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CONCEPTUAL DESIGNS FOR MODULAR OTEC SKSS

Final Report

February 29, 1980

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

M. Rosenblatt & Son, Inc.
New York, New York

U.S. Department of Energy

Solar Energy

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FINAL REPORT

VOLUME II

CONCEPTUAL DESIGNS

FOR MODULAR OTEC SKSS

Prepared For

U.S. Department of Commerce
Research Contracts Division
14th & Constitution Ave., N.W.
Washington, D. C. 20230

under

DoC Contract No. MO-A01-78-00-4230

by

M. ROSENBLATT & SON, INC.
350 Broadway
New York, New York 10013

February 29, 1980

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1.0 INTRODUCTION AND SUMMARY

This volume presents the results of the first phase of the Station Keeping Subsystem (SKSS) design study for 40 MW_e capacity Modular Experiment OTEC Platforms. The objectives of the study were:

- o Establishment of basic design requirements
- o Verification of technical feasibility of SKSS designs
- o Identification of merits and demerits
- o Estimates of sizes for major components
- o Estimates of life cycle costs
- o Deployment Scenarios and time/cost/risk assessments
- o Maintenance/repair and replacement scenarios
- o Identifications of interface with other OTEC subsystems
- o Recommendations for and major problems in preliminary design
- o Applicability of concepts to commercial plant SKSS designs

The work for this task was performed for the Department of Commerce, under contract No. MO-AIL-78-00-4230, by M. Rosenblatt & Son, Inc. (MR&S) as prime contractor and the following subcontractors:

- o Oceanics, Inc. (OI)
- o John Gadbois (JG)
- o Bryant Engineering (BE)
- o Sperry Systems Management (SSM)
- o Linnenbank International (LI)
- o Marine Supply Co. (MSC)
- o McClelland Engineers, Inc. (McC)

Before getting into conceptual design efforts and consideration of various concepts, a brief site suitability study was performed with the objective of determining the best possible location at the Punta Tuna (Puerto Rico) site from the standpoint of anchoring. This involved studying the vicinity of the initial location in relation to the prevailing bottom slopes and distances from shore.

All subsequent studies were performed for the final selected site.

The two baseline OTEC platforms were the APL BARGE, Figure 1, and the G & C SPAR, Figure 2. Basic particulars of these two platforms are summarized, respectively, in Tables 1 and 2.

The results of the study are presented in detail in the following sections. In brief, the overall objective of developing two conceptual designs for each of the two baseline OTEC platforms has been accomplished.

Specifically:

- A methodology was developed for conceptual designs and followed to the extent possible. At this stage, a full reliability/performance/optimization analysis based on a probabilistic approach was not used due to the numerous SKSS candidates to be evaluated. A deterministic approach was used as described in detail in Section 3.0.

- For both of the two baseline platforms, the APL BARGE and the G & C SPAR, all possible SKSS candidate concepts were considered and matrices of SKSS concepts were developed.

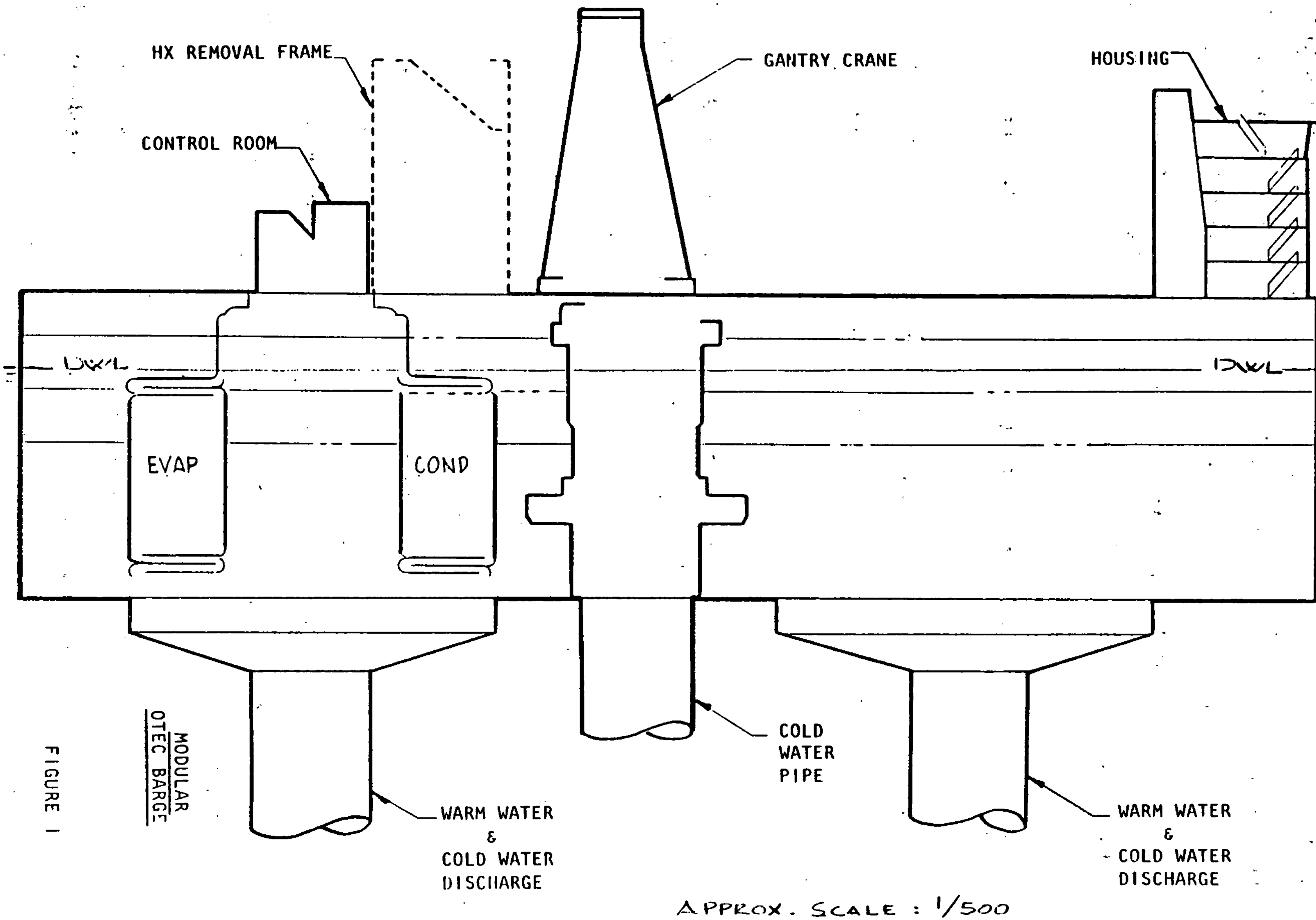
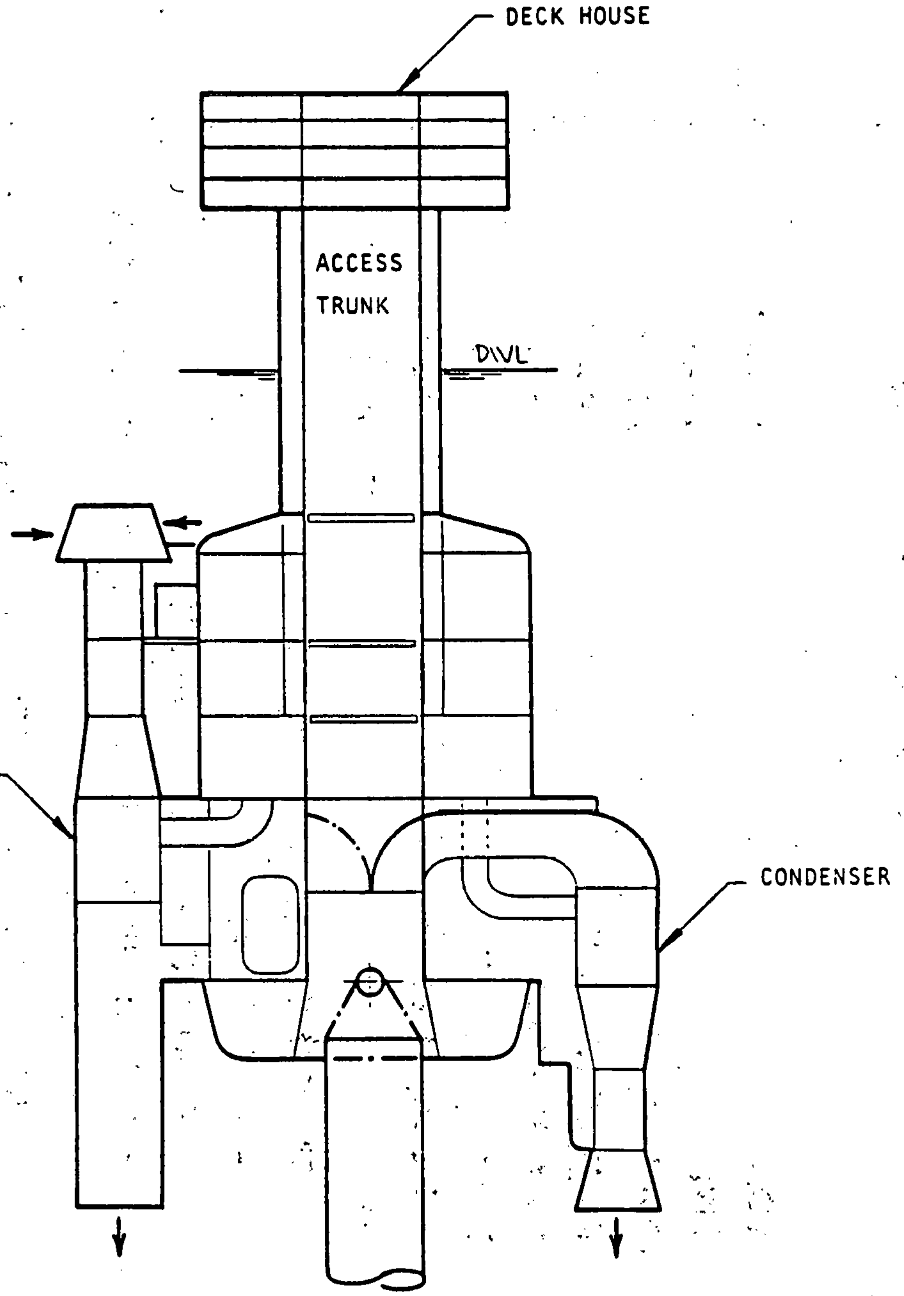


FIGURE I

MODULAR
OTEC BARGE

M. ROSENBLATT & SON, INC.

APPROX. SCALE : 1/600



MODULAR OTEC SPAR

FIGURE 2

PRINCIPAL HULL CHARACTERISTICS

LOA	381′–6″
LWL	378′–0″
B (HULL)	121′–0″
B (OVER WW PUMPS)	159′–0″
D (MAIN DECK)	77′–0″
D (UPPER DECK)	89′–0″
d (DLWL, HULL ONLY)	65′–0″
Δ+	67,901 LT.

CONDITIONS DEFINING DISPLACEMENT:

- 65-FT DRAFT
- ASSUMES APL HE's AT ALL WELLS
- VESSEL DISPLACEMENT INCLUDES DISPLACEMENT OF HE's
- CWP IN PLACE
- HULL FULLY OUTFITTED FOR 20 MW_e OPERATION

BALLAST (TO 65′ WL, 20 MW OPER.) 6,757 LT.

TABLE I: APL BARGE

18641-2 (W-11,244) ENCLOSURE (A)

TABLE 2

G & C SPAR PRINCIPAL CHARACTERISTICS

OTEC 10 & 40 MW_e Modular Applications Platforms

(SPAR CONFIGURATION)

			$10\ MW_e$ (Steel)	$40\ MW_e$ (Steel)
Overall Height	w/o	Discharge Pipes	260 (Ft)	315 (Ft)
	w/	Discharge Pipe	330	340
Maximum Diameter	w/o	Discharge Pipe	65	120
	w/	Discharge Pipe	120	125
Maximum Draft	w/o	Discharge Pipe	180	225
	w/	Discharge Pipe	250	350
Access Column		Outer Shell	32 O.D. x 115	32 O.D.x 120
		Inner Shell	20 O.D. x 115	20 O.D. x 120
Main Body		Maximum Diameter	65	120
		Minimum Diameter	48	72
		Overall Height	140	175
Heat Exchangers		Number	1 Evap/1 Cond	4 Evap/4 Cond
		Orientation	Vertical	Vertical
		Location	External	External
Discharge Pipes		Depth below Heat Exchangers	120	95
CWP Diameter			15	30
Habitability Section			75 x 75 x 27	90 x 90 x 36
Lightship Wgt			7994 LT	23247 LT
Lightship Wgt Less CWP			6097 LT	16732 LT
Ballast Wgt			2403 LT	1381 LT
Operating Wgt			17963 LT	42985 LT
Mooring Tension			4143 LT	6096 LT
KG			64.93 ft	77.50 ft
Radius of Gyration			78.52 ft	76.89 ft

- For those concepts which were found to be technically feasible, necessary calculations were performed to establish SKSS component sizes, cost estimates, deployment and maintenance requirements, and interface problems.

- On the basis of performance, cost, risk, and scheduling considerations, the feasible SKSS concepts were subjected to a comparison and the best two concepts were selected for each baseline platform.

The end results were summarized as follows:

1. For the 40 MW_e Modular Experiment SPAR Platform, the two best SKSS concepts were:

   - An eight-leg spread catenary using 5" wire rope and 4" chain for mooring lines

   - A tension leg type mooring concept with three vertical tension rods.

2. The two best SKSS concepts for the BARGE platform were:

   - A four-leg spread catenary with solid link type mooring lines

   - A single anchor leg type mooring with buoy moored by three closely spaced solid links.

3. The SKSS concepts recommended for the preliminary design studies were:

   - For the SPAR: The eight-leg wire rope and chain catenary mooring concept

- For the Barge: the single leg mooring concept with buoy moored by vertical solid link lines.

At this stage of the study, the results were presented to NOAA/DOE, and the 8-leg wire/chain catenary mooring concept for the SPAR platform was approved for use as baseline design in the next phase of the study.

For the Barge platform, a state-of-the-art catenary mooring system was approved due to extensive development requirements for the single buoy mooring concept.

4. The applicability of these concepts to the future commercial plant SKSS designs is discussed in Section 10; in summary however, it is believed that, for the Puerto Rico site:

   - The eight-leg catenary concept will not be applicable to commercial SPAR platforms, since the wire rope and chain sizes used for the modular platform are already at the boundary of the current state-of-the-art.

   - For a commercial SPAR platform, the most likely SKSS concepts will be multi-point HCL link catenaries or vertical tension leg moorings.

   - The single-leg mooring concept with buoy moored by vertical solid tension links may be applicable to commercial platforms.

2.0 BASIC DESIGN REQUIREMENTS

2.1 Design Criteria

2.1.1 Requirements and Assumptions

The basic design requirements, given by the DoC for use in the conceptual designs of this study, are the following:

1. SKSS designs will be prepared for two Modular experiment plant platforms,
   a) 40 MW SPAR MEP platform being developed by Gibbs & Cox
   b) 40 MW BARGE MEP platform designed by Applied Physics Laboratory (JHU).

2. The site for MEP platforms is Puerto Rico.
3. Watch circle radius requirement for the operational sea state is 10% of the depth of water. No specific watch circle requirements need be met at the design extreme sea state. However, SKSS must be adequate to prevent the grounding of the cold water pipe.

