formula is obtained from computed results using this approach.

$$\bar{C}_D = 0.066 v_c^{0.196} \quad (2-15)$$

with surface current speed, v_C , in knots.

A right circular cylinder having a 184-ft diameter and a 220-ft height with a submergence of 80 ft is assumed to represent the irregular profile of the spar configuration. Then

$$\begin{aligned}
 F_c &= \frac{1}{2} \rho C_D L D (0.9v_c)^2 \\
 F_x &= - F_c \cos \beta_3 \\
 F_y &= F_c \sin \beta_3 \\
 N_c &= 0
 \end{aligned}
 \tag{2-16}$$

Discharge pipes are not included in the configuration. The CWP area is 83,550 ft², and the equivalent drag coefficient is

$$\bar{C}_D = 0.051 v_c^{0.183} \tag{2-16}$$

2.4 PARAMETRIC LOAD ANALYSIS

The influence of design sea-state return period, barge heading, noncoincident wind, waves, and current are demonstrated in this section. A program was prepared based on the set of equations given in Section 2 of the Task I report (Ref. 10) and in the preceding subsections.

The results for the barge are presented in Table 2-4, indicating the increase in wind, wave, and current forces on the barge in head conditions for return periods of 1 to 200 years. The forces are highly sensitive to return period of the operational sea state; an increase from 3 to 5 years increases force by 58 percent while a decrease from 3 to 1 years results in a reduction in force of 24 percent. This is partly a result of the assumption that, in seas with

Table 2-4 SUMMARY OF LOADS - BARGE

(1) Coplanar Wind, Wave, and Current - 0 (Easterly)
Barge - Head Seas

Return Period (Years)	1	3 ⁽¹⁾	5	50	100 ⁽²⁾	200
Significant Wave						
Height (ft)	13.8	18.9	21.3	31.9	35.1	38.3
Modal Wave Period (sec)	8.6	10.0	10.6	12.5	13.0	13.5
Wind (kts)	25.4	29.5	62.4	75.6	79.1	82.4
Surface Current (kt)	1.7	1.7	2.1	2.3	2.4	2.4
Force (lb)						
- Wind	15 107	20 315	90 839	133 416	146 075	158 674
- Current	171 261	188 839	272 893	331 563	348 277	364 660
- Wave	55 982	110 274	142 324	343 080	422 194	510 221
Total	242 350	319 428	506 056	808 059	916 546	1 033 555

(2) Coplanar Wind, Wave, Current - 0 (Easterly)
Barge - 100-Year Return Period

Barge Heading (deg)	0	30	45	60	90
Wind Force (lb)					
F _x	146 075	64 369	50 641	36 866	15 383
F _y	7 104	221 647	213 905	218 381	228 050
Current Force (lb)					
F _x	348 277	293 066	231 007	155 715	0
F _y	0	195 314	310 205	411 864	506 674
Wave Force (lb)					
F _x	422 194	584 098	567 400	419 343	0
F _y	0	337 229	567 400	726 324	781 444
Vector Sum (lb)	916 573	1 209 572	1 374 059	1 480 115	1 516 246
Angle (deg)	0	38.7	52.1	65.7	90
Yaw Moment (ft-lb)	0.17	8.1	4.0	0.9	1.3
x 10 ⁶					

- (1) Operational Sea State
(2) Extreme Sea State

height greater than 21 ft, wind speed is that for hurricane conditions, or twice that of extrapolated observations. In contrast, an increase to 200 years or a decrease to 50 years for the extreme sea state return period results in only a 12 percent change in force on the barge. Since the watch circle requirement of 10-percent water depth applies to the operational sea state, it is possible that return period for this sea state can be traded against power transmission, holding power, and watch circle requirements.

The effect of barge heading, also shown in Table 2-4, is such that as the coincident wind, wave and current rotate from head to beam, the net force increases by 65 percent. In addition, the yaw moment increases to a maximum at 30 degrees. The ability to control barge heading is a benefit in terms of reducing platform loading imposed on the mooring in all sea states. Even in the selection of beam condition as extreme load for design, the ability to control heading provides that much additional strength margin for stationkeeping.

The effect of noncoincidence on loads is illustrated by assuming that the wind and wave are coincident and rotate about the most probable easterly direction while the current is either northeasterly or southwesterly. Results, shown in Table 2-5 for the barge heading East, indicate that net force increases as wind and waves approach from the port bow direction. Yaw moment increases if all loads are from the same quarter and decreases significantly if wind and wave are from the starboard bow. Rotation of the barge into the direction of prevailing current decreases barge force and increases moment while rotation of the barge into wind and waves results in the largest reduction in force and moment.

A comparison of the loads on barge and spar in the Operational and Extreme Sea States is shown in Table 2-6; other loading conditions are included in Appendix B.

Table 2-5 BARGE LOADS IN NONCOINCIDENT CONDITIONS

(1) Barge Heading East

Extreme Sea State (100 years)

See Fig. 2-1

Wind Direction (deg)	0	45	-45	45
Current Direction (deg)	0	25	25	-175
Wave Direction (deg)	0	45	-45	45
Net Force (10^6 lb)	0.97	1.3	1.1	1.3
Force Angle (deg)	0	45.4	33.9	-61.2
Net Moment (10^6 ft-lb)	1.2	5.5	.01	2.5

(2) Barge Heading - Variable

Extreme Sea State (100 years)

Barge Direction (deg)	0	25	45
Wind Direction (deg)	45	45	45
Current Direction (deg)	25	25	25
Wave Direction (deg)	45	45	45
Net Forces (10^6 lb)	1.3	1.0	0.9
Force Angle (deg)	45.4	22.6	3.8
Net Moment (10^6 ft-lb)	5.5	8.9	3.6

Table 2-6 BARGE AND SPAR ENVIRONMENTAL STATIC LOADS

Wind, Wave, Current Coplanar Head Seas

1) Operational Sea State

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(CFT-LB)	FXI	FYI
WIND	-20315.	-999.	-20315.	-999.	157369.	-10934.	0.
CURRENT	-139939.	0.	-139939.	0.	0.	-210203.	0.
WAVE	-110274.	0.	-110274.	0.	0.	-137229.	0.
TOTAL	-319429.	-999.	-319429.	-999.	157369.	-359256.	0.
VECTOR SUM		319429.					359256.

2) Extreme Sea State

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(CFT-LB)	FXI	FYI
WIND	-146075.	-7104.	-146075.	-7104.	1207039.	-77902.	0.
CURRENT	-343277.	0.	-343277.	0.	0.	-395039.	0.
WAVE	-422194.	0.	-422194.	0.	0.	-416319.	0.
TOTAL	-916546.	-7104.	-916546.	-7104.	1207039.	-979759.	0.
VECTOR SUM		916573.					979759.

2.5 REFERENCES

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Section 3

SKSS CONCEPTUAL DESIGNS

The conceptual designs studied include six barge mooring configurations of single and multiple anchor legs and four spar mooring configurations of single, multiple, and tensioned anchor legs, and the monopod arrangement. The study includes loads analysis, performance characteristics, reliability analysis, technical feasibility, sizing, deployment, and cost. The conceptual designs are presented in this section. Figure 3-1 illustrates the ten mooring configurations for the barge and spar.

3.1 BARGE MOORING CONFIGURATIONS

3.1.1 Multiple Anchor Leg (MAL)

The MAL mooring system consists of a radial, catenary pattern of ten (10) wire rope and chain combination anchor legs with two drag-embedment anchors per leg. The lines run through fairleads just below the waterline and up to the main deck structure (see Fig. 3-2). The lines can be tensioned with hydraulic jacks or winches which allow line tensioning for initial deployment and subsequent line load adjustments as necessary. The radial pattern of the mooring legs provides a rotational restraint on the platform, thus precluding interference with the electrical transmission cable and the cold water pipe. Watch circle radius is 8.8 percent of the depth for the operational sea state of a 3-year storm and 13.0 percent of the depth for the extreme sea state of a 100-year hurricane. Each 8 100 ft leg consists of 4 500 ft of at least 3 5/8-in.-diameter chain and 3 600 ft of 4 1/2-in.-diameter wire rope in a catenary profile. Sufficient material is added to the chain for life cycle wear and abrasion. This length of chain facilitates wire rope change-outs over the power plant life cycle. Chain weight allows the use of 20 000-lb drag-embedment anchors, which considerably reduce the mooring system cost and greatly simplify the deployment operation and support services. Floating

Fig. 3-1 Conceptual Design Study Mooring Configurations

crane barges are employed for controlled lowering of the chain and anchors to the seafloor. Figure 3-2 shows the arrangement of the MAL. Static performance analysis is presented in Appendix E and the results summarized in Table 3-1.

3.1.2 Multiple Anchor Leg - Single Point Moor

This system consists of a cluster of seven anchor lines running from a deadweight anchor to a buoy which supports the weight of the wire ropes and tension in the lines. The barge is connected to the buoy by either hawsers or a yoke assembly. The specific components of the system are a deadweight anchor weighing 15.7 million lb (dry), seven 4 1/2-in.-diameter wire ropes, a 30 ft-diameter, 200-ft-long spar buoy weighing approximately 750 000 pounds, and a minimum of two swivels, one at the anchor and the other at the buoy. Auxiliary machinery on the buoy includes hydraulic jacks and/or winches for line load equalization and tensioning. Direct lift methods do not presently exist for deployment of the large deadweight anchor since the load is beyond the capacity of existing heavy lift equipment. The deadweight anchor may be implanted by pouring fresh concrete in situ at ocean depth of 4 000 ft or by free-fall emplacement. A free-fall emplaced deadweight anchor of this size would either be floated out to the mooring site using attached flotation collars (and/or internal tanks) or loaded onto a barge and launched at the site. Pouring concrete in deep water and free-fall emplacement techniques are an extension to the present state of the art and require further development. An approach to placement of concrete (ref. 10) is to mix the concrete on a surface platform and convey the concrete to the seafloor by a pipeline suspended from a special outfitted barge or drillship. An integration of technology in the concrete, the oil and ocean industries may lead to accomplishment of the task using, for the most part, state-of-the-art knowledge and hardware. Technological development of the free-fall emplacement technique, as presented in the technical report for OTEC anchors (ref. 5), includes (1) hydrodynamic evaluation of the free-fall anchor, (2) soil penetration-deceleration force on the anchor, and (3) structural design to withstand construction, transport, free-fall, landing, and service loadings.

FIGURE 3-2
MAL MOORING SYSTEM

Table 3-1 MAL PERFORMANCE CHARACTERISTICS

Item	3-Year Storm	100-Year Storm
Horizontal Force on Barge (lb)	729 529	1 202 843
Anchor Leg Tension (lb)	624 200	790 500
Chain Safety Factor	3.06	2.42
Wire Rope Safety Factor	2.96	2.34
Watch Circle Radius (ft)	350	530
Watch Circle/Depth (percent)	8.8	13.3

A demonstration test is necessary. Figure 3-3 shows the arrangement of the MAL-SPM. The performance analysis is presented in Appendix E and the results are summarized in Table 3-2.

3.1.3 MAL-Turret

The conceptual design of the anchor legs and anchors for the MAL-Turret is identical to the MAL and consists of a radial, catenary pattern of ten wire rope and chain combination anchor legs with drag embedment anchors. In contrast to the MAL, the anchor legs lead through fairleads attached to the CWP below the hull and up to the turret in the main deck structure. The legs can be tensioned with hydraulic jacks or winches during deployment and subsequent operational adjustments as necessary. The turret head is secured to the end of the cold water pipe. Vertical and horizontal rollers mounted on shock absorbing units facilitate dampening of vertical and lateral thrusts and provide for ship rotation about the axis of the cold water pipe. The electrical transmission riser cable junction swivel is simplified by being above water. The conceptual design of the mooring turret is shown in Fig. 3-4.

Alternative approaches which allow for relative angular motion between barge and CWP are to add a joint to the CWP below the doubler (Fig. 3-5) or to add a U-joint to the turret (Fig. 3-6).

Fig. 3-3 MAL - SPM

Fig. 3-4 MAL-Turret Concept

Fig. 3-5 Turret Head Concept With Pipe Joint Flexibility

NOTES:

1. Pipe Joint Provides Angular and Rotational Movements
2. Cold Water Seal and Bumpers are elastomers

Fig. 3-6 U-Joint and Turntable Concept

NOTES:

1. U-joint and turntable provides angular and rotational movements
2. Cold water seal and bumpers are elastomers
3. Mooring leg secured at chain stopper and then disconnected from winch

Table 3-2 MAL-SINGLE POINT MOOR PERFORMANCE CHARACTERISTICS

Item	3-Year Storm	100-Year Storm
Horizontal Force (lb)	338 202	585 070
Vertical Force (lb)	3 382 000	5 861 700
Buoy Inclination (deg)	6	6
Anchor Leg Tension (lb)	3 398 800	5 890 800
Anchor Leg Safety Factor	3.81	2.20
Deadweight - Anchor WeightWet (lb)	9 000 000	9 000 000
Deadweight - Dry (lb)	15 697 700	15 697 700
Deadweight Safety Factor	2.66	1.54
Watch Circle Radius (ft)	400	400

An alternative to designing for beam sea loads is to apply head-sea loads to determine mooring holding power. This criterion is perhaps more consistent with the barge characteristics of low freeboard and barge roll in beam seas. In this case then six anchor legs instead of ten are required. The costs for this moor-turret are presented and evaluated in Sections 5 and 6.

Major components of the turret concept are the turret head weighing 353 000 lb, six vertical rollers, twelve horizontal rollers, ten winches, ten fairleads, a doubler around the cold water pipe, and six elastomeric bumpers.

3.1.4 MAL - Active Tensioning

The anchor legs and anchors for the MAL-active tensioning are also identical to those of the MAL and consist of a radial, catenary pattern of ten wire rope and chain combination lines with drag embedment anchors. The lines run through fairleads just below the waterline and up to the main deck structure. At this point, hydraulic jacks and/ winches respond to control signals initiated by tensiometers in each anchor leg. Take-up, hold or slack control signals are transmitted to the winches depending on yaw angle and the differential of actual restoring force to minimum and maximum tensions. By virtue of the frequent activity imposed on the system, the line handling

machinery for the active tensioning system is heavy duty. The active tensioning system provides an inherent, built-in control system for adjustment and monitoring of line tensions, excursions, yaw, and restoring forces during normal and abnormal conditions.

3.1.5 Single Anchor Leg - Single Point Moor (SAL - SPM)

This mooring concept, wherein a single anchor leg leads from a deadweight anchor to a mooring buoy, must necessarily be a tension anchor leg system to satisfy the watch circle requirement. The single leg must react up to 5.9-million-lb tension in the extreme sea state of 100-year return period. Wire rope with breaking strength of about half this amount is available. An anchor leg consisting of hollow cylindrical links would be difficult to maintain, particularly in the area of the pin joints. A single anchor leg chain with the requisite breaking strength is excessively heavy, lacks redundancy, requires a massive buoy, and is costly. The system is therefore not feasible with SOA technology. A second SAL-SPM for the ship is presented in Appendix D.

3.1.6 MAL - Rotary

The rotary system consists of carriages which run on a circular rail around the CWP or on the bottom of the ship. Anchor legs attached to these carriages are spaced from each other by chains which connect the carriages together. The ship rotates relative to the anchor legs. The top of the electric transmission cable is also supported by another carriage which rides on the circular rail. An electric slipring swivel allows the ship to rotate relative to the electric transmission cable.

The electrical swivel must be pressure resistant, as ingress of small amounts of water will eventually contaminate the oil or gas insulation. In addition, this concept requires electrical contact surfaces around the CWP, a termination difficult to seal and insulate. Finally, the necessary mechanical cable terminations require space and clearance which is not available in the

rotary concept (Appendix A). The interface of the electrical transmission system riser cable with the rotary system underwater renders this concept unfeasible, and it is not considered further in concept evaluation and ranking.

Section 3.2 SPAR MOORING CONFIGURATIONS

This section includes sections III, IV, and V of the IMODCO Task II Report.

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3.2.1 MULTIPLE ANCHOR LEG-SPAR MOOR (MAL-SPAR)

System Description

The multiple anchor leg mooring system proposed to moor the OTEC 40MW(e) SPAR consists of four catenary shaped anchor legs attached to the core of the spar. The anchor legs, consisting of chain and wire rope, are anchored to the seabed by series of anchors. At the spar, the anchor leg is attached to the core by a hawse pipe which has a chain stopper integral with the hawse pipe structure (See Figure 8).

Anchor Leg

The anchor leg has three segments joined together in series. The leading segment, attached to the SPAR, is 100 feet of 4 inch diameter chain. The chain is of U-3 quality with a breaking strength of 1632 kips. The second segment is 5000 feet of 4-1/2 inch diameter galvanized bridge wire rope. The wire rope has a breaking strength of 1850 kips. A protective coating of polyethylene, 1/4 inch thick is applied to the wire rope. The purpose of the coating is to retard corrosion and prevent abrasion. The final segment is 5900 feet of 4 inch diameter chain with two Bruce Anchors attached near the end (See Figure 9). Pretension is 300 kips per leg.

Chain to Wire Rope Connections

The connection between the wire rope and chain consist of an open wire rope socket and a swivel shackle.

The open wire rope socket can be designed and supplied by U.S. Steel Tiger Brand division. The wire rope is integrated into the nozzle of the socket so that no tensile capacity is lost in the connection. The entire connection is coated with a polyethylene boot to retard corrosion. A connection of this type weighs 990 pounds.

Attached to this socket is a chain swivel to which the anchor chain is connected. The purpose of having this swivel is to prevent twist in the mooring leg, which could cause the wire rope to kink.

Anchor System

The anchoring system for the multiple anchor leg system consists of two Bruce Mark II anchors arranged in series. The total holding power from the two anchors is 1750 kips. Separating the two anchors will be approximately 90 feet of chain. Care must be taken so that there are an even number of links between the anchors. An odd number of links would put the anchors 90 degrees out of phase of each other. The weight of the anchoring system, including the chain, is 51 kips.

Hawse Pipe

Four hawse pipe assemblies are attached to the outer shell of the power plant core. The hawse pipes are placed near the top of the core, between the evaporators and condensers.

Each hawse pipe is mounted to the core by two K-type joints which form a 35° angle on the vertical plane. These joints are made of tubular members and are welded at all junctions.

FIGURE 8

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DATE	DATE	DATE	DATE
DESIGNED BY	CHECKED BY	APPROVED BY	DATE
CHAIN DETAILS MULTIPLE ANCHOR LEG ARRANGEMENT			
FIG.	DATE	SCALE	APPROVED BY

FIGURE 9

There is also a shear plate connecting the hawser pipe to the power plant core. Refer to Figure 10 for details of the hawse pipe.

At the upper end of the hawse pipe is a chain stopper which holds the chain in position after it has been pretensioned. The chain stopper consists of two bars which pivot in the vertical direction. As chain is pulled up through the hawse, links which are 90 degrees out of phase with the opening between the bars force the bars upward. When the link has passed by the bars, the bars drop down and lock the chain in place (See Figure 10).

Above the chain stopper is a chain locker. After the system is pretensioned, there will be extra links of chain above the chain stopper which may be stored in the chain locker. The chain locker is welded on the hawse pipe below the chain stopper and it also welded onto the core of the power plant.

MAL Design Analysis

The computer analysis used in the design of the MAL concept is the same analysis procedure that IMODCO has developed in the design of over 70 catenary anchor leg moored buoys in the past 20 years. The description of this program is provided in Section VI. (Computer Program 'CEDP')

Analysis Procedure

The analysis procedure involves a parametric study of several anchor leg configurations. Each of the anchor legs is subjected to the environmental loads (on the spar and cold water pipe) provided to IMODCO by LMSC.

After the computer analysis for each anchor leg configuration is completed, the following design criteria are checked.

- The first criteria checked is the tension in the mooring leg. During the 3-year storm case a minimum safety factor of 3 must be met. In the 100-year storm, a safety factor of 2 is allowable.

- The excursions the spar experiences is checked second. The watch circle criteria states that during the 3-year storm case, the radius of the watch circle is no greater than 400 feet. During the 100-year storm, the only restriction is that the cold water pipe must not be grounded.

- The third criteria consideration checked is the anchor pullout. The minimum safety factor during the 3-year storm is 2, while anchor slip is allowed during the 100-year storm.

FIGURE 10

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On the basis of these criteria, the best anchor leg configuration is chosen. A major consideration in the analysis of choosing the anchor leg length was the slope of the seabed. The slope greatly increases the length necessary because the depth to the touchdown point increases to almost 5000 feet.

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Summary of Analysis

The summary of the analysis of the MAL-SPAR mooring system is shown in Table 3-1.

The MAL satisfactorily meets the requirements set forth in the SKSS Design Requirements. During the 3-year storm, the anchor legs maintain a high safety factor and the radius of the watch circle is less than 1/10 the water depth.

There are two problems though, that will need to be investigated in depth in order to assure a reasonable level of confidence.

- 1) Prevention of kinking the wire rope must be studied more closely. A kink in wire rope will greatly reduce its strength. If sufficient proof that a synthetic anchor leg can perform for 10 or more years is presented, the synthetic line can substitute for wire rope without greatly changing the design.
- 2) The setting of the anchors in this water depth may present a problem. Anchor manufacturers will be questioned as to the capabilities of setting anchors in over 5000 feet of water.

This concept is feasible for the OTEC/SKSS. There are no problems involved with it that can not be solved within the state-of-the-art knowledge.

MAL - MULTI POINT MOOR
PERFORMANCE CHARACTERISTICS

	3-YEAR RETURN	100-YEAR RETURN
HORIZONTAL FORCE	107 KIPS	410 KIPS
ANCHOR LEG TENSION	385 KIPS	700 KIPS
CHAIN SAFETY FACTOR	4.24	2.33
WIRE ROPE SAFETY FACTOR	4.81	2.64
WATCH CIRCLE RADIUS	298 FEET	887 FEET

TABLE 3-1

3.2.2 THE TENSION ANCHOR LEG SYSTEMS

System Descriptions

Two tension anchor leg (TAL) systems have been designed in the OTEC conceptual design phase. Both tension anchor leg systems, the TAL and the TAL-MONOPOD, are very similar in configuration. The main difference is that the TAL-MONOPOD uses the cold water pipe as a riser directly to the base universal joint while the TAL incorporates a separate riser for the bottom 1000 feet of the system, adding an extra articulation between the cold water pipe and the base. See Figures 11 and 12 for the general arrangements of these systems.

TAL Components

In the TAL concept, four items are added to the spar and cold water pipe to make the mooring system. They are the mooring base, riser shaft, and two universal joints. The universal joints are similar to those used in the SAL concept, and the description in II.1.4 holds for this concept.

Riser Shaft

The riser shaft performs the duty of transmitting all loads from the cold water pipe to the mooring base. The riser is a cylindrical shaft, made of steel, and is 5 feet in diameter with a length of 966 feet. Tension loading is the primary loading on the member, with virtually no bending loads.

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IMODCO			
INTEGRATED MARINE OPERATIONS DEVELOPMENT COMPANY			
DESIGN, CONSTRUCTION, OPERATION, MAINTENANCE, REPAIR, DEMOLITION			
TITLE			
TENSION ANCHOR LEG-MONOPOD			
GENERAL ARRANGEMENT			
FIG. NO.	DATE	DESIGNED BY	CHECKED BY

FIGURE 12

Mooring Base

The mooring base used for the TAL concept is the same as that described in Section II.1.6, the difference being the size and weight. For this concept the base weighs 5867 kips in air and is 70 feet square and 10 feet deep.

TAL-MONOPOD Components

Only two components are added to cold water pipe and spar to make up this total system, which are a universal joint and a mooring base. The universal joint is similar to that described in Section II.1.4 and the mooring base is the same as in Section IV.1.2.2. If the strength of the cold water pipe were sufficient, the base universal joint could be eliminated, thus simplifying the bottom connection, and the electrical cable transition at the bottom.

Modifications to Cold Water Pipe

The cold water pipe will need a design modification to accommodate the TAL and TAL-MONOPOD. This modification need will be a series of openings or ducts near the bottom of the pipe to allow water to flow into the pipe. This modification is necessary because of the mounting of the universal joint attachment structure to the bottom of the pipe.

Note: The cold water pipe would have to have sufficient strength to withstand the mooring loads (for the TAL and TAL-MONOPOD designs). The structural design, strength, and cost of the cold water pipe are beyond the scope of this study.

Tension Anchor Leg Design Analysis

Both a static and dynamic load analysis were performed in the design of the two tension anchor concepts. These analyses were used to derive loads transmitted to the mooring base from the spar and cold water pipe and also to find the maximum excursion of the system. The IMODCO computer programs used, which will be described in a later section, are 'TLM' and 'TOWER'. The results derived from the programs are in Table 4-1.

Also computed in the analysis of the tension anchor legs were the bending moments the cold water pipe would be subjected to. The computation, done by the IMODCO program 'WAVEM', assumes that the cold water pipe is a one piece structure, 30 feet in diameter. The results from this analysis are shown in Table 4-1.

Summary of Analysis

The feasibility of the two tension anchor leg systems is highly dependent on the load handling capability of the cold water pipe. The pipe must be able to withstand the tension and bending loads shown in Table 4-1 for a period of thirty years. Excellence in the engineering and fabrication of the cold water pipe will determine the success of these tension leg moorings.

The performance of the universal joints, mooring base, and riser shaft will also determine the success of the total system. The question associated with these components is whether the installation will be feasible. It will be difficult and expensive to install a base that weighs 5867 kips and is 70 feet square.

During the analysis, a net buoyancy of 900 kips for the spar TAL was assumed. Any increase in this buoyancy greatly increases the size of the base without providing a significant improvement in the spar's response. For example, if the net buoyancy is increased 500 kips, the spar inclines 1.5° less while the base weight increases 56%.

Based on Table 4-1, the TAL-MONOPOD appears to be a feasible concept for the OTEC/SKSS if the cold water pipe can handle the loads. However, the TAL system is not feasible because the entire superstructure submerges during the 100 year storm. This is due to the large inclination of the tension leg at the lower end of the system.

TAL
PERFORMANCE CHARACTERISTICS

	3-YEAR RETURN	100-YEAR RETURN
HORIZONTAL FORCE	120 KIPS	415 KIPS
RISER INCLINATION	7.91°	21°
CWP & SPAR INCLINATION	3.24°	9.35°
RISER TENSION	1045 KIPS	1180 KIPS
CWP TENSION	1010 KIPS	1120 KIPS
CWP BENDING MOMENT (MAX)	283,900 FT-KIPS	893,622 FT-KIPS

TAL-MONOPOD
PERFORMANCE CHARACTERISTICS

	3-YEAR RETURN	100-YEAR RETURN
HORIZONTAL FORCE	130 KIPS	430 KIPS
CWP & SPAR INCLINATION	4.01°	10.9°
CWP TENSION	1045 KIPS	1152 KIPS
CWP BENDING MOMENT (MAX)	341,562 FT-KIPS	946,804 FT-KIPS

TABLE 4-1

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3.3 INSTALLATION OF MOORINGS

Acoustic Instrumentation

Acoustical transponders will be utilized in the positioning of the anchors and mooring base.

The transponders will be lowered overboard in the vicinity of the base and anchor installations. When they are placed on the seabed, an acoustic signal will be sent and the line will be released. During installation of the transponders, drift due to current drag will be taken into consideration.

Base Installation

The mooring base will be transported on a barge to the installation site. The cable to assist in the mounting of the stab-in universal joint and the sheaves it will pass through will be integrated with the base at this time.

At the installation site, the base will be lowered into the water and to the seabed by crane barges. The base will be assisted into the proper location by signals from the transponders and feedback from the on board computer. Barges with sufficient capacity are in existence today.

SAL Installation

There are four main steps in the installation of the SAL. The following sections describe the conceptual procedure. Refer to Section V.2 for the first step, installation of the mooring base (See Figures 13 & 14).

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Riser Cable

The installation cable end passing through the base universal joint socket is fastened to the riser cable, and its other end is connected to a tensioning winch. As the installation cable is reeled onto the winch drum, the riser cable is played out until its upper end is reached.

Mooring Buoy

The mooring buoy may be towed to site. At the installation location, the upper end of the riser cable is attached to the buoy universal with a joining shackle. During this procedure, the installation and riser cables are kept under constant tension to prevent kinking. After the connection is made, ballast chambers in the buoy are flooded and the base universal joint is pulled into position and stabbed in. With the base universal joint in place, the ballast chambers are pumped out until the desired net buoyancy is obtained.

Yoke Installation

The yoke will be mounted on the OTEC vessel at the shipyard. The buoy end of the yoke will be supported by a small floodable barge. A small pedestal built on the center of this barge will allow the barge to pitch and roll independent of the yoke. A mounting point will be built into the yoke for this attachment.

Connected to the buoy end of the yoke will be two winching cables to assist in joining the yoke and tri-axial swivel. The upper half of the tri-axial swivel will be winched over to the front of the yoke, pulling the buoy 1 or 2 degrees

1

ACOUSTIC INSTRUMENTATION IS PLACED FOR
ACCURATE BASE LOCATION.

2

BASE IS TOWED TO SITE ON BARGE
AND LIFTED OFF USING CRANE VESSEL.

3

BASE IS LOWERED USING CRANE VESSEL. AS THE
BASE IS LOWERED THE INSTALLATION CABLE
IS PLAYED OUT.

4

FINAL POSITIONING OF BASE IS ACCOMPLISHED WITH
THE AID OF ACOUSTIC INSTRUMENTATION.

5

BUOY IS TOWED TO SITE AND INSTALLATION CABLE FROM BARGE,
THROUGH BASE, IS ATTACHED TO END OF RISER CABLE.

6

RISER CABLE IS PULLED DOWN TOWARD BASE AND UPPER
END IS FASTENED TO BUOY.

FIGURE 13

7

THE BUOY IS LOWERED INTO THE WATER UTILIZING A BARGE CRANE AND BALLASTED ENABLING THE U JOINT STAB-IN SECTION TO BE GUIDED INTO THE BASE AND LOCKED.

8

THE INSTALLATION CABLE IS REMOVED AND THE BUOY IS NOW INSTALLED.

9

THE OTEC BARGE AND YOKE ARE BROUGHT TO SITE. THE YOKE IS SUPPORTED USING A FLOODABLE BARGE.

10

WINCH CABLES ARE ATTACHED FROM THE BARGE, THROUGH THE BUOY TRIAXIAL SWIVEL TO THE YOKE. THE YOKE IS DRAWN INTO BUOY SWIVEL.

11

YOKE IS LOCKED IN PLACE AND INSTALLATION IS COMPLETE.

FIGURE 14

over with it. After contact is made between the yoke and the front of the tri-axial swivel, a second winch cable will be loosened, allowing a tongue on the tri-axial swivel to slide into a groove on the front of the yoke. After this contact is made, the weight of the tri-axial swivel will be supported by the yoke. The barge supporting the yoke will flood until the weight of the yoke is supported by the yoke/tri-axial swivel connection. At this point, a hydraulic safety latch will be applied temporarily securing the connection between the yoke and tri-axial swivel. Bolts will then be installed and tightened between the yoke and the tri-axial swivel, making fast the connection.

MAL Installation

The OTEC spar and cold water pipe will be on site when the mooring legs are to be installed. The following is the procedure for placement of the anchor leg (See Figures 15 & 16).