4. The design life for the MEP is 10 years; return periods for the design operational and extreme sea states are 3 years and 70 years respectively.

5. The primary SKSS shall be a moored configuration. Thrusters may be used as secondary systems.

Starting with these assumptions and taking into consideration possible SKSS configurations the criteria and characteristics for use in the designs of components and complete systems were compiled.

a. Excursion

Permissible excursion is determined by the design characteristics of the power cable. Depending on the nature of the power cable connection and the number of cables used, the maximum permissible watch circle would range from 10% to 30% of the water depth. The final power cable design has not been established, so a nominal 10% of depth watch circle radius will be used. Exceeding this permissible radius may be considered a tolerance failure.

b. Catastrophic failure

Catastrophic failure would be a major SKSS component failure which could lead to grounding of the cold water pipe. The probability of this failure must be maintained below an acceptable level. In the conceptual designs, a deterministic approach will be used so that appropriate factors of safety may serve as the criteria in lieu of minimum reliability values. If one SKSS component fails to meet the acceptable reliability level or the factor of safety, it will either be discarded as a viable alternative or strengthened to correct this deficiency.

c. Burden Variables

Burden variables are quantities such as weight and space requirements for the specific platforms which can sometimes be quantified but are best considered subjectively in comparing SKSS alternatives. These variables will either be definite limitations which restrict the development of the SKSS concepts, or will assist in the comparison and evaluation of SKSS alternatives with nearly equal cost and performance measures.

2.1.2 SKSS Materials and Components

a. Factors of Safety

The factors of safety to be used in the conceptual design studies will be based on the ultimate strength (or the breaking strength) of the wire rope and chain components.

For all other materials and components, allowable loads will be computed in accordance with "American Institute of Steel Construction" or other applicable specifications as discussed below for all probable SKSS materials.

In general, the minimum factor of safety for the design operational sea state is 3.0 and for the design extreme sea state 2.0.

b. <u>Corrosion</u>

The following corrosion resistance criteria will be used:

Carbon steel parts that are fully submerged at all times are to have an increased thickness for corrosion allowance equal to 1/16 inch per exposed surface.

Carbon steel parts that are in the splash zone are to have a corrosion allowance of 1/8 inch per exposed surface.

Non-corrosive materials may be required to have a smaller increase in thickness depending upon their relative corrosiveness.

Submerged parts can be cathodically protected with a protection life of ten years, or if this is not practical, then the design life can be reduced in accordance with the predicted cathodic protection life and routine replacements planned. As an example, galvanized wire rope is in this category with an estimated life of five years.

The propagation of fatigue cracks is very sensitive to the corrosion rate so that corrosion effects have a radical effect on the expected life of a structure.

As is the practice with most offshore structures, the SKSS structures may be protected by a sacrificial anode system during deployment and installation and by an impressed current system for long-term protection. The latter may not be required for the modular experimental plant. Wire ropes are typically galvanized and chains have no corrosion protection. Typically, a corrosion allowance of extra steel thickness is provided for fixed structures.

Some specific requirements exist in some classification society rules, e.g., the Det Norske Veritas (DnV) "Rules for Design, Construction, and Inspection of Fixed Offshore Structures" [6].

c. Probable SKSS Materials

When the list of possible SKSS configurations are considered, it becomes obvious that an overwhelming number of components will be manufactured of steel. Steels used may be of one type or the other depending on the service expected.

Other choices of materials for SKSS components may be ropes made of synthetic fibers and elastomers. The properties of these materials are discussed below.

Steels used in marine applications

A wide selection of steels are available for the extensive field of applications.

However, three general applications can be defined, and, therefore, three different groups of steels will result. These are, steels used in structural applications (the so-called mild steels), steels used in fabricated applications (or high-strength steels), and steels used in marine machine design applications (or so-called stainless steels).

It should be clearly understood that the above do not have sharp and clear definitions and that big overlaps exist. Also within each defined category there are tens or even hundreds of various groups, each suitable for a very narrow and specialized range of applications.

It is intended here to present one or two grades of steel within each category that will be the most representative or the most likely to be used for the SKSS and the site intended. The properties and design criteria for structural, high strength, and stainless steels are presented in Appendix F.

Synthetic Fibers Used for Ropes

A large number of synthetic fibers are in existence to be used for ropes. However, in mooring applications, the rope manufacturers use Kevlar, Nylon, Dacron, Polypropylene, and Polyethylene.

The physical and mechanical properties of these synthetic fibers vary substantially depending upon whether they are dry or wet. Additionally, each fiber can be made into various grades that possess a range of mechanical properties.

The allowable loads for these fibers when wound into ropes will, therefore, vary substantially depending on the application. For example, in a mooring application, if the watch circle is the critical design criterion, then, the allowable load will be very small, since the majority of the fibers do not have linear elongation characteristics. In general, when fatigue is taken under consideration for prolonged mooring applications, the factors of safety used are between 8 and 10 based on the breaking strength of the rope made from a synthetic fiber. A notable exception appears to be Kevlar, for which a safety factor of 4 - 5 will produce a life cycle roughly equivalent to that of wire rope. Kevlar is a fiber currently under intensive investigation for mooring applications. The material selection for each SKSS design will be made on the basis of loads and other requirements imposed by the site conditions.

Details on the properties and design criteria for Kevlar, Nylon, Dacron, Polypropylene, and Polyethylene can be found in Appendix **F**.

<u>Rubbers and Elastomers</u>

Rubbers and elastomers have recently found use in offshore applications. When sheets are bonded with steel sheets, they can produce products that have a variable bending stiffness.

Two materials are selected here that represent the entire family of Rubbers and Elastomers: Natural Rubber and Neoprene. Their physical and mechanical properties are similar, but their resistance to various chemicals differs substantially.

The site conditions and calculated loads will determine the characteristics to be expected of mooring lines.

Appendix F gives detailed criteria for natural rubber and neoprene.

d. <u>SKSS Components</u>

<u>Anchors</u>

The holding power of an anchor is frequently expressed as a ratio of the maximum horizontal pull to the anchor weight in air. The holding power is a function of the type of anchor, surface area of anchor resisting load, anchor embedment, and physical properties of soils in which the anchor is embedded. The types of anchors to be considered for SKSS designs include:

(1) drag anchors,

(2) direct embedment anchors,

(3) pile anchors,

(4) gravity anchors.

Brief descriptions and design criteria for each anchor type are included in Appendix E.

B. Anchor Connections

1. Shackle and Swivel

Shackles and swivels are shelf items and can be purchased from manufacturers based on their published safe loads.

The first design criterion is that the anchor shackles and swivels have a minimum factor of safety of 5.0 based upon their rated breaking strength.

The second design criterion is that the dimensions of the shackles and swivels be compatible with those of the chain they mate with the anchor.

2. Universal Joints

Universal joints are not standard mooring items; therefore every individual case will require a particular design.

First design criterion involves the design of structural members. The structural design should at least comply with the rules of AISC, with adequate allowances for fatigue.

Second criterion is that bearings should be permanently lubricated for the design life. Lubrication should be appropriate for underwater applications.

Seabed Line

1. Chain

The design criterion for the chain is that the maximum tension shall not exceed 33% of its breaking strength per API "Proposed Recommended Practices for Mooring". If the chain should meet this criterion for loads, then the fatigue effects will be considered.

2. Special Links

Design criteria valid for chains apply also to special links.

3. Special Sheathing

Special sheathing is occasionally applied on seabed lines to prevent damage by abrasion and to reduce corrosion.

The design criterion is that the sheathing will be abrasion resistant.

Mooring Line

1. Chain

Same comments apply as the Seabed Line "chain".

2. Wire Rope - Spiral Strand

The design criterion is that the maximum tension shall not exceed 33% of its breaking strength per API Proposed Recommended Practices for Mooring, based on expected fatigue life of approximately 5 years.

3. Wire Rope - Parallel Strand

Use of parallel strand wire rope is completely unknown in marine applications. Its primary advantage is that the straight wires can develop their maximum ultimate strength. Its disadvantage is that due to the nature of the bundle construction, it is difficult to protect against corrosion, since each and every wire is exposed to salt water.

Design criterion is that the factor of safety based on ultimate strength should be 2.2 if the wire bundle is sheathed according to manufacturer's recommendations. If the wire bundle is not sheathed, the safety factor should be increased to 4.0 based on the ultimate strength of the wires.

4. Tension Rods

Tension rods are structural design items. The general stress criteria for steel will apply. The allowable stresses should be based on the yield strength of the material.

5. Buoyant Links (HCL)

Same criteria as those for tension rods are applicable to the hollow cylindrical link type mooring lines.

6. Synthetic Ropes (Nylon, Kevlar, Dacron, etc.)

The primary advantage of synthetic ropes is high strength to weight ratio making this attractive for deep water moorings.

The design criterion is that the factor of safety must be between 8 - 10 for extended design fatigue life.

Fairlead

1. Bell-mouth tube: The structure, in general, should meet the general stress criteria; but the thickness of material in the zone of contact with the morring line must have a wear allowance of 1/4 inch if the zone is large, and proportionately greater if the wear zone is concentrated. .

2. Swivelling Sheave or Rollers: The thickness of material in the zone of contact with the mooring line must have a wear allowance of 1/4 inch.

   If the sheave or rollers are submerged, the sheave, swivel, and roller bearings must be permanently lubricated in a manner intended for underwater service. If they are not to be submerged, the bearings may be periodically lubricated.

Stopper

All types: The design load for the stopper is to be twice the design load of the mooring line. In addition, the stopper is to be capable of carrying three times the design load of the mooring line without structural failure, although yielding and structural distortion will be allowed.

Tensioner

All types: The SKSS may be designed such that no adjustment of length of the mooring lines is required, or it may be designed with a requirement to adjust the length of the mooring lines under load.

In the latter case, the design load on the tensioner is to be 1.5 times the maximum static load in the mooring line, or 1.0 times the design load in the mooring lines. In the case where no length adjustment is required, the design load on the tensioner is to be 1.5 times the installation deadload (weight) of the mooring line.

2.1.3 Basic Performance Analysis Procedures

Static and dynamic load analyses must be performed to ensure that the SKSS concept will satisfy permissible excursion limits and component strength requirements. A deterministic analysis will be used to obtain mooring line and anchor loadings in the conceptual design phase. This approach considers a static force resulting from lateral displacement of the platform and an oscillatory force which tends to oscillate the platform about its static equilibrium point. The SKSS should be designed to control the former and resist the latter. The static force is the vectorial addition of a static wind, current, and a high frequency wave drift force for a given simple design wave with characteristic height and period. The SKSS must provide an equal and opposite restoring force without exceeding the permissible excursion limits.

The oscillatory force is due to the low frequency wave inertial forces and is generally an order of magnitude greater than the combined static forces, (See Appendix C and References #1 and 2 cited therein). The maximum vessel offset is obtained by adding the single amplitude oscillatory excursion to the static offset. For the maximum design condition, the maximum offset is re-entered into the SKSS analysis to determine the maximum tension and anchor loads on the most severely loaded member. The SKSS will generally have a minimal effect on platform motions except possibly in the case of a vertical mooring.

2.1.4 Scheduling Constraints

The schedule for the OTEC program will place constraints on the time available for such activities as research and development, acquisition of materials and components, construction of components, and deployment of the SKSS. The latest DoE Ocean Engineering Plan calls for the modular experiment plant to be deployed on site in October 1984.

The time limitations will depend on information to be obtained from manufacturers on equipment availability and required development.

The allowable environmental states suitable for deployment operations will depend on the scenario established for the deployment. The weather windows, durations of time during which the environmental conditions will not exceed allowable levels, will have to match the required time for deployment.

2.2 ENVIRONMENTAL CONDITIONS

2.2.1 General

The environmental data needed for the analysis of SKSS designs can be divided into two groups: bottom data and surface data.

The bottom data available for the Punta Tuna site are given in (1)* and (2). The search for further information was not fruitful; however, three reports on bottom conditions at St. Croix, Vieques Island, and Southern Puerto Rico regions were made available to the project team, (3), (4), and (5). These reports do not contain specific information on the designated OTEC site at Punta Tuna with coordinates of 17° 57' N and 65° 52' W. Our subcontractor, McClelland Engineers, has extrapolated the data contained in these references to obtain an approximation of the soil conditions at the site, (see Section 2.3).

If the approach is to define some storm that is expected to occur once every so many years, and to consider the wind, wave and current conditions therin the worst to be experienced, then perhaps the definition of the "Bretschneider Storm" defined in (6) can be used. However, it is possible to consider and identify the combined spectrum of winds, waves, and currents in the form of "environmental states" and their probabilities of exceedance at the site.

*Numbers in brackets denote similarly numbered references and end of report.

Although both of the above approaches can probably be used in a reliability analysis, the latter should be more straightforward and realistic in that it does not involve the development of a single storm which when used in the design will result in successful operation of the system for a given period of time. With the "environmental state" approach, system reliabilities can be computed.

The Bretschneider report [6] does not contain the all-inclusive information needed to obtain these states. However, using the SSMO data [7] in conjunction with the data existing in [1] and [2], the environmental states can be developed.

Out subcontractor, A. H. Glenn & Associates, was asked to develop these states using the results of above-mentioned references, insofar as possible, and commenting on any differences of significant extent from their results. Section 2.1.2. describes the approach used by A. H. Glenn Associates, Inc. in determining the environmental states.

2.2.2 Surface Environmental Data

In references [1] and [7], both the English and the metric units are used. In developing the environmental states for the present study, the same units are used for each parameter (i.e., wave height in feet, wind speed in knots, current velocities in centimeters per second, etc.).

The results of analysis are summarized in tables listing wave, wind, current states and their probabilities of exceedance. Three wave directions (direction from which waves move) are considered: northeast, east, and southeast. These wave directions account for more than 92 percent of all wave directions occurring at the site because of the strongly prevailing easterly winds ("trade winds") of the Puerto Rico area.

Significant wave height, Hs, is the average height of the highest 33 1/3% of the waves. The waves are observed consecutively and all waves are considered (that is, no differentiation between a "sea" or "wind wave", and a "swell" is made). An actual measurement of significant wave height usually involves a 10 to 20 minute continuous recording of a wave gage.

Significant wave period, Ts, is the average period of the highest 33 1/3% of the waves, ... the same waves considered in the determination of the significant wave height.

The wind speed is stated [6] as a maximum 10 minute average and is given in knots (nautical miles per hour).

The still water depth at the site is specified as approximately 1200 meters. Because of the considerable depth at the site, storm tides are small (a few feet in the case of severe hurricanes). The astronomical tide range is also small (2 feet or less). The possible tidal variation of several feet, at the most, has negligible effect on the wave profile or wave forces in a water depth of approximately 1200 meters. For this reason, storm tides and astronomical tides are not considered herein.

The percentages of waves in period groups are summarized in the tables. The waves at the site are predominantly short period, locally generated wind waves, but some swell reaches the site. The Bretschneider wave period distributions are adjusted to include some longer period wave action since longer period wave action is present at this site and is important with respect to vessel motion problems.

Current speeds in centimeters per second are summarized for 100 meter depth intervals in the tables. The currents summarized are the vector totals of the geostrophic, tidal, and wind driven currents in the direction of motion of the waves.

The probability of exceedance of the environmental state is the percentage of time the environmental state (combined wave, wind, and current) in the specified direction, is exceeded. Thus an exceedance of 1% indicates that the environmental state in the specified direction is exceeded 3.6525 days total time per year.

The analysis procedure employed in developing environmental states is discussed in detail in Appendix D.