Anchor Leg Installation

The deployment barge will be assisted into position using the deployed acoustical transponders. The anchors and chain are lowered slowly into the water using an anchor windlass. When the end of the chain is reached, the wire rope is connected and the lowering continues. After the entire anchor leg is played out, a short length of chain, used for pretensioning is attached to the wire and is lowered into the water. At the other end of the chain segment is a marker buoy. This procedure is followed for all four anchor legs.

Chain Pretensioning

After the spar is positioned between the marker buoys, the

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chains will be tensioned one at a time through the hawse pipes. The tensioning will be done by either a winch in the superstructure of the OTEC spar or by a crane barge positioned over the hawse pipe, pulling on a cable.

TAL and TAL-MONOPOD Installation

The installation scenario of both tension anchor legs systems are the same. For the base deployment, refer to Section V.2.

Riser and OTEC Spar

In this explanation, the riser refers to either the cold water pipe (TAL-MONOPOD) or the combination cold water pipe and riser shaft (TAL) (See Figures 17 & 18).

The riser and OTEC spar will be towed to the installation site in the vertical position. The upending will take place in sufficient water depth to prevent grounding.

The installation cable passing through the base is attached to a cable which is connected to the base universal joint. A barge then winches the cable system, positioning the base universal joint over the base socket. When alignment is correct, the spar is ballasted down so that the universal joint may stab into the base. After the connection is made, the spar ballast tanks are pumped out until proper pretension is obtained.

1

PLACEMENT OF ACOUSTIC INSTRUMENTATION FOR ANCHOR POSITION.

2

POSITIONING OF BARGE FOR ANCHOR PLACEMENT USING ACOUSTIC INSTRUMENTATION.

3

ANCHOR AND CHAIN LOWERED INTO WATER. END OF CHAIN IS SHACKLED TO WIRE ROPE.

4

WIRE ROPE PLAYED OUT OFF OF SPOOL. AFTER ANCHOR HITS BOTTOM BARGE MOVES TOWARDS CENTER OF MOORING ARRAY.

5

UPPER CHAIN SEGMENT SHACKLED TO WIRE ROPE AND LOWERED INTO THE WATER.

6

BARGE PRETENSIONS CHAIN LEG TO SET ANCHORS.

FIGURE 15

7

8

9

10

11

12

1

ACOUSTIC INSTRUMENTATION IS PLACED FOR ACCURATE BASE LOCATION.

2

BASE IS TOWED TO SITE ON BARGE AND LIFTED OFF USING CRANE VESSEL.

3

BASE IS LOWERED USING CRANE VESSEL. AS THE BASE IS LOWERED THE INSTALLATION CABLE IS PLAYED OUT.

4

FINAL POSITIONING OF BASE IS ACCOMPLISHED WITH THE AID OF ACOUSTIC INSTRUMENTATION.

5

THE OTEC STRUCTURE WITH INSTALLATION CABLE ATTACHED TO THE U-JOINT ATTACHMENT IS MADE PRIOR TO THE UPRIGHTING OF THE OTEC STRUCTURE.

6

THE OTEC STRUCTURE IS TOWED TO THE INSTALLATION SITE.

FIGURE 17

7

THE OTEC STRUCTURE INSTALLATION CABLE IS SPLICED TO THE BASE CABLE.

8

THE SPLICED CABLE IS LOWERED & PULLED THROUGH THE BASE UNDER TENSION TO AVOID KINKING.

9

THE OTEC STRUCTURE IS POSITIONED OVER BASE. THE INSTALLATION CABLE IS REELED IN AT THE BARGE.

10

THE STRUCTURE IS SLOWLY FLOODED AND THE U-JOINT STAB-IN GUIDED INTO THE BASE AND LOCKED.

11

THE STRUCTURE IS DEBALLASTED UNTIL PROPER BUOYANCY IS REACHED.

12

INSTALLED STRUCTURE

IMODCO	
DATE	BY
TENSION ANCHOR LEG	
INSTALLATION PROCEDURE	
FILE	DATE

FIGURE 18

Section 4

TRADE STUDIES

4.1 ANCHOR LEG

The effect of wire-rope-to-chain length ratio versus excursion, restoring force, and pretensioning is examined for a radial, catenary pattern of 10 mooring lines. Chain total length is held constant at 4 500 ft while the wire rope length is varied. This length of chain facilitates wire rope change-out over the power plant life cycle by permitting lift of the wire-chain connection to the surface. The results of a static configuration analysis are shown in Appendix E. Effective wire rope length for 4,000-nominal-ft depth is indicated at 3 600 ft. A length ratio below 0.8 would result in a greater length of chain lifted off the seafloor and greater excursion. Further studies will include variation of water depth and a sloping sea floor.

Reference 4-1 examines performance characteristics for all wire rope, all chain, and wire rope and chain combination lines for deep water application. As water depth increases, the all wire rope system becomes a viable candidate because the all chain mooring line becomes less effective at greater water depths. Most of the chain strength is required just to support its own bulk weight. Further, the single wire rope line exhibits lower total weight, a smaller angle below the horizontal at the ocean surface (indicating a larger restoring force), and reduced pre-tension requirement. However, wire rope lengths and weights are at the limit or exceed manufacturer's capability. Other considerations regarding wire rope lines are the proximity of the barge to the anchor, chafing on the seafloor, and frequent changeouts. Results of the evaluation indicate a wire rope/chain combination mooring line would be an improvement over the single component mooring line. Desirable characteristics of the combination include closer proximity of the barge to the anchor, relatively small amount of chain motion on the ocean floor during an

excursion, and wire rope within manufacturable limits. In addition, the combination system requires less restoring force; higher total suspended mooring line weight, and higher pretension.

Anchor leg evaluation includes synthetic rope-chain combination, all-wire rope system, all-chain and combination chain-wire rope system. Table 4-1 shows the results of the rating. The evaluation and ranking are based on present day state of the art and practice, engineering judgment, and information gleaned from references 4-1 through 4-10. The primary factors which preclude synthetic lines are weight in-effectiveness and high change-out frequency.

Frequent visual inspections and change-outs are standard preventive maintenance procedures on SPMs utilizing large mooring hawsers. An all-wire rope system leads to seafloor abrasion and frequent change-out of the entire leg. The all-chain anchor leg has high pretension, poor excursion characteristics, and excessive weight at depth of 4 000 ft even though it is lighter and effective at shallower depths. The combination chain and wire rope ranks first for deep water mooring.

Table 4-1 ANCHOR LEG EVALUATION

Condition	Synthetic Rope-Chain(1)	All Wire Rope	All Chain	Combination Chain-Wire
1 Weight Effectiveness	10	5	8	1
2 Available Restoring Force	3	3	1	3
3 Pretension Value Range	10	3	7	3
4 Abrasive Resistance	1	8	1	1
5 Fabrication to State of Art	5	5	1	1
6 Excursion Range	10	3	10	3
7 Amenable to Commercial Plant Size	8	5	10	3
8 Changeout Frequency	10	7	1	3
Ranking	4	2	3	1

Relative Rating 1-Favorable, 10-Unfavorable

NOTE (1) With maximum length of rope without touching seafloor

A comparison of single anchor leg versus multiple anchor leg moors indicates superiority of the multiple anchor leg. Major disadvantages of the single leg moor are high vertical loading requiring a large deadweight anchor, high installation costs, poor redundancy, and frequent changeout. (See Table 4-2). Performance characteristics of a single point moor and a multiple point moor are presented in Appendix E.

4.2 ANCHORS

Three basic anchor types are examined for SKSS concept design. The results of the review are shown in Table 4-3. Selection of an anchor is primarily dependent on the force components imposed at the anchor and on sea floor conditions. Plate anchors are eliminated primarily because they are not capable of developing the mooring line capacities required for OTEC in deep water. The drag embedment anchor is eliminated from consideration with respect to the SAL-SPM because of the excessive vertical force component. Deadweight, poured concrete and pile anchors are viable candidates for the SAL-SPM and MAL-SPM. However, developmental efforts are required to extend the state of the art in deployment; one approach to deployment of the deadweight anchor is implantation by free-fall. Reference 4-5 presents a plan for development and demonstration test of free-fall emplaced deadweight anchors for OTEC power plants.

A relative cost comparison of three anchor types considers engineering, fabrication, transportation to site, lowering, embedment and testing. The bar graph of the comparative study is shown in Fig. 4-1. Costs for the drag embedment anchor are assessed to be the lowest of the three candidates. The engineering, fabrication, and lowering or embedment costs are dependent upon the state of the art and practice associated with each type. For example, the commercially available drag embedment anchors require nominal consideration from the standpoint of the engineering phase through embedment. On the other hand, coring pile anchors or pouring fresh concrete in 4 000 ft of

LOCKHEED OCEAN SYSTEMS
4-4
RELATIVE
COST

COST ITEMS

- 1 ENGINEERING
- 2 FABRICATION
- 3 TRANSPORTATION TO SITE
- 4 LOWERING/IMPLANTATION
- 5 TESTING

FIGURE 4-1
RELATIVE COST COMPARISON OF
THREE ANCHOR TYPES

Table 4-2 SINGLE ANCHOR LEG VERSUS MULTIPLE ANCHOR LEG MOORING

Single Anchor Leg		Multiple Anchor Leg	
Advantages	Disadvantages	Advantages	Disadvantages
1. Minimal Scope low anchor leg weight/cost 2. Minimal Winch and tensioners 3. Minimal seafloor motion and no abrasion 4. Amenable to platform disconnect 5. Lowest inter- ference with electrical trans- mission cable	1. High vertical loading, large dead weight/pile 2. Poor redundancy 3. Not amenable to commercial plant size 4. Depth error sensitive 5. Requires develop- ment 6. High installation cost 7. Very stiff due to high pretensioning 8. Complex buoy/ hawser arrangement 9. Complex test conduct	1. No Extension to state of art 2. High redundancy 3. Amenable to system changeout 4. Adaptable to commercial plant size 5. Nominal pre- tensioning <u>OTHER</u> Weight effective Nominal installation weather window	1. Large number of legs requires long deployment and inspection time 2. Clearance with cold water pipe and elec- trical transmission cable 3. Maximum scope tensioning 4. Seafloor slope sensitive 5. Chain abrasion

Table 4-3 ANCHOR SELECTION

Condition	Anchor Types			
	Drag Embedment	Dead- Weight		Pile
		Lowered	Poured in Place	
1. Compliant to sand, mud, clay	3	3	3	7
2. Ship and equipment support	1	4	9	10
3. Ease of transport to site	1	4	7	7
4. Fabrication to state of the art	1	6	8	8
5. Compliant to sea floor variation	3	3	3	7
6. Relative cost	3	7	10	10
7. Developmental complexity	1	5	8	9
8. Implant sensitivity to depth	1	4	8	9
9. Vertical load capacity	10	3	3	3
10. Horizontal load capacity	3	3	3	3
11. Omnidirectional stability	7	4	4	3
Ranking for MAL	1	2	3	3
Ranking for TAL/SAL	4	1	2	3

Relative rating 1-Favorable, 10-Unfavorable

water requires at least four to six times the effort required to engineer, fabricate, and implant drag embedment anchors. Extensions to the state of the art requires the integration of technologies from concrete, oil, and ocean industries as discussed in Ref.4-10. Free-fall emplacement technique for deadweight anchors requires extensive technological development.

An evaluation of the holding power factors versus anchor type, shown in Table 4-4, indicates that the drag embedment anchor is ranked first for the MAL.

4.3 WEATHER WINDOWS

The review of this trade study is shown in Fig. 4-2. Weather window requirement for mooring deployment is governed by the support equipment and operation complexity. Differences between drag embedment and either poured concrete or pile systems begin with the preparation for implantation. Two crane barges are required for lowering of drag embedment anchors as compared to establishing and maintaining dynamic positioning, pipe riser handling operations, and batching and mixing of cement. Deployment complexity of the free-fall deadweight anchor is between the concrete placement anchor and seafloor coring. Weather window requirements for lowering and implantation for the drag-embedment and the deadweight systems are about the same, with the primary effort in tensioning the ten legs after the anchors are implanted. The weather window requirement for lowering and implantation of freshly poured concrete or pile, over two-and-a-half times that for embedment anchors, includes coring, conveying of concrete, curing, and mooring line adjustments.

Table 4-5 presents an evaluation summary of SKSS candidate concepts. Three of these — MAL, MAL-Turret, and MAL-Rotary — have multiple, catenary anchor legs with drag-embedment anchors. The remaining four concepts are tensioned anchor legs with deadweight, pile or freshly poured concrete anchors. An assigned rating of 9 or 10 negates the mooring concept for the evaluation factor under consideration.

FIGURE 4-2
ANCHOR WEATHER WINDOW REQUIREMENTS

4.4 ALTERNATE SITE

An alternate site within the Virgin Islands Basin was considered in the event that the sloped seafloor off Punta Tuna was too steep for mooring. This extremely flat basin, nearly devoid of local relief, is located 10 miles southeast of Punta Tuna in 6 000 ft of water. The flat seafloor is a desirable feature for mooring systems, but is not a necessary condition for satisfactory stationkeeping of the OTEC plant. Anchor leg tension can be maintained tangent to the seafloor by adjusting anchor location and leg length in a MAL. The relatively large weight requirement of the deadweight anchors resulting from a large vertical force component on the anchor, will accommodate the 18 deg seafloor slope. Increase of water depth from an average of 4 000 to 6 000 ft constitutes a moderate extension to the state of the art in practically all areas of SKSS. The cost of the mooring will ultimately be appreciably higher. The Virgin Island Basin is therefore not considered a necessary or favorable tradeoff with the Punta Tuna site.

The TAL and TAL-Monopod essentially fix the CWP inlet, thereby preventing CWP grounding. A shallower mooring site closer to shore is appropriate for these SKSS concepts; the resultant reduction in costs without loss in performance would be significant, particularly in the area of operational costs.

Table 4-4 HOLDING POWER VERSUS ANCHOR TYPE

Holding Power Factors	Dead- Weight	Pile	Drag(1) Embedment
Installation Test	5	9	3
Depth factor	+	—	+
Reliability	+	-	+
State of the art	+	—	+
Weather window	+	—	+
Cost	+	—	++
Support services	+	—	+
Implantation	4	8	3
Penetration	+	+	+
Equipment support	+	—	+
Landing/implant considerations	+	-	+
Structural integrity	+	-	+
Compatibility to clay, sand, mud	3	7	3
Compatibility to hard seafloor	5	3	7
Compatibility to slope variation	7	3	5
Vertical load capacity	3	3	7
Horizontal load capacity	3	3	3
Weight effectiveness	7	5	3
Omnidirectional qualities	4	3	7
Ductility	3	7	3
	First With TAL & SAL	Second With TAL & SAL	First With MAL

Relative Rating 1-Favorable, 10-Unfavorable

Note: (1) MAL Concept Only

Table 4-5 MOORING CONCEPT EVALUATION

Evaluation Factor	SAL(1) SPM	(1) MAL	MAL(1) Turret	MAL(1) Rotary	MAL(1) SPM	(2) MAL	TAL(2)	TAL(2) Monopod
1. CWP and Platform Interface	2	3	5	5	2	3	6	6
2. Excursion Control	10	1	1	1	1	1	3	1
3. Engineering Design Effort	3	3	7	8	5	3	5	6
4. Anchor Technology Development	6	3	3	3	6	3	5	6
5. Electrical Trans-Transmission Cable Interface	10	3	6	10	3	3	3	3
6. Rotational Restraint	10	3	1	1	2	2	2	2
7. Winch and Tensioner Design	2	4	5	6	3	4	2	2
8. Implant Support Services	2	3	4	4	4	3	5	6
9. Amenable to System Changeout	7	2	2	2	6	2	7	8
Total	52	25	34	40	32	24	38	40
Ranking	5	1	3	4	2	1	2	3

Relative Rating 1-Favorable, 10-Unfavorable

Notes: (1) For ship
(2) For spar

4.5 REFERENCES

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Section 5

COST ANALYSIS

The main body of this chapter discusses the approach followed and the results obtained in estimating the capital, operating, and overall life cycle cost (LCC) of the various SKSS configurations presented earlier in this report. The first section of the chapter provides a summary of SKSS capital costs as estimated by IMODCO for the baseline configurations, and the second discusses three alternative cost scenarios and the resulting capital cost estimate for the various SKSS concepts. The third section then discusses the calculation of LCC's and presents low, medium, high and expected value LCC's for each configuration. Finally, the last section in the chapter discusses the likely range of costs resulting from possible SKSS operational failures.

5.1 COST ESTIMATES

The capital cost of the baseline designs for all SKSS concepts considered and estimated by IMODCO are summarized in Table 5-1. All estimates are in mid-1979 dollars, and include contingency, freight, storage, insurance, handling costs, and fee. As can be seen, the total capital costs of all but the TAL systems are quite similar ranging from just over 22 to slightly over \$28 million; the costs of the simpler TAL concepts are significantly lower. The TAL monopod concept, eliminating the requirement for a tension leg member, offers the lowest cost of all, but it may impose additional requirements on the cold water pipe (CWP) which cannot be taken into account explicitly in this study.

In all cases, deployment and installation costs account for approximately half of total costs. While this is not unusual in offshore activities, it is somewhat unfortunate as this is probably the least accurate component of the overall estimate; indeed, at this stage of concept definition it is not

Table 5-1 BASELINE DESIGN COST ESTIMATES, \$K.

Component & Life	SAL SPM Ship	MAL Spread Spar	MAL Spread Ship	MAL Active Tension- ing Ship	MAL Turret Ship	MAL SPM Ship	TAL Spar	TAL Monopod Ship
Chain	230	2 101	4 682	4 682	2 160			
Wire Rope and Connectors	237	2 061	4 510	4 950	2 705	5 695		
Mooring Base/ Anchors	3 350	435	547	547	328	891	4 237	4 237
Mooring Buoy	6 185					2 380		
U-Joints	825						700	350
Yoke	1 525							
Tri-Axial Swivels	980							
Shackles and Stoppers		62						
Hawse Assembly		5 211						
Auxiliary Machinery			3 210	4 167	3 210	3 370		
Turret Assembly					6 575			
Hawsers						76		
Vetco Connectors							138	140
Tension Leg							2 478	
Engineering Labor	932	655	800	971	1 228	1 006	460	365
Deployment	11 000	11 500	11 500	11 500	11 500	11 500	10 250	8 000
TOTAL	25 264	22 025	25 249	26 817	27 706	24 918	18 263	13 092

feasible to discriminate sufficiently among MAL-type concepts as regards deployment costs. Chain and wire rope are significant cost contributors in all the MAL-type concepts, and account for between 10 and 40 percent of overall costs. Other major cost items within this family are auxiliary machinery, such as winches and sheaves, the hawser assembly in the spar spread moor, and the turret assembly for the ship platform; as expected, the auxiliary machinery required for the active tensioning MAL is somewhat costlier than that used in other concepts.

It is interesting to compare the cost structure of the SPM system with that of the somewhat similar SAL SPM. The mooring buoy, swivel, U-joint and yoke required by the latter account for nearly 40 percent of its cost; the equipment performing the equivalent function in the MAL SPM is significantly less expensive. The reverse is true for the anchor leg component, with the SAL SPM having the advantage in this area. However, the difference in mooring base costs is perhaps the most striking of those among the cost components shown for both systems since one would expect the larger MAL base to be the costlier of the two. The reason for the comparatively low cost of this mooring base lies in the extremely low-cost anchor design and construction approach assumed for the MAL system (see Section 3.1.2). While the resulting costs are indeed strikingly lower than those of the much smaller (but conventional) SAL SPM design, realization of the MAL SPM mooring base concept requires a significant advance on the current state of practice.

The primary objective of the cost estimates shown in Table 5-1 is to provide a design concept selection parameter. Consequently, in preparing these estimates, particular attention was paid to ensuring comparability among the various designs, rather than great accuracy in any particular estimate. Because the design is still conceptual, caution must be exercised in using these data as point design cost estimates.

5.2 COST SCENARIOS

Again, because the design is conceptual, possible variations in the actual cost of the various SKSS concepts around their estimated cost must be taken

into account. (See Table 5-1.) To this end, three alternative cost scenarios were formulated by increasing or decreasing the estimates of major component cost items to yield respectively low, medium, and high cost cases for each SKSS design. These cost scenarios were then used in the life cycle cost (LCC) calculation procedure described in Section 5.3 below, with respective (assumed) probabilities of occurrence of 0.25, 0.50 and 0.25. The relatively small variation allowed in each component's estimated cost is due to the objective of arriving at reasonable high and low total cost cases with probabilities of occurrence of 0.25 each. Allowing wider variations in each individual estimate would have resulted in extreme overall high and low cost cases with very low combined probabilities of occurrence.

Table 5-2 summarizes the variations around the baseline estimate allowed for each cost component in the three cost scenarios. Since the 30-year life required of the SKSS designs exceeds that normally expected of chain, it was assumed that the baseline estimate represented a rather optimistic design and it was allocated to the low cost case. To allow for the greater chain thickness that may be required in practice, the baseline estimate was increased by 15 and 30 percent, respectively for the medium and high cost cases. Six main types of SKSS components, grouped together in the second entry of the table, are considered to require no significant deviation from current practice and, consequently, are considered low cost risk items; their cost is allowed to vary between 90 and 120 percent of the baseline estimates. Large turrets and tension legs are considered to represent inherently higher cost risks; as a result, the estimates for these items are allowed to range from 80 to 140 percent of the baseline. A similar range is assumed for deployment costs since, as mentioned above, their estimates are likely to prove least accurate of all. In addition, Table 5-2 reflects an assumed asymmetry in cost probability distributions, which are assumed to be skewed towards higher values. This is in agreement with recent offshore experience in the North Sea (1).

Table 5-2 PERCENTAGE VARIATION FROM BASELINE COMPONENT COST ESTIMATES IN EACH COST SCENARIO

Cost Component	Cost Scenario		
	Low	Medium	High
Chain	0	+15%	+30%
Mooring Base/Anchors			
Mooring Buoy			
Auxiliary Machinery	-10%	0	+20%
Yoke			
Swivel			
Hawse Assembly			
Turret			
Tension Leg	-20%	0	40%
Deployment			

Two further modifications were made to the baseline cost data in developing three cost scenarios. The baseline estimates do not include allowances for weather downtime within the estimated deployment costs. Consequently, an additional cost entry was generated for weather downtime, amounting to 0, 20, and 40 percent of deployment cost for the low, medium and high cost scenarios, respectively. In addition, as there is considerable uncertainty concerning the actual life of wire rope, this was allowed to be a variable in the LCC calculation taking values of 10, 7.5 and 5 years, respectively, for the low, medium and high cost cases. All other SKSS components are assumed to possess 30-year lives with the sole exception of MAL SPM hawsers, which are assumed to require yearly replacement. The capital cost of hardware is considered, while cost of the changeout operation itself is neglected, although this latter cost may be considerable.

Table 5-3, 5-4, and 5-5 summarize the three resulting cost scenarios. These tables are similar in structure to Table 5-1 except for the addition of a weather downtime cost component, and thus require little comment. However, the combined effects of assumed weather downtime and increased deployment costs result in the overall installation cost in the high cost scenario being

Table 5-3 LOW COST SCENARIO ESTIMATES, \$K

Component	SAL SPM	MAL Spread Spar	MAL Spread Ship	MAL Active Tension- ing	MAL Turret	MAL SPM	TAL	TAL Monopod
Chain	230	2 101	4 082	4 682	2 160			
Wire Rope and Connectors*	237	2 061	4 510	4 950	2 705	5 695		
Mooring Base/ Anchors	3 015	392	492	492	235	802	3 813	3 813
Mooring Buoy	5 566					2 142		
U-Joints	825						700	350
Yoke	1 372							
Tri-Axial Swivels	882							
Shackles & Stoppers		62						
Hawse Assembly		4 690						
Auxiliary Machinery			2 889	3 750	2 889	3 033		
Turret Assembly					5 260			
Hawsers						76		
Vetco Connectors							138	140
Tension Leg							1 982	
Engineering Laser	932	655	800	971	1 228	1 006	460	365
Deployment	8 800	9 200					18 200	6 400
Weather Downtime	0	0	0	0	0	0	0	0
TOTAL	21 859	19 161	22 573	24 045	23 737	21 954	15 293	11 068

*10-year life

Table 5-4 MEDIUM COST SCENARIO ESTIMATES, \$K

Component	SAL SPM	MAL Spread Spar	MAL Spread Ship	MAL Active Tension- ing	MAL Turret	MAL SPM	TAL	TAL Monopod
Chain	264	2 416	5 384	5 384	2 484			
Wire Rope and Connectors*	237	2 061	4 510	4 950	2 705	5 695		
Mooring Base/ Anchors	3 350	435	547	547	328	891	4 237	4 237
Mooring Buoy	6 185					2 380		
U-Joints	825						700	350
Yoke	1 525							
Tri-Axial Swivels	980							
Shackles & Stoppers		62						
Hawse Assembly		5 211						
Auxiliary Machinery			3 210	4 167	3 210	3 370		
Turret Assembly					6 575			
Hawsers						76		
Veteo Connectors							138	140
Tension Leg							2 478	
Engineering Laser	932	655	800	971	1 228	1 006	460	365
Deployment	11 000	11 500	11 500	11 500	11 500	11 500	10 250	8 000
Weather Downtime	2 200	2 300	2 300	2 300	2 300	2 300	2 050	1 600
TOTAL	27 498	24 640	28 251	29 819	30 330	27 218	20 313	14 692

*7.5-year life

Table 5-5 HIGH COST SCENARIO ESTIMATES, \$K

Component	SAL SPM	MAL Spread Spar	MAL Spread Ship	MAL Active Tension- ing	MAL Turret	MAL SPM	TAL	TAL Monopod
Chain	299	2 731	6 087	6 08	2 808			
Wire Rope and Connectors*	237	2 061	4 510	4 950	2 705	5 695		
Mooring Base/ Anchors	4 020	522	656	656	394	1 069	5 084	5 084
Mooring Buoy	7 422					2 856		
U-Joints	825						700	350
Yoke	1 830							
Tri-Axial Swivels	1 176							
Shackles & Stoppers		62						
Hawse Assembly		6 253						
Auxiliary Machinery			3 852	5 000	3 852	4 044		
Turret Assembly					9 205			
Hawsers						76		
Veteo Connectors							138	140
Tension Leg							3 469	
Engineering Laser	932	655	800	971	1 228	1 006	460	365
Deployment	15 400	16 100	16 100	16 100	16 100	16 100	14 350	11 200
Weather Downtime	9 240	9 660	9 660	9 660	9 660	9 660	8 610	9 408
TOTAL	41 381	38 044	41 665	43 424	45 952	40 506	32 811	26 547

*5-year life

three times that in the low cost case; such wide variations in installation cost are common in offshore operations.

5.3 LIFE CYCLE COST ANALYSIS

The capital cost schedules shown in Tables 5-3 through 5-5 are used to calculate the LCC of each SKSS for the three cost scenarios discussed in Section 5-2. This calculation was carried out by a computer program, a listing of which is included in Appendix C. This section first presents a brief summary of the operations performed by the program and then discusses the results of the analysis.

The first step in the calculation of LCCs is to generate a cash disbursement schedule spanning the entire life of the SKSS. As a result, the program operates on the capital cost data in Tables 5-3 through 5-5, according to the following rules:

- o The OTEC platform and SKSS are to start operation at the beginning of 1984 and have a 30-year operational life, thus ending operation at the end of 2013.
- o All capital cost expenditures take place the year preceding operational requirement of the capital item in question; thus, initial capital expenses are incurred in 1983.
- o Scrapping or disposal costs are assumed to be one half of deployment costs, and to occur in 2014, the year following the end of operations.
- o Yearly local tax and marine insurance charges are expected to be roughly 3.5 percent of initial capital cost.
- o The yearly cost of inspection and routine maintenance of the platform is estimated at approximately 1 percent of initial capital cost.
- o All costs escalate at a yearly rate of 7 percent except for tax and insurance charges which remain fixed as a proportion of original (accounting) cost.

Once the disbursement schedule has been generated, each year's cash flows are totaled and their present value in 1979 is then obtained following the

end-of-year financial analysis convention and a 10 percent discount rate; the result of this operation is the overall LCC of each system for a given cost scenario. The expected value LCC for each SKSS concept is then obtained as the sum of the LCCs for the three scenarios weighed by their probability of occurrence. Before discussing the results of applying this procedure to the cost data in Table 5-3 through 5-5, it may be well to note that the values given above for escalation and discount rates are those suggested for use in the recently completed Power System Development-II study.

Table 5-6 lists the LCCs calculated as outlined above for the eight SKSS concepts under consideration; computer printouts of the disbursement schedule and LCC for a typical SKSS configuration and cost scenario can be found in Appendix C. The expected value LCCs of the four MAL type SKSS for the ship platform are clustered quite closely together, and their costs can thus be regarded as being equivalent for all practical purposes. The SAL SPM offers substantially lower costs; however, as discussed in Section 3.1.5, this concept seems unlikely to meet major design requirements. The SKSS designs prepared for the spar platform offer somewhat lower LCCs, partly reflecting the lesser mooring system loads associated with this platform. The TAL concept appears to offer significant cost advantages over the MAL SPM spread moor amounting to nearly a third of the latter's cost. As noted before, the savings shown for the TAL monopod over the standard TAL concept do not take into account the greater cold water pipe (CWP) length required by this concept; of course, the resulting CWP cost penalty can be minimized by selecting a lesser operational depth. In summary, the two TAL systems appear to be subject to the greatest cost uncertainty among the concepts considered; their high cost case estimate being over double that given for the low cost scenario.

5.4 COST EQUIVALENCE OF OPERATIONAL FAILURES

The preceding sections have discussed the estimation of the predictable (and dominant) component of LCCs associated with the various SKSS design concepts.

In this section, we will consider a second type of SKSS-related costs which cannot be included directly in the LCC calculations discussed above; these are the costs incurred as a result of SKSS component failure in the course of OTEC operations. For purposes of this discussion, it is desirable to distinguish three main types of operational failure: (1) relatively small or mild failures requiring repair but not

Table 5-6 SKSS CONCEPT LCC's 1979 \$K

	Cost Scenario			Expected Value
	Low	Medium	High	
<u>Ship Platform</u>				
SAL SPM	33448	41984	62587	45000
MAL MPM	39764	50781	75382	54177
MAL Active Tensioning	45352	53881	79245	58090
MAL Turret	38268	49866	75464	53366
MAL SPM	39657	53234	77039	55791
<u>Spar Platform</u>				
MAL MPM	31140	40715	62508	43770
TAL	22723	30067	48158	32753
TAL Monopod	16530	21856	38880	24780

resulting in significant plant downtime, (2) serious failures requiring major repair operations and/or plant downtime, and (3) catastrophic failures, possibly leading to loss of the OTEC plant.

The first type of failures will not be discussed here in any detail since their cost impact is likely to prove negligible and is in any case partly accounted for within the inspection and maintenance cost component already included in the LCCs calculated above. The second and third types correspond in practice to the occurrence of events with major detrimental operational impacts, such as mooring leg breaks or anchor dragging. In the case of the MAL systems, such events would probably result in plant shutdowns until repair can be effected, but are unlikely in themselves to threaten the survival of the OTEC platform, given the redundancy inherent in such systems. This is not

the case for SAL or TAL SKSS designs, however. Major failure in the single anchor leg components of these systems would result in loss of stationkeeping capability, which may well result in loss of the entire OTEC plant, particularly as such failure is likely to occur in the course of storms. The remainder of this section will discuss the relationship between cost and both major remedial and catastrophic failure occurrences due to the stochastic nature of these occurrences, and to the wide range of physical events and conditions they encompass. The discussion is of necessity unrigorous and its objective is solely to provide a rough estimate of the cost impact of such failures.

A large component of the overall cost of failures resulting in significant plant downtime is the cost of foregone electricity sales. For a 40-MW(e) plant, operating at a capacity factor of 0.80 and selling electricity at a (levelized) price of 65 mils/kWh, this cost is approximately \$1.5 million/month. It is perhaps reasonable to assume that approximately one month is a reasonable lower bound for likely downtime resulting from a serious SKSS failure. Repair will require the use of specialized support craft which may not be immediately available and would in any case be more likely to be found in the Mexican Gulf area than in the neighborhood of Puerto Rico. Indeed a practical upper bound for such downtime may well be in excess of 6 months, since some of the support vessels that might be required for SKSS repair, such as deep-diving submersibles, may be quite rare and their use consequently difficult to obtain; for purposes of this discussion, 6 months will be assumed to be the highest likely downtime for SKSS repair.

These extremely rough downtime estimates suggest that the associated cost of foregone electricity sales is likely to lie somewhere between \$1 and \$9 million. The cost of the SKSS repair itself depends, of course, on the specific failure mode involved, and could easily be quite high, because it may involve retrieval of mooring legs and anchors for the ocean bottom, and/or major component replacement; the cost of required support craft is expected to account for the majority of these costs. As a rough estimate, overall repair costs can probably be expected to be in the neighborhood of half of original

deployment costs, or approximately \$4 to \$6 million for the SKSS concepts discussed here. Combining this estimate with that for foregone electricity sales yields an overall estimate of failure-related costs of between five and \$15 million. Thus, it may be permissible, for the sake of simplicity to associate a rough order of magnitude cost estimate of \$10 million (1979) with the occurrence of a "typical" SKSS failure requiring extended shutdown of the OTEC plant.

As mentioned before, the type of failure considered above, which for a MAL type system would lead to a plant shutdown until repairs were completed, for a SAL or TAL type SKSS could easily result in the loss of the OTEC plant. In this event, the costs incurred would be equal to the market value of the plant; this market value cannot be evaluated a priori but, in view of the assumed continuous inflation, it is likely to be of the same magnitude in nominal terms as the original capital cost of the plant. For a prototype 40-MW(e) plant, this cost is likely to be \$5000/kW(e), or approximately \$200 million (in 1979 currency). This huge potential loss can be prevented by a relatively moderate investment in emergency backup equipment. In the event of SKSS failure, it is estimated that the OTEC plant would require a propulsion system of approximately 10,000 hp to maintain station during a storm, or in a three knot current; the cost of a such system is estimated at roughly \$5 million.

In addition, it would be desirable to provide the platform with an auxiliary emergency moor, designed for use in conjunction with the propulsion system; the cost of this mooring system is likely to be approximately \$1 million. Consequently, an overall investment of roughly \$6 million dollars appears to be sufficient to prevent the possible loss of the platform through failure of a nonredundant SKSS. Adding this figure to the TAL LCC, shown in Table 5-6, would only reduce the TAL's apparent cost advantage over the MAL; the TAL SKSS remains some 10 percent less costly than the MAL concept. Full use of the propulsion system would result in a fuel consumption cost penalty of some

\$10,000/day, a comparatively small figure which is unlikely to have a material impact on the rough estimate of \$10 million for the cost of a "typical" serious SKSS failure.

Of course, the effect of failure on expected SKSS LCC's costs depends also on the probability and time of occurrence of such failures. While no statistically relevant body of data on mooring system failure has been found, informed opinion suggests that SKSS concepts meeting design requirements are likely to provide highly reliable, with (subjectively estimated) failure probabilities over their lifetime in the range of 0.1 to 0.2. Assuming that a failure were to occur, the probability distribution of its time of occurrence is likely to be skewed toward the later years of operation; consequently, for the purpose of this section, it is conservative to assume that such failure occur during the fifteenth year, the midpoint of the plant's operational life. Multiplying the estimated failure costs by a probability of occurrence of 0.15 and then discounting the expected costs back to 1979 yields an equivalent present cost of roughly \$1 million for the "typical" serious failure, and of \$20 million for the catastrophic failure. These figures can then be compared to the LCCs in Table 5-6 to assess the likely impact of failure costs on actual SKSS LCCs.

Somewhat surprisingly, the expected present value of the cost of a noncatastrophic failure, such as could be experienced by MAL concepts is not very large in comparison with most SKSS LCCs and average roughly 2 percent of these costs. This suggests that only major improvements in reliability are likely to justify the selection of higher-cost SKSS systems for use with OTEC platforms. However, the expected present value of catastrophic failure costs is much larger, amounting to roughly one half of overall SKSS LCCs. This simply shows that the possibility of such failure should be minimized, perhaps by the addition of emergency backup equipment as discussed above. In this context, it may be noted that the expected present cost of catastrophic failure is roughly three times higher than the investment required to significantly reduce its probability of occurrence, thus clearly justifying such investment.

REFERENCE

- 1 "North Sea Costs Evaluation Study," Energy Paper Number 7, Her Majesty's Stationery Office, London, 31 December 1975

Section 6

SKSS CONCEPT EVALUATION AND RANKING

In this section, the candidate SKSS concepts are evaluated in terms of performance, cost risk and required development. SKSS performance is assessed in relation to state of the art in deep water mooring technology. Those concepts found to be possible are so identified. Impact on other OTEC systems is assessed in an examination of interfaces. The relative risks of each concept are compared with life cycle cost and a ranking is established. A second ranking based on extent of technology development concludes this section.

6.1 PERFORMANCE ASSESSMENT

Each of the concepts is assessed in terms of satisfying design criteria and requirements. The SKSS concepts for the barge followed by those for the spar are treated separately to discriminate between these two different platforms.

6.1.1 BARGE

Single Anchor Leg-Single Point Moor. The primary flaw in this concept is the unavailability of a single-wire rope or synthetic line with proven capabilities to handle the anchor leg tension in the extreme sea state. Extensive development of such lines is required before this concept can be considered feasible. The alternative is to lower the line tension safety factor from 2 to 1, a high risk solution at best. Anchor deployment must also be developed. The IMODCO design has an excessive watch circle of 23 percent water depth, exceeding the requirement of 10 percent. The spar buoy submergence and yoke angle are excessive in the extreme sea state. This system is sensitive to errors in anchor depth. The relatively small excursion in the extreme sea state will prevent cold water pipe grounding, leading to

consideration of a reduction in mooring depth from 4000 to 3300 ft with associated cost reduction. Positive features of this system are barge weathervaning capability and possible system removal via the stab-in device at the base, for survey and replacement.

Multiple Anchor Leg. The concept satisfies all design criteria and requirements and is therefore considered feasible within present state of the art. The stand-off buoy riser cable is selected over the catenary direct descent Electrical Transmission System (ETS) concept for this system, allowing a watch circle of 18 percent water depth as opposed to the design requirement of 10 percent. Consideration must be given to the clearance requirement of ten anchor legs and four riser cables, and to the sensitivity of the concept to the large seafloor slope at the site.

Multiple Anchor Leg - Single Point Moor. This concept appears to satisfy the design requirements. However, development of the unconventional multiple, parallel line concept is required to demonstrate assumption of equal-load division among the lines. A swivel at the base is not acceptable due to the imposed requirement for a swivel in the ETS which is well beyond state of the art and not considered possible. Deployment of a large gravity anchor, although considered feasible, is not within the state-of-the-art and will therefore require a development program. A catenary, direct descent with surface swivel riser cable is used with this system commensurate with the ten percent-water-depth watch circle.

Multiple Anchor Leg - Turret. This system satisfies the design criteria and is considered to be feasible. A considerable increase in design effort is required compared with the MAL concept, particularly in the hull-CWP-SKSS-ETS interfaces. The discharge pipes interfere with the anchor legs requiring relocation of these pipes to the barge ends or discharging in a pipe concentric with the CWP. An electrical swivel in the ETS is required.

The significant benefit gained is the ability to control ship heading, leading to potential reductions in ship motions as well as SKSS fatigue loading in

comparison with the non-azimuthing concepts such as MAL, MAL-Active Tensioning. This concept requires the thrusters, included in the barge, to provide yaw moment to turn the platform into the desired heading. Thus, occasional demands on plant power are associated with this concept. It is anticipated that fewer than the four thrusters in the APL design will be required to provide restoring yaw moment in the hurricane. If this is the case, then failure of a thruster is not critical to the heading control operation. Further, once a desired heading is achieved, the thrusters are stopped and the turret is locked in position.

Multiple Anchor Leg-Active Tensioning. The concept satisfies the design requirements and is considered feasible. Partial heading control is realizable, with some reduction in motion and loads. An additional feature is the ability to provide for load equalization and monitoring. Plant output is required intermittently to power the winches. An electrical swivel in the ETS is not required with this concept.

6.1.2 SPAR

Multiple Anchor Leg. The assessment of the Barge MAL is applicable to the Spar MAL. The concept is considered to be feasible. Consideration must be given to clearance of the anchor legs between adjacent power modules, particularly in the presence of spar yaw rotation.

Tension Anchor Leg. The concept satisfies the design criteria and requirements and is considered feasible with one qualification. A significant flaw in performance is submergence of the spar completely below the water surface in storms. Spar modifications required for this concept to be technically acceptable are an increase in column diameter, increased scantlings to accept greater hydraulic pressure and complete watertight integrity of platform superstructure. The TAL imposes tensile and bending moment loads on the CWP which must be considered in the CWP structural design process. The ten-degree off vertical criterion for the vertical descent riser cable is exceeded. A positive aspect of spar submergence is elimination of

wind load and reduction in wave excitation, leading to lower drift force and motions. Alternatively, a change in TAL configuration is required to reduce spar submergence to an acceptable level.

Other considerations include sensitivity to errors in base depth, lack of redundancy and major CWP interface design effort. Since the CWP inlet position is well restricted, it is possible to moor the plant in shallower water, say 3200 ft depth, leading to elimination of the riser, a significant cost element, as well as reduced SKSS and ETS deployment and operational costs. The vertical descent ETS, the most suitable concept for the TAL, involves greater deployment complexity compared with the catenary ETS.

Tension Anchor Leg Monopod. The Monopod is similar to the TAL so that the above assessment applies to this concept. Spar submergence is not as great as in the TAL, so that the impact on the spar is less for the Monopod. If the mooring depth requirement is reduced then CWP extension would not be necessary; the TAL and Monopod would be essentially identical SKSS concepts. Both concepts provide for design simplicity and ocean system integration.

6.2 Risk Versus Cost

In this section the life cycle cost and relative risk are evaluated to compare the cost effectiveness of each SKSS concept. The results of the relative risk assessment conducted in Task I (Ref 2-10) the expected value life cycle costs presented in Section 4 and the ETS costs (Appendix A) are referenced. An additional cost of \$1 million is added to the ETS cost estimates to account for the electrical swivel where required, while an additional \$7 million is added to the CWP cost to extend the pipe for the TAL-Monopod. The latter cost increment is based on a linear extrapolation of the 2,700-ft CWP cost of \$22 million as reported by Gibbs & Cox. The SAL-SPM is included for completeness even though it is not feasible with the current state of the art. The TAL and TAL-Monopod are included assuming that a solution to the problem of spar submergence can be found.

The life cycle costs for each SKSS concept, summarized in Table 6-1, are added to the acquisition and deployment cost of the ETS best-suited to each SKSS. This is done to aid in ranking concepts; however, the final ranking is identical if ETS costs are excluded. The totals are divided by the largest total cost of \$66 million for the MAL-Active Tensioning. Similarly, the risk-criticality factors are divided by the risk for the SAL-SPM.

The lowest cost Barge SKSS concept, the SAL-SPM, is 25 percent less than the highest cost concept, the MAL-Active Tensioning. The cost spread for the spar SKSS concept is 28 percent. The lowest risk Barge SKSS (MAL-Turret) has 233 percent lower risk than the highest risk SAL-SPM. The lowest risk spar SKSS, the MAL, has 33 percent lower risk than the highest risk concept (Monopod).

These normalized costs and risks are combined with a weighting factor ranging from 0 to 1 (see Table 6-2). The sum is interpreted as a relative figure of merit, the absolute value of which has little significance in terms of SKSS operational cost, for example, but does provide a cost-risk basis for ranking the concepts. A low weighting reduces the importance of cost and increases the significance of risk while the opposite holds for a high weighting factor. The results for the Barge SKSS are that the MAL-Turret ranks first for all cases except that which ignores risk ($W=1$), in which case it is second to the SAL-SPM. The Spar TAL concept ranks highest for cost equal to or higher in importance than risk. In the case where risk is more significant than cost, the MAL ranks first and the TAL second.

In Section 5.4, the present cost of two SKSS failure modes was estimated to be \$1 million and \$20 million for serious and catastrophic failures, respectively. The catastrophic failure is assumed to have a probability of occurrence proportional to the net risk factor. This factor, normalized by the maximum risk factor, provides a means for weighing the cost of failure depending on the relative risk of each SKSS concept. The total costs of Barge SKSS and failure are shown in Table 6-3 to be low for the MAL-Turret and high for the MAL-SPM. The TAL-Monopod and TAL are the first and close second ranked concept for the spar. These rankings are similar to that obtained in combining life cycle cost and risk-criticality (Table 6-2).

Table 6-1 SUMMARY OF COST AND RISK CRITICALITY

Platform	SKSS	Expected Value of Life Cycle Cost (\$M)	(1) ETS Cost (\$M)	SKSS LCC Plus ETS Cost (\$M)	Net Risk Criticality Factor	Normalized Total Cost	Normalized Risk Criticality
Barge	SAL-SPM	45.0	7.9	52.9	172	0.80	1.00
Barge	MAL	54.2	6.9	61.1	86	0.93	0.50
Barge	MAL-Turret	53.4	7.9	61.3	52	0.93	0.30
Barge	MAL-Active Tensioning	58.1	7.9	66.0	104	1.00	0.61
Barge	MAL-SPM	55.8	7.9	63.7	156	0.97	0.91
Spar	MAL	43.8	6.9	50.7	82	0.77	0.48
Spar	TAL	32.8	8.3	41.1	102	0.62	0.59
Spar	TAL-						
	Monopod	31.8 (2)	8.3	40.1	110	0.61	0.64

(1) Acquisition, Deployment Cost Plus Swivel (\$1M) as required

(2) Includes 900-ft extension to CWP (\$7M)

To illustrate the sensitivity of the SKSS to errors in the holding power requirement, an arbitrary increase of 30 percent is assumed for the MAL wire and chain breaking strength. The resultant increase in expected value of life cycle cost for the barge is \$2.6 million or 5 percent, and \$1.2 million or 3 percent for the spar. This level of sensitivity indicates the need to define loads accurately while at the same time providing sufficient conservatism and ample safety factors to contribute to high reliability.

6.3 SKSS TECHNOLOGY DEVELOPMENT

In this section, the SKSS concepts are ranked according to the extent of development required to advance the state of the art in ocean mooring technology. The concept descriptions in Section 3 and evaluations in Section 6.1 provide

Table 6-2 COST VERSUS RISK-CRITICALITY OF SKSS CONCEPTS

$$T = \frac{\text{Cost}}{\text{Max Cost}} \times W + \frac{\text{Risk}}{\text{Max Risk}} (1-W)$$

	T(W=0)	Rank	T(W=0.25)	Rank	T(W=0.5)	Rank	T(W=0.75)	Rank	T(W=1)	Rank (1)
<u>SHIP</u>										
SAL-SPM	1.0	5	0.95	5	0.90	4	0.85	3	0.8	1
MAL	0.5	2	0.61	2	0.72	2	0.84	2	0.93	2
MAL-TUR	0.3	1	0.46	1	0.62	1	0.77	1	0.93	2
MAL-A.T.	0.61	3	0.71	3	0.81	3	0.90	4	1.00	4
MAL-SPM	0.91	4	0.93	4	0.94	5	0.96	5	0.97	3
<u>SPAR</u>										
MAL	0.48	1	0.55	1	0.63	2	0.70	3	0.77	3
TAL	0.59	2	0.60	2	0.61	1	0.61	1	0.62	2
MONOPOD	0.64	3	0.63	3	0.63	2	0.62	2	0.61	1

(1) 1-Highest, 10-Lowest

the basis for this assessment. The ranking factors presently in use to assess OTEC technology are as reported in Task I.

Score

State of the Art

10. Technology is nonexistent
9. Massive high-risk R&D
8. Extensive relatively high-risk R&D
7. Extensive moderate-risk R&D
6. Nominal moderate-risk R&D
5. Limited offshore experience
4. Nominal low-risk R&D
3. Relatively little R&D requiring no testing
2. Little R&D and no testing
1. Existing Technology fully adequate

Fig. 6-1 Life Cycle Cost Versus Risk Criticality

Table 6-3 LIFE CYCLE COST COMBINED WITH COST OF FAILURE

Platform	SKSS	Expected Value of LCC (\$M)	Net Risk Factor	Net Risk/Max Net Risk	Present Cost of Failure (\$M)	T (\$M)	Rank
Barge	SAL-SPM	45.0	26	1.0	20	65.0	3
Barge	MAL	54.2	11	0.42	20	62.6	2
Barge	MAL-Turret	53.4	6	0.23	20	58.0	1
Barge	MAL-Active Tensioning	58.1	12	0.46	20	67.3	4
Barge	MAL-SPM	55.8	25	0.96	20	75.0	5
Spar	MAL	43.8	9	0.35	20	50.8	3
Spar	TAL	32.8	11	0.42	20	41.2	2
Spar	TAL-Monopod	31.8 ⁽¹⁾	10	0.38	20	39.4	1

$$T = LCC + \frac{\text{Net Risk}}{\text{Max Net Risk}} \times \text{Cost of Failure}$$

(1) Includes 900-ft extension to CWP (\$7M)

A high score indicates that extensive technology development is required. The anchor leg, mooring leg, anchor, swivel and deployment are evaluated in terms of current state of technology. The mooring leg is applicable to the SAL-SPM and MAL-SPM; a score of 10 for the other concepts indicates that these systems do not require a mooring leg.

Existing technology is most nearly adequate for the MAL and least adequate for the SAL-SPM; the MAL is ranked first, with the MAL-Active Tensioning and MAL-Turret a close second and third, respectively.

Table 6-4 SKSS TECHNOLOGY DEVELOPMENT

SKSS Concept	Anchor Leg	Mooring Leg	Anchor	Swivel	Deployment	Total	Rank	
							Barge	Spar
SAL-SPM	8	4	6	2	7	27	5	
MAL	4	1	1	1	2	9	1	1
MAL-Turret	4	1	1	4	2	12	3	
MAL-Active								
Tensioning	5	1	1	1	2	10	2	
MAL-SPM	5	4	6	2	7	24	4	
TAL	7	1	3	2	4	17		2
TAL-Monopod	7	1	3	2	4	17		2

(1) 1-Favorable, 10-Unfavorable or N.A.

Section 7

CONCLUSIONS AND RECOMMENDATIONS

OTEC SKSS conceptual designs - five concepts for the barge and three for the spar - are presented including performance and configuration characteristics, interfaces, deployment, life cycle cost, and problem areas. Sensitivity of barge loads to sea state return period and heading is examined.

Concept feasibility is demonstrated for the basic multiple anchor leg (MAL) moor as well as two MAL variations - Turret and Active Tensioning. The MAL-SPM requires development of deadweight anchor deployment techniques and parallel line performance in a single leg. The MAL-Rotary, requiring a riser cable connector beyond state of the art, is considered unfeasible. The single anchor leg (SAL) moor is technically feasible, although not realizable today due to the strength limitation of commercially available wire rope. Two concepts for mooring the spar and incorporating the CWP are the TAL and TAL-Monopod. These are shown to be feasible with the proviso that further development, including spar modification, is necessary due to excessive spar submergence in storm conditions.

MAL design features requiring attention in preliminary design are clearance of risers and anchor legs, effect of bottom slope, and extensive component design and interfacing for the MAL-Turret, particularly in the areas of hull and CWP. The TAL will require, in addition to reduction of spar submergence, extensive interfacing with the CWP designers, particularly in dynamic loads analysis to demonstrate CWP capacity to support mooring requirements.

The lowest cost barge SKSS feasible in terms of present state of the art is the MAL-Turret with a capital cost of \$27.7 million and an expected value life cycle cost of \$53.4 million. This concept, with the lowest risk-criticality factor, ranks first in two different assessments of cost versus risk, and third in technology development. The MAL ranks with the MAL-Turret in cost if

the ETS is taken into account, second in risk-criticality, second in the combined evaluations of risk and cost, and first in technology development.

The spar TAL-Monopod is the lowest cost SKSS with a capital cost of \$13.1 million and an expected value life cycle cost of \$24.8 million; significantly lower in cost than the moors for the barge. The monopod allows reduction of mooring depth to approximately 3,200 ft. The MAL has the lowest risk criticality factor and highest cost. However, in assessing risk versus cost, the TAL-Monopod or the TAL rank ahead of the MAL. MAL requires less development than the TALs.

Another factor in concept evaluation is the extent of concept and technology development required for mooring a commercial OTEC plant. It is likely that an increase in holding power is the significant requirement change for that application. The MAL for the barge and spar, and TAL for the spar appear to be the concepts best suited to larger plants, the MAL because of its ability to provide greater holding power by the addition of more legs or increase in wire-chain diameter, and because it is least likely to require technology development, and the TAL because of the potential to reduce costs with acceptable risk, particularly significant in commercial applications. The larger commercial spar could have greater restoring force, thereby limiting submergence with the TAL mooring. The MAL-Turret would require development to larger diameter turrets due to the increase in CWP diameter as well as electrical swivel development for larger power capacity for the commercial plant. The higher development costs which are evident for the MAL-Turret can be traded with the derived benefits of heading control only when the cost benefits of lower OTEC plant motions on plant output can be ascertained.

On the basis of the results obtained in this conceptual design phase, the recommended SKSS concepts for preliminary design are the MAL-Turret for the barge and the TAL-Monopod for the spar. The potential benefits to be gained by these systems as indicated by their high rankings will only be realized if their development is pursued. In the event that the turret or monopod prove unattractive as development progresses, the MAL designed for the turret can be a back up configuration for one or both platforms.

The depth requirement of 4000 ft appears to be excessive in mooring the spar with the TAL or monopod, a reduction in depth to a minimum of 3100 ft is recommended to reduce SKSS costs. The watch circle requirement of ten percent of water depth should be reexamined in view of the results of the SKSS-ETS interface study. A greater watch circle is feasible for the standoff buoy ETS configuration.

APPENDIX A

Interface of OTEC Electrical Transmission and Stationkeeping System

Prepared For
LOCKHEED MISSILES AND SPACE COMPANY

by

Simplex Wire and Cable Company
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INTERFACING OF OTEC PLANT
ELECTRICAL CABLE SYSTEM
AND MOORING SYSTEM

Simplex Development Engineering Report #69

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Interfacing of OTEC Plant
Electrical Cable System and Mooring System

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Summary

LMSC has proposed eight basic mooring concepts for the 10-40 MW OTEC plant and some additional variations in its proposal D085241. In a previous report to LMSC (Ref. 1), Simplex has described three basic concepts for deploying the riser cables and their support systems. This report describes the applicability of the various riser cable deployment concepts. It also details some trade-offs in the design or specification of the particular cable systems.

From the standpoint of the power cable system, the mooring systems can be divided into three major groups: the tension anchor legs (TAL), the single point moors (SAL), and the other multiple anchor leg (MAL) systems. The physical deployment characteristics of the electric transmission cables (ETC) will be basically the same for each particular mooring system within any one group. It is important to note that four cables may be necessary for the electrical transmission system as described in reference 1. A matrix of the possible combinations of specific mooring systems and specific cable systems is shown in Table I. As noted in Table I, some of these designs will require an electrical swivel to parallel the mechanical swivel. Such a device is untried, even at the power level of 10 MW. The feasibility of scaling this device to a 400 MW level is questionable. Because this device applies to two major groups of mooring systems, it is discussed separately from other aspects of the system.

An estimate of riser cable system costs based on the stand-off buoy system is approximately 10 million dollars. It might range from 10 to 8.3 million as the watch circle decreases from 30% of water depth to 10% of water depth. A riser cable of the catenaried direct descent would cost about 6.9 million dollars and the vertical descent would cost about 8.3 million dollars relative to the base system cost. Neither of the latter two riser systems are easily adaptable to watch circles greater than 10% and the cost remains reasonably constant up to that point.

Riser Power Cable System for MAL Moorings

All of the MAL systems, with the exception of the MAL single buoy moor, are basically similar from the standpoint of the cable system. It appears that the MAL's will allow much more potential motion of the OTEC plant than will the TALs, and the MALs will not allow rotation of the CWP as will the SALs.

This combination of mooring characteristics makes the highly catenaried direct descent or the stand-off buoy system seem the most viable. The stand-off buoy system allows the greatest potential watch circle and the greatest flexibility for tailoring the system to particular locations. It will be described first.

	Vertical Descent	Catenaried Direct Descent	Stand-Off Buoy	Comments
SAL single point moor	Probable	Must clear CWP	No	Needs electric swivel surface & subsurface
MAL	No	Possible	Probable	
Mal active tensioning	No	Possible	Probable	Must allow for changing configuration of mooring
Mal turret	No	Possible	Probable	Needs electrical swivel
MAL rotary	No	Possible	Probable	Needs underwater electric swivel Extremely difficult to interface cable hardware with rotary
MAL single moor	Possible	Must clear CWP	No	Needs electrical swivel
TAL	Probable	Possible	Possible	Attachment to CWP must be developed
TAL monopod	Probable	Possible	Possible	

TABLE I

Figure I
Stand-off Buoy System
for MAL Mooring

Stand-off Buoy Cable Support System

The system is shown in Figure I. The stand-off buoy cable system provides a mechanism for control of both slack and tension in the cable. Major motions of the plant are accommodated by changes in the catenary geometry of the suspended cable. The system is designed to operate from one extreme condition beyond which the catenary tension rises at too great a rate, to an opposite extreme position beyond which the cable ends hang nearly vertically. (At this vertical position the cable can be damaged from sharp bends or twisting upon itself.)

The tightest condition of the catenary should be a span-to-length ratio of 0.8. Beyond that point, tension begins to climb at an unacceptable rate. The slack condition at the other extreme is a span-to-length ratio of 0.5. At this position, the cable end is at an angle of 77° below the horizontal. This is considered the greatest angle to which the cable should be allowed to move. Thus, the span-to-length ratio of the cable should be in the range 0.5 to 0.8, and the watch circle has a diameter 0.3 times the length of deployed cable. The nominal plant-to-buoy distance is then selected to be 0.65 times the cable length. By adjusting this distance and proportionally adjusting the cable length, the watch circle can be adjusted within some reasonable limits. It has been assumed that a catenary length of twice the water depth is a good working maximum length. A minimum length of cable is that necessary for a watch circle radius of 10% of water depth, which seems to be the tightest circle being specified.

For the Puerto Rico site in 4000' of water, the following table has been compiled.

TABLE II

Cable Length vs. Watch Circle for Stand-off Buoy System

<u>Length of Cable</u>	<u>Nominal Buoy-to-plant Distance</u>	<u>Max. Watch Circle Diam.</u>	<u>Radius % of Water Depth</u>
8000' (max.)	5200'	2400'	30%
5000'	3250'	1500'	18.8%
3400'	2720	1020'	12.8%
2670'	1730'	800'	10.0%

As seen in Table II, the length of cable deployed in the main catenary can vary significantly, depending upon desired watch circle.

The length of cable deployed will be subject to other design factors such as:

1. Distance from plant to appropriate touchdown points
2. Avoidance of mooring and anchors
3. External hazards to suspended cable (snagging or interference)
4. Effects of current on swing motions of catenary
5. Effects of natural oscillations of the cable

The total design tension in the cable will probably not be greatly affected by the length of the suspended catenary because as the tension in it becomes lower, it soon becomes less than the tension in the cable descending to the ocean floor from the buoy. Cable fatigue in tension, bending, and twisting is being investigated, but very little is known about fatigue of the insulation under simultaneous electrical and mechanical stresses. It may be necessary to limit cable length and/or cable tension to alleviate fatigue in the cable. Therefore, the watch circles associated with particular cable lengths in Table II may have to be adjusted somewhat when further analysis is complete. The preliminary analyses indicate that probably the 5000' of deployed cable is a good starting figure.

Analyses to date have assumed that the stand-off buoy would be within a few hundred feet of the surface, that is, both ends of the catenary would be at nearly the same height. There is an advantage to placing the buoy at a minimal depth if pressure resistant termination devices are necessary on the buoy. This area of concern is not yet well defined. Obviously, there would be some advantages to placing the buoy at greater depths to avoid not only waves, but also most effects of ocean currents on much of the riser cable system.

Catenaried Direct Descent System

The primary advantage of the catenaried direct descent system is simplicity. Hardware is minimized and installation costs are minimized. However, the extent of plant watch circle which can be accommodated is substantially less than the stand-off buoy system. Design flexibility to accommodate varying bottom conditions or to detune the system is also reduced.

Typical dimensions for an installation in 4000' of water with a 1:3 slope to the ocean floor is shown in Figure II.

From the standpoint of protecting the cable from abrasion and finding a suitable area for the cable to touch down, it has been assumed that no more than 1000' of cable would be allowed to lift off the bottom when the plant moves from a position nearest the touchdown to a position farthest from the touchdown. This limits plant movement to a watch circle of approximately 300 feet radius. An anchor and bend restrictor system designed to allow the cable to tighten on the anchor during the farther extreme of plant tension might allow this system to operate up to a 400-foot watch circle radius,

Figure II
Catenaried Direct
Descent for
MAL Mooring

Scale
0 1000 feet

it not substantially beyond that. The length of cable used in such an installation would not vary enough to affect costs.

Direct Descent Riser Cable for TAL Moored OTEC Plants

The small watch circles and negligible base movements allowed by the TAL and monopod mooring concepts have opened up the possibility of a direct descent riser cable. Descent along the CWP for these systems will involve the following design considerations.

Starting from the sea floor, two different methods of bringing the cable up to the CWP have been envisioned for the TAL and monopod designs. In preliminary analysis of this portion of the riser cable, the following assumptions have been made:

- Worst design case is a $\pm 10^\circ$ tilt of the CWP from the vertical in a straight line deflection
- Sea floor has a slope of 1:3
- Rotation of the plant about its axis has been ignored

For a TAL mooring, the riser cable will attach to the base of the CWP, assumed to be 1000 ft. above the sea floor. From here, it will either pass through a stand-off buoy, then reaching bottom, or it will hang in a simple catenary to the ocean bottom. The stand-off buoy concept is covered previously and will not be repeated here. For a straight catenary descent, static tension and angle of departure restrictions place the cable touchdown point roughly 500 to 1000 feet from the platform anchor. Compensation for plant movements requires that up to 450 more feet of cable lie free on the bottom. This provides slack for lift up of the cable under extension. At the end of this length, the cable should be anchored to produce the horizontal tension needed to maintain the catenary. Favorable bottom conditions are necessary for the area in which the cable is touching down to avoid abrasion of the cable as it moves on and off the ocean floor, or is dragged sideways by plant motion. The effects of abrasion on the cable behavior should be investigated more carefully.