After completing the analysis as summarized above, tabulations are obtained describing the wave period, wind speed, wave period distribution, and current speed distribution versus depth for the significant wave heights of 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 45, and 50 feet. Table 3 is a sample Environmental State tabulation.

Each significant wave height tabulation includes the probability of exceedance of that environmental state, and the tabulations are repeated for the three directions from which waves move or wind blows.

The 35 environmental states thus obtained describe the complete spectrum of environmental conditions that the SKSS may experience during its lifetime. Table 4 is a listing of the 13 environmental states considered for each wave direction. All 35 data sheets are included in Appendix D.

Representative environmental states (E.S.) to be used in the calculations for mooring loads and reliability/performance/optimization analyses are then selected. The number of E.S. is reduced to seven for the conceptual design studies.

Table 5 lists the tentatively selected environmental states for use in conducting basic calculations in the conceptual design phase. The number of E.S. may have to be further reduced in the preliminary design stage.

TABLE 3: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	15.0 Ft.
Significant Wave Period, T_s	8.5 Secs.
Wind Speed[1]	27. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.9
2.5 - 4.4	6.9
4.5 - 6.4	20.3
6.5 - 8.4	35.6
8.5 - 10.4	26.3
10.5 - 12.4	7.5
12.5 - 14.4	1.5
14.5 - 16.4	0.5
16.5 - 18.4	0.3
18.5 Plus	0.2

Current Speed Versus Depth, Meters	
0	94 Cm/Sec
100	68
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.564 Percent

Note: [1]Direction from which waves move or wind blows.

ENV'NMTL STATE NO.	SIGNIFICANT WAVE HGT. (HS)	WIND SPEED (KT.)	SIGNIFICANT WAVE PERIOD (Ts) (Sec.)
0	0	0	--
1	2.0	10	4.0
2	4.0	14	4.7
3	6.0	17	5.4
4	8.0	20	6.1
5	10.0	22	6.8
6	15.0	27	8.5
7	20.0	31	9.7
8 Doss*	25.0	40	10.4
9	30.0	60	11.0
10	35.0	80	11.7
11	40.0	89	12.4
12 Dess**	45.0	94	13.0
13	50.0	99	13.7

TABLE 4: ENVIRONMENTAL STATES CONSIDERED FOR EACH DIRECTION

*Design Operational Sea State corresponding to 3 year return period.

**Design extreme (survival) sea state corresponding to 70 year return period.

ENV'NMTL STATE NO.	SIGNIFICANT WAVE HGT. (HS)	WIND SPEED (KT.)	PROB. OF EXCEEDANCE
1	2.0	10	38.07
2	4.0	14	21.88
3	6.0	17	12.41
5	10.0	22	3.38
8 Doss	25.0	40	0.0181
10	35.0	80	0.0000159
12 Dess	45.0	94	0.00000143

TABLE 5 ENVIRONMENTAL STATES FOR USE IN CONCEPTUAL DESIGN CALCULATIONS

2.2.3 Bottom Data

The government furnished information [2] indicates that the gross bottom conditions at the Punta Tuna site are as follows:

Approximate depth: 1200 m. (4000 ft.)

Bottom condition: Silts and sand, high in carbonate content.

Approximate bottom slope: 1:3.0

McClelland Engineers, Inc. was asked to conduct a brief investigation by studying existing information in references [1], [9] and [10]. They have projected that the sediments in the general area of the site possibly could be predominantly calcareous oozes to an approximate penetration of about 650 ft. below the sea floor. Calcareous oozes are composed essentially of the calcium carbonate remains of open sea organisms and vary in texture from sandy silt to clayey silt [4], [5] and [9]. The average water content and unit dry weight values reported for calcareous oozes in the area [3] are consistent with those found on a world-wide basis [9]. Based on experience with calcareous ooze samples from deep continental margins, it can be recommended that structures in the calcareous oozes be designed for an angle of internal friction at 20^{o}.

A copy of McClelland Engineers' complete report is included in Appendix G.

2.3 Site Suitability Study

2.3.1 Original Site

The original experimental modular plant site given in (2) for consideration is about 3 miles offshore south west of Punta Tuna, Puerto Rico. The site characteristics are shown in Tables 6 and 7 Figures 3 and 4 define the location of this site.

The largest problem this site presents with regard to the design of an OTEC SKSS is the large bottom slope of nearly 15 degrees, (see bottom profiles for the site, Figures 5 and 6). This presents difficulties for the anchor design. A drag anchor will tend to simply slide down slope rather than set itself when dragged over the bottom; drilled, driven, or explosively set piles will be very difficult to start on a slope, and a gravity anchor will have a greater tendency to overturn which is one of its normal modes of failure. Each of these problems could be solved for the bottom slope considered but the costs of the anchors and possibly of the mooring legs will be higher than those for a flat horizontal bottom.

The large water depth of 4,600 feet tends to increase the cost and complexity of the mooring system but this cannot be reduced substantially without increasing the risk of grounding the cold water pipe. A horizontal clearance of 5,000 feet is considered reasonable since it would take a major or total failure of all SKSS concepts under consideration to reach this excursion exceedance.

TABLE 6

OTEC DEMONSTRATION SITE

AT PUNTA TUNA, PUERTO RICO

SITE LOCATION:	17° 57 N, Latitude 65° 52 W, Longitude
APPROXIMATE DEPTH AT SITE	4,600 Ft.
DISTANCE FROM SHORE	16,080 Ft. = 3.1 Mile = 2.6 NM (5.10KM)
DISTANCE TO NEAREST GROUNDING POINT	Approximately 5000 Ft.
APPROXIMATE BOTTOM SLOPE	
From the NOAA Chart of Bathymetry (Figure 3)	12.92
From Charts (Figure 4)	17.00
From Puerto Rico Office Data (Table 7)	13.68
	Average Bottom Slope = 14.4°
BOTTOM SOIL CONDITION	Calcareous oozes composed essentially of calcium carbonate with a texture of sandy to clayey silts.

TABLE 7

DATA RECEIVED FROM PUERTO RICO OFFICE

(Reference No. 11)

SITE LOCATION: 17° 57N, 65° 52W

APPROXIMATE DEPTH

NORTH TO SOUTH 1.125 MILES
(In Fathoms)

537

539

580 DIFFERENCE 241 FATHOMS (1,446 FT.)
In 1-1/8 MILES

659

778

APPROXIMATE BOTTOM SLOPE $= \frac{1,446}{1.125 \times 5280} = 13.68^{\circ}$

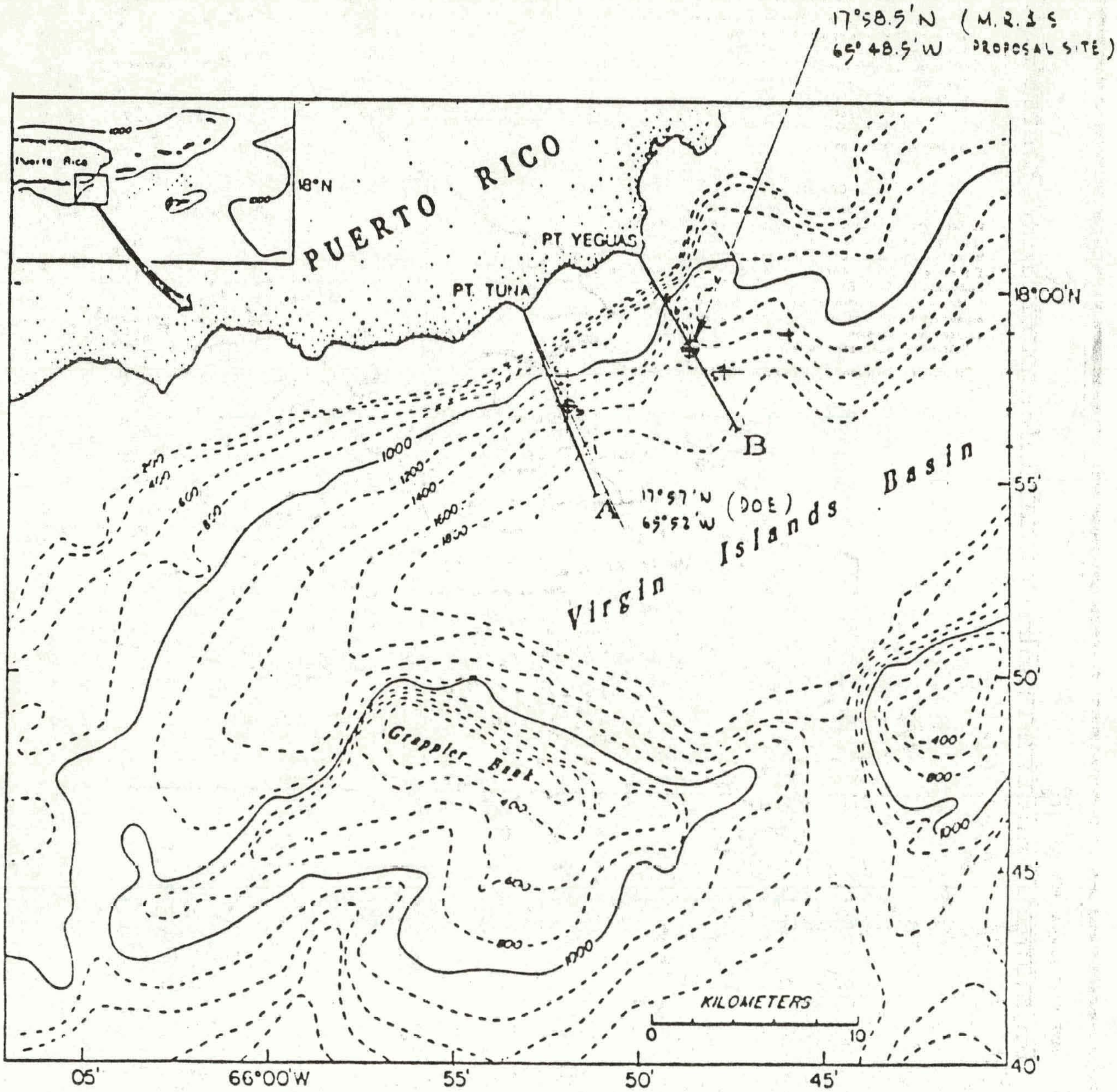


Chart of the bathymetry in the western portion of the Virgin Islands Basin (hatched area in inset) southeast of Puerto Rico. Depth contours are in meters corrected for the speed of sound in sea water (Matthews, 1939). Data courtesy of NOAA, National Ocean Survey and from a bathymetric survey conducted during the present study.

Figure 3: BATHYMETRIC CHART
(From Reference No. 12)

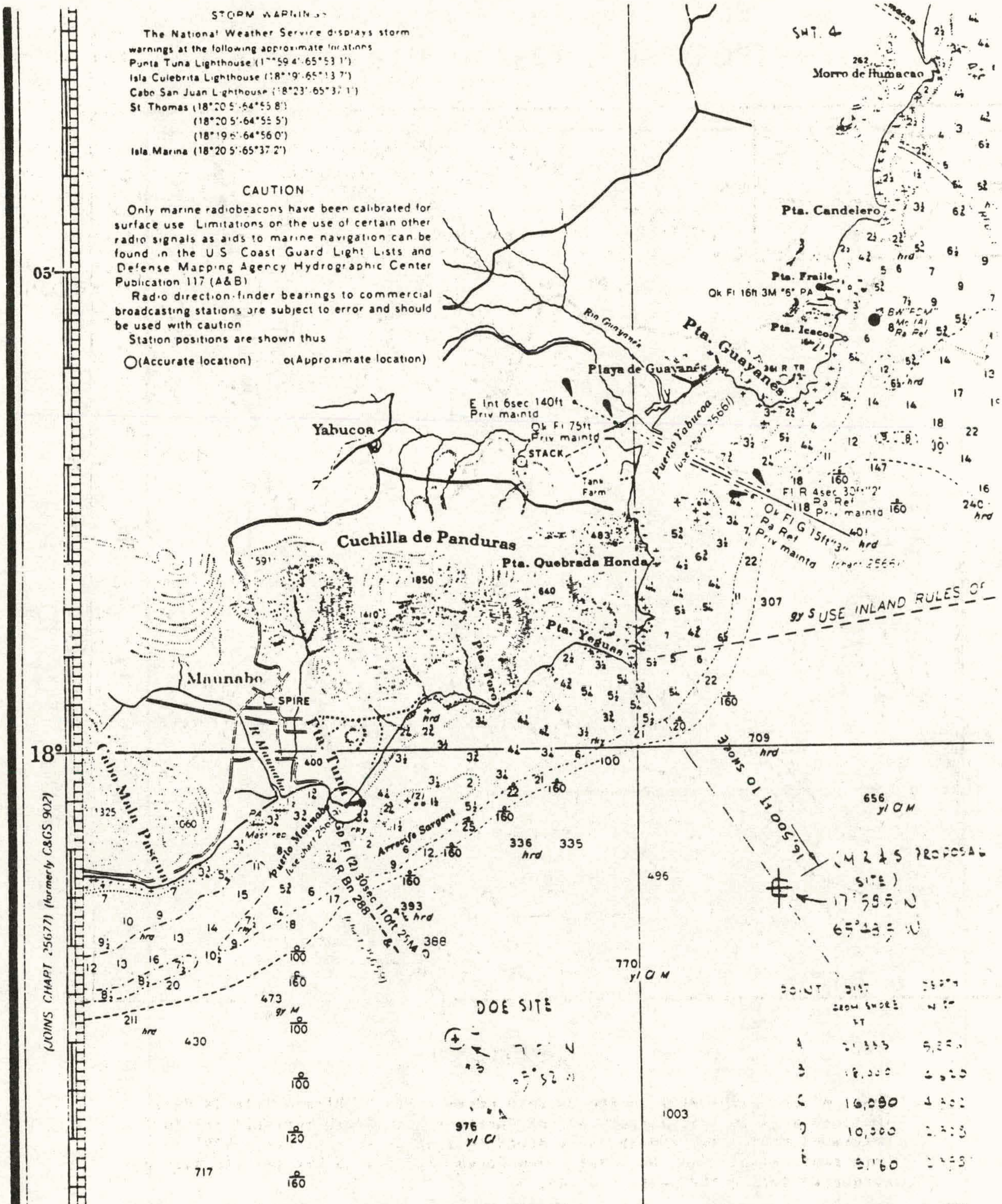


FIGURE 4: NOAA CHART

(From Reference No. 13)

21st Ed., Oct. 30/76

25650

(formerly C&GS 904)

CAUTION

This chart has been corrected from the Notice to Mariners published weekly by the Defense Mapping Agency Hydrographic Center and the Local Notice to Mariners issued periodically by each U.S. Coast Guard district to the print date shown in the lower left hand corner.