For the monopod, the supporting structure allows the riser cable to be attached down to the platform anchor. However, a catenary attachment on the order of 100 feet from the sea floor is necessary to absorb plant motions. An extra length of free cable to allow lift off will have to be laid, as with the longer catenary. But the bottom end, in this case, will require a bend limiting anchor.

The smaller catenary will reduce the static tension on the cable and lessen the magnitude of the cable motions, aiding abrasion resistance. It is not clear whether the shorter catenary will exhibit smaller strains than the longer catenary, and hence, have better fatigue life. But the longer catenary will be far easier to lay. The larger catenary length to water depth ratio will create greater laying control. Also, the longer catenary attachment to the plant

Figure III

TAL - Long Catenary Cable System

Figure IV

TAL Monopod - Short Catenary Cable System

structure is 1000 feet above the shorter catenary attachment, requiring submersible equipment to work at a much shallower depth. The actual point of attachment on the monopod will be a compromise in between these two points, based on deployment and in service load considerations.

The riser cable will join the CWP through a bend restricting bell housing and pass along the CWP through spaced supports. These supports will provide horizontal control to avoid chafing against the CWP, but vertical support of the cable will be nearly impossible at the present state-of-the-art. Static dynamic tensions, electric heating and twisting torque in the cable will create complex strains that make mating of the cable and CWP in the vertical direction extremely difficult. In the absence of this support, the top connection of the cable will be forced to withstand tensions up to 33,000 lbs. To relieve this situation, buoyancy can be added to the cable. Both internal and external buoyancy are being considered, but internal buoyancy will require a departure from current power cable practice. The design of external buoyancy brings up some interesting design problems. First, the cable may significantly add to the hydrodynamic load on the CWP, especially in the area of vortex shedding. In this case, the cable flotation may also have to perform as a fairing. Also, the buoyancy material will thermally insulate the power cable, causing it to operate at higher temperatures. Thus, careful design of the buoyancy to avoid overheating, or design the cable to allow for less efficient heat transfer will be necessary.

The riser cable must be fixed to a point on the CWP below the CWP universal joint. This allows the suspension load to be taken off the cable to permit the flexibility for it to pass around the universal. Without added buoyancy, the cable load at this connection could range to 33,000 lbs. with a minimum possible tension of 20,000 lbs. This assumes a cable weight of 5 lbs/ft. in seawater. For the TAL, cable weight is needed to give some measure of stability to the catenary. For the shorter catenary, the load on the CWP could become negligible, but the longer catenary may still produce a load of roughly 7500 lbs. The CWP must be able to withstand this loading, and a reinforcing structure may be needed.

Single Point Moored Systems

The single point moored systems will utilize the same riser cable concepts discussed earlier, but they bring about unique problems. A SAL single point mooring, assuming a catenary, will require termination hardware that is far from the state-of-the-art. A catenaried SAL is subject to complete reversals in direction. To accommodate the plant motions while avoiding the CWP would make the design of a suitable ETC catenary extremely difficult. Coupled with the problems of holding the needed tolerances in laying a cable of this sort, a catenary descent seems an unlikely option. The other possibility would be to run the cable down the anchor leg and through a swivel at the bottom to accommodate rotation of the buoy in its watch circle. Electric swivels at this power level are not currently available for atmospheric conditions. A swivel to operate at a 4000-ft. depth may not

is practical to develop. This is discussed in the following section. Under these considerations, the SAL mooring concept seems incompatible with present riser cable concepts.

The MAL single point mooring will have cable deployment characteristics similar to the TAL moorings. The main differences being attachment to the mooring lines and surface support of the cable loads. The ETC catenary can come off the mooring lines at a height of no more than 1000 ft. above the sea floor to avoid fouling the CWP. Catenary configurations would be the same as similar ones for TAL moorings, but more free cable would be needed to withstand the greater watch circle movements of the MAL system. The riser cable would then join the mooring through some manner of bend restricting support structure. When attached at 1000 feet above bottom, the nominal horizontal tension would be roughly 4500 lbs. and could reach four times that amount in extreme conditions. This tension will decrease with increasing depth of attachment, but the difficulty of deploying the cable increases with increasing depth. The attachment point will represent a trade-off, based on cable laying capabilities, submersible equipment range, support structure design and riser cable strength. At the surface, the buoy must provide an additional 7,500 to 36,000 lbs. of buoyancy for support of the power cable. This value is the entire cable load, since vertical support along the cable is impractical. However, horizontal stabilization is needed to prevent chafing and fouling with the mooring lines.

The catenaried MAL-single point moored systems will have similar cable configurations to other MAL moorings. However, complete rotation of the ship would prohibit use of a stand-off buoy. With the same watch circle, the two concepts will use the same cable catenary descent. The length of the mooring yoke necessary for the CWP to clear the mooring lines should be adequate to also clear the electric cable.

Electrical Swivels

The single point mooring, the turret mooring, and the rotary mooring will all require a rotary device for transmission of electrical power from a rotating source to a fixed power cable. This device will be referred to as an electrical swivel. Two key points about the swivel should be noted at the beginning of this discussion. First, other aspects of the electrical transmission system (ETS) for the 10-40MW OTEC plant are being designed as a low voltage version of a 400MW plant. The feasibility of scaling an electrical swivel to 400MW size is questionable, and therefore a swivel system for the 40MW system may not be the best solution from the standpoint of transferring knowledge gained from the 40MW system to the 400MW system. Second, the electrical swivel must provide for at least three-phase power transmission, and also include a spare phase to be consistent with other parts of the ETS.

The design of the electrical swivel system itself (or plant-mounted turret system) must include careful consideration of the system electrical requirements. The voltages being considered for the 40MW system range from 35kVac to 138kVac. Each of the four phases must be dielectrically isolated from ground potential and from adjacent phases. This will likely require a dielectric such as oil or a gaseous dielectric such as SF₆. This isolation requirement is probably the single most difficult electrical design problem for a swivel or turret electrical connection. Insulation of high-potential components from ground and from adjacent phases is of paramount importance. Dielectric contamination by wear of moving parts in the electric field, and water vapor penetration of the device are also important considerations. The design of such a device must take into account the transient over-voltages associated with switching surges and lightning. For example, a 35kV system must expect to experience peak line-to-ground transient voltage of about 200kV, while a 138kV system must withstand transient peak voltages of at least 650kV. The assumption is made that the design concept would later be extended to still higher commercial OTEC plant system voltages of as much as 345kVac or + 400kVdc with their still higher transient voltage withstand requirements. Further, in order to be consistent with the plan for other parts of the electrical system, the swivel should allow inspection, maintenance, or repair of a single phase while the other phases are operating. Thus the space available around each phase of the swivel becomes substantial. In the case of the SAL and MAL single point moors, the electrical swivel would be located on the mooring buoy and could be a device of relatively small diameter. It would presumably be in a dry compartment, probably directly below, or in the center of, the mechanical turntable. This appears to be a reasonable location for a swivel device.

In the case of the MAL turret moor, the electrical swivel could be similar to the swivel on the mooring buoy. However, the proximity of mooring equipment, piping, and piping swivels, may complicate the design of the electrical swivel. As previously noted, the requirement for insulation of all "live" electrical components is of paramount importance.

Figure V

Classical Bell Mouth Bend Restrictor
(Full Bell in one plane
Half Bell in the other)

The MAL rotary moor or the bottom mounted SAL swivel, appears to present substantial problems. The device must be pressure resistant. Ingress of small amounts of water vapor will eventually contaminate the insulation oil or SF₆ gas. In addition, the MAL rotary system appears to call for contact surfaces which would extend all the way around the CWP and would thus be extremely difficult to seal and insulate.

In addition to the difficulty in providing the electrical swivel, the MAL rotary also appears to have difficulty in accommodating the necessary mechanical cable termination. These requirements are discussed in the following section.

Terminations

Another aspect of the electrical transmission system that will bear upon the design of the mooring system is the termination hardware. Both the strength member and the electrical conductor of a suspended power cable must be terminated. In addition, bend restriction hardware will be necessary, and it may be placed near the termination. The space taken up by the strength termination must be several feet in diameter and 5 to 10 feet long. Structural members must be present to take the load of the cable, which may amount to a substantial fraction of 100,000 lbs. The electrical terminations will probably be SF₆ insulated to reduce necessary working clearances, but even so, a 35kV system of four cables would probably require a termination area 10 ft. x 10 ft. x 15 ft.

Bend restriction hardware will have to limit bending to a minimum radius at least as large as 15 feet, and possibly larger, in order to limit stresses in the cable and improve fatigue life. Conventional bell-mouth restrictors for the 15 foot radius would be 20 feet long and at least 10 feet across. If the bend radius becomes larger, innovative equipment may be necessary to limit size, but it cannot be expected to be substantially smaller. The mounting of the bend restrictor must be strong enough to resist the moments created by the horizontal components of cable tension.

Costs of Cable System

The base for costs of the cable system will be the stand-off buoy concept, which we estimate to be the most expensive. This system cost has been estimated at approximately 10 million dollars. Because of uncertainty in the final cable, system, installation design, and in production facilities necessary, these figures cannot be considered accurate to better than $\pm 50\%$. Cost estimates for all other systems have been based on our perception of differences from the base system and therefore probably represent an accurate figure relative to the base costs.

Some of the figures assumed for the cable in this section are not exactly those of the latest ideas in cable design, cited elsewhere in this report and in reference 1. The figures used in this section, however, still represent a cable within the $\pm 50\%$ cost range previously cited.

No allowance has been made in these costs for an electrical swivel. It appears that their costs may be more appropriately estimated as a part of the overall system design after their basic design has been further defined.

As described, the OTEC Plant will employ a separate cable system for each phase plus a spare. Each cable system will consist of a termination at the plant from which a cable will extend in catenary to a submerged buoy. The buoy will be anchored to the bottom by a mooring line. From the buoy, another cable, called the riser, will extend to the ocean bottom where it will mate through an underwater connector to the main submarine power feeder cable.

Cable being considered for use is assumed to be armored with two layers of galvanized steel wires. It is estimated that such a cable would weigh approximately 5 lbs/ft. in sea water and would cost approximately \$33 to \$34 per ft.

The length of catenary cable will depend upon the radius of the watch circle permitted for the plant. By definition, watch circle radius is given as a percentage of the water depth. Typical watch circles being considered are 25%, 12½% and 10% of the water depth which has been projected to be 4000 feet. The following table lists the quantity of cable assumed for the catenary section:

Table III

<u>Nom. Watch Circle (%)</u>	<u>Length of Cable in Catenary (ft.)</u>
25	8000
12½	4000
10	3400

These figures provide some safety allowance above those listed in the section on buoyed systems.

Length of the riser cable is determined only by the relative position between the subsurface buoy and the bottom termination, and is estimated to be approximately 2 times the water depth. An additional length equal to the water depth will be implaced on the bottom to facilitate its connection with the bottom cable.

The subsurface buoy must provide sufficient buoyancy to hold the riser cable taut. Generally, the buoyancy required is approximately twice the total weight in water of those components being suspended. Due to the weight in water of the cable and the mooring line, the buoy must develop approximately 100,000 lbs. positive buoyancy. Cost of the buoys has been estimated for syntactic foam at \$3 to \$4 per lb. buoyancy.

The buoy will be held in place at a depth of about 200 ft. by a mooring line attached to an anchor on the ocean bottom. This line must be capable of 1,150,000 to 1,250,000 lbs. breaking strength. Seven-inch diameter polyester or nylon ropes, among others, are acceptable candidates. Currently, this size rope costs approximately \$85/ft.

Weight of the anchor is approximately 1.5 times greater than the buoyancy. Anchors generally cost about 50¢ to 55¢ per lb.

The following table lists the requirements for the major components of the suspension system:

Table IV

Basic Performance Requirements
for Suspension System

Water depth, $d = 4000$ ft.
Riser Cable Length, $2d + d = 12000$ ft.
Suspended Cable Wt. = 43,200 lbs. in sea water
Mooring Line Wt. = 10,260 lbs. in sea water
Total Suspended Wt. = 53,500 lbs.
Required Buoyancy = 100,000 lbs.
Weight of anchor = 150,000 lbs.

Ancillary equipment and hardware will be required at the plant as well as on the buoy and at cable terminations. On-plant hardware will include potheads, armor terminations, cable bend restrictors, and some handling equipment. These devices are estimated to total \$0.5 million. Miscellaneous hardware used on the buoy for bend restriction and installation guides probably will account for \$50,000 per buoy. An electrical connector/armor termination to be installed at the interface between the riser cable and the main power feeder cable may be quite special if two different kinds of cable are used. If this connector/termination is necessary it probably will cost about \$300,000 per mateable pair. Actual connection between the two cables will be made at the surface, then lowered to the sea bottom.

Installation of each phase will include implacing the anchor, deploying the buoy, laying the cable, and making the connection between the riser cable and the main power feeder cable.

A cable ship will be needed to pay-out the cable. It is estimated that the following schedule will be achieved to lay all four cable systems:

Table V:

Cable Ship Time for Installation

<u>Ship's Itinerary</u>	<u>Time (days)</u>
Staging to cable plant	9
Plant to site	11
Return	13
On Site	<u>6</u>
Total elapsed time	39

Currently, cable ships cost \$40,000/day.

A large crane barge and two tugs also will be required. The tugs will assist the cable ship, as well as position the barge for implantment of the anchor and buoy. It is estimated that the following schedule will be achieved to deploy all three suspension systems:

Table VI:

Support Vessel Time for Installation

<u>Itinerary</u>	<u>Time (days)</u>
Staging to site	3
Return	3
Installation time	3 x 4 = 12
Contingency	<u>2</u>
Total elapsed time	20

Currently, the cost of a crane barge and two tugs is \$60,000/day.

The following table summarizes the estimate of costs to install the system as described:

Table VII:

Cost of Basic Standoff Buoy System

<u>Description</u>	<u>Cost (millions of dollars)</u>
Cable	3.1
Suspension System	
Buoy	1.4
Anchor	.3

<u>Description</u>	<u>Cost (millions of dollars)</u>
Mooring Line	.3
Hardware	.4
Platform Hardware	.5
Subsea Connector	1.2
Cable Ship	1.6
Other vessels	<u>1.2</u>
Total	10.0

Of the items listed in the table above, 60% of the cable, all the mooring line, all hardware items, the subsea connector, and all ship and vessel costs are fixed no matter how large a watch circle is permitted. These items constitute \$7.1 million, while the remaining \$2.9 million would be variable in relation to the size of the watch circle, as shown in the following table:

Table VIII:

Variable Costs of Standoff Buoy System

<u>Watch Circle</u>	<u>Variable Costs (million dollars)</u>
25%	2.9
12½%	1.95
10%	1.23

The catenaried direct descent system would not require a buoy or mooring line, and would probably require about 14000 ft. of cable. The anchor would probably be shifted from the buoy mooring to the cable itself. Hardware to hold the cable to the anchor would be about half the cost of the buoy hardware. Other vessels for installation might be cut by probably 30%. Thus, costs for the catenaried direct descent are approximately:

Table IX:

Cost of Catenaried Direct Descent System

Cable	\$2.2 M
Anchor	.3 M
Anchor Hardware	.2 M
Platform Hardware	.5 M
Subsurface Conn.	1.2 M
Cable Vessel	1.6 M
Other vessels	<u>.9 M</u>
Total	\$6.9 M

The vertical descent system presents greater unknowns in hardware and installation costs. As much as 12000 feet of riser cable might be necessary depending upon the final installation plan. Attachment and terminating hardware might amount to 6 times the cost of buoy hardware. Installation costs would probably be no less than the stand-off buoy system.

Table X

Cost of Vertical Descent System

Cable	\$1.9 M
Attachment Hardware	2.4 M
Submarine Connection	1.2 M
Cable Vessel	1.6 M
Other Vessels	<u>1.2 M</u>
Total	\$8.3 M

Summary of Components of Electrical Transmission Cable System

1. Cable

The electrical transmission cables used with the 10-40 MW OTEC power plants will probably be either conventional overarmored submarine cables or specially designed center strength member cables. Such cable could be 4 to 6 inches in diameter and weigh about 5 lbs/ft. in seawater. Order of magnitude measurements of similar overarmored cables yield the following section properties:

$$\begin{aligned} \text{AE (force per unit strain)} &\approx 30 \times 10^6 \text{ lb} \\ \text{EI (bending stiffness)} &\approx 5 \times 10^4 \text{ lb/ft}^2 \end{aligned}$$

The expected electrical system will require four power cables, three for each phase of a three-phase AC circuit and a spare.

2. Anchor

All of the cable systems will require an anchor to provide horizontal tensions of up to 10 tons. This force is needed to support the designed catenaries and restrain bottom movements of the cable. For catenaries of roughly 1000 ft. or more, the extra cable provided for lift-up will isolate the anchor from cable bending. All other anchors will require some manner of bend restricting housing whose dimensions will be approximately 30' x 15' x 15'.

3. Stand-off Buoy

For stand-off systems, a buoy will be needed with an estimated net buoyancy of 100,000 lbs. The buoy must support the cable and allow it to endure bend radii of no less than 15 ft. Design of the stand-off buoy will be a major effort, but within the state-of-the-art. If, however, a deep-water buoy is called for, the buoy system will require a good deal of development work.

4. Bend Restrictor

In all the cable systems, bend restriction is needed where the riser cable meets the OTEC ship, CWP or mooring. A bell housing to perform this task will be the same size as the anchor bell housing, roughly 30' x 15' x 15'. Other methods of bend restriction, such as cable over-armor, would save space but are not yet fully developed for power cable of this size. Horizontal loads up to 7000 lbs. can be expected at this restrictor.

5. CWP/Mooring Connectors

For direct descent cables, the cable will be attached to the CWP or mooring lines. These attachments will provide only horizontal support to prevent abrasion or fouling with other plant components.

6. Mechanical Termination

The strength members of the ETC must be terminated to take the bulk of the mechanical loads before electrical termination. The cable forces, composed of the cable weight, catenary horizontal tension and dynamic loads (such as wave loading, current drag and vortex shedding) could total up to 45,000 lbs. With CWP attachment, the mechanical support must occur below the CWP universal. The CWP must be reinforced to tolerate this loading. Also, the mechanical termination must be sealed to prevent corrosion when placed below the water line.

7. Electrical Termination

Electrical termination of the cables will probably be SF₆ gas-insulated to save space. Equipment is state-of-the-art with the exception of termination equipment for a center strength cable, and such equipment is seen as requiring only a relatively routine development effort. Probable minimum dimensions of the termination area are 10 feet x 10 feet x 15 feet.

Reference

1. Simplex Development Engineering Report #65, March 29, 1979. "Preliminary Requirements on the OTEC Station-keeping Subsystem Imposed by the Electrical Transmission System", prepared for LMSC as report of Task I of Contract NA-79-SAC-00635.

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APPENDIX B

Wave Drift Force and Environmental Loads

WAVE DRIFT FORCES

COMPARES SEVERAL THEORIES TO ESTABLISH WAVE DRIFT FORCES ON BARGE.

- 1) N. SALVESEN, SECOND ORDER STEADY STATE FORCE AND MOMENTS ON SURFACE SHIPS IN COLLING WAVES, INT'L. SYMPOSIUM ON THE DYNAMICS OF MARINE VEHICLES AND STRUCTURES IN WAVES, LONDON 1974, pp. 212-226.

ANALYTICAL COEFFICIENTS FOR MARINER = LRP = 528 ft, $C_B = 0.632$
ZERO FORWARD SPEED

APPROX. RESISTANCE (FIG. 1) $\bar{F}_x$, LONGIT. FORCE @ $\beta = 120^\circ$, $\bar{F}_y$; YAW MOMENT $\bar{M}$

$$\lambda/L \quad \bar{F}_x = F_x / \rho g \alpha^2 B^2/L \quad \bar{F}_y = F_y / \rho g \alpha^2 B^2/L \quad \bar{M} = M / \rho g \alpha^2 BL$$

0.2	—	3	-0.05
0.4	—	7	0.10
0.6	3	3	0.2
0.8	1.5	1	0.08
1.0	0.6	0.5	0.02
1.4	~0	~0	~0

ASSUMES APPLICABLE TO APL BARGE, $B/T = 121/65 = 2$.
IGNORES CLWP & DISCHARGE PIPES!

$$\rho g \alpha^2 B^2/L = 1.98 \times 32.2 \times 121^2 / 378 = 2469 \text{ lb/ft}^2 \text{ OF WAVE AMPL. } \alpha$$

$$\rho g \alpha^2 BL = 1.98 \times 32.2 \times 1^2 \times 121 \times 378 = 2,927,232 \text{ ft-lb/ft}^2$$

$$\lambda = \frac{2\pi g}{\omega^2}, \quad \omega = \sqrt{\frac{2\pi g}{\lambda}} = \sqrt{\frac{2\pi g}{\lambda}} \sqrt{\frac{F}{\lambda/L}}$$

BASED ON REMBEY & HERMANS, OTC 1500, 1971, Eqn. (14)

$$F \propto 2 \int_0^\infty S(\omega) R(\omega) d\omega$$

$$\therefore F \propto 2 \int_0^\infty S(\omega) \bar{F}(\omega) d\omega$$

THE SPECTRUM, $S(W)$, FOR 100 YR STORM GIVEN BY BROTSCHNIGER, APRIL 1979, LOOK LAB REPORT, FIGURE 2-B.

$1/L$	F_x	F_y	M	$W(R/S)$	$f(H_z)$	$S(W)(ft^2 sec)$	ΔW	$S F_{x \Delta W}$	$S F_{y \Delta W}$	$S M \Delta W$
0.2	-	3	-0.01	1.64	0.26	11.2	0.48	-	16.1	-0.27
0.4	-	7	0.1	1.16	0.18	68.3	.48	-	229.1	3.28
0.6	3	3	0.2	0.94	0.15	162.6	.72	107.3	107.3	2.11
0.8	1.5	1	0.08	0.82	0.13	311.0	.12	560	37.3	2.29
1.0	0.6	0.5	0.02	0.73	0.12	438.1	.09	23.7	19.0	0.79
1.2	0.2	0.2	0.01	0.67	0.11	620	.06	7.4	7.4	0.37
1.4	0.0	0.1	0.0	0.62	0.10	869.3	.05	0	4.4	0
								194.4	416	14.31

$$F_x = 2469 \times 2 \times \frac{194.4}{2\pi} = 152,800 \text{ lb} \quad \text{WAVE DRIFT, HEAD SEAS, 100 YR.}$$

$$F_y = 2469 \times 2 \times \frac{416}{2\pi} = 326,900 \text{ lb} \quad \text{WAVE DRIFT, 120°, 100 YR.}$$

$$M = 2,927,232 \times 2 \times \frac{14.31}{2\pi} = 13 \times 10^7 \text{ FT LB} \quad \text{WAVE MOMENT, 120°, 100 YR.}$$

THE THREE YEAR STORM SPECTRUM, $H_z = 19.9$, $T_p = 9.6$, SWS
BROTSCHNIGER SPECTRUM, ENVIRON. DATA PROCESS, 12/72, FIG. 7.8.

W	S	$S F_{x \Delta W}$	$S F_{y \Delta W}$	$S M \Delta W$
1.64	9.1	-	13.1	-0.22
1.16	51.9	-	174.4	2.49
0.94	112.1	74	74	4.93
0.82	185.7	53.4	22.3	1.78
0.73	230.9	12.5	10.4	0.42
0.67	270.4	3.2	3.3	0.16
0.62	281.2	0	1.4	0.0
		123.2	298.9	9.56

$$F_x = 696,829 \text{ lb} \quad \text{WAVE DRIFT, HEAD, 3 YR.}$$

$$F_y = 234,968 \text{ lb} \quad \text{WAVE DRIFT, 120°, 3 YR.}$$

$$M = 8.9 \times 10^6 \text{ FT LB} \quad \text{WAVE MOMENT, 120°, 3 YR.}$$

2) RANKIN & HERMAN, THE SLOW DRIFT OSCILLATIONS OF A MOORED OBJECT IN CHOPPY SEAS, DTC 1500, 1971

DRIFT FORCE COEFFICIENT, C_d , FOR RECTANGULAR CYLINDER IN BOOM WAVES.
($B/T=2.5$). EMPIRICAL.

$$F_y = \frac{1}{2} \rho g B p_a^2 R^2$$

$$\bar{F} = \int_0^\infty \int_0^\infty \bar{F} dw \quad F = \rho g B \int_0^\infty \int_0^\infty R^2 dw$$

(Salverston) $F_y \rho g B \alpha^2 = \frac{1}{2} \rho g B p_a^2 R^2$ (Rankin)

$$F_y = \frac{1}{2} \frac{L}{B} R^2 \quad (= 1.56 R^2)$$

$$KT = \frac{w^2}{g} T, \quad w = \sqrt{\frac{g}{T}} \sqrt{KT}, \quad T = 65 \text{ ft.}$$

		100 YR. STORM WAVE				3 YR. STORM			
KT	R	w	f	Δw	∫	∫ R ² Δw	∫	∫ R ² Δw	
0	0	0	0	0	0	0	0	0	
0.1	0.2	0.22	0.04	.09	0	0	-	-	
.2	.4	.31	.05	.09	39.6	0.57	-	-	
.3	.65	.39	.06	.08	594.5	20.1	-	-	
.4	.83	.45	.07	.06	1197.7	53.6	21.2	0.9	
.5	.94	.50	.08	.05	1413.3	62.4	117.5	5.2	
.6	.98	.55	.09	.05	1170.9	56.2	231.1	11.1	
.7	1.0	.59	.09	.04	1170.9	46.8	231.1	9.2	
1.0	1.	.70	.11	.11	620	68.2	270.4	29.7	
2.0	1.	1.0	.16	.3	120	36.0	86.3	25.9	
-	-	2.0	.38	1.0	-	-	3.6	3.6	
						343.87	85.6		

$$F_y = \rho g B \int_0^\infty \int_0^\infty S(w) R^2(w) dw$$

$$= 62.4 \times 121 \times 343.87 / \text{ft} \times 2$$

$$= 827,600, \quad 100 \text{ YR.} \quad \text{vs.} \quad 205,700 \text{ LB, } 3 \text{ YR.}$$

$$\# \quad 205,700 \text{ LB, } 3 \text{ YR.}$$

3) KIM AND CHOW, PREDICTION OF DRIFTING FORCES AND MOMENT ON AN OCEAN PLATFORM FLOATING IN OBLIQUE SEAS, INT'L. SHIPBUILDING PROGRESS, 20, No. 230, OCT. 1973.

ANALYTICAL COEFFICIENTS FOR SHIP (SERIES 60)

$$L = 5 \text{ ft}, B = .667 \text{ ft}, T = .267 \text{ ft}$$

$$L/B = 7.5, B/T = 2.5$$

BROAD SEAS, SHIP PROB

$$\bar{K} = K / \frac{1}{2} \rho g a^2 L, \bar{M} = M / \frac{1}{2} \rho g a^2 L^2$$

λ/L	$\bar{K}$	$\bar{M}$	w	f	$\sqrt{f}$	Δw	100 yr		3 yr	
							$\sum \bar{K} \Delta w$	$\sum \bar{M} \Delta w$	$\sum \bar{K} \Delta w$	$\sum \bar{M} \Delta w$
0.2	0.75	.01	1.64	0.26	11.2	0.48	4.03	0.05	9.1	3.3
0.4	0.71	.01	1.16	0.18	68.3	.48	23.28	0.33	5.1	17.7
0.6	0.26	.01	0.94	0.11	162.6	.22	9.3	0.36	11.1	6.4
0.8	0.25	.005	0.82	0.13	311	.12	9.3	0.19	18.2	5.6
1.0	0.22	0.0	0.73	0.12	438.1	.09	8.7	0	23.5	4.6
1.2	0.19	0.	0.67	0.11	620	.06	7.1	0	23.4	3.1
1.4	0.15	0.	0.62	0.10	889.3	.05	6.5	0	23.2	2.1
1.6	0.11	0.	0.58	0.09	1170.9	.04	5.2	0	23.1	1.0
							73.41	0.93	43.8	0.6

$$\frac{1}{2} \rho g a^2 L^2 = 0.5 \times 64 \times 378^2 = 4.572 \times 10^6 \text{ ft-lb/ft}^2$$

$$\frac{1}{2} \rho g a^2 L = 0.5 \times 64 \times 378 = 12096 \text{ lb/ft}^2$$

$$F = 12096 \times 2 \times 73.41/2 = 283,296 \text{ lb}$$

$$M = 4.572 \times 10^6 \times 2 \times 0.93/2 = 1.35 \times 10^6 \text{ ft-lb}$$

Wave Drift Force, 100 yr, Beam

" " Moment, 100 yr, Beam

$$F = 12096 \times 2 \times 43.8/2 = 168,700 \text{ lb}$$

$$M = 4.572 \times 10^6 \times 2 \times 0.65/2 = 9.5 \times 10^5 \text{ ft-lb}$$

Wave Drift Force, 3 yr, Beam

" " Moment, " "

4) POTVIN, SECOND-ORDER THEORY OF OSCILLATING CYLINDERS,
JOURNAL OF SHIP RESEARCH, 15, No. 4, Dec. 1971, pp. 295-324

TWO-DIMENSIONAL, SHIP SECTION, $B/T = 2$ BEAM WAVER, COUPLED SWAY & HEAV

$$K = \frac{BW^2}{2g}, \quad W = \sqrt{\frac{29.4}{8} K} = \sqrt{\frac{2 \times 32.2}{121}} \sqrt{K} = .73 \sqrt{K}$$

K	$\bar{F}_{CH}^{(2)}$	W (R/S)	f(H ₁)	GW	100 YR		3 YR STORM	
					N	$\int \bar{F}_{GW}$	N	$\int \bar{F}_{GW}$
.1	0	.23	.04	.17	0	0	0	0
.3	.05	.40	.06	.17	595	5.06	0	0
.5	.18	.52	.08	.08	143	20.35	117	1.7
.7	.27	.61	.10	.09	869	21.12	281	6.8
1.0	.32	.73	.12	.12	438	16.82	231	8.9
1.3	.32	.83	.13	.10	311	9.95	186	6.0
1.7	.29	.95	.15	.12	163	5.28	112	3.6
1.9	.25	1.01	.16	.06	120	1.8	86	1.3
						80.38		28.3

ASSUMING BARGE WITH NO END EFFECTS,

$$F = \bar{F}_{CH}^{(2)} \times 2fg\left(\frac{B}{2}\right)^2 L \times \epsilon^2, \text{ WHERE}$$

$$\epsilon = \max(a_i \frac{B}{6^2}), \quad a_i \approx \frac{H_{1/3}}{2}$$

$$3 YR: \quad \epsilon = \frac{(18.9/2) \times 1.9}{121^2} = .012, \quad \epsilon^2 = 1.34 \times 10^{-4}$$

$$100 YR: \quad \epsilon = \frac{(35.1/2) \times 1.9}{121^2} = .040, \quad \epsilon^2 = 0.0016$$

$$2fg\left(\frac{B}{2}\right)^2 L = 2 \times 64 \times \left(\frac{121}{2}\right)^2 \times 371 = 1.738 \times 10^8$$

$$\therefore F_{100} = \frac{80.38 \times 0.0016}{2\pi} \times 1.738 \times 10^8 \times 2 = 17.1 \times 10^6 \text{ LB}$$

$$\therefore F_3 = \frac{28.3}{2\pi} \times 1.34 \times 10^{-4} \times 1.738 \times 10^8 \times 2 = 209,800 \text{ LB}$$

Motion of Large Structures in Waves at Zero Froude Number
O.M. FENTONSON, F.C. MICHOLSON, INT'L SYMPOSIUM ON THE DYNAMICS OF
MARINE VEHICLES & STRUCTURES IN WAVES, LONDON 1978, pp 91-106.