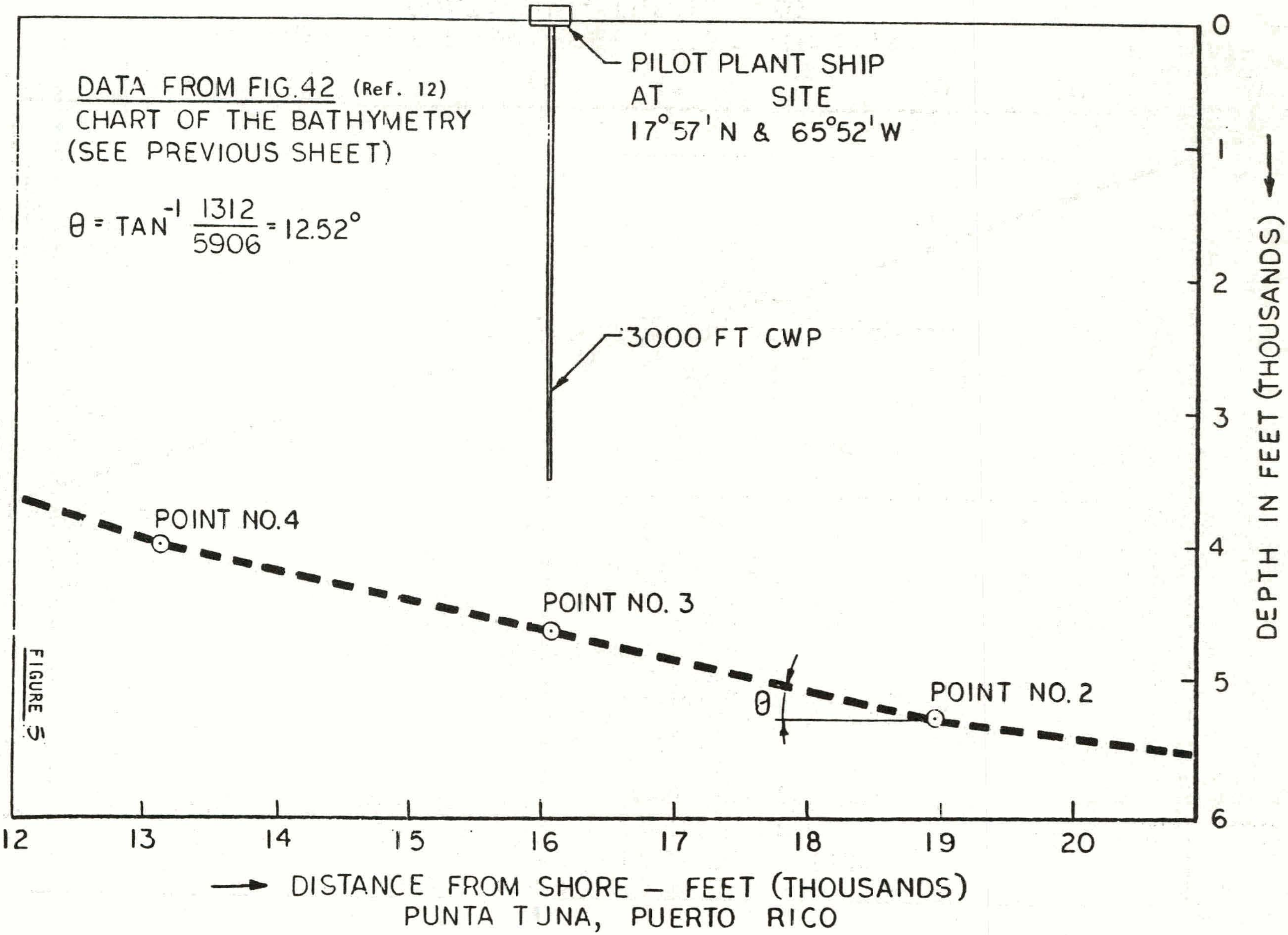
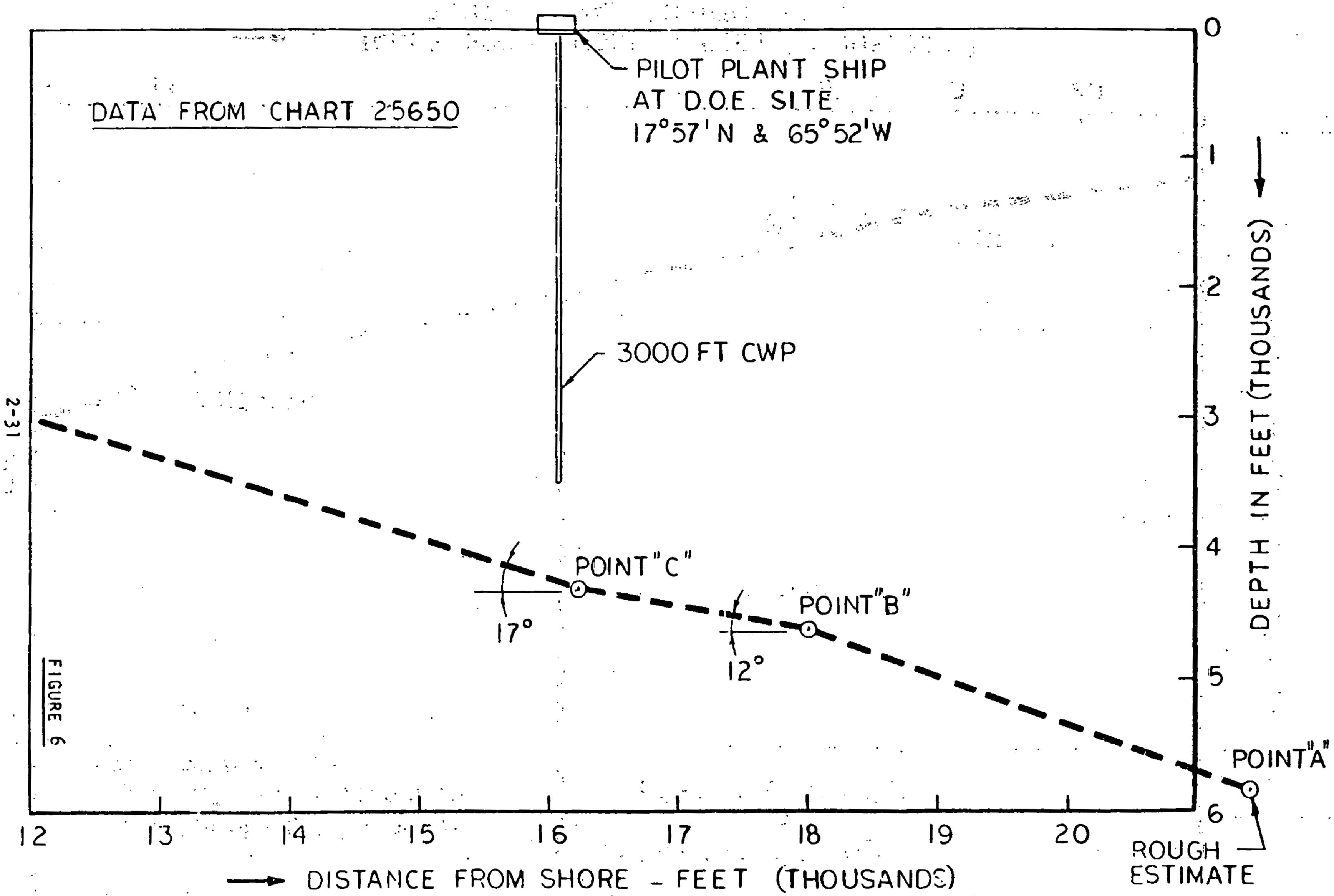


FIGURE 5

SHEET 3



PUNTA TUNA, PUERTO RICO

FIGURE 6

2.3.2 Selection of a Better Site

Because of the difficulties presented by the sloped ocean bottom at the site, a brief study was conducted to search for a site with approximately the same distance from shore, the same depth of water under the platform, and the same or greater clearance to the grounding point for the cold water pipe but with significantly less bottom slope. A site was found southwest of Punta Yeguas which met these conditions. The proposed site characteristics are shown in Table 8, and the bottom profile in Figure 7.

After discussion with A. H. Glenn & Associates, who had developed the original environmental states tabulation, it was concluded that the environment at the original site would not significantly differ from that for the proposed site which is only four miles northeast of the former. The bottom composition, as defined by McClelland Engineers Inc., should also apply to the proposed site.

The new proposed site also has its problems. While the bottom slope directly under the platform is much lower than the original site, a sharp increase in bottom slope exists about 2600 feet north of the site. For vertical or inclined tension leg moorings this presents no problem since the anchors are grouped almost directly below the platform. For a catenary mooring, however, it may present a significant problem for the anchor design since the anchor would have to be located on a steep slope at least for some legs of a multi-leg catenary mooring. Somewhat more favorable bottom conditions were found by moving the site further offshore to approximately 19,000 ft. The bottom depth is 5200 feet at this location, and the site coordinates are 17° 58.2'N, 65° 48.2'W.

TABLE 8 PROPOSED SITE CHARACTERISTICS

Site Coordinates	17° 58.5° N Latitude
	65° 48.5° W Longitude
Approximate Depth at Site	4850 Feet
Distance from Shore (Punta Yeguas)	16,500 Feet - 3.1 Miles
Approximate Bottom Slope	4.4 Degrees

Bottom Composition - Same as original Site (Table 6)

Distance to Nearest Grounding Point - Approximately 5500 Feet

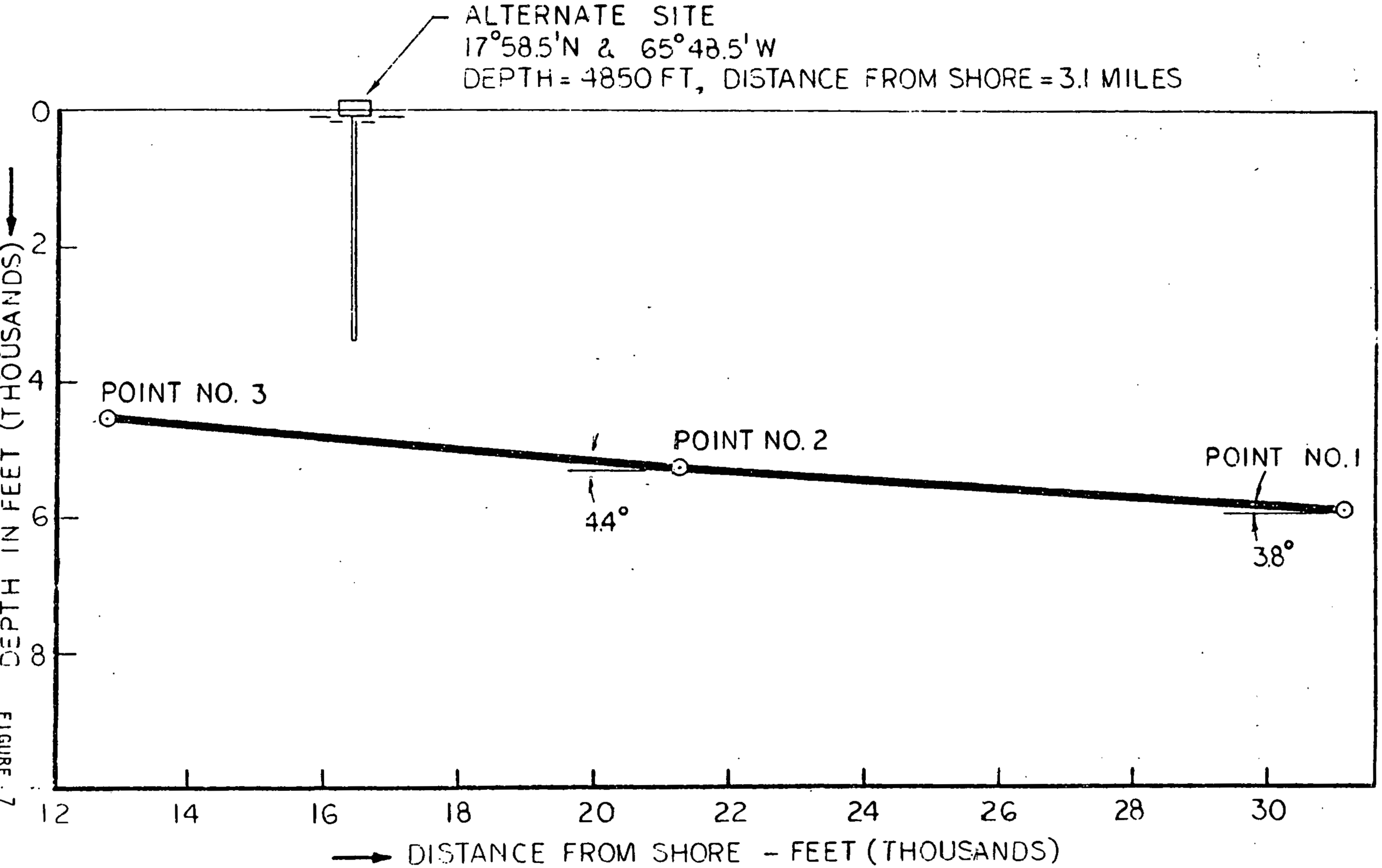


FIGURE 7

SHEET 2-34

Another potential problem area is the formation of a turbidity current in the submarine canyon north east of the site location. If such a current should develop, there could be substantial damage to the bottom cable and the anchors.

3.0 METHODOLOGY FOR CONCEPTUAL DESIGN STUDIES

The technical approach used in conducting the preliminary evaluations and performing the conceptual designs on feasible SKSS candidates is schematically described in Figures 8 and 9.

The basic sequence of events in the process can be summarized as follows:

1. The static drag forces for the two baseline OTEC platforms are computed for the seven environmental states [ES] established (See Table 5).

2. A matrix of candidate SKSS concepts is developed; one concept is selected at a time from the matrix for evaluation.

3. Computations are performed for this concept, using two environmental states corresponding to the "design operational" and "design extreme" sea states, as indicated in Table 5, to estimate:

   - The forces acting on the mooring legs
   - The anchor reaction required
   - The expected static excursion

   These computations are performed using hand calculations wherever possible, or a programmable calculator, and the CALMS program [14] for applicable SKSS concepts to check the results.

4. Using the baseline platform motions data supplied by APL [15] and by Gibbs & Cox [16] as input, the oscillatory forces which tend to oscillate the platform about its static equilibrium point are estimated.

5. The maximum reaction forces are then computed and the maximum platform displacements are obtained by the addition of oscillatory excursion to the static excursion.

6. Based on the criterion that the SKSS must provide an opposite restoring force equal to the maximum reaction force without exceeding the permissible excursion limit of 10% of the water depth, the acceptability of the concept is determined. Appropriate factors of safety are used in determining the acceptability of individual SKSS components.

7. Should the SKSS concept be found not capable of resisting the maximum load or should it result in excessive excursions, necessary modifications are made to SKSS components, if possible, until an acceptable design is obtained. The concept is dropped if this is not possible, and another concept is selected from the matrix.

8. After the acceptability of a concept is established as above, the sizes of major SKSS components, and their materials of manufacture, are finalized. For the SKSS design thus established, the following brief investigations are performed:
   - technical feasibility of components and materials is verified
   - deployment procedures and scenarios of the SKSS components are estimated
   - budgetary cost estimates are prepared for the concept in question
   - approximate time schedules and risk assessments are carried out.

- interface of the SKSS components with other OTEC subsystems are considered and any potential problem areas are identified.
- a qualitative discussion on the fatigue life of major SKSS components is made.
- minor modifications are made, in an iteration, to any major components which may be found unacceptable regarding any of the above mentioned criteria.

9. If an SKSS concept is found to be acceptable in all areas of consideration, it is established as a viable candidate for the baseline OTEC platform in question. All viable candidates are then subjected to a comparison on the basis of costs, burden variables, and estimated effectiveness, and the two best candidates for each platform are selected.

10. The arrangements, cost estimates, deployment scenarios, maintenance and replacement procedures, and time schedules for the two designs for each platform are developed to a conceptual level of detail. For all of the feasible concepts, prior to the selection of two for each platform, costs/deployment/replacement studies are also performed but to a lesser extent.