ANALYTICAL, 3D, BOX SHIPS $L \times B \times d = 90 \times 90 \times 40 \text{ m}$. $L = B$
INCLUDES MOTION, HEAVE AND ROLLING REGULAR WAVE.

$$F_x = \bar{F}_x \rho g L a^2$$

SINCE

$$a_i^2 = \int_{w_i}^{w_i + \Delta w} S(w) dw \quad \times \frac{1}{\Delta w} \text{ is } S(F)$$

$$|\bar{F}_x| = \rho g L \int_0^a S(w) F_x(w) dw \times 2 \text{ (SEE REMARKS & COMMENTS)}$$

$$\frac{\lambda}{B} = \frac{g T^2}{2\pi B} = \frac{31.2}{2\pi \times 90 \times 1.28} \quad T^2 = 0.017 T^2$$

$$w = \frac{\sqrt{2\pi g}}{\lambda} \frac{1}{1.28} = \frac{1}{1.28} \frac{\sqrt{2\pi g}}{1.28} = \frac{1}{1.28} \frac{\sqrt{2\pi g}}{1.28} = 1.29 / \sqrt{1.28} \text{ FOR APL BARGE}$$

FOR GRAM SEAS

$T_{(SEC)}$	N/B	$w(1/4)$	$f(H_z)$	$\bar{F}$	$\int_0^T (F_{TSC})$	$\int_0^T (F_{TSC})$	ΔW	$\int_0^T \Delta W \bar{F}$	$\int_0^T \Delta W \bar{F}$
10	1.74	0.98	0.156	0.5	96	136	0.09	4.3	6.1
11	2.10	0.89	0.142	.4	140	205	.09	5.0	7.4
12	2.5	0.82	0.130	.34	186	311	.07	4.4	7.4
13	2.93	0.76	0.120	.28	231	438	.06	3.7	7.4
14	3.4	0.70	0.112	.26	265	580	.06	4.1	9.1
15	3.91	0.65	0.104	.36	281	760	.05	5.1	13.7
16	4.44	0.61	0.098	.70	275	930	.04	7.7	26.0
17	5.02	0.58	0.092	.30	240	1110	.03	2.2	10.0
18	5.55	0.55	0.088	.17	210	1230	.03	1.1	6.3
19	6.14	0.52	0.083	.13	153	1370	.03	0.6	5.3
20	6.8	0.50	0.079	(.09)	102	1416	.02	0.2	2.5
21	7.5	0.47	0.075	(.05)	60	1425	.03	0.1	2.1
22	8.2	0.45	0.072	0	37	1350	.02	0	2
								37.6	103.3

$$F = \rho g L \int_0^T F_{TSC} dw \times \frac{1}{2} \times 2$$

$$= 1.98 \times 32.2 \times 371 \times 37.6 = 283,096 \text{ lbs (3 YR.) BEAM}$$

$$\times 103.3 = 777,261 \text{ lbs (100 YR.)}$$

6/10/79
RLP

Wave Deck Force for Bridge in Head Seas

$$\frac{1}{L} = \frac{gT^2}{2\pi L} = 0.017 T^2 \quad \text{FOR } 90 \times 90 \times 45 \text{ m BRIDGE.}$$

$$\omega = \frac{1}{\sqrt{L}} \frac{\sqrt{2\pi g}}{\sqrt{\lambda/L}} = \frac{1}{\sqrt{378}} \frac{\sqrt{2\pi g}}{\sqrt{\lambda/L}} = 0.73 \frac{1}{\sqrt{\lambda/L}} \quad \text{FOR BRIDGE IN HEAD SEAS}$$

<u>T(sec)</u>	<u>λ/L</u>	<u>$\bar{F}$</u>	<u>$\omega(\text{r/s})$</u>	<u>$f(H_z)$</u>	<u>$N_2(\text{or } 3\sigma)$</u>	<u>$N_{100}(\text{or } 4\sigma)$</u>	<u>$\Delta\omega$</u>	<u>$\int \Delta\omega \bar{F}$</u>	<u>$\int_{100} \Delta\omega$</u>
10	1.74	.5	0.55	.088	210	1230	.05	5.25	30.75
11	2.10	.4	0.50	.080	117	1000	.05	2.30	28.00
12	2.5	.34	0.46	.073	45	1375	.09	0.61	18.7
13	2.93	.28	0.43	.068	13	1200	.03	0.11	10.1
14	3.4	.26	0.40	.063	1	830	.03	0.01	6.5
15	3.91	.24	0.37	.059	0	510	.03	0	5.5
16	4.44	.2	0.35	.055	0	160	.02	0	2.2
17	5.02	.3	0.33	.052	0	(50)	.02	0	0.3
18	5.57	.17	0.31	.049	0	(4)	.02	0	0.01
8	1.088	(.5)	0.70	0.111	265	580	.15	12.9	43.5
6	0.612	(.5)	0.93	0.149	115	171	.23	13.2	19.7
4	0.272	(.5)	1.40	0.223	19	(50)	.37	3.5	5.6
2	0.068	(.5)	2.80	0.446	0	0	1.4	0	0
								44.92	170.86

$$I^* = \rho g B \times 2 \times \frac{1}{2\pi} \int_0^{\omega} S(F) \bar{F}(\omega) d\omega$$

$$= 1.98 \times 32.2 \times 121 \times 2 \times \frac{1}{2\pi} \times 44.92 = 110,305 \text{ lb FOR 3 IN. HEAD}$$

$$\times 170.86 = 419,563 \text{ lb FOR 100 YR.}$$

EXAMPLE: Box $L \times B \times d = 90 \times 90 \times 40 \times 20$ meters
 $295 \times 295 \times 131$ ft³ (0-2)

$B/d = 2.25, \Delta = 325,722$ LT

(TABLE 3) $H_{1/2} = 16.5$ ft

$\bar{T} = 8.50$ sec

$T_0 = 11.3$ sec ($\Rightarrow f_0 = .088$ sec⁻¹)

$\bar{F}_H = 140$ tonnes (308,700 lbs)

CHECK: use Fig. 28 (MICHELAN) for $\bar{F}_H$ STRAIGHT, SINCE SAME BODY. $\omega = \frac{2\pi}{T}$

T (sec)	$\bar{F}$	ω (1/s)	$f(H_{1/2})$	$\sqrt{f(H_{1/2})}$	$\Delta \omega$	$\sum \Delta \omega \bar{F}$	$\sum \Delta \omega$
10	0.1	0.628	0.1	239	.162	19.9	38.7
11	0.4	0.571	0.091	272.5	.057	6.2	15.1
12	0.34	0.52	.083	265.4	.051	4.6	13.5
13	0.28	0.48	.077	222.2	.04	2.5	8.9
14	0.26	.45	.071	147.2	.03	1.2	4.4
15	0.36	.42	.067	91.1	.03	1.0	2.7
16	0.70	.39	.063	43.9	.03	0.9	1.3
17	0.30	.37	.059	14.6	.02	0.1	0.3
8	(0.5)	.74	.125	122.3	.17	10.4	21.6
6	(0.5)	1.05	.167	35.5	.26	4.6	9.2
						50.9	116.3

$F = \rho g L \int \bar{F} d\omega = \frac{1}{2\pi} \times 2$
 $= 1.98 \times 32.2 \times 295 \times 50.9 \times \frac{1}{2\pi} \times 2$
 $= 304,727$ lbs VS 308,700 lbs ✓

BEUTCHING DER SPECTRUM

$S(f) = 5 \left(\frac{H_{1/2}}{4} \right)^2 T_0 \left(\frac{f_0}{f} \right)^5 e^{-\frac{5}{4} \left(\frac{f}{f_0} \right)^4}$
 $= 5 \left(\frac{16.5}{4} \right)^2 11.3 \left(\frac{.088}{f} \right)^5 e^{-1.25 \left(\frac{.088}{f} \right)^4}$
 $= 961.38$

CHECK $a^2 = \int_0^\infty S d\omega = 18.51, a_1 = 9.3, a_{1/2} = 8.6, H_{1/2} = 12.2$ (VS 16.5)

MAKING:

$F_x = 0.5 \rho g a^2 h$
 $\approx 0.5 \times 1.98 \times 32.2 \times \left(\frac{16.5}{2} \right)^2 \times 295$
 $= 640,069$ lbs

ω IS A FUNCTION OF f , NOT ω
 WITH ω NOT f
 OR ω NOT f
 ALSO $\times 2$ (SEE REMARKS ABOVE)

COMPARISON OF WAVE DRIFT FORCES AND MOMENT

Sources	OPERATIONAL SEA STATE		EXTREME SEA STATE	
	$F_y (LB)$	$M (FTLB)$	$F_y (LB)$	$M (FTLB)$
SALVESEN (120°)	234,908	9.9×10^6	326,900	1.3×10^7
REMBERT & HERMANS	205,700	—	827,600	—
Kim & Chou	168,700	0.95×10^6	283,296	1.35×10^6
POTASH	209,800	—	7.1×10^6	—
FAJENSEN	283,096	—	777,761	—
LMSC-TATE I	420,517		330,376	

OTHER FACTORS

- (1) CLWP
- (2) DISCHARGE PIPES
- (3) SPAR

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 3

PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 0.DEG. CURRENT FROM 0.DEG.

WAVE FROM 0.DEG.

SIGNIFICANT WAVE HEIGHT(FT)= 19.9

MODAL WAVE PERIOD(SEC.)= 10.0

WIND SPEED(KT)= 29.5

SURFACE CURRENT(KT)= 1.7

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-20315.	-999.	-20315.	-999.	167969.	-10934.	0.
CURRENT	-199939.	0.	-199939.	0.	0.	-210203.	0.
WAVE	-110274.	0.	-110274.	0.	0.	-137229.	0.
TOTAL	-319429.	-999.	-319429.	-999.	167969.	-359266.	0.

VECTOR SUM 319429. 359266.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 1

PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 0.DEG. CURRENT FROM 0.DEG.

WAVE FROM 0.DEG.

SIGNIFICANT WAVE HEIGHT(FT)= 13.9

MODAL WAVE PERIOD(SEC.)= 9.5

WIND SPEED(KT)= 25.4

SURFACE CURRENT(KT)= 1.7

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-15107.	-735.	-15107.	-735.	124937.	-9057.	0.
CURRENT	-171261.	0.	-171261.	0.	0.	-190341.	0.
WAVE	-55992.	0.	-55992.	0.	0.	-70136.	0.
TOTAL	-242350.	-735.	-242350.	-735.	124937.	-269034.	0.

VECTOR SUM 242351. 269034.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 5

PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 0.DEG. CURRENT FROM 0.DEG.

WAVE FROM 0.DEG.

SIGNIFICANT WAVE HEIGHT(FT)= 21.3

MODAL WAVE PERIOD(SEC.)= 10.6

WIND SPEED(KT)= 52.4

SURFACE CURRENT(KT)= 2.1

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-90939.	-4417.	-90939.	-4417.	750647.	-49445.	0.
CURRENT	-272993.	0.	-272993.	0.	0.	-302529.	0.
WAVE	-142324.	0.	-142324.	0.	0.	-172127.	0.
TOTAL	-506056.	-4417.	-506056.	-4417.	750647.	-523101.	0.

VECTOR SUM 506056. 523101.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 50
 PLATFORM HEADING=0+DEG. (0 IS EAST) WIND FROM 0+DEG. CURRENT FROM 0+DEG.
 WAVE FROM 0+DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 31.9
 MODAL WAVE PERIOD(SEC.)= 12.5
 WIND SPEED(KT)= 75.9
 SURFACE CURRENT(KT)= 2.3

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-133415.	-6489.	-133415.	-6489.	1102479.	-71151.	0.
CURRENT	-331593.	0.	-331593.	0.	0.	-356755.	0.
WAVE	-343090.	0.	-343090.	0.	0.	-355256.	0.
TOTAL	-303059.	-6489.	-303059.	-6489.	1102479.	-793132.	0.

VECTOR SUM 303095. 793132.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 100
 PLATFORM HEADING=0+DEG. (0 IS EAST) WIND FROM 0+DEG. CURRENT FROM 0+DEG.
 WAVE FROM 0+DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 35.1
 MODAL WAVE PERIOD(SEC.)= 13.0
 WIND SPEED(KT)= 79.1
 SURFACE CURRENT(KT)= 2.4

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-146075.	-7104.	-146075.	-7104.	1207099.	-77902.	0.
CURRENT	-349277.	0.	-349277.	0.	0.	-335039.	0.
WAVE	-422194.	0.	-422194.	0.	0.	-416819.	0.
TOTAL	-915546.	-7104.	-915546.	-7104.	1207099.	-379759.	0.

VECTOR SUM 915573. 379759.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 200
 PLATFORM HEADING=0+DEG. (0 IS EAST) WIND FROM 0+DEG. CURRENT FROM 0+DEG.
 WAVE FROM 0+DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 39.3
 MODAL WAVE PERIOD(SEC.)= 13.5
 WIND SPEED(KT)= 92.4
 SURFACE CURRENT(KT)= 2.4

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-159674.	-7716.	-159674.	-7716.	1311202.	-94621.	0.
CURRENT	-354650.	0.	-354650.	0.	0.	-402940.	0.
WAVE	-510221.	0.	-510221.	0.	0.	-430747.	0.
TOTAL	-1033555.	-7716.	-1033555.	-7716.	1311202.	-969308.	0.

VECTOR SUM 1033594. 969308.

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PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 3
 PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 45.DEG. CURRENT FROM 25.DG
 S.WAVE FROM 45.DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 19.9
 MODAL WAVE PERIOD(SEC.)= 10.0
 WIND SPEED(KT)= 29.5
 SURFACE CURRENT(KT)= 1.7

PLATFORM	BARGE.....				SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	X(FT-LB)	FYI
WIND	-7043.	-29749.	-7043.	-29749.	245932.	-7661.
CURRENT	-167693.	-95495.	-155657.	-106596.	1500194.	-190509.
WAVE	-195537.	-195537.	-195537.	-195537.	-672022.	-97035.
TOTAL	-360273.	-300730.	-348237.	-321990.	1074004.	-295205.

VECTOR SUM 474211. 352999.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 100
 PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 45.DEG. CURRENT FROM 25.DG
 S.WAVE FROM 45.DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 35.1
 MODAL WAVE PERIOD(SEC.)= 13.0
 WIND SPEED(KT)= 79.1
 SURFACE CURRENT(KT)= 2.4

PLATFORM	BARGE.....				SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	X(FT-LB)	FYI
WIND	-50641.	-213905.	-50641.	-213905.	1767699.	-55095.
CURRENT	-309339.	-157497.	-297094.	-196599.	2719572.	-348964.
WAVE	-567400.	-567400.	-567400.	-567400.	-956163.	-294735.
TOTAL	-927430.	-938802.	-905125.	-977904.	3530109.	-699793.

VECTOR SUM 1332497. 966602.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 3
 PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 45.DEG. CURRENT FROM 25.DG
 S.WAVE FROM 45.DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 19.9
 MODAL WAVE PERIOD(SEC.)= 10.0
 WIND SPEED(KT)= 29.5
 SURFACE CURRENT(KT)= 1.7

PLATFORM	BARGE.....				SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	X(FT-LB)	FYI
WIND	-7043.	+29749.	-7043.	+29749.	245932.	7661.
CURRENT	-167693.	-95495.	-155657.	-106596.	1500194.	-190509.
WAVE	-195537.	195537.	-195537.	195537.	672022.	97035.
TOTAL	-360273.	70295.	-348237.	49194.	2413049.	15960.

VECTOR SUM 351694. 295631

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS) = 3
 PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM -45.DEG. CURRENT FROM 25.D
 SG. WAVE FROM -45.DEG.
 SIGNIFICANT WAVE HEIGHT(FT) = 13.9
 MODAL WAVE PERIOD(SEC.) = 10.0
 WIND SPEED(KT) = 29.5
 SURFACE CURRENT(KT) = 1.7

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-7043.	29749.	-7043.	29749.	-245932.	-7551.	7551.
CURRENT	-157593.	-35495.	-155557.	-105595.	1500194.	-190509.	-93936.
WAVE	-195537.	195537.	-195537.	195537.	572022.	-97035.	97035.
TOTAL	-360273.	129790.	-348237.	109639.	1926334.	-295205.	15360.
VECTOR SUM	354904.					295531.	

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS) = 100
 PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM -45.DEG. CURRENT FROM 25.D
 SG. WAVE FROM -45.DEG.
 SIGNIFICANT WAVE HEIGHT(FT) = 35.1
 MODAL WAVE PERIOD(SEC.) = 13.0
 WIND SPEED(KT) = 79.1
 SURFACE CURRENT(KT) = 2.4

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-50641.	213905.	-50641.	213905.	-1757599.	-55095.	55095.
CURRENT	-309399.	-157497.	-297084.	-195598.	2719572.	-343954.	-162724.
WAVE	-567400.	567400.	-567400.	567400.	955163.	-294735.	294735.
TOTAL	-927430.	623909.	-905125.	594707.	1907035.	-699793.	197096.
VECTOR SUM	1077559.					723397.	

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS) = 100
 PLATFORM HEADING=0.DEG. (0 IS EAST) WIND FROM 30.DEG. CURRENT FROM 30.D
 SG. WAVE FROM 30.DEG.
 SIGNIFICANT WAVE HEIGHT(FT) = 35.1
 MODAL WAVE PERIOD(SEC.) = 13.0
 WIND SPEED(KT) = 79.1
 SURFACE CURRENT(KT) = 2.4

PLATFORM	BARGE.....					SPAR....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-54369.	-221647.	-54369.	-221647.	4104939.	-67465.	-38951.
CURRENT	-299065.	-195314.	-244657.	-255840.	2657566.	-333453.	-192519.
WAVE	-594099.	-337229.	-594099.	-337229.	-1352213.	-350975.	-209409.
TOTAL	-941594.	-754190.	-993124.	-915716.	5410297.	-761393.	-439979.
VECTOR SUM	1209572.					379759.	

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS) = 100
 PLATFORM HEADING=0+DEG. (0 IS EAST) WIND FROM 45+DEG. CURRENT FROM 45+DE
 G. WAVE FROM 45+DEG.
 SIGNIFICANT WAVE HEIGHT(FT) = 35.1
 MODAL WAVE PERIOD(SEC.) = 13.0
 WIND SPEED(KT) = 73.1
 SURFACE CURRENT(KT) = 2.4

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-50641.	-213905.	-50641.	-213905.	1767699.	-55035.	-55035.
CURRENT	-231007.	-310205.	-119945.	-377753.	1259759.	-272264.	-272263.
WAVE	-567400.	-567400.	-567400.	-567400.	-956163.	-294735.	-294735.
TOTAL	-949048.	-1031510.	-737985.	-1159059.	2071295.	-622034.	-622033.
VECTOR SUM	1374059.					379759.	

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS) = 100
 PLATFORM HEADING=0+DEG. (0 IS EAST) WIND FROM 60+DEG. CURRENT FROM 60+DE
 G. WAVE FROM 60+DEG.
 SIGNIFICANT WAVE HEIGHT(FT) = 35.1
 MODAL WAVE PERIOD(SEC.) = 13.0
 WIND SPEED(KT) = 73.1
 SURFACE CURRENT(KT) = 2.4

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-36866.	-213331.	-36866.	-213331.	597905.	-33951.	-67465.
CURRENT	-155715.	-411364.	-47324.	-447126.	301346.	-192520.	-333453.
WAVE	-419343.	-726324.	-419343.	-726324.	?	-208409.	-360975.
TOTAL	-611924.	-1356569.	-503533.	-1331331.	899251.	-439930.	-761393.
VECTOR SUM	1480115.					379759.	

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS) = 100
 PLATFORM HEADING=0+DEG. (0 IS EAST) WIND FROM 90+DEG. CURRENT FROM 90+DE
 G. WAVE FROM 90+DEG.
 SIGNIFICANT WAVE HEIGHT(FT) = 35.1
 MODAL WAVE PERIOD(SEC.) = 13.0
 WIND SPEED(KT) = 73.1
 SURFACE CURRENT(KT) = 2.4

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	15333.	-229050.	15333.	-229050.	12932.	-.	-77902.
CURRENT	-.	-506674.	-.	-506674.	-.	-1.	-385039.
WAVE	-.	-791444.	-.	-791444.	1352213.	-.	-416913.
TOTAL	-15333	-1516162	15332	-1516169	1365201.	-.	-329759.
VECTOR SUM	1516246.					379759.	

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 100
 PLATFORM HEADING=45 DEG. (0 IS EAST) WIND FROM 45 DEG. CURRENT FROM
 175 DEG. WAVE FROM 45 DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 35.1
 MODAL WAVE PERIOD(SEC.)= 13.0
 WIND SPEED(KT)= 79.1
 SURFACE CURRENT(KT)= 2.4

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-50641.	-213905.	-50641.	-213905.	1767699.	-55035.	-55035.
CURRENT	200404.	22159.	-347637.	-3391.	-243775.	333573.	33559.
WAVE	-567400.	-567400.	-567400.	-567400.	-956163.	-294735.	-294735.
TOTAL	-417637.	-759136.	-965679.	-799696.	562791.	33754.	-316261.

VECTOR SUM 1247454. 319057.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 100
 PLATFORM HEADING=25 DEG. (0 IS EAST) WIND FROM 45 DEG. CURRENT FROM 25 DEG.
 25 DEG. WAVE FROM 45 DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 35.1
 MODAL WAVE PERIOD(SEC.)= 13.0
 WIND SPEED(KT)= 79.1
 SURFACE CURRENT(KT)= 2.4

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-39435.	-209274.	7342.	-227495.	7746903.	-55035.	-55035.
CURRENT	-348277.	0.	-315546.	-147139.	0.	-348964.	-162724.
WAVE	-525332.	-131409.	-395727.	-395727.	-1171056.	-294735.	-294735.
TOTAL	-963654.	-400633.	-704031.	-770400.	5575947.	-699733.	-512544.

VECTOR SUM 1043636. 366602.

PLATFORM ENVIRONMENTAL STATIC LOADS

RETURN PERIOD OF STORM(YRS)= 100. PLATFORM HEADING=45 DEG. (0 IS EAST) WIND FROM 45 DEG. CURRENT FROM 25 DEG. WAVE FROM 45 DEG.
 SIGNIFICANT WAVE HEIGHT(FT)= 35.1
 MODAL WAVE PERIOD(SEC.)= 13.0
 WIND SPEED(KT)= 79.1
 SURFACE CURRENT(KT)= 2.4

PLATFORM	BARGE.....					SPAR.....	
	FX(LB)	FY(LB)	FXI	FYI	N(FT-LB)	FXI	FYI
WIND	-146075.	-7104.	-93269.	-108314.	1207033.	-55035.	-55035.
CURRENT	-323097.	56764.	-131246.	-319151.	2359149.	-343964.	-162724.
WAVE	-422134.	0.	-299536.	-299536.	0.	-294735.	-294735.
TOTAL	-991366.	59660.	-529049.	-726011.	3566236.	-699733.	-512544.

VECTOR SUM 397735. 366602.

APPENDIX C

Life Cycle Cost Disbursement Schedules

C-1

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LOCKHEED MISSILES & SPACE COMPANY. INC.

MAL TURRET LOW SKSS DESIGN LCC AND DISBURS SCHEDULE IN THEN YEAR \$K

	1983	1984	1985	1986	1987	1988	1989	1990
CHAIN	2831.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	3546.	0.	0.	0.	0.	0.	0.	0.
ANCHORS	387.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	3787.	0.	0.	0.	0.	0.	0.	0.
TURRET	6895.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	1610.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	12059.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	31114.	0.	0.	0.	0.	0.	0.	0.
TAX & INS	0.	1089.	1089.	1089.	1089.	1089.	1089.	1089.
MAINT	311.	333.	356.	381.	408.	436.	467.	500.
TOTAL	31426.	1422.	1445.	1470.	1497.	1525.	1556.	1589.

	1991	1992	1993	1994	1995	1996	1997	1998
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	6975.	0.	0.	0.	0.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	0.	0.	6975.	0.	0.	0.	0.	0.
TAX & INS	1089.	1089.	1089.	1209.	1209.	1209.	1209.	1209.
MAINT	535.	572.	612.	655.	701.	750.	802.	858.
TOTAL	1624.	1661.	8676.	1864.	1910.	1959.	2011.	2067.

	1999	2000	2001	2002	2003	2004	2005	2006
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	0.	0.	13721.	0.	0.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	0.	0.	0.	0.	13721.	0.	0.	0.
TAX & INS	1209.	1209.	1209.	1209.	1209.	1445.	1445.	1445.
MAINT	919.	983.	1052.	1125.	1204.	1288.	1378.	1475.
TOTAL	2128.	2192.	2261.	2334.	16134.	2733.	2824.	2920.

	2007	2008	2009	2010	2011	2012	2013	2014
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	0.	0.	0.	0.	0.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	49112.
SUBTOTAL	0.	0.	0.	0.	0.	0.	0.	49112.
TAX & INS	1445.	1445.	1445.	1445.	1445.	1445.	1445.	1445.
MAINT	1578.	1689.	1807.	1933.	2069.	2214.	2369.	2534.
TOTAL	3023.	3134.	3252.	3379.	3514.	3659.	3814.	53092.

LCC IN 1979 IN \$K= 38268.0

ASSUMPTIONS : .07 ESCALATION; .10 DISCOUNT RATE; .035 TAX AND INS

MAL TURRET MID SKSS DESIGN LCC AND DISBURS SCHEDULE IN THEN YEAR \$K

	1983	1984	1985	1986	1987	1988	1989	1990
CHAIN	3256.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	3546.	0.	0.	0.	0.	0.	0.	5694.
ANCHORS	430.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	4208.	0.	0.	0.	0.	0.	0.	0.
TURRET	8618.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	1610.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	15074.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	3015.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	39756.	0.	0.	0.	0.	0.	0.	5694.
TAX & INS	0.	1391.	1391.	1391.	1391.	1391.	1391.	1391.
MAINT	398.	425.	455.	487.	521.	558.	597.	638.
TOTAL	40154.	1817.	1847.	1879.	1913.	1949.	1988.	7724.

	1991	1992	1993	1994	1995	1996	1997	1998
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	0.	0.	0.	0.	0.	9783.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	0.	0.	0.	0.	0.	0.	0.	9783.
TAX & INS	1467.	1467.	1467.	1467.	1467.	1467.	1467.	1467.
MAINT	683.	731.	782.	837.	895.	958.	1025.	1097.
TOTAL	2150.	2198.	2249.	2303.	2362.	2425.	2492.	12346.

	1999	2000	2001	2002	2003	2004	2005	2006
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	0.	0.	0.	0.	15709.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	0.	0.	0.	0.	0.	0.	15709.	0.
TAX & INS	1809.	1809.	1809.	1809.	1809.	1809.	1809.	2016.
MAINT	1174.	1256.	1344.	1438.	1538.	1646.	1761.	1885.
TOTAL	2983.	3065.	3153.	3247.	3347.	3455.	19279.	3901.

	2007	2008	2009	2010	2011	2012	2013	2014
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	0.	0.	0.	0.	0.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	61390.
SUBTOTAL	0.	0.	0.	0.	0.	0.	0.	61390.
TAX & INS	2016.	2016.	2016.	2016.	2016.	2016.	2016.	2016.
MAINT	2017.	2158.	2309.	2470.	2643.	2828.	3026.	3238.
TOTAL	4033.	4174.	4325.	4487.	4660.	4845.	5043.	66645.

LCC IN 1979 IN \$K= 49866.0

ASSUMPTIONS = .07 ESCALATION; .10 DISCOUNT RATE; .035 TAX AND INS

MAL TURRET HIGH

2808,2705,394,3852,9205,1228,161

MAL TURRET HIGH SKSS DESIGN LCC AND DISBURS SCHEDULE IN THEN YEAR \$K

	1983	1984	1985	1986	1987	1988	1989	1990
CHAIN	3681.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	3546.	0.	0.	0.	0.	4973.	0.	0.
ANCHORS	516.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	5049.	0.	0.	0.	0.	0.	0.	0.
TURRET	12066.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	1610.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	21104.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	12662.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	60234.	0.	0.	0.	0.	4973.	0.	0.
TAX & INS	0.	2108.	2108.	2108.	2108.	2108.	2158.	2158.
MAINT	602.	645.	690.	738.	790.	845.	904.	967.
TOTAL	60836.	2753.	2798.	2846.	2898.	7926.	3062.	3125.

LOCKHEED MISSILES & SPACE COMPANY, INC.

	1991	1992	1993	1994	1995	1996	1997	1998
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	6975.	0.	0.	0.	0.	9783.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	0.	0.	6975.	0.	0.	0.	0.	9783.
TAX & INS	2158.	2158.	2158.	2228.	2228.	2228.	2228.	2228.
MAINT	1035.	1107.	1185.	1268.	1357.	1452.	1553.	1662.
TOTAL	3193.	3266.	10318.	3496.	3585.	3680.	3781.	13673.

	1999	2000	2001	2002	2003	2004	2005	2006
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	0.	0.	0.	13721.	0.	0.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	0.
SUBTOTAL	0.	0.	0.	0.	13721.	0.	0.	0.
TAX & INS	2326.	2326.	2326.	2326.	2326.	2464.	2464.	2464.
MAINT	1778.	1903.	2036.	2178.	2331.	2494.	2669.	2855.
TOTAL	4105.	4229.	4362.	4505.	18378.	4958.	5133.	5320.

	2007	2008	2009	2010	2011	2012	2013	2014
CHAIN	0.	0.	0.	0.	0.	0.	0.	0.
WIRE ROPE	0.	19244.	0.	0.	0.	0.	0.	0.
ANCHORS	0.	0.	0.	0.	0.	0.	0.	0.
AUX MACH	0.	0.	0.	0.	0.	0.	0.	0.
TURRET	0.	0.	0.	0.	0.	0.	0.	0.
ENG LABOR	0.	0.	0.	0.	0.	0.	0.	0.
DEPLOYMENT	0.	0.	0.	0.	0.	0.	0.	0.
W DOWNTIME	0.	0.	0.	0.	0.	0.	0.	0.
SCRAP	0.	0.	0.	0.	0.	0.	0.	85946.
SUBTOTAL	0.	19244.	0.	0.	0.	0.	0.	85946.
TAX & INS	2464.	2464.	2658.	2658.	2658.	2658.	2658.	2658.
MAINT	3055.	3269.	3498.	3743.	4005.	4285.	4585.	4906.
TOTAL	5520.	24978.	6156.	6400.	6662.	6943.	7243.	93510.

LCC IN 1979 IN \$K: 75464.0

ASSUMPTIONS : .07 ESCALATION; .10 DISCOUNT RATE; .035 TAX AND INS

```

1      C: PROGRAM P00 CALCULATES LIFE CYCLE COSTS FOR SKSS PROJECT
2      REAL CD(15,3),TC(20,35),TIC(35),ESC,R,TI,OM,TIM
3      INTEGER DOYR,STYR,LIFE,HLIFE,TYPE,SC,ST,CEY,DAT(35)
4      INTEGER ALIFE,ASTYR
5      STRING NAMES(20)(10),CON(17)
6      3000 CONTINUE
7          TIM=0
8          IC=0
9          LOC=0
10         ACCEPT CON,TYPE
11         DO 300 M=1,TYPE
12             CD(M,2)=1983
13             ACCEPT NAMES(M),CD(M,1),CD(M,3)
14         300 TIM=TIM+CD(M,1)
15             GO TO 302
16     3001 IC=IC+1
17             TIM=0
18             LOC=0
19             TYPE=TYPE-1
20             ACCEPT CON
21             ACCEPT (CD(M,1),M=1,TYPE)
22             ACCEPT (CD(M,3),M=1,TYPE)
23             DO 301 M=1,TYPE
24                 TIM=TIM+CD(M,1)
25     301 CONTINUE
26     302 TYPE=TYPE+1
27             CD(TYPE,1)=CD(TYPE-2,1)/2
28             CD(TYPE,2)=2014
29             CD(TYPE,3)=30
30             NAMES(TYPE)="SCRAP"
31             DATA DOYR/1979/,ASTYR/1984/,ALIFE/30/
32             DATA ESC/.07/,R/.10/,TI/.035/
33             OM=TIM*.01
34             NAMES(TYPE+1)="SUBTOTAL"
35             NAMES(TYPE+2)="TAX & INS"
36             NAMES(TYPE+3)="MAINT"
37             NAMES(TYPE+4)="TOTAL"
38             C: LOAD COST DATA ITEMS INTO OVERALL COST ARRAY TC
39             LIFE=ALIFE+2
40             STYR=ASTYR-1
41             DO 105 J=1,LIFE
42                 TIC(J)=0
43             DO 105 I=1,TYPE+4
44     105 TC(I,J)=0
45             DO 100 I=1,LIFE
46     100 DAT(I)=STYR+I-1
47             HLIFE=LIFE/4
48             CEY=STYR-DOYR
49             DO 110 I=1,TYPE
50                 N=ENTIER((LIFE-1)/CD(I,3))
51                 SC=CD(I,2)-STYR+1

```

```

52      DO 110 J=1,M
53      ST =SC+(J-1)*CD(I,3)
54      110  TC(I,ST)=TC(I,ST)+CD(I,1)
55      C: ESCALATE COST ARRAY AND CALCULATE TOTAL COST, O&M,
        TAKES AND INSURANCE BY YEAR; LAST STEP IS CALCULATION OF LOC
56      DO 130 J=1,LIFE
57      DO 120 I=1,TYPE
58      TC(I,J)=TC(I,J)*((1+ESC)**(CEY+J-1))
59      TC(TYPE+1,J)=TC(TYPE+1,J)+TC(I,J)
60      IF (TC(I,J).NE.0 .AND. J.GT.CD(I,3))
        TIC(J)=TIC(J)+TC(I,J)-TC(I,J-ENTIER(CD(I,3)))
        ELSE, TIC(J)=TIC(J)+TC(I,J)
61      120  CONTINUE
62      TC(TYPE+2,J+1)=TIC(J)*TI
63      TC(TYPE+3,J)=OM*((1+ESC)**(CEY+J-1))
64      130  TC(TYPE+4,J)=TC(TYPE+1,J)+TC(TYPE+3,J)
65      DO 140 J=1,LIFE
66      IF (J.EQ.1) GO TO 140
67      TC(TYPE+2,J)=TC(TYPE+2,J)+TC(TYPE+2,J-1)
68      TC(TYPE+4,J)=TC(TYPE+4,J)+TC(TYPE+2,J)
69      140  LOC=LOC+TC(TYPE+4,J)/((1+R)**(CEY+J-1))
70      C: WRITE OUTPUT
71      WRITE (1,1000) CON
72      1000  FORMAT (//////,A17," SKSS DESIGN LOC AND DISBURS
        SCHEDULE IN THEN YEAR $K",////)
73      WRITE (1,1200) (DAT(I),I=1,HLIFE)
74      1200  FORMAT (13X,10I7)
75      DO 200 I=1,TYPE+4
76      200  WRITE (1,1300) NAMES(I),(TC(I,J),J=1,HLIFE)
77      1300  FORMAT (1X,A10,2X,10F7.0)
78      WRITE (1,1400)
79      1400  FORMAT (//)
80      WRITE (1,1200) (DAT(I),I=HLIFE+1,2*HLIFE)
81      DO 210 I=1,TYPE+4
82      210  WRITE (1,1300) NAMES(I),(TC(I,J),J=HLIFE+1,2*HLIFE)
83      WRITE (1,1400)
84      WRITE (1,1200) (DAT(I),I=2*HLIFE+1,3*HLIFE)
85      DO 220 I=1,TYPE+4
86      220  WRITE (1,1300) NAMES(I),(TC(I,J),J=2*HLIFE+1,3*HLIFE)
87      WRITE (1,1400)
88      WRITE (1,1200) (DAT(I),I=3*HLIFE+1,LIFE)
89      DO 230 I=1,TYPE+4
90      230  WRITE (1,1300) NAMES(I),(TC(I,J),J=3*HLIFE+1,LIFE)
91      WRITE (1,1100) DOYR,LOC,ESC,R,TI
92      1100  FORMAT (//,20X,"LOC IN ",I4," IN $K:",F10.1,/,2X,
        "ASSUMPTIONS :",F4.2," ESCALATION:",F4.2,
        " DISCOUNT RATE:",F5.3," TAX AND INS",//)
93      IF (IC.EQ.2) GO TO 3000 .ELSE. GO TO 3001
94      3000  STOP
95      END

```

APPENDIX D*

Conceptual Designs for OTEC Stationkeeping Subsystems

*Sections III, IV, and V of the IMODCO Task II Report are located in Section 3.2.

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Reference Number:

Date:

CONCEPTUAL DESIGNS
FOR
OTEC STATIONKEEPING SUBSYSTEMS

IMODCO PROJECT 1103

29 June 1979

Prepared as part of Contract NA-79-SAC-00635 for
NOAA and DOE under Subcontract YF80C1350F for LMSC

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SECTION I

TASK DESCRIPTION

I.1 Introduction

IMODCO is currently engaged in a subcontract from Lockheed Missiles and Space Company (LMSC) to study mooring systems for the OTEC Stationkeeping Subsystem. This subcontract is part of a program to build OTEC power cycle systems in the 10-40 Megawatt range.

Eight alternative designs were originally considered, and IMODCO was tasked with studying four of these (including one which LMSC would also study). Refer to Figure 1. Presented herein are IMODCO's results for Task II, Conceptual Design. This will be followed by a preliminary design of a single concept, pending review and selection by NOAA and DOE.

I.2 Concept Proposals

The four conceptual designs considered by IMODCO are:

- 1) Single Anchor Leg - Single Point Moor (SAL)
- 2) Multiple Anchor Leg - Multi Point Moor (MAL)
- 3) Tension Anchor Leg (TAL)
- 4) Tension Anchor Leg - Monopod (TAL-MONOPOD)

FIGURE 1

SECTION II

SINGLE ANCHOR LEG-SINGLE POINT MOOR (SAL)

II.1 System Description

The single point mooring terminal proposed for the OTEC vessel and cold water pipe employs a yoke which attaches the vessel to the mooring buoy. The mooring buoy is a buoyant structure which is connected to a gravity mooring base on the seabed by a wire rope anchor leg and universal joints which allow the buoy to rotate in any direction. The mooring yoke is attached at the top of the tower by means of a tri-axial universal joint which accommodates all movements of the yoke relative to the tower. The yoke is connected to the OTEC vessel's structural extensions by means of pivot joints, which permit the vessel to pitch relative to the yoke. See Figure 2.

II.1.1 Mooring Buoy

The mooring buoy consists of a large buoyancy chamber near the upper end of the buoy and a ballast chamber at the bottom. The overall net buoyancy of the system is 250 kips. This balance of buoyancy and ballast is necessary to support the large weight at the top of the structure while keeping the chain tensions at acceptable levels. This balance also provides seakeeping stability in all design environments.

The buoy structure is an all welded steel structure, with concrete used as ballast. The moment provided by the buoyancy provides a restoring force in response to the vessel displacements caused by environmental forces. The

FIGURE 2

IMODCO

structure is designed to transmit the design axial load from the mooring yoke to the anchor leg.

The buoyancy chamber is segmented into a series of watertight compartments by means of decks and bulkheads. Access to each compartment is gained by watertight manholes. To assist in installation, the lower compartments of the buoyancy chamber may be ballasted with water and later deballasted. After final inspection and tests, the completed buoy is placed afloat in order to check its weight, and trim.

Integrity of all watertight compartments will be demonstrated by air testing them to pressures in accordance with the pertinent requirements of the American Bureau of Shipping.

II.1.2 Tri-Axial Swivel Universal Joint

A patented IMODCO tri-axial swivel universal joint (See Figure 3 for a sketch of a typical unit) is mounted at the top of the buoy. It is designed to withstand the maximum design loads in tension and compression imposed by the vessel through the mooring yoke, and to transmit such loads through the rotating table to the buoy structure.

The universal joint is mounted on a turntable. The mooring yoke is attached to the universal joint by two pivot joints located at 90° to the pedestal joints. The table rotates by means of a precision bearing designed to withstand radial and axial loads. This arrangement permits the yoke three degrees of freedom. The universal joint is designed to rotate 360° in yaw, and pitch at least 90 degrees up and 30 degrees down to accommodate the yoke motion.

FIGURE 3
IMODCO TRI-AXIAL SWIVEL

The couplers of the universal joint are fabricated from steel plate, and are provided with press fitted, self-lubricated journal and thrust bushings.

Rotating surfaces in contact with the bushings are protected against corrosion by a weld deposited overlay of Monel.

All yoke/bushing and bushing/coupler contact surfaces are parallel to assure full area contact.

II.1.3 Mooring Yoke

The mooring yoke is a fabricated tubular steel structure, configured as an A-frame. It is attached at its apex to the tri-axial universal joint and at its base to two pivot joints fitted on the bow of the vessel (See Figure 4).

The yoke is designed to withstand the maximum design loads generated by the vessel under 100 year storm conditions. By means of the pivot attachment joints, the vessel is permitted to pitch with respect to the yoke.

The hinges connecting the mooring arm to the fixed structural yoke extension from the vessel are designed for minimum maintenance. It is intended that connection of the mooring arm to the vessel through these hinges shall take place in the shipyard prior to any float-out to assure positive connection and to minimize installation time.

II.1.4 Universal Joints

Two universal joints are utilized in the design. One is mounted at the lower end of the mooring buoy and the other is mounted in the center of the mooring base. The universal

FIGURE 4
IMODCO MOORING YOKE

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joints are designed to allow the necessary rotation of the buoy and anchor leg during all environmental conditions. In addition, the universal joint attached to the buoy is capable of rotation of up to 90° from the vertical in one direction, to aid in assembly, transportation and installation (See Figure 5 for a typical universal joint).

The couplers of the universal joints are fabricated from steel plate, and are provided with press fitted, self-lubricated journal and thrust bushings. Rotating surfaces in contact with the bushings are protected against corrosion by a weld-deposited overlay of Monel.

A hydraulically operated locking device is provided for securing the universal joint to the mooring base. The lower portion of the universal joint has a stab-in section which, when coupled with guide wire equipment, allows for more positive positioning and securing into the mooring base during the installation sequence.

II.1.5 Anchor Leg

The anchor leg assembly connects the mooring buoy to the mooring base, through which all loads are transferred. The anchor leg consists of 4-1/2 inch diameter galvanized bridge wire rope and a section of joining and kenter shackles. The shackles can be adjusted in length to accommodate for installation errors in a water depth which varies from the design water depth.

The ends of the wire rope are attached to joining shackles with open wire rope sockets which will be designed for this special application by U.S. Steel or equivalent manufacturer.

IMODCO
ARTICULATED RISER WITH YOKE
BASE UNIVERSAL JOINT

Both ends of the anchor leg are attached to the universal joints by joining shackles.

The wire rope is covered with a polyethylene jacket which is 1/4 inch thick. The wire rope sockets are also coated with polyethylene boot.

II.1.6 Mooring Base

The mooring base is designed to withstand the loads generated by the yoke moored vessel under the 100 year storm conditions. A gravity base design is based on design loads only because no soils and seabed data has been provided.

The typical mooring base is an all welded, fabricated steel structure. The mooring base is designed to receive the stub-in taper of the base universal joint, and is fitted with receivers to mate with the latching rams of the universal joint to lock the universal joint into place. Padeyes are strategically located on the mooring base for lifting the base, and for guiding the cable used during the installation of the riser. The base will be ballasted with concrete to obtain the necessary weight to resist the mooring forces.

II.2 Conceptual Design Analysis

The method of analysis used to derive the design loads in the mooring system during the storm and operational conditions is based on empirically derived, proprietary design procedures.

II.2.1 Wave, Wind, and Current Forces on the Moored Vessel

Combined wind and current loads on the vessel are derived using data and procedures determined from model testing and analysis of tankers wherein drag and lift coefficients for wind and current were derived as a function of ship heading. For a given direction of wind and current, the position and heading of a moored vessel may be calculated and the mooring forces caused by wind and current determined. This is computerized so that the relative angle between the current and wind directions may be varied to find the relationship causing the maximum force. (Refer to Table 2-2)

Wave forces on the moored vessel are determined from proprietary information developed by EXXON with whom IMODCO has a license agreement for design, construction, and sale of the SALM concept of offshore mooring terminals. The force-deflection curve for the terminal (Figure 6) is derived using the computer program 'TLM' developed by IMODCO for that purpose.

The maximum design loads resulting from combined wind, waves, and current are derived using an energy approach developed by EXXON for single anchor leg moorings. The method is similar to that described in Offshore Technology Conference paper 1536, (1972 Maddox, N.R.) and is based on

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OTEC/SKSS

SAL-SINGLE POINT MOOR

FORCE-DEFLECTION CURVE

FIGURE 6

extensive model tests of SALM terminals, details of which are proprietary. A brief summary of the procedure is as follows:

- 1) The significant energy is found as a function of the vessel and the significant height of the waves (proprietary procedures).
- 2) The position and significant mooring force required to absorb this energy are determined using the static deflection curves.
- 3) A ratio of design maximum to significant force is derived based on a selected probability of exceedance and the storm duration (proprietary procedures).
- 4) The significant mooring force is multiplied by this ratio to determine design mooring forces.
- 5) The position of the mooring subjected to the design mooring force is found and used to derive the mooring force on the components of the system.

II.2.2 Mooring Buoy Sizing

The sizing of the mooring buoy required a trade-off study between the following key items:

- 1) Minimizing the net buoyancy to keep the anchor leg tension low.
- 2) Providing sufficient buoyant restoring force to keep horizontal displacements small.
- 3) Positioning the buoyancy so that the buoy remains stable in the trough of the largest wave.

Several configurations were analyzed to arrive at the conceptual design presented here. From the analysis it was

MOD 40

found that a long buoy with buoyancy placed near the top and ballasted at the lower end is required to satisfy the design requirements. See Figure 7 for buoy size.

II.2.3 Mooring Base Design

The mooring base was designed to resist all loads by means of gravitational resistance. The weight of the base was designed to meet the following requirements:

- 1) Resist the vertical uplift imposed by the buoyancy and mooring loads.
- 2) Prevent horizontal movement due to the horizontal loads.
- 3) Resist the overturning moment caused by the application of the horizontal component at the universal joint pin.

No settlement analysis was performed because no seabed survey has been performed. It is assumed though, that a settlement will occur because the seabed surface is yellow clay.

The base weight for this concept is 4420 kips. It has a square cross-section of 60 feet by 60 feet and is 10 feet deep. The base is a steel supported structure which is ballasted with concrete.

FIGURE 7

II.3 Summary

A summary of the concept's performance is shown in Table 2-1. From a review of the Table it can be noted that there are several major problems involved with this concept.

Tension in the anchor leg is the most serious of these problems. Various buoy sizes were used in the design analysis with no success in finding one that would keep the anchor leg tension at acceptable levels. No wire rope or synthetic line with proven capabilities is presently capable of handling the load. Chain cannot be used because of its tremendous weight. Buoyancy modules at intervals along the anchor chain were briefly considered in order to reduce the weight of chain in water. The size and strength requirements for these modules appear to make this approach unattractive.

The angle the chain makes from the vertical in the 3-year storm is 15° and may be too severe for the electrical transmission cable. This angle causes cold water pipe excursion of 1067 feet. Simplex will need to design around this problem.

These problems severely limit the adaptability of the SAL-Single Point Moor to the OTEC program. Unless a lightweight and extremely strong (B.S. > 7500 kips) anchor leg is developed, this concept can be considered not feasible.

**SAL - SINGLE POINT MOOR
PERFORMANCE CHARACTERISTICS**

	3-YEAR RETURN	100-YEAR RETURN
HORIZONTAL FORCE	140 KIPS	460 KIPS
BUOY INCLINATION	6.7°	11°
ANCHOR LEG INCLINATION	15°	15.3°
YOKE TENSION	376 KIPS	1588 KIPS
ANCHOR LEG TENSION	588 KIPS	1802 KIPS
ANCHOR LEG SAFETY FACTOR	3.15	1.03
WATCH CIRCLE RADIUS	925 FEET	937 FEET

TABLE 2-1

SAL-SINGLE POINT MOOR
ENVIRONMENTAL LOADS

	3-YEAR RETURN	100-YEAR RETURN
WIND AND CURRENT ON SHIP	59 KIPS	223 KIPS
CURRENT ON CWP	46 KIPS	112 KIPS
WAVE ON SHIP AND CWP	35 KIPS	125 KIPS
TOTAL HORIZONTAL LOAD	140 KIPS	460 KIPS

TABLE 2-2

SECTION VI

COMPUTER PROGRAMS

VI.1 General

All computer programs used were run on IMODCO's in-house computer, a Digital Equipment Corporation PDP 11/70. Computer programs used for analysis were developed and used prior to this study and are proprietary to IMODCO. Descriptions given here are to acquaint the customer with IMODCO's procedures. All the computer programs have been compared to model test results (also proprietary to IMODCO) over the past several years to assure their validity.

VI.1.2 'Tension Leg Mooring' (TLM) Program

TLM is a quasi-static analysis program which determines loads based on an energy approach developed for single anchor leg moorings. The energy approach was developed on the basis of many tests by Exxon, thereby giving the static analysis inherent dynamic characteristics.

The program gives significant and maximum loads and inclinations resulting from the combined action of wind, wave, and current. Tensions and force components given by the program can be used directly to design the base, anchor leg and mooring yoke.

VI.1.3 'TOWER' Computer Program

This computer program is used for the analysis of the static/dynamic response of offshore tower structures.

The natural frequencies and mode shapes of the total tower structure is obtained by solving the characteristic equation with stiffness and inertia matrices. In the tower program, the hydrodynamic wave force is obtained by either the Morison equation or diffraction theory. The wave theory used can be either Airy's linear wave theory or Stoke's fifth order.

The dynamic response of the tower structure is obtained by performing a numerical integration of the matrix equation of motion. The integration method used here is the Newmark method.

VI.1.4 'WAVEM' Computer Program

WAVEM provides the wave and current induced bending moments on towers. Using this program, the tower is input at its maximum angle and the wave and current are passed by.

The program uses the Morison equation for calculating flow-induced loads on the structure. The accuracy of this method has been checked favorably with model tests.

VI.1.5 'CEDP' Computer Program

CEDP is written to perform a catenary anchor leg mooring analysis using the energy deflection method. The mooring system is assumed to be a static system consisting of non-linear springs (chain, wire rope or synthetic).

The buoy is displaced by increments to produce a table of mooring loads and potential energy absorbed by the mooring.

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Options of the program provide the ability to specify unequal anchor leg properties, location of attachment to the buoy, and the pretension angle of the anchor leg.

Program output includes the buoy horizontal position (watch circle radius), maximum anchor leg tension, potential energy absorbed by the system, and the horizontal force.

IMODCO

SECTION VII

CONCEPT DESIGN PRICING

VII.1 OTEC Cost Summary

On the following pages are the rough order-of-magnitude costs for the OTEC/SKSS conceptual designs. Cost estimates are given for all eight concepts (refer to Figure 1), including both IMODCO and LMSC designs.

VII.1.1

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: SAL - SINGLE POINT MOOR

HARDWARE¹

Anchor Leg	467,000
Mooring Base	3,350,000
Mooring Buoy	6,185,000
Base & Buoy U-Jts	825,000
Yoke	1,525,000
Tri-axial Swivel	980,000

LABOR²

932,000

TOTAL HARDWARE & LABOR

14,264,000

MOBILIZATION/DEMOBILIZATION

1,000,000

INSTALLATION

4,500,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$25,264,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings; construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

VII.1.2

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: MAL (SPAR MOOR)

HARDWARE¹

Chain	2,101,000
Wire Rope	2,021,000
Wire Rope Connectors	40,000
Hawse Pipe & Shear Plate	1,945,000
Hawse Pipe Connectors	3,266,000
Anchor Shackles	8,500
Swivel Shackles	43,000
Chain Stoppers	10,500
Anchors	435,000

LABOR²

655,000

TOTAL HARDWARE & LABOR

10,525,000

MOBILIZATION/DEMOBILIZATION

1,000,000

INSTALLATION

5,000,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$22,025,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

VII.1.3

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: MAL-MPM (ACTIVE TENSIONING)

HARDWARE¹

Wire Rope	4,850,000
Wire Rope Connectors	100,000
Chain	4,682,000
Anchors	547,000
Auxiliary Machinery	4,167,000

LABOR²

971,000

TOTAL HARDWARE & LABOR

15,324,000

MOBILIZATION/DEMOBILIZATION

1,000,000

INSTALLATION

5,000,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$26,824,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

VII.1.4

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: MAL-MPM (TURRET)

HARDWARE¹

Wire Rope	2,645,000
Chain & Fittings	2,160,000
Wire Rope Connectors	60,000
Anchors	328,000
Auxiliary Machinery	3,210,000
Turret Assembly	6,575,000

LABOR²

1,228,000

TOTAL HARDWARE & LABOR

16,206,000

MOBILIZATION/DEMObILIZATION

1,000,000

INSTALLATION

5,000,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$27,706,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

VII.1.5

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: MAL-MPM (SPREAD MOORING)

HARDWARE¹

Wire Rope	4,410,000
Wire Rope Connectors	100,000
Chain	4,682,000
Auxiliary Machinery	3,210,000
Anchors	547,000

LABOR²

800,000

TOTAL HARDWARE & LABOR

13,749,000

MOBILIZATION/DEMOBILIZATION

1,000,000

INSTALLATION

5,000,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$25,249,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

VII.1.6 COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: MAL-SPM

HARDWARE¹

Wire Rope	5,560,000
Wire Rope Connectors	135,000
Anchor Base	891,000
Buoy	2,380,000
Mooring Hawasers	76,000
Auxiliary Machinery	3,210,000
Hawser Winches	160,000

LABOR ²	1,006,000
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TOTAL HARDWARE & LABOR	13,418,000
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MOBILIZATION/DEMOBILIZATION	1,000,000
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INSTALLATION	5,000,000
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DIVING	4,000,000
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DIVING CONSUMMABLES	1,500,000
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TOTAL SUPPLY & INSTALLATION COST	\$24,918,000
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NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

VII.1.7

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: TAL (SPAR MOOR)

HARDWARE¹

Base Structure	4,237,000
Vetco Connecotr, U-Jt To TAL	138,000
U-Jt Assembly	700,000
Tension Leg	2,478,000

LABOR²

460,000

TOTAL HARDWARE & LABOR

8,013,000

MOBILIZATION/DEMOBILIZATION

1,000,000

INSTALLATION

3,750,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$18,263,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

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VII.1.8

COST ESTIMATE SUMMARY SHEET

PROJECT: OTEC 40 MW, SKSS

CONFIGURATION: TAL-MONOPOD (SPAR MOOR)

HARDWARE¹

Base Structure	4,237,000
Vetco Connector U-Jt to TAL	140,000
Base U-Jt Assembly	350,000

LABOR²

365,000

TOTAL HARDWARE & LABOR

5,092,000

MOBILIZATION/DEMOBILIZATION

1,000,000

INSTALLATION

1,500,000

DIVING

4,000,000

DIVING CONSUMMABLES

1,500,000

TOTAL SUPPLY & INSTALLATION COST

\$13,092,000

NOTES:

1. Hardware cost estimates include contingency, freight, storage, insurance, handling costs and fee.
2. Labor activities include engineering and consulting, development of manuals and drawings, construction supervision, installation planning and supervision, and liaison and reporting. The cost estimates include contingency, engineering burden, G & A, and fee.
3. Cost estimates include the above items in an attempt to reflect realistic total costs. Costs are based on supplying all services and equipment; a reduced scope may result in unit cost increases.
4. Cost estimates are for June 1979. Escalations are not included.
5. Cost estimates are for planning and study purposes only; this is not an offer to supply these systems.

APPENDIX E

Mooring Static Analysis

OBJECTIVE

The objective of this analysis is to calculate the configuration of a multiple-anchor-leg mooring system, in a current, with various loading conditions applied to the moored platform. Solution of this problem requires the determination of forces on, and coordinates of, an array of cables attached to the surface platform and extending out to anchors emplaced on the sea floor.

METHOD OF SOLUTION

Vector equations describing the static force balance of an anchor cable (see Reference 1) are integrated along the cable length from the platform attachment point to the ocean floor. This is an iterative process which varies the vertical tension component at the platform attachment point until the chain or last cable segment is tangent to the ocean bottom. Chain length remaining, after the tangency condition, is stretched on the bottom, between the tangent point and the anchor.

A second iteration procedure varies the two horizontal tension components of each anchor cable to achieve a position and force balance with the platform current and wind load. This technique can be utilized to provide analysis of either a taut moor or a slack moor as in the present investigation.

DISCUSSION

Figure 1 shows the radial pattern of 10 anchor cables attached at a radius of 50 feet from the center of the platform. These cables are numbered in a clockwise direction when viewed from above starting with the cable nearest the wind and current direction. The angular difference between cable directions will be held constant throughout this study. These 10 mooring lines are spaced 36 degrees apart.

Typical mooring line contours are displayed in Figure 2. These are the upstream and downstream lines in a 10 anchor leg moor. The upstream mooring line has pulled a much greater length of chain off the bottom than the downstream line in this diagram. Resistance of this moor to platform excursion is provided by an increase in line tension when the additional length of chain is lifted on the upstream side. Greater mooring stiffness can be provided by spreading out the anchors while the length of each mooring leg remains constant. Spreading the anchors will result in increasing the initial tension (pretension) in each mooring leg before a displacement force loading is applied to the platform.

Length of chain, in excess of that lifted from the bottom in worst conditions, is not useful in providing additional restraint on platform excursion. Excess chain lies on the ocean bottom and provides other than the additional frictional damping for lateral motions. System handling requirements here impose a chain length lower limit which is larger than that necessary to meet mooring excursion boundaries. Changing out one of the wire rope sections, without disturbing the anchor, requires that the chain length used is somewhat greater than the water depth (4500 feet for this study). Since the water depth for this study is 4000 feet, this length allows the wire rope-chain junction to be pulled out of the water during the process of changing the wire rope, without disturbing the anchor.

GROUND RULES FOR THE TRADE STUDY

A mooring array consisting of 10 anchor legs was used throughout this study. This number of anchor legs reduces the maximum cable tension, experienced during 3 year storm conditions, to a value consistent with the working limits of $1/3$ cable breaking strength, without the use of premium strength wire rope.

Each anchor leg was made up of a length of $4\frac{1}{2}$ inch wire rope of modulus 19×10^6 psi and breaking strength 1.85×10^6 lbs plus 4500 feet of $3\text{-}5/8$ inch

MOORING LINE CONFIGURATION

100 YEAR STORM

3600 Feet Wire Rope

SURFACE

EXCURSION

CURRENT
PLATFORM LADING
1802543 lbs.

Cable 6

3000

2000

1000

WIRE ROPE

WIRE ROPE

CHAIN

WATER DEPTH - FEET

-3000

-2000

-1000

0

1000

2000

3000

4000

5000

DISTANCE - FEET

Figure 2

chain. The wire rope has a weight in water of 30.6 lbs/ft and the chain 139.3 lbs/ft.

Length of the wire rope section was varied during the trade study. A different amount of pretension was used for each length of wire-rope selected. Each value of pretension (Figure 5) was sufficient to prevent any portion of wire rope from touching the bottom on the downstream side of the moor under 100 year storm loading conditions.

Wire rope lengths of less than 4000 feet do not require a value of pretension greater than the weight of cable and chain supported to satisfy this criterion. However, setting the anchors at a reasonable range introduces a horizontal tension component of 200,000 pounds or greater which adds vectorially to the vertical weight component of tension for the 3600 feet of wire rope. This effect is illustrated in Figure 3 with the horizontal range from the platform to the anchors plotted as a function of wire rope length. rope.

TRADE STUDIES

The length of the wire rope segment of each of the mooring legs was varied from 3600 feet to 5600 feet. Corresponding pre-tensions necessary ranged from 425,400 to 574,400 pounds. See Figure 5.

Values of maximum tension and maximum length of chain lifted from the ocean bottom during the 100-year storm are plotted in Figure 4 versus wire rope length. Both of these maxima occur on leg number 1.

Figure 5 displays the resulting platform excursion and pretension as a function of wire rope length.

Variation of these parameters indicates that shorter lengths of wire rope provide lower maximum tensions, but increase the platform excursion.

MULTIPLE ANCHOR LEG MOOR

ANCHOR RANGE ALTERS PRE-TENSION

Figure 3

MULTIPLE ANCHOR LEG MOOR
TRADE STUDY
100 year Storm

10 ANCHOR LEGS
PLATFORM LOAD 1202843

Figure 4

A length of 3600 feet of wire rope gives excursions which are within system limits of 10 percent of water depth in a 3 year storm. This length also produces a maximum tension of approximately 1/3 breaking strength, in leg number 1, for the 3 year storm condition. Maximum tension and platform restoring force variation with platform excursion are displayed in Figure 6, for the 3600 foot length of wire rope.

A listing of the mooring configuration under the 3 year storm load (729,529 lbs.) and the 100 year storm load (1,202,843 lbs.) is included. Column titles indicate

S, SS	(ft)	Unstretched and stretched distance along cable
TX, TY, TZ	(lbs)	Tension (X,Z horizontal), (Y vertical) components
X, Y, Z	(ft)	Spatial coordinates (X,Z horizontal), (Y vertical)

Neutral platform position is X,Z = 0
 Y = Depth

The mooring line coordinates in the listing begin at the platform attachment points (as shown in Figure 1) for each mooring leg.

REFERENCE

LMSC TM 5724-74-68, "Final Report--Mooring Analysis/Deployment Transient," dated December 1974, by K. G. Nikkel, M. C. Wilson, J. V. Rattayya, and M. A. Chisholm.