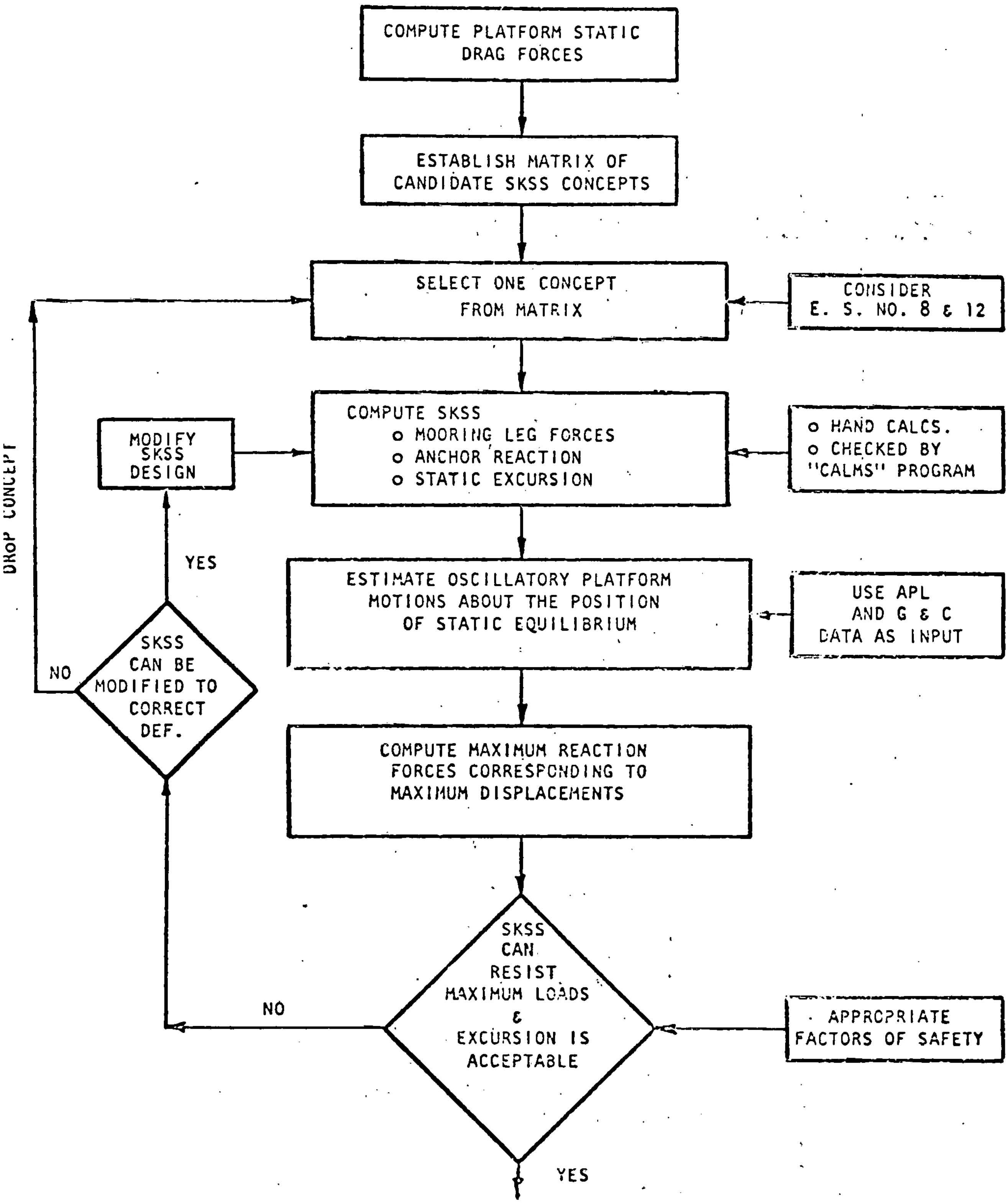

COMPUTE PLATFORM STATIC DRAG FORCES
ESTABLISH MATRIX OF CANDIDATE SKSS CONCEPTS
SELECT ONE CONCEPT FROM MATRIX
CONSIDER E. S. NO. 8 & 12
COMPUTE SKSS
o MOORING LEG FORCES
o ANCHOR REACTION
o STATIC EXCURSION
MODIFY SKSS DESIGN
o HAND CALCS.
o CHECKED BY "CALMS" PROGRAM
DROP CONCEPT
YES
NO
ESTIMATE OSCILLATORY PLATFORM MOTIONS ABOUT THE POSITION OF STATIC EQUILIBRIUM
USE APL AND G & C DATA AS INPUT
SKSS CAN BE MODIFIED TO CORRECT DEF.
COMPUTE MAXIMUM REACTION FORCES CORRESPONDING TO MAXIMUM DISPLACEMENTS
SKSS CAN RESIST MAXIMUM LOADS & EXCURSION IS ACCEPTABLE
NO
APPROPRIATE FACTORS OF SAFETY
YES

FIGURE 3

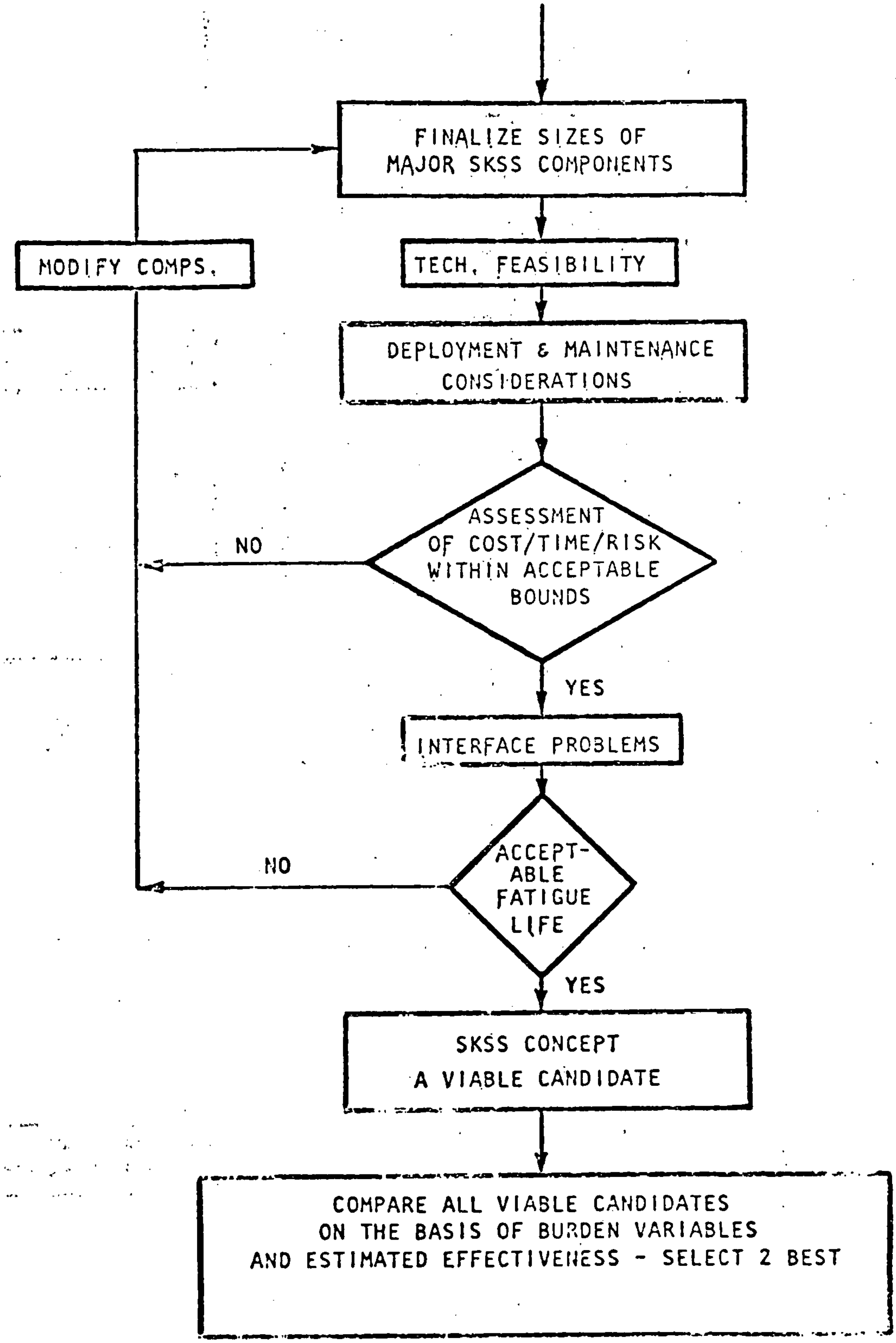

FINALIZE SIZES OF MAJOR SKSS COMPONENTS
MODIFY COMPS.
TECH. FEASIBILITY
DEPLOYMENT & MAINTENANCE CONSIDERATIONS
ASSESSMENT OF COST/TIME/RISK WITHIN ACCEPTABLE BOUNDS
NO
YES
INTERFACE PROBLEMS
ACCEPT-ABLE FATIGUE LIFE
NO
YES
SKSS CONCEPT A VIABLE CANDIDATE
COMPARE ALL VIABLE CANDIDATES ON THE BASIS OF BURDEN VARIABLES AND ESTIMATED EFFECTIVENESS - SELECT 2 BEST

FIGURE 3

4.0 DEVELOPMENT OF A MATRIX OF CANDIDATE SKSS CONCEPTS

4.1 General Considerations

The limitation specified in the RFP for this study is that the primary SKSS for the Modular Experiment OTEC platforms will be a moored system and that other station-keeping approaches, including dynamic positioning, may be used as a secondary SKSS in addition to the primary subsystem, if justified.

The need for the development of an initial matrix of SKSS concepts suitable for this study is obvious. In establishing which specific mooring concepts are to be included in the matrix, the following criteria must be considered:

- o Environmental characteristics of the site
- o Characteristics of the OTEC platforms
- o Current state-of-the-art of the mooring concepts
- o Practical design considerations
- o OTEC program schedule requirements

Two basic site characteristics, water depth and bottom slope govern many of the characteristics of a suitable SKSS design. The OTEC design site at Puerto Rico with a bottom slope of 4.4 degrees and depth of 4850 to 5400 feet presents a challenging design problem. Very few mooring systems have been designed to operate in this water depth over a ten year life time and develop a holding force capability in excess of 1,000 kips which happens to be the lower survival limit of modular plant mooring systems.

The need for high reliability and near term deployment dates calls for emphasis on the use of current state-of-the-art components which do not require significant development and testing time. For the SPAR platform with a maximum drag force of 1300 kips, use of state-of-the-art components may be practicable. For the barge with a maximum drag force ranging from 4040 kips (head seas) to 6400 kips (beam seas), new technological development would appear necessary.

Interface of the SKSS with other platform systems must be considered. Some SKSS concepts call for mooring legs connected to the cold water pipe which clearly would impact the pipe's structural characteristics. Weight and space requirements of the SKSS must be reasonably compatible with the platform conceptual designs developed to date. In the case of the barge, an SKSS concept which permits the barge to "weathervane" or remain head to the waves is desirable since the cold water pipe stresses at the CWP/hull connection are greatly reduced as compared to those for the beam seas.

The selection of one or the other type of SKSS concepts for inclusion into the evaluation matrix will largely depend on the possibility of practical realization of this concept by the deployment date (1984) for the Modular Experiment platform. All components of the SKSS concept selected must demonstrate a capability of either being available as off-the-shelf equipment or of successfully being developed by the deployment date.

4.2 Generic Mooring Concepts

All possible generic SKSS concepts, as applied to offshore platform designs to date, have been considered and the following four categories have resulted as candidates for the Modular Experiment platforms.

- o Spread Catenary
- o Tension Leg
- o Rotary Mooring

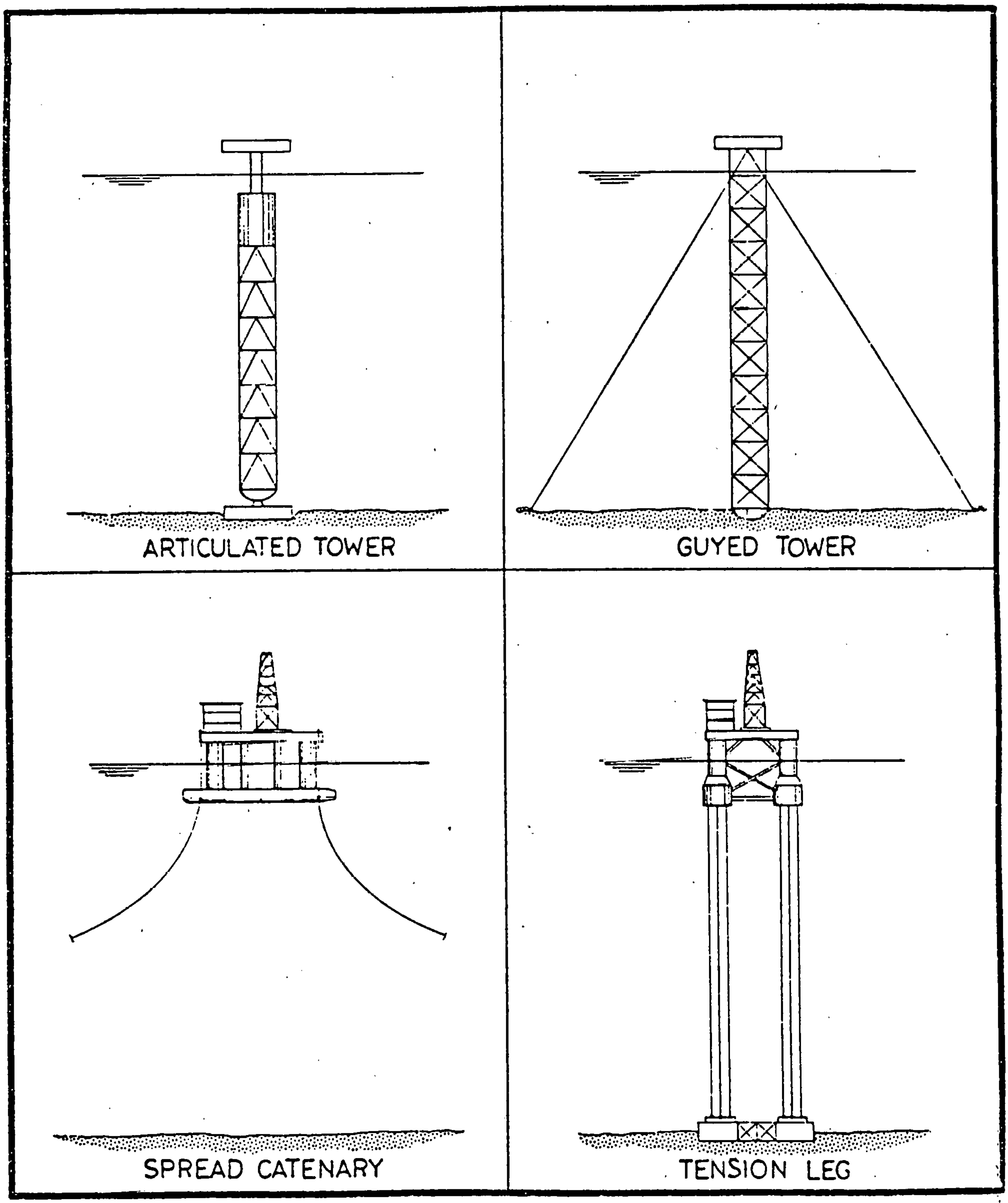
Figure 10 presents the concepts, either built or designed, presently existing in the offshore drilling industry for the fixed, catenary, and tension-leg variations. A schematic description of the rotary mooring concept (turret) can be seen in Figure 12.

Each of the generic concepts is discussed in the following subsections:

4.2.1 Spread Catenary Mooring

The conventional spread catenary type mooring system is a standard generic concept which deserves serious study for application to Modular Experiment OTEC Platforms.

Some marine designers have suggested that the maximum design conditions for a feasible catenary mooring is between 4000 to 5000 feet water depth with a holding capability of 1000 kips. Despite the difficulty of achieving the even higher performance required for both experimental modular platforms in question, a conventional catenary mooring must be studied because of the advantages of using an extensively developed concept which for



GENERIC SKSS CONCEPTS

FIGURE 10 (EXTRACTED FROM REF. 17)

the SPAR platform at least may be able to utilize standard components. Generic variations of the catenary mooring would include addition of thrusters or active winch controls for more precise positioning, and as a concept unique to OTEC, mooring off the cold water pipe. Because of the very large holding force requirements for the barge, use of conventional or available SKSS components may not be possible but stronger mooring legs and anchor components could be developed to make this mooring concept feasible.

The sketch shown in Figure 11 identifies the components of a catenary type mooring system and presents the nomenclature to be used in this report.

4.2.2 Tension Leg Mooring

A tension leg SKSS concept offers several attractive advantages for the SPAR platform. The required cable or tension rod lengths are much less than for a catenary mooring and anchor deployment may be much simpler if only one anchor is required. The platform will exhibit significantly reduced heave, pitch and roll response in waves which reduce the wave induced stress loadings on the cold water pipe and other seawater system components. The primary disadvantages are that large leg tensions are generated by cyclic wave loading and surge, sway and yaw motions from steady-state forces may be large. Resultant forced motions in the horizontal plane may be made small by detuning the SKSS from significant wave frequencies with the proper choice of tension line properties.

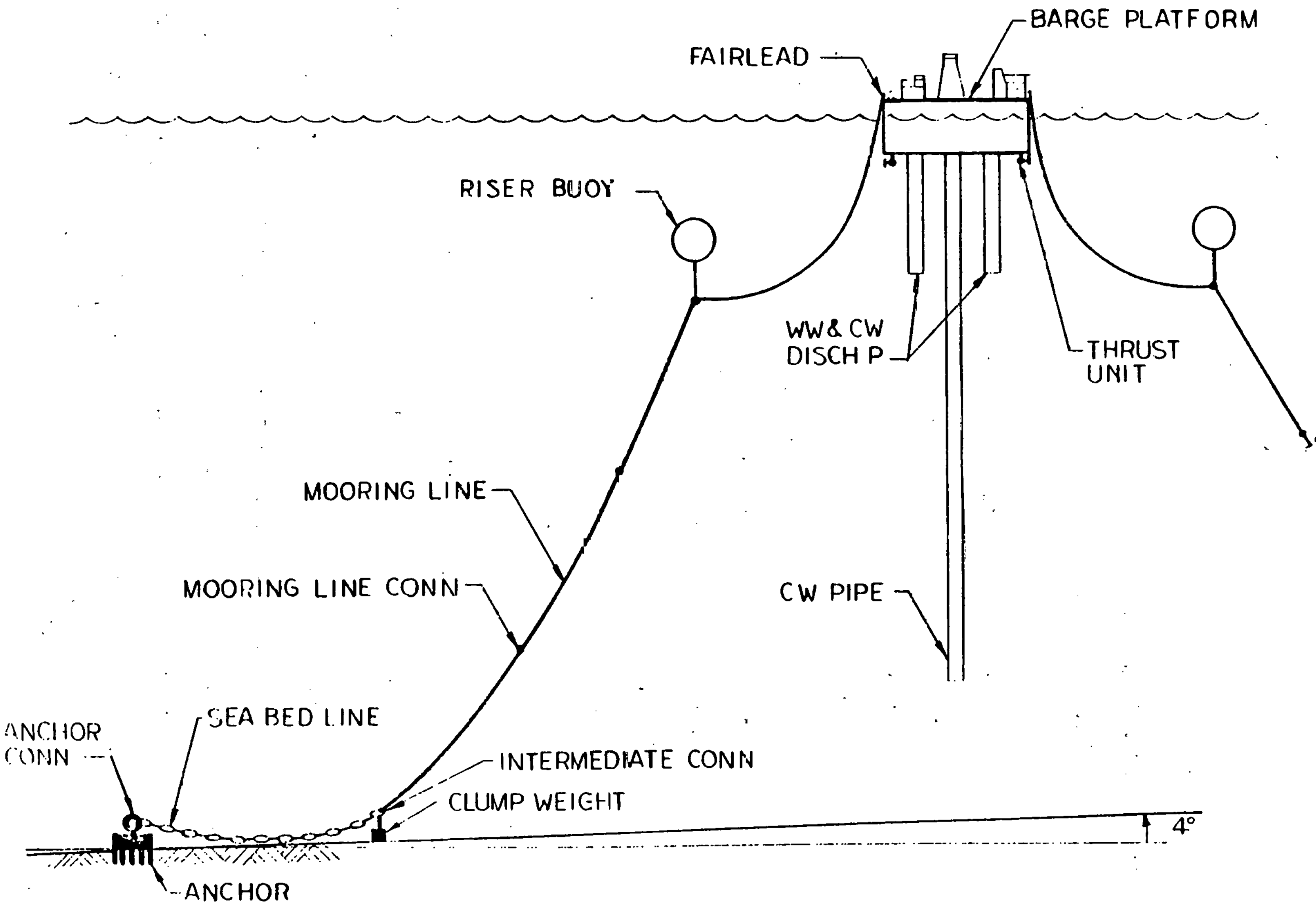


FIGURE II

SKSS NOMENCLATURE

Because of the possible advantage presented by the vertical tension mooring, its use with the barge should also be considered although the line loadings generated by the heave forces will be enormous.

4.2.3 Rotary Mooring Concepts

a) Turret Mooring (Figure 12)

The turret or rotary mooring concept would appear to offer a distinct advantage for the barge since the platform would be able to weathervane into the total vectoral environmental loading, thus significantly reducing the drag force on the platform. The vessel rotation into the weather can be accomplished with hydraulic jacks between the vessel and turret or with a rack welded on the turret and a driven pinion mounted on the vessel for light to moderate environmental conditions. For heavy to extreme weather, lateral thrusters on the vessel would be necessary to maintain or change heading. If needed, a sophisticated directional control system could be installed with an automatic heading control tracking a preset compass point of a computer system to determine the direction of minimum environmental loading and issue the appropriate commands.

The vessel take-off point for the riser cable must be within the turret, otherwise the riser cable will wrap around the mooring lines as the vessel rotates. Two rotary configurations could be considered, one with the turret amidships and another with the turret in the bow or stern. Thrusters would be required in both cases.

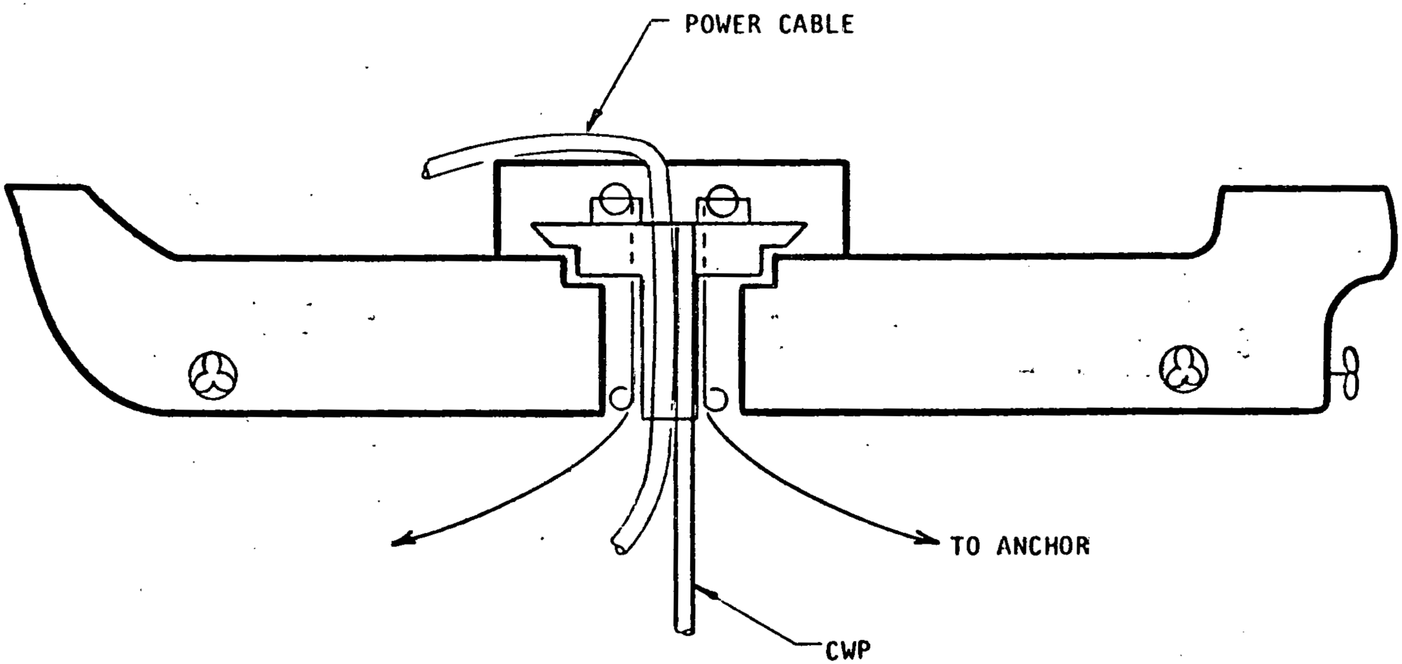


FIGURE 12

The principal advantages offered by the turret mooring concept are that the mooring loads are reduced resulting in a cost savings on anchors, mooring legs and possibly deck hardware and that sway motions of the platform are reduced permitting a feasible cold water pipe design.

The disadvantages of the turret system are imposing. The barge structure at the turret location will be extremely heavy, the turret area would be very crowded, the expense for constructing the turret is substantial since tight tolerances are required and two problems unique for the barge OTEC plant are that means must be devised to transfer both electrical energy transmission and the cold seawater flow from a fixed turret to a rotating ship. Possibly a slip ring mechanism could be developed to permit the passing of large amounts of electrical power from the turret to the barge but a problem solution for the transfer of seawater is not evident. If a bow or stern mounted turret were considered, the seawater system would be unaffected since the cold water pipe is no longer inside the turret. However there would now be interference between the cold water intake and discharge pipes and the mooring legs. Even a vertical tension mooring probably would face this difficulty and it will be shown in Section 6.0 that this concept is not feasible for the barge platform.

b) <u>Single Anchor Leg Mooring With Buoy</u> (Figure 26)

The single leg mooring concept was added to the design matrix in an effort to obtain a weathervaning capability for the SKSS. This concept solves the principal problems of interference with the seawater system and permits the SKSS to be designed for a lower drag force. One outstanding problem which remains to be solved is the interface with the riser cable. To avoid fouling with the cold water and discharge pipes the riser cable must be run up the mooring leg and across the rigid structure to the barge. The problem of providing transfer of electrical power over a pivot connection must be solved.

The primary advantage of the single leg mooring (SLM) over a vertical tension mooring for the barge is the de-coupling of the barge heave, roll and pitch motions from the mooring legs.

4.3 Generic Mooring Arrays

The term mooring array refers to the basic layout of a generic SKSS concept concerning the number of mooring legs and their orientation. A mooring array may be either omnidirectional or unidirectional. An omnidirectional array is symmetrical so the holding force is also developed symetrically as the environmental load is applied from any direction. A unidirectional array is asymmetrical and develops a greater resisting holding force to oppose a prevailing or predominant environmental load. Configurations of both types are considered in this conceptual design.

The selection of a mooring array is governed by the direction of the prevailing environmental loading, proximity of shallow water, the bottom slope in all directions from the site and desired redundancy and reliability of principal SKSS components.

4.3.1 SPAR Platform

Figures 13 to 19 show the selected initial mooring arrays for the SPAR platform. An asymmetrical array is considered with redundancy provided toward the east. This direction is chosen since the prevailing environmental force comes from the northeast to southeast sector about 92 percent of the time; if line failure occurrs on the north to west sector the platform would tend to drift into deeper water whereas failure on the south to east sector will cause drift toward shallow water and the land mass to the north will reduce the impact of severe storms from that direction. Most of the concepts involving mooring off the cold water pipe were given less extensive consideration because of the attendent problems of an adverse impact on the cold water pipe design and the difficulty of maintaining the mooring connections to the CWP at very deep depth. The mooring concept proposed by Gibbs & Cox was also added to our design matrix because it presented an interesting solution to the problem of interference of the CWP with the SLM system. However, deployment and maintenance considerations and the lack of leg redundancy will appear to be the major drawbacks to this idea.

4.3.2 Barge Platform

The mooring arrays selected for study for the barge platform, Figures 20 to 26, are very similar to the SPAR except that an additional generic concept was added to try to obtain a weathervaning SKSS.

4.4 Primary SKSS Components

The most important SKSS components are the mooring legs and anchors. Winch systems, thruster units, deck hardware and other components may be considered for a given SKSS concept but these have relatively little bearing on the final selection of the most suitable SKSS. From a reliability, performance and cost standpoint mooring legs and anchors are the primary SKSS components.

4.4.1 Mooring Legs

Mooring legs can be considered in the following groups:

- o Wire
- o Chain
- o Synthetics
- o Tension Rod
- o Hollow Cylindrical Links
- o Solid Bar Links

These components may be used in a single segment or multi-segment catenary with clump weight or riser buoys added as necessary. The properties of the above components are described in Section 2.0 and in the respective appendixes mentioned therein.

4.4.2 Anchors

Anchors can be considered in the following groups:

- o Deadweight or Gravity
- o Pile
- o Drag Embedment
- o Implosion Embedment

These anchor types are described in the report for task # [2]. Elements of the different anchor types may be grouped together, for example piles may be used with a deadweight anchor to reduce the anchor structural weight or groups of anchors may be used instead of one large anchor.