MULTIPLE ANCHOR LEG MOOR
TRADE STUDY
100 Year Storm

10 ANCHOR LEGS
PLATFORM LOAD 1202843 lbs

Figure 5

MULTIPLE ANCHOR LEG MOOR

TRADE STUDY

10 ANCHOR LEGS

2600 FT. WIRE ROPE

Figure 6

1	1	S	SS	TX	TY	TZ	X	Y	Z	TTOT
2	0	*****		LEG 1						
3		.0	.0	-368820.	503586.	-2.	-299.3	4000.0	-.0	624201.
4		180.0	180.6	-369079.	497914.	-2.	-192.1	3854.6	-.0	619788.
5		360.0	361.2	-369180.	492339.	-2.	-84.2	3709.8	-.0	615379.
6		540.0	541.8	-369245.	486788.	-2.	24.6	3565.6	-.0	610986.
7		720.0	722.4	-369294.	481247.	-2.	134.1	3422.0	-.0	606611.
8		900.0	903.0	-369334.	475712.	-2.	244.5	3279.1	-.0	602254.
9		1080.0	1083.6	-369367.	470181.	-2.	355.6	3136.7	-.0	597915.
10		1260.0	1264.2	-369396.	464653.	-2.	467.6	2995.0	-.0	593596.
11		1440.0	1444.8	-369421.	459127.	-2.	580.4	2854.0	-.0	589296.
12		1620.0	1625.4	-369444.	453603.	-2.	694.0	2713.7	-.0	585017.
13		1800.0	1805.9	-369465.	448080.	-2.	808.5	2574.0	-.0	580758.
14		1980.0	1986.5	-369483.	442559.	-2.	923.8	2435.0	-.0	576521.
15		2160.0	2167.1	-369501.	437038.	-2.	1039.9	2296.8	-.0	572305.
16		2340.0	2347.6	-369517.	431518.	-2.	1156.9	2159.3	-.0	568111.
17		2520.0	2528.2	-369531.	425999.	-2.	1274.8	2022.5	-.0	563940.
18		2700.0	2708.7	-369545.	420481.	-2.	1393.5	1886.5	-.0	559793.
19		2880.0	2889.3	-369558.	414963.	-2.	1513.2	1751.3	-.0	555668.
20		3060.0	3069.8	-369570.	409446.	-2.	1633.7	1616.8	-.0	551568.
21		3240.0	3250.4	-369581.	403929.	-2.	1755.1	1483.2	-.0	547493.
22		3420.0	3430.9	-369592.	398412.	-2.	1877.4	1350.4	-.0	543443.
23		3600.0	3611.5	-369602.	392896.	-2.	2000.7	1218.5	-.0	539419.
24		.0	.0	-369602.	392896.	-2.	2000.7	1218.5	-.0	539419.
25		210.0	213.0	-369621.	363627.	-2.	2147.5	1068.3	-.0	518502.
26		420.0	420.0	-369638.	334359.	-2.	2300.2	924.2	-.0	498426.
27		630.0	630.0	-369652.	305093.	-2.	2459.0	786.9	-.0	479296.
28		840.0	840.0	-369664.	275828.	-2.	2624.1	657.2	-.0	461229.
29		1050.0	1050.0	-369673.	246565.	-2.	2795.6	536.0	-.0	444356.
30		1260.0	1260.0	-369681.	217303.	-2.	2973.5	424.5	-.0	428818.
31		1470.0	1470.0	-369687.	188043.	-2.	3157.6	323.6	-.0	414763.
32		1680.0	1680.0	-369692.	158784.	-2.	3347.7	234.4	-.0	402349.
33		1890.0	1890.0	-369695.	129527.	-2.	3543.4	158.2	-.0	391729.
34		2100.0	2100.0	-369698.	100271.	-2.	3743.9	95.9	-.0	383055.
35		2310.0	2310.0	-369700.	71017.	-2.	3948.4	48.5	-.0	376459.
36		2520.0	2520.0	-369702.	41763.	-2.	4156.0	16.9	-.0	372054.
37		2730.0	2730.0	-369704.	12510.	-2.	4365.3	1.5	-.0	369916.
38		2819.8	2819.8	-369705.	0.	-2.	4455.1	.0	.0	369705.
39	0	*****		LEG 2						
40		.0	.0	-275203.	476537.	-182162.	-309.2	4000.0	29.4	579661.
41		180.0	180.6	-275528.	470883.	-182106.	-223.0	3851.9	86.3	575161.
42		360.0	361.1	-275656.	465317.	-182083.	-136.2	3704.3	143.7	570666.
43		540.0	541.7	-275738.	459770.	-182068.	-48.6	3557.4	201.6	566188.
44		720.0	722.3	-275801.	454233.	-182056.	39.7	3411.1	259.8	561728.
45		900.0	902.8	-275852.	448701.	-182047.	128.7	3265.4	318.6	557286.
46		1080.0	1083.3	-275894.	443172.	-182038.	218.4	3120.4	377.8	552863.
47		1260.0	1263.9	-275932.	437646.	-182031.	308.9	2976.0	437.5	548459.
48		1440.0	1444.4	-275965.	432122.	-182024.	400.1	2832.2	497.6	544076.
49		1620.0	1625.0	-275995.	426599.	-182018.	492.0	2689.2	558.3	539713.
50		1800.0	1805.5	-276022.	421078.	-182012.	584.7	2546.9	619.4	535372.
51		1980.0	1986.0	-276046.	415558.	-182007.	678.2	2405.2	681.0	531052.
52		2160.0	2166.5	-276069.	410038.	-182002.	772.4	2264.3	743.2	526754.
53		2340.0	2347.1	-276090.	404520.	-181997.	867.4	2124.2	805.8	522480.
54		2520.0	2527.6	-276110.	399001.	-181992.	963.2	1984.8	868.9	518228.
55		2700.0	2708.1	-276129.	393484.	-181988.	1059.8	1846.2	932.6	514000.
56		2880.0	2888.6	-276146.	387967.	-181984.	1157.1	1708.5	996.7	509797.
57		3060.0	3069.1	-276163.	382450.	-181980.	1255.3	1571.5	1061.4	505619.

3 year Storm
Platform Loading
729 529 lbs.

11
101

58	3240.0	3249.6	-276179.	376934.	-181976.	1354.3	1435.4	1126.7	501467.	
59	3420.0	3430.1	-276193.	371418.	-181972.	1454.1	1300.2	1192.4	497341.	
60	3600.0	3610.6	-276207.	365902.	-181968.	1554.8	1165.8	1258.8	493242.	
61	.0	.0	-276207.	365902.	-181968.	1554.8	1165.8	1258.8	493242.	
62	210.0	210.0	-276235.	336634.	-181960.	1675.0	1013.0	1338.0	471951.	
63	420.0	420.0	-276259.	307367.	-181952.	1800.7	866.5	1420.7	451553.	
64	630.0	630.0	-276282.	278101.	-181944.	1932.0	727.4	1507.2	432175.	
65	840.0	840.0	-276301.	248835.	-181936.	2069.2	596.6	1597.6	413959.	
66	1050.0	1050.0	-276319.	219571.	-181927.	2212.4	475.3	1691.9	397066.	
67	1260.0	1260.0	-276334.	190309.	-181918.	2361.5	364.8	1790.0	381670.	
68	1470.0	1470.0	-276348.	161047.	-181910.	2516.4	266.4	1892.0	367961.	
69	1680.0	1680.0	-276359.	131787.	-181901.	2676.8	181.5	1997.6	356132.	
70	1890.0	1890.0	-276370.	102528.	-181892.	2842.1	111.4	2106.4	346377.	
71	2100.0	2100.0	-276379.	73271.	-181883.	3011.6	57.5	2217.9	338874.	
72	2310.0	2310.0	-276387.	44016.	-181875.	3184.3	20.9	2331.6	333775.	
73	2520.0	2520.0	-276395.	14761.	-181866.	3359.0	2.4	2446.5	331191.	
74	2626.0	2626.0	-276398.	0.	-181862.	3447.5	.0	2504.7	330862.	
75	1	S	SS	TX	TY	TZ	X	Y	Z	TTOT
76	0*****				LEG 3					
77	.0	.0	-94901.	413966.	-227753.	-334.2	4000.0	47.5	481919.	
78	180.0	180.5	-95332.	408390.	-227715.	-298.4	3845.3	133.2	477205.	
79	360.0	360.9	-95500.	402854.	-227699.	-262.1	3691.1	219.8	472503.	
80	540.0	541.4	-95610.	397328.	-227689.	-225.4	3537.5	307.2	467817.	
81	720.0	721.9	-95693.	391806.	-227681.	-188.3	3384.6	395.4	463150.	
82	900.0	902.3	-95761.	386287.	-227674.	-150.8	3232.2	484.6	458501.	
83	1080.0	1082.8	-95819.	380769.	-227668.	-113.0	3080.5	574.6	453871.	
84	1260.0	1263.2	-95870.	375252.	-227663.	-74.7	2929.5	665.6	449261.	
85	1440.0	1443.7	-95915.	369736.	-227658.	-35.9	2779.1	757.5	444672.	
86	1620.0	1624.1	-95956.	364221.	-227654.	3.2	2629.4	850.4	440103.	
87	1800.0	1804.5	-95994.	358707.	-227650.	42.7	2480.4	944.2	435557.	
88	1980.0	1985.0	-96028.	353193.	-227646.	82.7	2332.2	1039.0	431032.	
89	2160.0	2165.4	-96060.	347679.	-227642.	123.1	2184.8	1134.8	426531.	
90	2340.0	2345.8	-96090.	342166.	-227638.	164.0	2038.1	1231.6	422054.	
91	2520.0	2526.2	-96119.	336652.	-227635.	205.3	1892.2	1329.4	417602.	
92	2700.0	2706.6	-96145.	331140.	-227632.	247.0	1747.2	1428.3	413175.	
93	2880.0	2887.0	-96171.	325627.	-227629.	289.3	1603.1	1528.2	408774.	
94	3060.0	3067.4	-96195.	320115.	-227626.	331.9	1459.8	1629.2	404401.	
95	3240.0	3247.8	-96218.	314602.	-227622.	375.1	1317.5	1731.3	400056.	
96	3420.0	3428.2	-96240.	309090.	-227620.	418.7	1176.1	1834.5	395739.	
97	3600.0	3608.6	-96261.	303578.	-227617.	462.8	1035.7	1938.8	391453.	
98	.0	.0	-96261.	303578.	-227617.	462.8	1035.7	1938.8	391453.	
99	210.0	210.0	-96303.	274317.	-227610.	516.0	876.2	2064.5	369230.	
100	420.0	420.0	-96343.	245057.	-227604.	572.4	724.1	2197.9	348049.	
101	630.0	630.0	-96381.	215796.	-227596.	632.3	581.0	2339.4	328112.	
102	840.0	840.0	-96417.	186536.	-227588.	695.9	448.5	2489.3	309659.	
103	1050.0	1050.0	-96451.	157277.	-227580.	763.1	328.7	2648.1	292970.	
104	1260.0	1260.0	-96484.	128018.	-227571.	834.1	223.8	2815.5	278364.	
105	1470.0	1470.0	-96516.	98760.	-227561.	908.6	136.4	2991.2	266182.	
106	1680.0	1680.0	-96547.	69504.	-227550.	986.2	68.8	3174.2	256771.	
107	1890.0	1890.0	-96577.	40248.	-227539.	1066.3	23.4	3362.8	250442.	
108	2100.0	2100.0	-96606.	10994.	-227528.	1147.8	1.8	3554.9	247432.	
109	2178.9	2178.9	-96617.	0.	-227524.	1178.7	.0	3627.6	247188.	
110	0*****				LEG 4					
111	.0	.0	37116.	350545.	-167473.	-365.0	4000.0	47.6	390265.	
112	180.0	180.4	36678.	345071.	-167490.	-382.2	3838.2	125.5	385321.	
113	360.0	360.8	36508.	339577.	-167496.	-399.4	3676.9	204.4	380395.	
114	540.0	541.1	36397.	334078.	-167501.	-416.8	3516.2	284.3	375485.	
115	720.0	721.5	36312.	328576.	-167504.	-434.4	3356.0	365.3	370592.	

3 year Storm

116	900.0	901.9	36243.	323074.	-167507.	-452.2	3196.4	447.4	365717.	
117	1080.0	1082.2	36185.	317571.	-167509.	-470.1	3037.3	530.5	360860.	
118	1260.0	1262.6	36133.	312067.	-167512.	-468.3	2878.9	614.8	356022.	
119	1440.0	1442.9	36087.	306563.	-167514.	-506.7	2721.2	700.3	351203.	
120	1620.0	1623.3	36046.	301058.	-167516.	-525.4	2564.1	786.9	346406.	
121	1800.0	1803.6	36008.	295553.	-167518.	-544.3	2407.7	874.7	341629.	
122	1980.0	1984.0	35973.	290048.	-167519.	-563.4	2252.1	963.7	336875.	
123	2160.0	2164.3	35940.	284543.	-167521.	-582.8	2097.2	1054.1	332144.	
124	2340.0	2344.6	35909.	279038.	-167522.	-602.4	1943.1	1145.7	327433.	
125	2520.0	2524.9	35880.	273532.	-167524.	-622.3	1789.9	1238.6	322756.	
126	2700.0	2705.2	35853.	268027.	-167525.	-642.5	1637.5	1332.9	318102.	
127	2880.0	2885.6	35827.	262521.	-167527.	-663.0	1486.0	1428.5	313474.	
128	3060.0	3065.9	35802.	257015.	-167528.	-683.7	1335.5	1525.6	308876.	
129	3240.0	3246.2	35779.	251510.	-167530.	-704.8	1186.0	1624.1	304308.	
130	3420.0	3426.5	35756.	246004.	-167531.	-726.1	1037.5	1724.1	299771.	
131	3600.0	3606.8	35735.	240498.	-167532.	-747.8	890.1	1825.6	295268.	
132	.0	.0	35735.	240498.	-167532.	-747.8	890.1	1825.6	295268.	
133	210.0	210.0	35691.	211249.	-167536.	-774.3	722.8	1949.8	271971.	
134	420.0	420.0	35650.	182000.	-167539.	-803.0	564.6	2084.8	249928.	
135	630.0	630.0	35610.	152751.	-167543.	-834.3	418.0	2231.7	229502.	
136	840.0	840.0	35571.	123501.	-167547.	-863.2	286.3	2391.7	211163.	
137	1050.0	1050.0	35534.	94252.	-167552.	-905.0	173.9	2565.0	195499.	
138	1260.0	1260.0	35498.	65001.	-167558.	-944.5	85.5	2751.2	183197.	
139	1470.0	1470.0	35462.	35750.	-167564.	-986.2	26.5	2948.1	174967.	
140	1680.0	1680.0	35427.	6498.	-167571.	-1029.3	.9	3151.8	171398.	
141	1726.6	1726.6	35420.	0.	-167573.	-1038.9	-.0	3197.4	171275.	
142	1	S	SS	TX	TY	TZ	X	Y	Z	TTOT
143	0*****			LEG	5					
144	.0	.0	96769.	307843.	-81106.	-390.0	4000.0	29.4	332731.	
145	180.0	180.3	96383.	302437.	-81133.	-442.7	3833.3	73.7	327629.	
146	360.0	360.6	96236.	296970.	-81144.	-496.1	3667.1	118.7	322547.	
147	540.0	541.0	96140.	291488.	-81151.	-550.3	3501.3	164.4	317481.	
148	720.0	721.3	96067.	286001.	-81157.	-605.3	3336.0	210.9	312429.	
149	900.0	901.6	96008.	280510.	-81162.	-661.2	3171.2	258.1	307393.	
150	1080.0	1081.9	95958.	275017.	-81166.	-718.0	3006.9	306.1	302374.	
151	1260.0	1262.2	95914.	269522.	-81170.	-775.7	2843.2	354.9	297372.	
152	1440.0	1442.5	95876.	264025.	-81173.	-834.3	2680.1	404.5	292388.	
153	1620.0	1622.8	95841.	258528.	-81177.	-893.9	2517.7	455.0	287423.	
154	1800.0	1803.0	95809.	253030.	-81180.	-954.5	2355.8	506.4	282478.	
155	1980.0	1983.3	95780.	247531.	-81183.	-1016.2	2194.7	558.6	277554.	
156	2160.0	2163.6	95753.	242032.	-81186.	-1079.0	2034.3	611.8	272652.	
157	2340.0	2343.9	95728.	236532.	-81188.	-1142.8	1874.7	666.0	267774.	
158	2520.0	2524.1	95704.	231032.	-81191.	-1207.9	1715.8	721.2	262920.	
159	2700.0	2704.4	95682.	225531.	-81194.	-1274.1	1557.9	777.3	258093.	
160	2880.0	2884.6	95662.	220031.	-81196.	-1341.5	1400.8	834.6	253293.	
161	3060.0	3064.9	95642.	214529.	-81199.	-1410.2	1244.7	892.9	248523.	
162	3240.0	3245.1	95623.	209028.	-81202.	-1480.3	1089.7	952.4	243783.	
163	3420.0	3425.4	95606.	203527.	-81204.	-1551.7	935.7	1013.0	239077.	
164	3600.0	3605.6	95589.	198025.	-81207.	-1624.4	782.8	1074.8	234405.	
165	.0	.0	95589.	198025.	-81207.	-1624.4	782.8	1074.8	234405.	
166	210.0	210.0	95557.	168785.	-81212.	-1714.8	609.6	1151.6	210273.	
167	420.0	420.0	95528.	139544.	-81219.	-1815.9	446.8	1237.5	187603.	
168	630.0	630.0	95503.	110303.	-81227.	-1929.3	298.9	1334.0	166989.	
169	840.0	840.0	95483.	81061.	-81236.	-2056.4	171.8	1442.1	149288.	
170	1050.0	1050.0	95466.	51816.	-81246.	-2197.7	73.9	1562.3	135645.	
171	1260.0	1260.0	95453.	22567.	-81256.	-2350.7	14.5	1692.6	127370.	
172	1422.0	1422.0	95444.	0.	-81264.	-2473.4	.0	1797.1	125354.	
173	0*****			LEG	6					

3 year Storm

174	.0	.0	111706.	293162.	-2.	-399.5	4000.0	-.0	313723.
175	180.0	180.3	111348.	287777.	-2.	-464.2	3831.7	-.0	308568.
176	360.0	360.6	111211.	282318.	-2.	-529.7	3663.7	-.0	303432.
177	540.0	540.9	111123.	276842.	-2.	-596.3	3496.2	-.0	298311.
178	720.0	721.2	111056.	271358.	-2.	-664.1	3329.1	-.0	293204.
179	900.0	901.5	111002.	265871.	-2.	-732.9	3162.5	-.0	288112.
180	1080.0	1081.8	110956.	260380.	-2.	-803.0	2996.4	-.0	283036.
181	1260.0	1262.1	110917.	254888.	-2.	-874.3	2830.8	-.0	277976.
182	1440.0	1442.3	110882.	249394.	-2.	-946.9	2665.8	-.0	272932.
183	1620.0	1622.6	110850.	243899.	-2.	-1020.8	2501.3	-.0	267908.
184	1800.0	1802.9	110822.	238403.	-2.	-1096.1	2337.5	-.0	262902.
185	1980.0	1983.1	110796.	232906.	-2.	-1172.8	2174.4	-.0	257916.
186	2160.0	2163.4	110772.	227408.	-2.	-1250.9	2012.0	-.0	252953.
187	2340.0	2343.6	110750.	221910.	-2.	-1330.7	1850.3	-.0	248011.
188	2520.0	2523.9	110729.	216412.	-2.	-1411.9	1689.5	-.0	243095.
189	2700.0	2704.1	110710.	210913.	-2.	-1494.9	1529.4	-.0	238203.
190	2880.0	2884.3	110692.	205413.	-2.	-1579.5	1370.3	-.0	233340.
191	3060.0	3064.6	110676.	199914.	-2.	-1665.9	1212.1	-.0	228505.
192	3240.0	3244.8	110660.	194414.	-2.	-1754.1	1055.0	-.0	223701.
193	3420.0	3425.0	110645.	188913.	-2.	-1844.2	898.9	-.0	218930.
194	3600.0	3605.2	110631.	183413.	-2.	-1936.3	744.0	-.0	214195.
195	.0	.0	110631.	183413.	-2.	-1936.3	744.0	-.0	214195.
196	210.0	210.0	110605.	154175.	-2.	-2051.5	568.5	-.0	189746.
197	420.0	420.0	110585.	124936.	-2.	-2182.1	404.1	-.0	166847.
198	630.0	630.0	110569.	95696.	-2.	-2330.8	256.1	-.0	146230.
199	840.0	840.0	110560.	66453.	-2.	-2500.2	132.4	-.0	128994.
200	1050.0	1050.0	110555.	37205.	-2.	-2690.1	43.8	-.0	116648.
201	1260.0	1260.0	110553.	7954.	-2.	-2895.4	2.1	.0	110839.
202	1317.1	1317.1	110553.	0.	-2.	-2952.4	.0	.0	110553.
203	1	S	SS	TX	TY	TZ	X	Y	Z
204	0*****			LEG	7				
205	.0	.0	96769.	307843.	81104.	-390.0	4000.0	-29.4	332730.
206	180.0	180.3	96384.	302437.	81132.	-442.7	3833.3	-73.7	327628.
207	360.0	360.6	96236.	296969.	81142.	-496.1	3667.1	-118.7	322546.
208	540.0	541.0	96140.	291488.	81150.	-550.3	3501.3	-164.4	317480.
209	720.0	721.3	96067.	286000.	81156.	-605.3	3336.0	-210.9	312428.
210	900.0	901.6	96008.	280509.	81160.	-661.2	3171.2	-259.1	307392.
211	1080.0	1081.9	95958.	275016.	81165.	-718.0	3006.9	-306.1	302373.
212	1260.0	1262.2	95915.	269521.	81169.	-775.6	2843.2	-354.9	297371.
213	1440.0	1442.5	95876.	264025.	81172.	-834.3	2680.1	-404.5	292387.
214	1620.0	1622.8	95841.	258527.	81175.	-893.9	2517.6	-455.0	287422.
215	1800.0	1803.0	95809.	253029.	81179.	-954.5	2355.8	-506.4	282477.
216	1980.0	1983.3	95780.	247530.	81182.	-1016.2	2194.7	-558.6	277553.
217	2160.0	2163.6	95753.	242031.	81184.	-1079.0	2034.3	-611.8	272651.
218	2340.0	2343.9	95728.	236531.	81187.	-1142.8	1874.7	-666.0	267773.
219	2520.0	2524.1	95704.	231031.	81190.	-1207.9	1715.8	-721.2	262919.
220	2700.0	2704.4	95682.	225531.	81193.	-1274.1	1557.9	-777.4	258092.
221	2880.0	2884.6	95662.	220030.	81195.	-1341.5	1400.8	-834.6	253292.
222	3060.0	3064.9	95642.	214529.	81198.	-1410.2	1244.7	-892.9	248522.
223	3240.0	3245.1	95624.	209027.	81200.	-1480.3	1089.7	-952.4	243782.
224	3420.0	3425.4	95606.	203526.	81203.	-1551.7	935.7	-1013.0	239076.
225	3600.0	3605.6	95589.	198024.	81205.	-1624.4	782.8	-1074.8	234404.
226	.0	.0	95589.	198024.	81205.	-1624.4	782.8	-1074.8	234404.
227	210.0	210.0	95557.	168784.	81211.	-1714.8	609.6	-1151.7	210272.
228	420.0	420.0	95528.	139544.	81218.	-1815.9	446.8	-1237.5	187602.
229	630.0	630.0	95504.	110302.	81226.	-1929.3	298.9	-1334.0	166988.
230	840.0	840.0	95483.	81060.	81234.	-2056.4	171.8	-1442.1	149287.
231	1050.0	1050.0	95467.	51815.	81244.	-2197.7	73.9	-1562.3	135644.

3 year Storm

232	1260.0	1260.0	95453.	22567.	81255.	-2350.7	14.5	-1692.6	127370.
233	1422.0	1422.0	95445.	0.	81263.	-2473.4	.0	-1797.1	125353.
234	0*****			LEG 8					
235	.0	.0	37116.	350543.	167471.	-365.0	4000.0	-47.6	390262.
236	180.0	180.4	36677.	345069.	167487.	-382.2	3838.2	-125.5	385318.
237	360.0	360.8	36507.	339575.	167494.	-399.4	3676.9	-204.4	380392.
238	540.0	541.1	36396.	334075.	167498.	-416.8	3516.2	-284.3	375482.
239	720.0	721.5	36312.	328574.	167502.	-434.4	3356.0	-365.3	370589.
240	900.0	901.9	36243.	323072.	167505.	-452.2	3196.4	-447.4	365714.
241	1080.0	1082.2	36184.	317569.	167507.	-470.1	3037.3	-530.5	360857.
242	1260.0	1262.6	36133.	312065.	167509.	-488.3	2878.9	-614.8	356019.
243	1440.0	1442.9	36087.	306561.	167511.	-506.7	2721.2	-700.3	351201.
244	1620.0	1623.3	36045.	301056.	167513.	-525.4	2564.1	-786.9	346403.
245	1800.0	1803.6	36007.	295551.	167515.	-544.3	2407.7	-874.7	341626.
246	1980.0	1984.0	35972.	290046.	167517.	-563.4	2252.1	-963.8	336872.
247	2160.0	2164.3	35939.	284541.	167519.	-582.8	2097.2	-1054.1	332141.
248	2340.0	2344.6	35909.	279036.	167520.	-602.4	1943.1	-1145.7	327435.
249	2520.0	2524.9	35880.	273530.	167522.	-622.3	1789.9	-1238.6	322753.
250	2700.0	2705.2	35853.	268025.	167523.	-642.5	1637.5	-1332.9	318099.
251	2880.0	2885.6	35827.	262519.	167525.	-663.0	1486.0	-1428.5	313471.
252	3060.0	3065.9	35802.	257013.	167526.	-683.7	1335.5	-1525.6	308873.
253	3240.0	3246.2	35778.	251507.	167527.	-704.8	1186.0	-1624.1	304305.
254	3420.0	3426.5	35756.	246001.	167529.	-726.1	1037.5	-1724.1	299768.
255	3600.0	3606.8	35734.	240495.	167530.	-747.8	890.1	-1825.6	295265.
256	.0	.0	35734.	240495.	167530.	-747.8	890.1	-1825.6	295265.
257	210.0	210.0	35691.	211247.	167533.	-774.3	722.8	-1949.8	271968.
258	420.0	420.0	35649.	181996.	167537.	-803.0	564.6	-2084.8	249925.
259	630.0	630.0	35609.	152748.	167541.	-834.3	417.9	-2231.7	229499.
260	840.0	840.0	35571.	123499.	167545.	-868.2	286.3	-2391.6	211160.
261	1050.0	1050.0	35534.	94249.	167550.	-905.0	173.9	-2565.0	195496.
262	1260.0	1260.0	35497.	64999.	167556.	-944.5	85.5	-2751.2	183194.
263	1470.0	1470.0	35462.	35748.	167562.	-986.2	26.5	-2948.1	174964.
264	1680.0	1680.0	35427.	6496.	167569.	-1029.3	.9	-3151.8	171396.
265	1726.6	1726.6	35419.	0.	167570.	-1038.9	-.0	-3197.4	171273.
266	1 S	SS	TX	TY	TZ	X	Y	Z	TTOT
267	0*****			LEG 9					
268	.0	.0	-94895.	413956.	227741.	-334.1	4000.0	-47.5	481904.
269	180.0	180.5	-95326.	408380.	227703.	-298.3	3845.3	-133.2	477190.
270	360.0	360.9	-95494.	402844.	227688.	-262.1	3691.1	-219.8	472487.
271	540.0	541.4	-95604.	397318.	227678.	-225.4	3537.5	-307.2	467802.
272	720.0	721.9	-95687.	391796.	227669.	-188.3	3384.6	-395.4	463135.
273	900.0	902.3	-95755.	386277.	227663.	-150.8	3232.2	-484.6	458486.
274	1080.0	1082.8	-95813.	380759.	227657.	-112.9	3080.5	-574.7	453856.
275	1260.0	1263.2	-95864.	375242.	227652.	-74.6	2929.5	-665.6	449246.
276	1440.0	1443.7	-95909.	369726.	227647.	-35.9	2779.1	-757.5	444656.
277	1620.0	1624.1	-95950.	364211.	227643.	3.2	2629.4	-850.4	440088.
278	1800.0	1804.5	-95987.	358697.	227638.	42.8	2480.4	-944.2	435541.
279	1980.0	1985.0	-96022.	353183.	227635.	82.7	2332.2	-1039.0	431017.
280	2160.0	2165.4	-96054.	347669.	227631.	123.2	2184.8	-1134.8	426516.
281	2340.0	2345.8	-96084.	342156.	227627.	164.0	2038.1	-1231.6	422039.
282	2520.0	2526.2	-96112.	336643.	227624.	205.3	1892.2	-1329.4	417586.
283	2700.0	2706.6	-96139.	331130.	227621.	247.1	1747.2	-1428.3	413159.
284	2880.0	2887.0	-96164.	325617.	227617.	289.3	1603.1	-1528.2	408759.
285	3060.0	3067.4	-96189.	320105.	227614.	331.9	1459.8	-1629.2	404385.
286	3240.0	3247.8	-96212.	314592.	227611.	375.1	1317.5	-1731.3	400040.
287	3420.0	3428.2	-96234.	309080.	227608.	418.7	1176.1	-1834.5	395724.
288	3600.0	3608.6	-96255.	303568.	227605.	462.8	1035.7	-1938.8	391437.
289	.0	.0	-96255.	303568.	227605.	462.8	1035.7	-1938.8	391437.

3 year storm

290	210.0	210.0	-96297.	274308.	227599.	516.0	876.2	-2064.5	369214
291	420.0	420.0	-96337.	245047.	227592.	572.4	724.1	-2197.9	348033
292	630.0	630.0	-96374.	215786.	227585.	632.3	581.0	-2339.3	328096
293	840.0	840.0	-96411.	186527.	227577.	695.9	448.5	-2489.3	309643
294	1050.0	1050.0	-96445.	157267.	227569.	763.1	328.7	-2648.1	292954
295	1260.0	1260.0	-96478.	128008.	227559.	834.1	223.8	-2815.5	278348
296	1470.0	1470.0	-96510.	98750.	227550.	908.6	136.4	-2991.2	266167
297	1680.0	1680.0	-96541.	69494.	227539.	986.2	68.8	-3174.1	256756
298	1890.0	1890.0	-96571.	40238.	227528.	1066.3	23.4	-3362.8	250428
299	2100.0	2100.0	-96600.	10984.	227517.	1147.8	1.8	-3554.9	247419
300	2178.8	2178.8	-96611.	0.	227513.	1178.6	0	-3627.5	247176
301	0*****	0*****	LEG 10						
302	.0	.0	-275231.	476559.	182174.	-309.3	4000.0	-29.4	579696
303	180.0	180.6	-275557.	470905.	182118.	-223.1	3851.9	-86.4	575196
304	360.0	361.1	-275685.	465338.	182095.	-136.3	3704.3	-143.8	570702
305	540.0	541.7	-275767.	459792.	182080.	-48.7	3557.4	-201.6	566224
306	720.0	722.3	-275830.	454254.	182068.	39.6	3411.1	-259.9	561763
307	900.0	902.8	-275880.	448722.	182059.	128.6	3265.4	-318.6	557321
308	1080.0	1083.3	-275923.	443194.	182050.	218.4	3120.4	-377.9	552899
309	1260.0	1263.9	-275961.	437668.	182043.	308.8	2976.0	-437.5	548495
310	1440.0	1444.4	-275994.	432144.	182036.	400.0	2832.3	-497.7	544112
311	1620.0	1625.0	-276023.	426621.	182030.	492.0	2689.2	-558.3	539749
312	1800.0	1805.5	-276050.	421100.	182024.	584.7	2546.9	-619.5	535408
313	1980.0	1986.0	-276075.	415580.	182019.	678.1	2405.3	-681.1	531088
314	2160.0	2166.5	-276098.	410060.	182014.	772.4	2264.4	-743.2	526791
315	2340.0	2347.1	-276119.	404541.	182009.	867.4	2124.2	-805.8	522516
316	2520.0	2527.6	-276139.	399023.	182004.	963.1	1984.9	-869.0	518264
317	2700.0	2708.1	-276158.	393506.	182000.	1059.7	1846.3	-932.6	514037
318	2880.0	2888.6	-276175.	387988.	181996.	1157.1	1708.5	-996.8	509833
319	3060.0	3069.1	-276192.	382472.	181992.	1255.3	1571.5	-1061.5	505655
320	3240.0	3249.6	-276207.	376955.	181988.	1354.3	1435.4	-1126.7	501503
321	3420.0	3430.1	-276222.	371440.	181984.	1454.1	1300.2	-1192.5	497377
322	3600.0	3610.6	-276236.	365924.	181980.	1554.8	1165.9	-1258.8	493276
323	.0	.0	-276236.	365924.	181980.	1554.8	1165.9	-1258.8	493276
324	210.0	210.0	-276264.	336656.	181972.	1675.0	1013.0	-1338.0	471986
325	420.0	420.0	-276288.	307389.	181964.	1800.7	866.6	-1420.8	451590
326	630.0	630.0	-276310.	278122.	181956.	1932.0	727.5	-1507.3	432212
327	840.0	840.0	-276330.	248857.	181948.	2069.2	596.7	-1597.6	413997
328	1050.0	1050.0	-276348.	219593.	181939.	2212.4	475.4	-1691.9	397103
329	1260.0	1260.0	-276363.	190330.	181930.	2361.5	364.9	-1790.0	381706
330	1470.0	1470.0	-276376.	161069.	181922.	2516.4	266.4	-1892.0	367998
331	1680.0	1680.0	-276388.	131809.	181913.	2676.8	181.5	-1997.6	356169
332	1890.0	1890.0	-276398.	102550.	181904.	2842.1	111.5	-2106.4	346413
333	2100.0	2100.0	-276407.	73293.	181895.	3011.6	57.6	-2217.9	338908
334	2310.0	2310.0	-276416.	44037.	181887.	3184.3	20.9	-2331.6	333808
335	2520.0	2520.0	-276423.	14783.	181878.	3359.0	2.4	-2446.5	331222
336	2626.1	2626.1	-276427.	0.	181874.	3447.6	0	-2504.8	330893

3 year Storm

1	1	S	SS	TX	TY	TZ	X	Y	Z	TTOT
2	0	*****			LEG 1					
3		.0	.0	-516905.	598068.	0.	-481.3	4000.0	.0	790491.
4		180.0	180.8	-517131.	592395.	0.	-362.8	3863.5	.0	786356.
5		360.0	361.5	-517220.	586819.	0.	-243.5	3727.6	.0	782223.
6		540.0	542.3	-517278.	581267.	0.	-123.7	3592.3	.0	778105.
7		720.0	723.1	-517321.	575725.	0.	-3.2	3457.6	.0	774003.
8		900.0	903.8	-517356.	570190.	0.	117.9	3323.4	.0	769918.
9		1080.0	1084.6	-517385.	564659.	0.	239.7	3189.8	.0	765851.
10		1260.0	1265.3	-517411.	559131.	0.	362.2	3056.9	.0	761801.
11		1440.0	1446.1	-517433.	553605.	0.	485.3	2924.5	.0	757770.
12		1620.0	1626.8	-517453.	548081.	0.	609.0	2792.8	.0	753758.
13		1800.0	1807.6	-517472.	542558.	0.	733.4	2661.7	.0	749764.
14		1980.0	1988.3	-517488.	537036.	0.	858.5	2531.2	.0	745790.
15		2160.0	2169.0	-517504.	531516.	0.	984.2	2401.4	.0	741835.
16		2340.0	2349.8	-517518.	525996.	0.	1110.6	2272.2	.0	737900.
17		2520.0	2530.5	-517531.	520477.	0.	1237.7	2143.7	.0	733985.
18		2700.0	2711.2	-517543.	514958.	0.	1365.5	2015.9	.0	730091.
19		2880.0	2891.9	-517555.	509441.	0.	1493.9	1888.8	.0	726218.
20		3060.0	3072.7	-517565.	503923.	0.	1623.1	1762.4	.0	722366.
21		3240.0	3253.4	-517575.	498406.	0.	1752.9	1636.7	.0	718536.
22		3420.0	3434.1	-517585.	492890.	0.	1883.4	1511.7	.0	714727.
23		3600.0	3614.8	-517594.	487374.	0.	2014.6	1387.4	.0	710941.
24		.0	.0	-517594.	487374.	0.	2014.6	1387.4	.0	710941.
25		210.0	210.0	-517611.	458105.	0.	2169.7	1245.8	.0	691218.
26		420.0	420.0	-517626.	428838.	0.	2329.2	1109.2	.0	672190.
27		630.0	630.0	-517639.	399572.	0.	2493.1	978.0	.0	653918.
28		840.0	840.0	-517651.	370307.	0.	2661.7	852.7	.0	636466.
29		1050.0	1050.0	-517660.	341043.	0.	2834.7	733.8	.0	619906.
30		1260.0	1260.0	-517669.	311781.	0.	3012.4	621.9	.0	604308.
31		1470.0	1470.0	-517676.	282520.	0.	3194.5	517.3	.0	589750.
32		1680.0	1680.0	-517681.	253260.	0.	3381.0	420.8	.0	576311.
33		1890.0	1890.0	-517686.	224001.	0.	3571.7	333.0	.0	564070.
34		2100.0	2100.0	-517690.	194744.	0.	3766.4	254.2	.0	553107.
35		2310.0	2310.0	-517693.	165488.	0.	3964.7	185.3	.0	543500.
36		2520.0	2520.0	-517695.	136232.	0.	4166.3	126.5	.0	535320.
37		2730.0	2730.0	-517698.	106978.	0.	4370.7	78.5	.0	528635.
38		2940.0	2940.0	-517700.	77724.	0.	4577.4	41.7	.0	523501.
39		3150.0	3150.0	-517701.	48471.	0.	4785.8	16.3	.0	519965.
40		3360.0	3360.0	-517703.	19218.	0.	4995.4	2.6	.0	518060.
41		3498.0	3498.0	-517704.	0.	0.	5133.3	.0	.0	517704.
42	0	*****			LEG 2					
43		.0	.0	-366617.	547401.	-234632.	-491.2	4000.0	29.4	699363.
44		180.0	180.7	-366923.	541741.	-234567.	-396.1	3858.9	90.2	695081.
45		360.0	361.4	-367044.	536171.	-234540.	-300.4	3718.3	151.3	690803.
46		540.0	542.0	-367122.	530623.	-234522.	-204.1	3578.4	212.9	686542.
47		720.0	722.7	-367181.	525084.	-234508.	-107.2	3439.1	274.8	682297.
48		900.0	903.4	-367230.	519551.	-234497.	-9.6	3300.3	337.1	678070.
49		1080.0	1084.1	-367270.	514021.	-234487.	88.5	3162.2	399.7	673861.
50		1260.0	1264.7	-367306.	508494.	-234478.	187.3	3024.7	462.8	669672.
51		1440.0	1445.4	-367337.	502970.	-234471.	286.7	2887.9	526.2	665501.
52		1620.0	1626.0	-367365.	497446.	-234464.	386.7	2751.6	590.1	661350.
53		1800.0	1806.7	-367391.	491925.	-234457.	487.4	2616.1	654.3	657218.
54		1980.0	1987.3	-367414.	486404.	-234451.	588.7	2481.2	719.0	653107.
55		2160.0	2168.0	-367436.	480884.	-234445.	690.5	2347.0	784.0	649017.
56		2340.0	2348.6	-367456.	475365.	-234440.	793.2	2213.5	849.5	644948.
57		2520.0	2529.2	-367475.	469846.	-234434.	896.5	2080.8	915.4	640900.

100 year Storm
Platform Loading
1202843 lbs

100 year Storm

58	2700.0	2709.9	-367493.	464328.	-234429.	1000.4	1948.7	981.5	636874.
59	2880.0	2890.5	-367509.	458811.	-234425.	1104.9	1817.4	1048.3	632871.
60	3060.0	3071.1	-367525.	453294.	-234420.	1210.2	1686.8	1115.4	628890.
61	3240.0	3251.7	-367540.	447778.	-234416.	1316.9	1557.8	1183.2	625859.
62	3420.0	3432.4	-368231.	442775.	-234838.	1422.5	1428.9	1251.2	621927.
63	3600.0	3613.0	-368245.	437259.	-234834.	1529.8	1300.7	1319.6	618018.
64	.0	.0	-368245.	437259.	-234834.	1529.8	1300.7	1319.6	618018.
65	210.0	210.0	-368271.	407990.	-234826.	1657.0	1154.7	1400.7	597681.
66	420.0	420.0	-368295.	378723.	-234817.	1788.6	1014.2	1484.6	578110.
67	630.0	630.0	-368316.	349457.	-234808.	1924.6	879.7	1571.3	559385.
68	840.0	840.0	-368336.	320191.	-234800.	2065.2	752.0	1660.9	541594.
69	1050.0	1050.0	-368353.	290927.	-234791.	2210.3	631.7	1753.4	524833.
70	1260.0	1260.0	-368369.	261663.	-234782.	2359.9	519.4	1848.8	509202.
71	1470.0	1470.0	-368383.	232401.	-234774.	2514.1	416.1	1947.1	494808.
72	1680.0	1680.0	-368396.	203140.	-234765.	2672.6	322.4	2048.1	481763.
73	1890.0	1890.0	-368407.	173880.	-234756.	2835.1	239.3	2151.7	470179.
74	2100.0	2100.0	-368417.	144621.	-234748.	3001.5	167.4	2257.7	460166.
75	2310.0	2310.0	-368426.	115364.	-234739.	3171.2	107.5	2365.8	451829.
76	2520.0	2520.0	-368435.	86107.	-234731.	3343.8	60.3	2475.8	445261.
77	2730.0	2730.0	-368442.	56852.	-234722.	3518.6	26.5	2587.1	440541.
78	2940.0	2940.0	-368450.	27597.	-234714.	3694.8	6.3	2699.4	437730.
79	3138.1	3138.1	-368457.	0.	-234707.	3861.8	.0	2805.8	436861.
80	1	S	SS	TX	TY	TZ	X	Y	Z
81	0	*****	*****	*****	*****	*****	*****	*****	*****
82	.0	.0	-117741.	440359.	-255183.	-518.2	4000.0	46.8	522396.
83	180.0	180.5	-118168.	434774.	-255138.	-477.2	3848.1	135.3	517772.
84	360.0	361.0	-118336.	429235.	-255120.	-435.8	3696.8	224.7	513159.
85	540.0	541.5	-118445.	423706.	-255108.	-394.0	3546.2	314.8	508563.
86	720.0	722.0	-118528.	418182.	-255098.	-351.7	3396.1	405.8	503985.
87	900.0	902.5	-118596.	412662.	-255090.	-309.1	3246.6	497.5	499425.
88	1080.0	1083.0	-118654.	407142.	-255083.	-266.0	3097.8	590.2	491885.
89	1260.0	1263.5	-118704.	401625.	-255077.	-222.5	2949.7	683.6	490365.
90	1440.0	1444.0	-118749.	396108.	-255072.	-178.6	2802.2	777.9	485865.
91	1620.0	1624.5	-118790.	390592.	-255066.	-134.3	2655.4	873.1	481386.
92	1800.0	1804.9	-118827.	385077.	-255062.	-89.6	2509.3	969.2	476928.
93	1980.0	1985.4	-118862.	379562.	-255057.	-44.4	2364.0	1066.1	472493.
94	2160.0	2165.9	-118894.	374048.	-255053.	1.2	2219.4	1164.0	468080.
95	2340.0	2346.3	-118924.	368534.	-255049.	47.3	2075.6	1262.8	463691.
96	2520.0	2526.8	-118952.	363020.	-255045.	93.8	1932.5	1362.5	459327.
97	2700.0	2707.2	-118978.	357507.	-255041.	140.8	1790.3	1463.2	454986.
98	2880.0	2887.7	-119003.	351994.	-255037.	188.2	1649.0	1564.8	450672.
99	3060.0	3068.1	-119027.	346481.	-255034.	236.1	1508.5	1667.4	446384.
100	3240.0	3248.6	-119050.	340968.	-255030.	284.4	1368.9	1771.0	442123.
101	3420.0	3429.0	-119072.	335455.	-255027.	333.2	1230.2	1875.6	437889.
102	3600.0	3609.4	-119093.	329943.	-255024.	382.5	1092.4	1981.2	433685.
103	.0	.0	-119093.	329943.	-255024.	382.5	1092.4	1981.2	433685.
104	210.0	210.0	-119135.	300681.	-255016.	441.7	935.8	2107.9	411869.
105	420.0	420.0	-119174.	271420.	-255009.	504.1	786.2	2241.4	391025.
106	630.0	630.0	-119212.	242159.	-255001.	569.8	644.7	2381.9	371319.
107	840.0	840.0	-119247.	212898.	-254992.	639.0	512.8	2529.9	352940.
108	1050.0	1050.0	-119281.	183638.	-254983.	711.7	391.9	2685.4	336107.
109	1260.0	1260.0	-119314.	154379.	-254974.	788.0	283.9	2848.5	321061.
110	1470.0	1470.0	-119345.	125120.	-254963.	867.7	190.6	3018.8	308066.
111	1680.0	1680.0	-119375.	95863.	-254953.	950.6	113.9	3195.8	297390.
112	1890.0	1890.0	-119405.	66606.	-254941.	1036.1	55.8	3378.5	289290.
113	2100.0	2100.0	-119433.	37351.	-254930.	1123.7	17.7	3565.4	283987.
114	2310.0	2310.0	-119461.	8097.	-254918.	1212.5	.8	3754.9	281637.
115	2368.1	2368.1	-119469.	0.	-254914.	1237.1	.0	3807.5	281521.

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[illegible]

174	840.0	840.0	72472.	55628.	-68904.	-2049.5	103.7	1427.0	114431.
175	1050.0	1050.0	72455.	26381.	-68915.	-2190.0	24.6	1560.6	103417.
176	1239.4	1239.4	72443.	0.	-68926.	-2325.7	.1	1689.7	99994.
177	0*****	0*****	LEG	6					
178	.0	.0	82408.	262498.	-13.	-583.1	4000.0	-.3	275129.
179	180.0	180.3	82032.	257096.	-13.	-637.5	3828.1	-.3	269866.
180	360.0	360.5	81890.	251630.	-13.	-692.8	3656.5	-.3	264620.
181	540.0	540.8	81797.	246150.	-13.	-749.1	3485.3	-.3	259385.
182	720.0	721.0	81727.	240663.	-13.	-806.5	3314.4	-.3	254162.
183	900.0	901.3	81670.	235173.	-13.	-865.0	3144.0	-.3	248951.
184	1080.0	1081.5	81622.	229681.	-13.	-924.8	2973.9	-.3	243753.
185	1260.0	1261.8	81581.	224186.	-13.	-985.8	2804.3	-.3	238569.
186	1440.0	1442.0	81544.	218691.	-13.	-1048.0	2635.2	-.3	233399.
187	1620.0	1622.2	81511.	213194.	-13.	-1111.7	2466.6	-.3	228245.
188	1800.0	1802.5	81481.	207697.	-13.	-1176.8	2298.5	-.2	223108.
189	1980.0	1982.7	81453.	202199.	-13.	-1243.4	2131.0	-.2	217989.
190	2160.0	2162.9	81428.	196700.	-13.	-1311.5	1964.2	-.2	212888.
191	2340.0	2343.1	81404.	191201.	-13.	-1381.2	1798.0	-.2	207809.
192	2520.0	2523.3	81383.	185702.	-13.	-1452.7	1632.6	-.2	202752.
193	2700.0	2703.5	81362.	180202.	-13.	-1525.9	1467.9	-.2	197719.
194	2880.0	2883.7	81343.	174702.	-13.	-1601.0	1304.2	-.2	192711.
195	3060.0	3063.9	81325.	169202.	-13.	-1678.1	1141.3	-.2	187731.
196	3240.0	3244.1	81309.	163701.	-13.	-1757.2	979.4	-.2	182782.
197	3420.0	3424.3	81293.	158200.	-13.	-1838.4	818.6	-.1	177865.
198	3600.0	3604.4	81278.	152699.	-13.	-1921.9	658.9	-.1	172983.
199	.0	.0	81278.	152699.	-13.	-1921.9	658.9	-.1	172983.
200	210.0	210.0	81250.	123461.	-13.	-2028.6	478.1	-.1	147798.
201	420.0	420.0	81229.	94222.	-13.	-2154.4	310.2	-.1	124403.
202	630.0	630.0	81214.	64982.	-13.	-2304.6	163.8	-.1	104012.
203	840.0	840.0	81207.	35737.	-13.	-2483.0	54.0	-.0	88723.
204	1050.0	1050.0	81205.	6486.	-13.	-2685.4	1.9	-.0	81463.
205	1096.6	1096.6	81204.	0.	-13.	-2731.9	.1	.0	81204.
206	1	S	SS	TX	TY	TZ	X	Y	Z
207	0*****	0*****	LEG	7					
208	.0	.0	73818.	282464.	68778.	-572.1	4000.0	-29.6	299942.
209	180.0	180.3	73422.	277044.	68800.	-616.7	3830.4	-71.3	294750.
210	360.0	360.6	73271.	271571.	68809.	-661.9	3661.1	-113.8	289575.
211	540.0	540.9	73172.	266086.	68814.	-707.9	3492.2	-157.0	284414.
212	720.0	721.1	73098.	260595.	68819.	-754.7	3323.8	-201.0	279266.
213	900.0	901.4	73037.	255102.	68823.	-802.3	3155.8	-245.8	274132.
214	1080.0	1081.7	72986.	249607.	68826.	-850.8	2988.3	-291.5	269012.
215	1260.0	1262.0	72941.	244110.	68830.	-900.2	2821.3	-338.1	263908.
216	1440.0	1442.2	72901.	238612.	68833.	-950.5	2654.8	-385.6	258821.
217	1620.0	1622.5	72865.	233114.	68835.	-1001.7	2488.9	-434.0	253751.
218	1800.0	1802.7	72832.	227615.	68838.	-1054.0	2323.6	-483.4	248700.
219	1980.0	1983.0	72802.	222115.	68840.	-1107.3	2159.0	-533.8	243668.
220	2160.0	2163.2	72774.	216614.	68843.	-1161.7	1995.0	-585.2	238657.
221	2340.0	2343.4	72748.	211114.	68845.	-1217.2	1831.8	-637.8	233669.
222	2520.0	2523.7	72724.	205613.	68847.	-1273.9	1669.4	-691.4	228704.
223	2700.0	2703.9	72701.	200111.	68850.	-1331.9	1507.8	-746.3	223764.
224	2880.0	2884.1	72680.	194610.	68852.	-1391.1	1347.1	-802.4	218852.
225	3060.0	3064.3	72659.	189108.	68854.	-1451.6	1187.3	-859.7	213968.
226	3240.0	3244.5	72640.	183606.	68856.	-1513.5	1028.5	-918.4	209115.
227	3420.0	3424.7	72622.	178104.	68859.	-1576.8	870.9	-978.4	204295.
228	3600.0	3604.9	72605.	172602.	68861.	-1641.6	714.4	-1039.9	199511.
229	.0	.0	72605.	172602.	68861.	-1641.6	714.4	-1039.9	199511.
230	210.0	210.0	72571.	143361.	68866.	-1723.2	537.1	-1117.3	174818.
231	420.0	420.0	72541.	114120.	68873.	-1816.8	371.5	-1206.1	151753.

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232	630.0	630.0	72515.	84878.	68880.	-1924.8	223.8	-1308.7	131176.
233	840.0	840.0	72495.	55635.	68890.	-2049.4	103.7	-1427.1	114440.
234	1050.0	1050.0	72478.	26388.	68901.	-2190.0	24.6	-1560.7	103425.
235	1239.4	1239.4	72466.	0.	68911.	-2325.7	.1	-1689.7	100000.
236	0*****	*****	LEG	8					
237	.0	.0	26144.	343015.	160899.	-543.1	4000.0	-45.8	379778.
238	180.0	180.4	25704.	337532.	160911.	-555.5	3837.3	-122.8	374808.
239	360.0	360.7	25534.	332033.	160916.	-567.9	3675.1	-200.7	369854.
240	540.0	541.1	25423.	326532.	160919.	-580.4	3513.5	-279.7	364917.
241	720.0	721.5	25338.	321029.	160921.	-593.0	3352.4	-359.8	359996.
242	900.0	901.8	25269.	315525.	160923.	-605.8	3191.8	-441.0	355092.
243	1080.0	1082.2	25210.	310020.	160925.	-618.7	3031.9	-523.3	350207.
244	1260.0	1262.5	25159.	304515.	160927.	-631.7	2872.5	-606.7	345340.
245	1440.0	1442.8	25113.	299010.	160928.	-645.0	2713.8	-691.3	340493.
246	1620.0	1623.2	25071.	293504.	160929.	-658.3	2555.8	-777.2	335666.
247	1800.0	1803.5	25033.	287999.	160931.	-671.9	2398.5	-864.3	330860.
248	1980.0	1983.8	24998.	282493.	160932.	-685.6	2241.9	-952.6	326077.
249	2160.0	2164.2	24965.	276987.	160933.	-699.6	2086.1	-1042.3	321317.
250	2340.0	2344.5	24934.	271481.	160934.	-713.7	1931.0	-1133.3	316581.
251	2520.0	2524.8	24905.	265975.	160935.	-728.0	1776.8	-1225.6	311870.
252	2700.0	2705.1	24878.	260468.	160936.	-742.5	1623.5	-1319.4	307186.
253	2880.0	2885.4	24852.	254962.	160937.	-757.2	1471.1	-1414.5	302529.
254	3060.0	3065.7	24827.	249456.	160938.	-772.1	1319.6	-1511.2	297902.
255	3240.0	3246.0	24803.	243949.	160939.	-787.2	1169.1	-1609.4	293305.
256	3420.0	3426.3	24781.	238443.	160940.	-802.6	1019.7	-1709.1	288740.
257	3600.0	3606.6	24759.	232936.	160941.	-818.2	871.4	-1810.3	284208.
258	.0	.0	24759.	232936.	160941.	-818.2	871.4	-1810.3	284208.
259	210.0	210.0	24715.	203686.	160944.	-837.2	703.1	-1934.5	260771.
260	420.0	420.0	24673.	174436.	160946.	-858.0	544.1	-2070.0	238622.
261	630.0	630.0	24633.	145186.	160949.	-880.7	397.2	-2218.2	218152.
262	840.0	840.0	24594.	115936.	160952.	-905.5	266.0	-2380.2	199879.
263	1050.0	1050.0	24556.	86685.	160956.	-932.4	155.3	-2556.4	184456.
264	1260.0	1260.0	24519.	57434.	160960.	-961.3	70.6	-2746.1	172650.
265	1470.0	1470.0	24483.	28182.	160965.	-991.9	17.3	-2946.7	165237.
266	1672.3	1672.3	24448.	0.	160970.	-1022.1	-.0	-3145.8	162816.
267	1	S	SS	TX	TY	TZ	X	Y	Z
268	0*****	*****	LEG	9					TTOT
269	.0	.0	-117569.	440049.	254808.	-517.6	4000.0	-47.5	521913.
270	180.0	180.5	-117996.	434464.	254763.	-476.7	3848.1	-136.0	517287.
271	360.0	361.0	-118164.	428925.	254744.	-435.3	3696.8	-225.3	512673.
272	540.0	541.5	-118274.	423396.	254732.	-393.5	3546.1	-315.4	508076.
273	720.0	722.0	-118357.	417872.	254723.	-351.3	3396.0	-406.3	503497.
274	900.0	902.5	-118425.	412351.	254715.	-308.6	3246.5	-498.0	498936.
275	1080.0	1083.0	-118482.	406832.	254708.	-265.6	3097.6	-590.6	494395.
276	1260.0	1263.5	-118533.	401315.	254702.	-222.1	2949.4	-684.0	489874.
277	1440.0	1444.0	-118578.	395798.	254696.	-178.2	2801.9	-778.2	485373.
278	1620.0	1624.5	-118619.	390282.	254691.	-133.9	2655.1	-873.4	480893.
279	1800.0	1804.9	-118656.	384767.	254686.	-89.2	2509.0	-969.4	476434.
280	1980.0	1985.4	-118690.	379252.	254682.	-44.0	2363.6	-1066.3	471998.
281	2160.0	2165.9	-118722.	373737.	254677.	1.6	2219.0	-1164.2	467584.
282	2340.0	2346.3	-118752.	368223.	254673.	47.6	2075.1	-1262.9	463194.
283	2520.0	2526.8	-118780.	362710.	254669.	94.1	1932.1	-1362.6	458828.
284	2700.0	2707.2	-118807.	357196.	254665.	141.0	1789.8	-1463.2	454487.
285	2880.0	2887.7	-118832.	351683.	254662.	188.4	1648.4	-1564.8	450172.
286	3060.0	3068.1	-118856.	346170.	254658.	236.3	1507.9	-1667.4	445883.
287	3240.0	3248.5	-118879.	340658.	254655.	284.6	1368.3	-1770.9	441621.
288	3420.0	3429.0	-118900.	335145.	254651.	333.5	1229.6	-1875.5	437387.
289	3600.0	3609.4	-118921.	329633.	254648.	382.7	1091.8	-1981.0	433181.

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290 .0 .0 -118921. 329633. 254648. 382.7 1091.8 -1981.0 433181.
291 210.0 210.0 -118963. 300371. 254641. 441.9 935.1 -2107.7 411360.
292 420.0 420.0 -119003. 271110. 254633. 504.3 785.5 -2241.2 390513.
293 630.0 630.0 -119040. 241849. 254625. 570.0 644.0 -2381.7 370804.
294 840.0 840.0 -119076. 212588. 254617. 639.1 512.0 -2529.7 352424.
295 1050.0 1050.0 -119110. 183328. 254608. 711.9 391.2 -2685.2 335591.
296 1260.0 1260.0 -119142. 154069. 254598. 788.2 283.2 -2848.3 320550.
297 1470.0 1470.0 -119174. 124810. 254588. 867.9 189.9 -3018.6 307563.
298 1680.0 1680.0 -119204. 95552. 254577. 950.8 113.4 -3195.7 296899.
299 1890.0 1890.0 -119233. 66296. 254566. 1036.4 55.4 -3378.3 288817.
300 2100.0 2100.0 -119261. 37040. 254554. 1123.9 17.4 -3565.3 283537.
301 2310.0 2310.0 -119290. 7786. 254542. 1212.7 .8 -3754.8 281216.
302 2365.9 2365.9 -119297. 0. 254539. 1236.4 -.0 -3905.4 281108.
303 0***** LEG 10
304 .0 .0 -368271. 548608. 235542. -494.2 4000.0 -29.8 701480.
305 180.0 180.7 -368576. 542947. 235477. -399.0 3859.0 -90.6 697201.
306 360.0 361.4 -368697. 537377. 235450. -303.2 3718.6 -151.8 692927.
307 540.0 542.1 -368775. 531829. 235432. -206.7 3578.7 -213.4 688669.
308 720.0 722.7 -368834. 526290. 235418. -109.7 3439.5 -275.4 684428.
309 900.0 903.4 -368882. 520757. 235407. -12.0 3300.9 -337.7 680204.
310 1080.0 1084.1 -368923. 515227. 235397. 86.3 3162.9 -400.4 675999.
311 1260.0 1264.7 -368958. 509700. 235388. 185.2 3025.5 -463.5 671813.
312 1440.0 1445.4 -368990. 504176. 235380. 284.7 2888.8 -527.0 667646.
313 1620.0 1626.0 -369018. 498653. 235373. 384.9 2752.7 -590.9 663498.
314 1800.0 1806.7 -369044. 493131. 235367. 485.7 2617.2 -655.2 659370.
315 1980.0 1987.3 -369067. 487610. 235361. 587.1 2482.5 -713.9 655262.
316 2160.0 2168.0 -369089. 482090. 235355. 689.2 2348.4 -785.0 651175.
317 2340.0 2348.6 -369109. 476571. 235349. 791.9 2215.0 -850.5 647109.
318 2520.0 2529.3 -369128. 471052. 235344. 895.3 2082.3 -916.4 643065.
319 2700.0 2709.9 -369145. 465534. 235339. 999.3 1950.4 -982.7 639042.
320 2880.0 2890.5 -369162. 460017. 235334. 1103.9 1819.1 -1049.4 635042.
321 3060.0 3071.1 -369178. 454500. 235330. 1209.3 1688.7 -1116.5 631065.
322 3240.0 3251.8 -369193. 448984. 235325. 1315.3 1559.0 -1184.1 627110.
323 3420.0 3432.4 -369207. 443468. 235321. 1421.9 1430.1 -1252.1 623180.
324 3600.0 3613.0 -369220. 437952. 235317. 1529.3 1301.9 -1320.5 619273.
325 .0 .0 -369220. 437952. 235317. 1529.3 1301.9 -1320.5 619273.
326 210.0 210.0 -369246. 408603. 235308. 1656.6 1156.0 -1401.7 598945.
327 420.0 420.0 -369270. 379416. 235300. 1788.3 1015.5 -1465.6 579381.
328 630.0 630.0 -369292. 350149. 235291. 1924.3 881.1 -1572.3 560663.
329 840.0 840.0 -369311. 320884. 235282. 2064.9 753.4 -1661.8 542877.
330 1050.0 1050.0 -369329. 291520. 235274. 2210.1 633.1 -1754.3 526117.
331 1260.0 1260.0 -369344. 262356. 235265. 2359.7 520.9 -1849.6 510486.
332 1470.0 1470.0 -369358. 233094. 235256. 2513.9 417.5 -1947.8 496089.
333 1680.0 1680.0 -369371. 203833. 235248. 2672.4 323.8 -2048.8 483037.
334 1890.0 1890.0 -369382. 174573. 235239. 2835.0 240.6 -2152.3 471441.
335 2100.0 2100.0 -369393. 145314. 235230. 3001.3 168.5 -2258.3 461411.
336 2310.0 2310.0 -369402. 116057. 235222. 3171.1 108.5 -2366.3 453052.
337 2520.0 2520.0 -369410. 86800. 235213. 3343.6 61.2 -2476.2 446456.
338 2730.0 2730.0 -369418. 57544. 235205. 3518.4 27.0 -2587.5 441704.
339 2940.0 2940.0 -369425. 28290. 235197. 3694.6 6.6 -2699.7 438854.
340 3143.1 3143.1 -369432. 0. 235189. 3865.8 .0 -2808.7 437943.

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