4.5 Initial Screening of Candidate Concepts

4.5.1 Generic Mooring Arrays

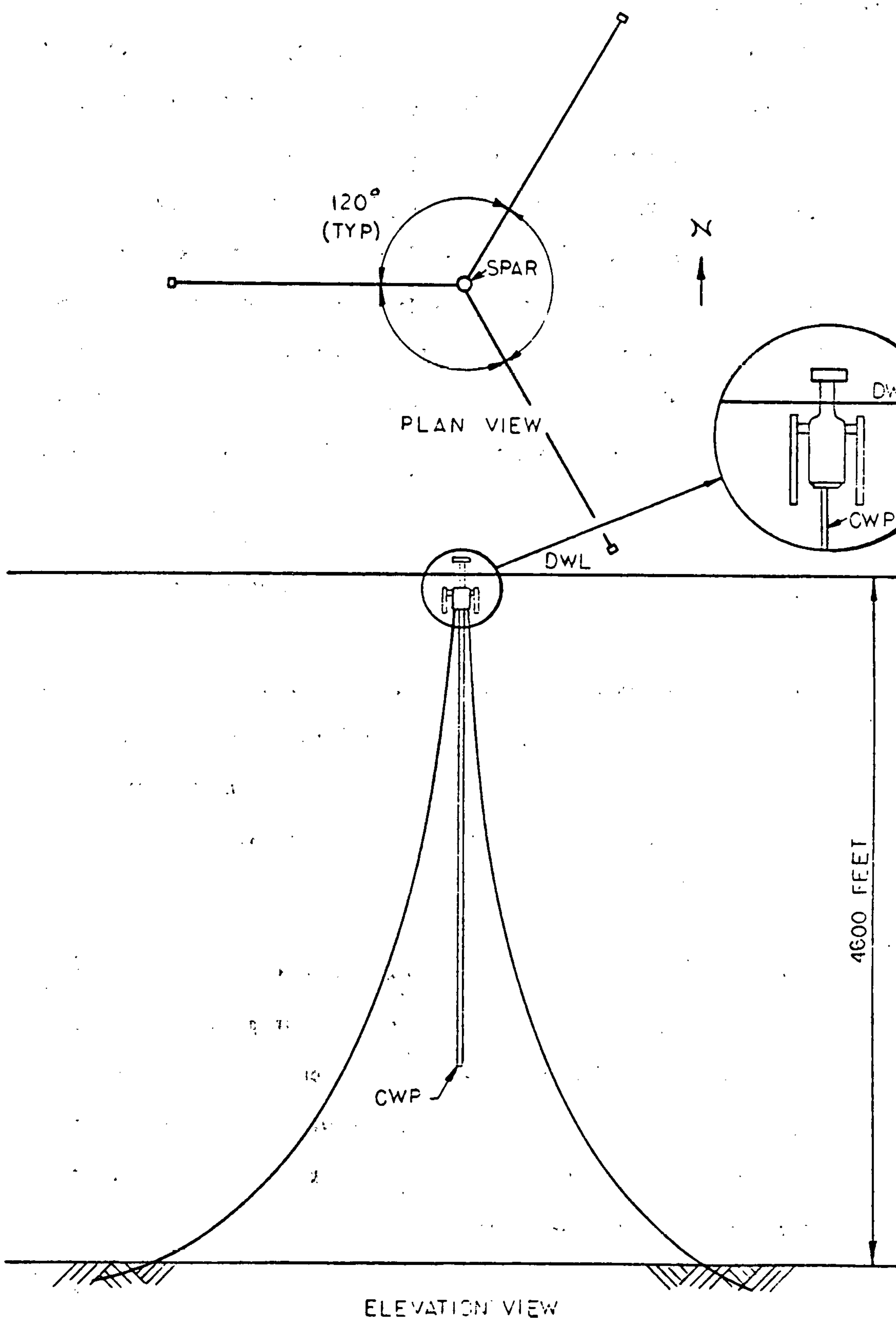
Some of the mooring arrays were eliminated early in the design sequence. Three leg catenary and four leg asymmetrical moorings were eliminated because they exhibited excessive excursion and individual line tension. All vertical tension concepts had to be eliminated for the barge platform because of the enormous leg loadings generated by vertical wave forces. The single leg mooring avoids this problem and may still be considered.

4.5.2 Mooring Legs

Single segment catenaries of wire or chain are not feasible for the barge platform and are feasible for the SPAR only if very long line lengths (more than 15,000 feet) are considered. All chain legs were dropped since more than 40% of the chain strength is required its weight in the design water depth of 5400 feet. For wire, about 30% of its strength is required to support its weight. The use of composite segments of wire-chain offers some promise and was studied extensively. The only mooring lines which can be considered as single segment lines are HCL or solid bar links,

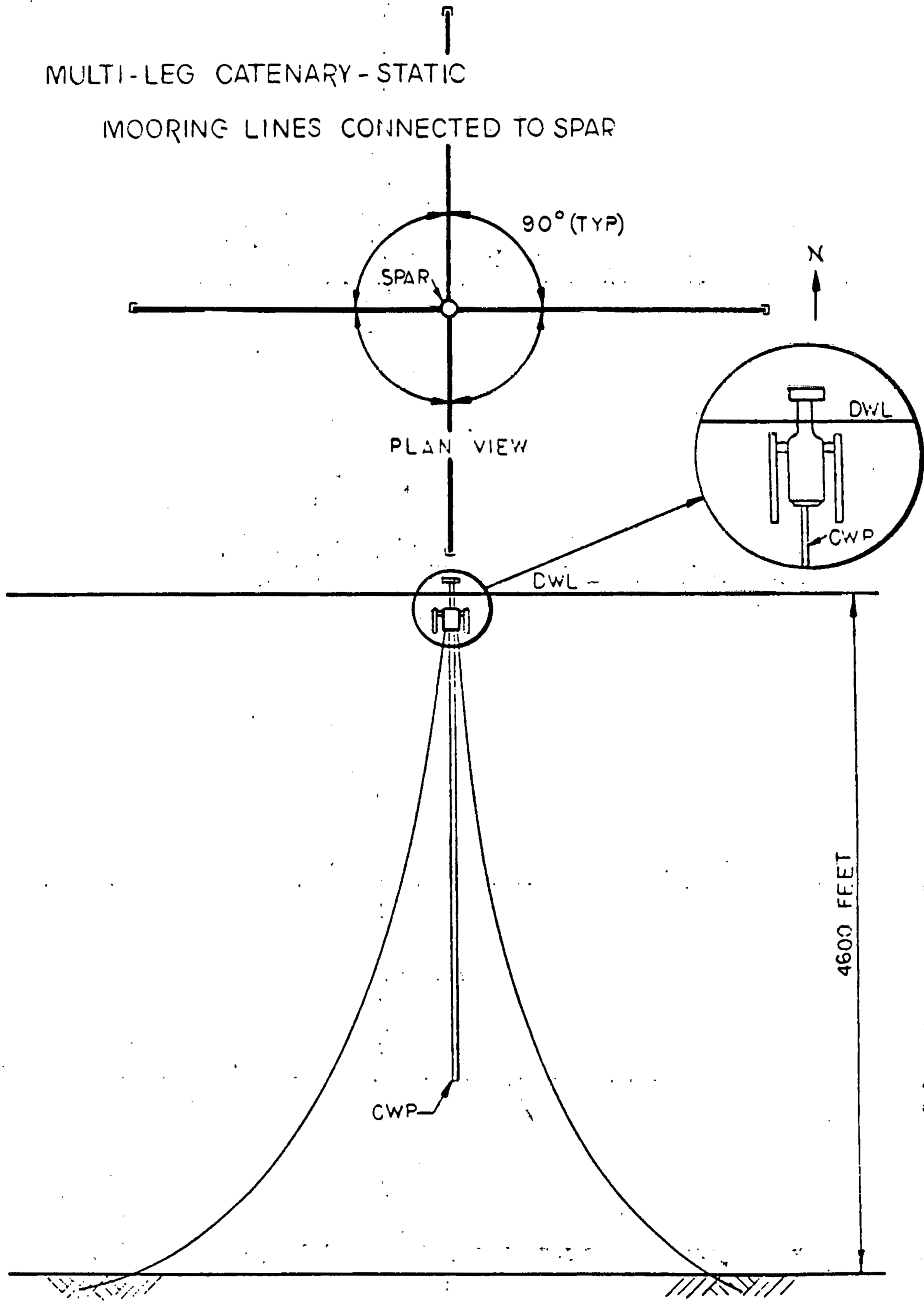
Synthetic lines with the possible exception of Kevlar do not have a sufficiently high breaking strength. Among these, only Kevlar can be used up to a size of 10 inches diameter which is the largest size expected to be available by 1984. Kevlar has the desirable qualities of a high strength to weight ratio and good fatigue life but suffers the disadvantages of high cost, high required factors of safety and questionable availability in the sizes required.

Anchor designs were quickly narrowed down to deadweight anchors or combination deadweight-pile anchors. Drag embedment anchors could be considered for a few 8 leg catenary systems where the anchor line makes nearly a zero angle with the bottom but pile and implosion embedment anchors will not be able to develop adequate holding capability.



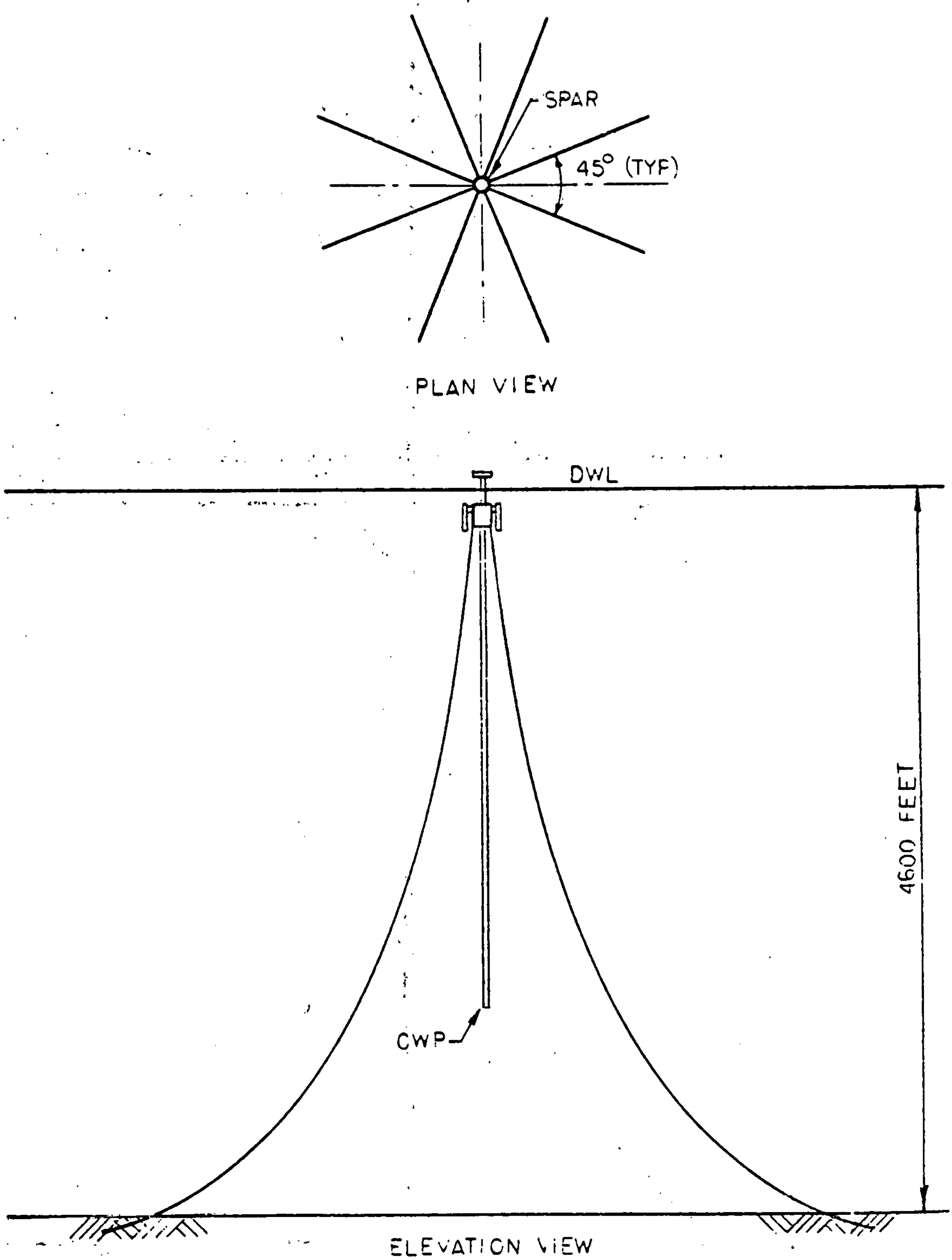
3 LEG SYMMETRICAL SPREAD MOORING

Figure 13



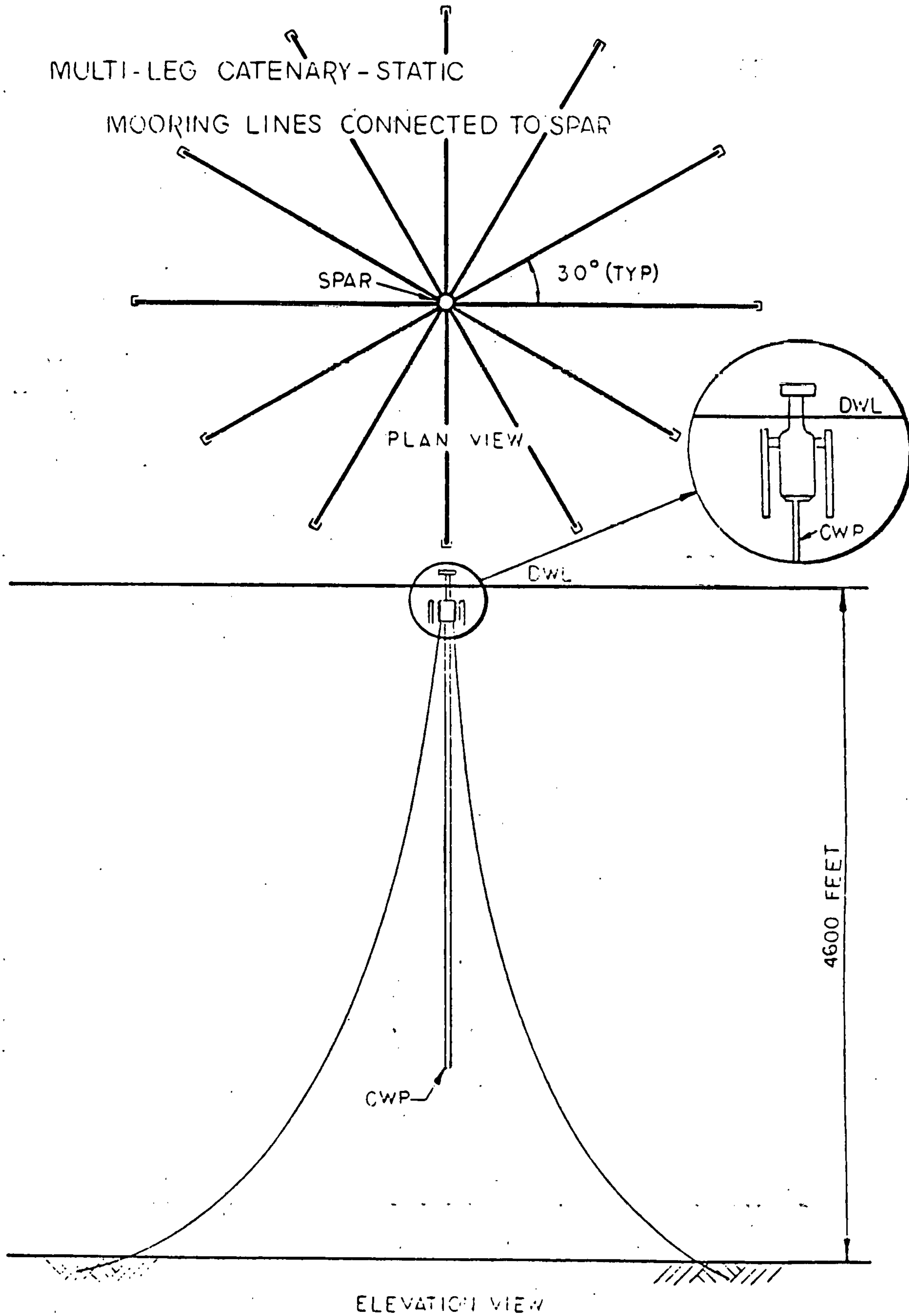
4 LEG SYMMETRICAL SPREAD MOORING

FIGURE 14



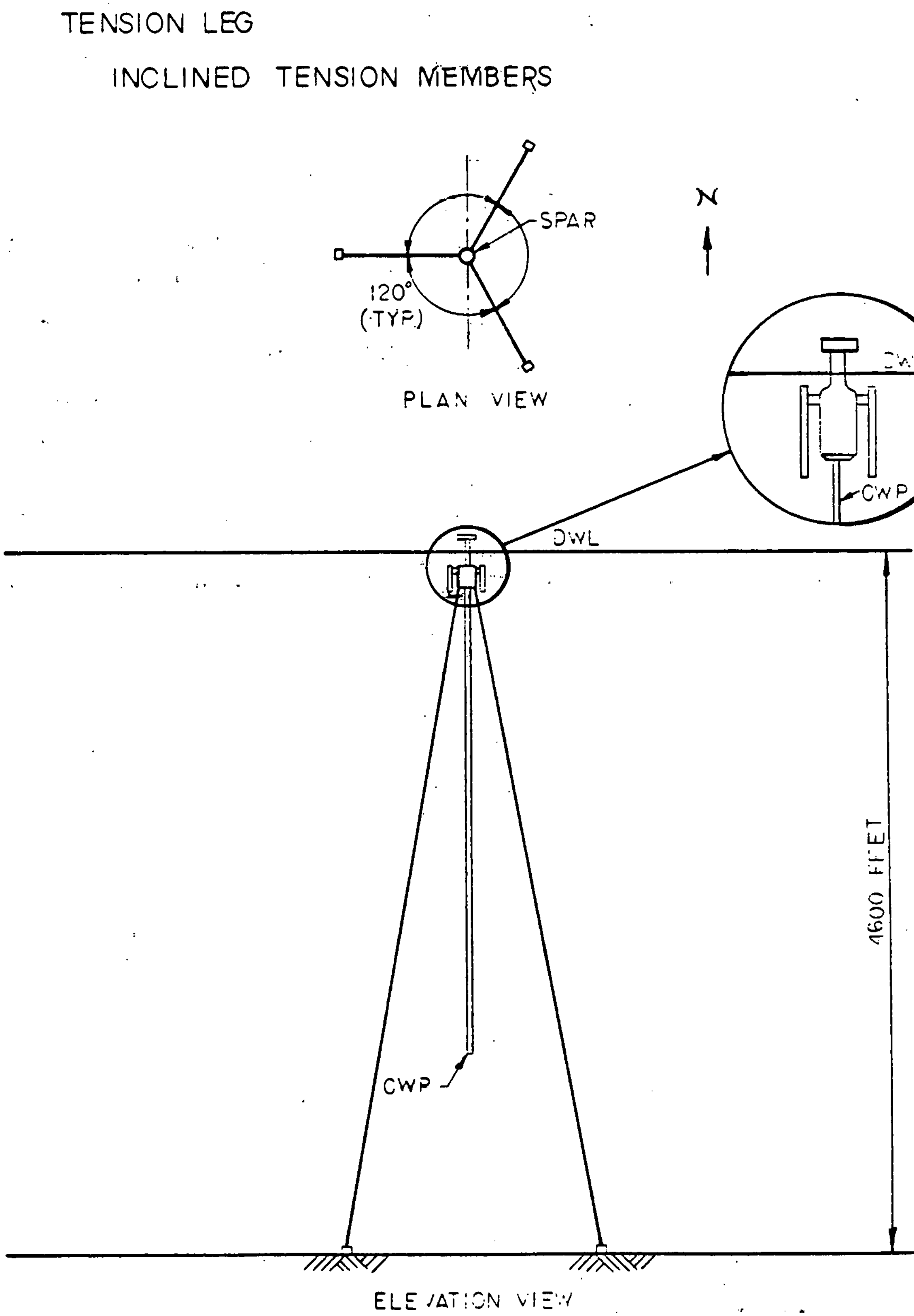
8 LEG SYMMETRICAL SPREAD MOORING

FIGURE 15



12 LEG SYMMETRICAL SPREAD-MOORING

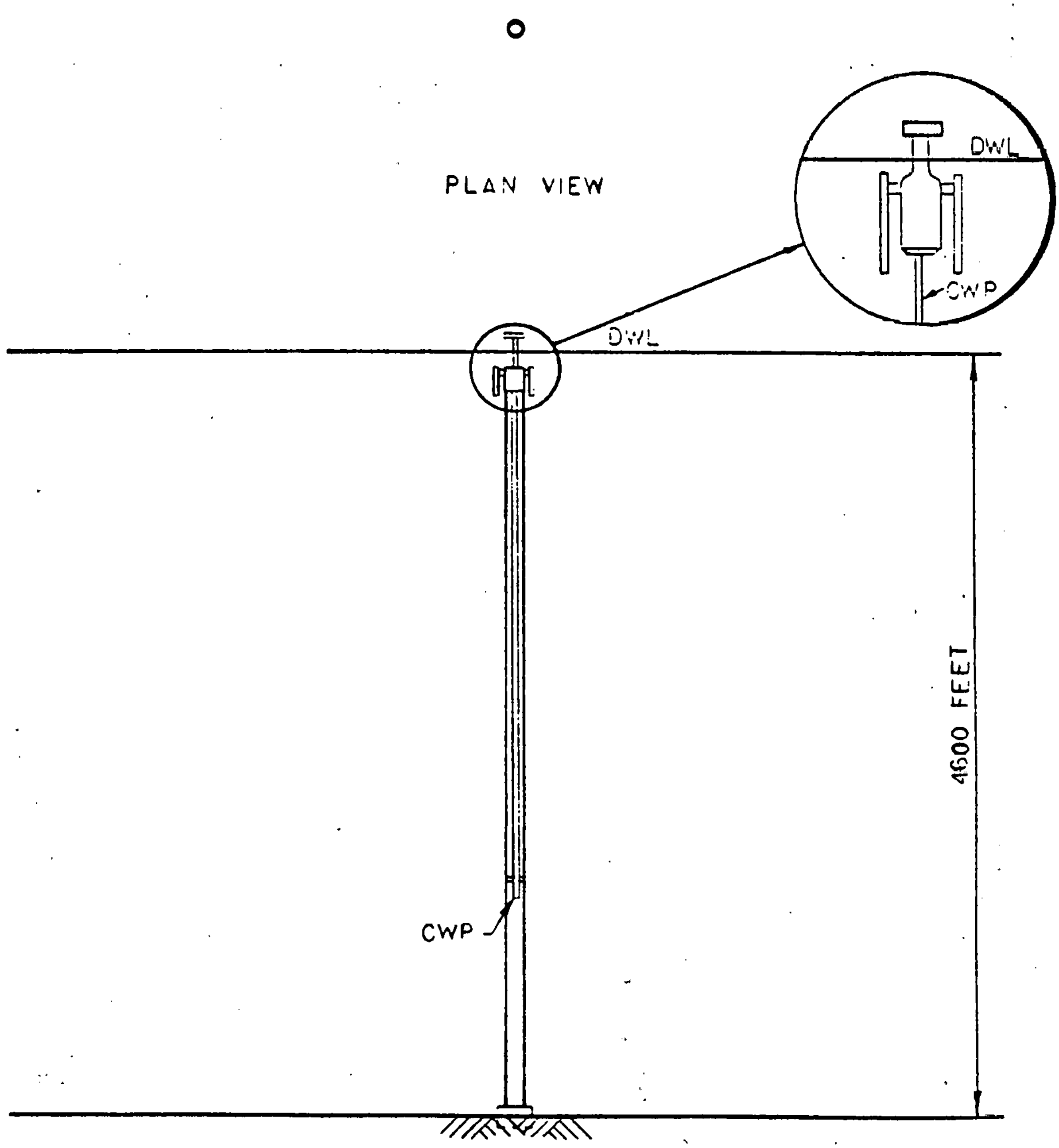
FIGURE 16



3 LEG SYMMETRICAL SPREAD MOORING

FIGURE 17

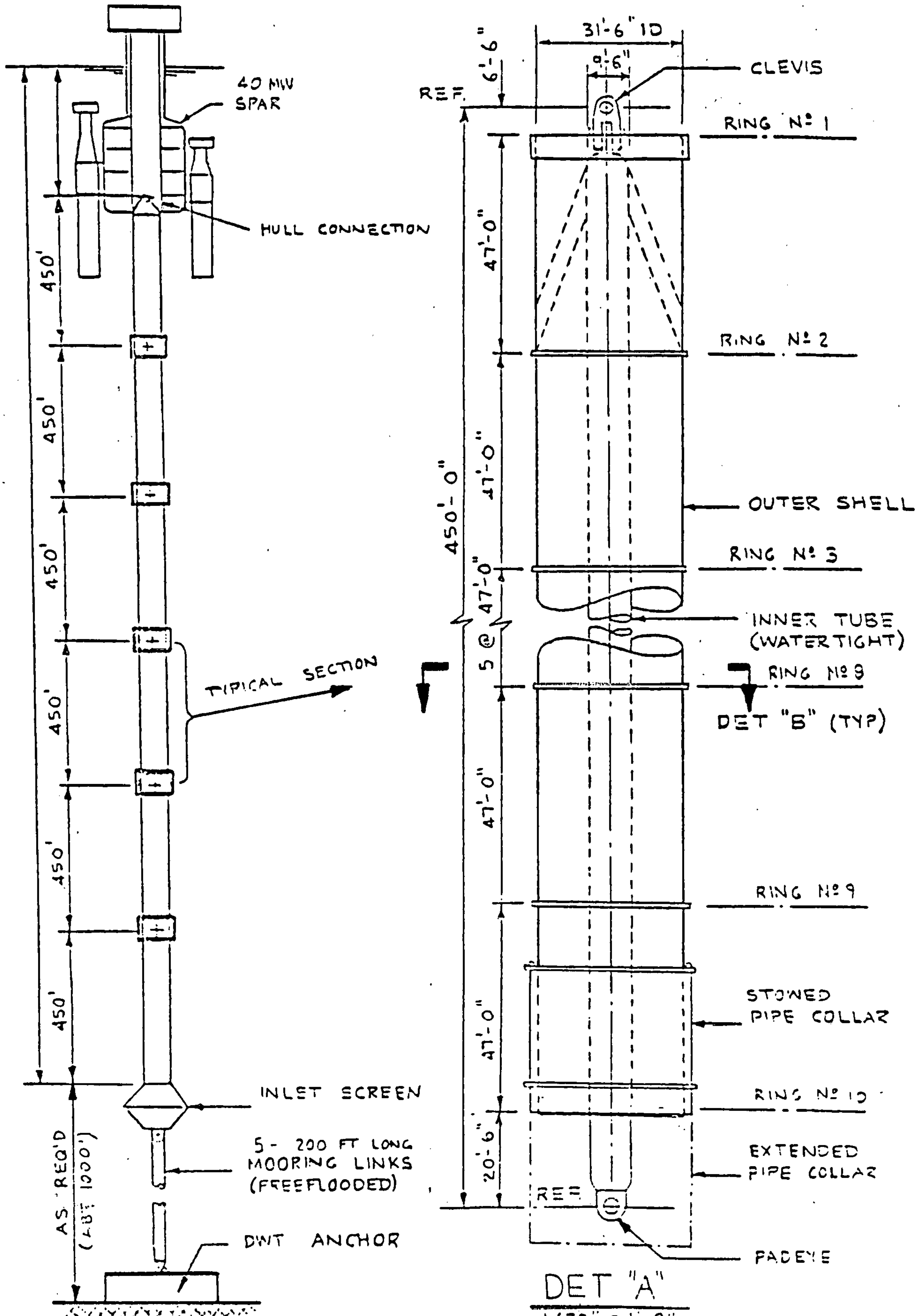
VERTICAL TENSION MEMBERS



ELEVATION VIEW

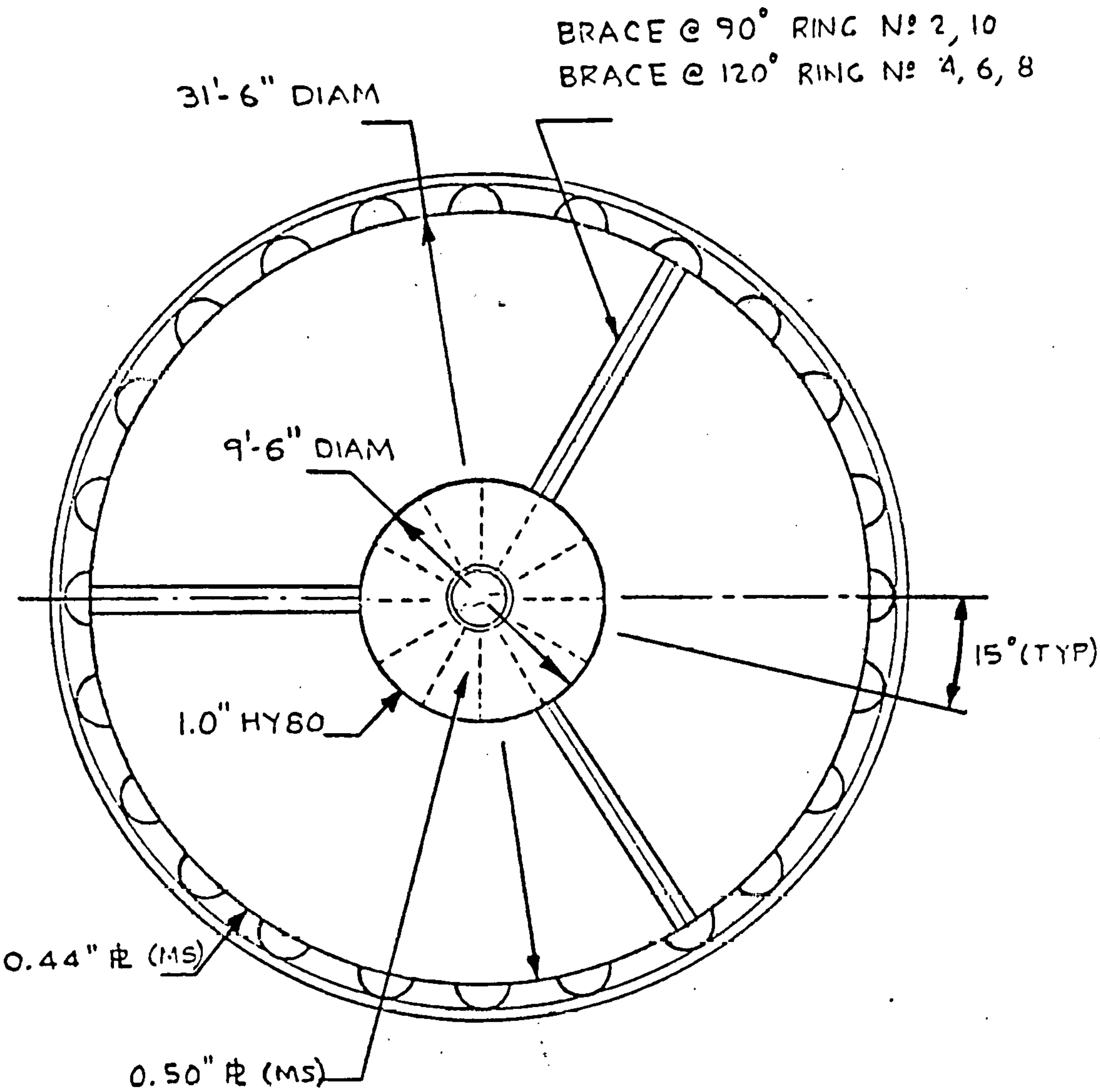
VERTICAL MOORING GUIDED AT CWP

FIGURE 18



DET "A"
1/32" = 1'-0"

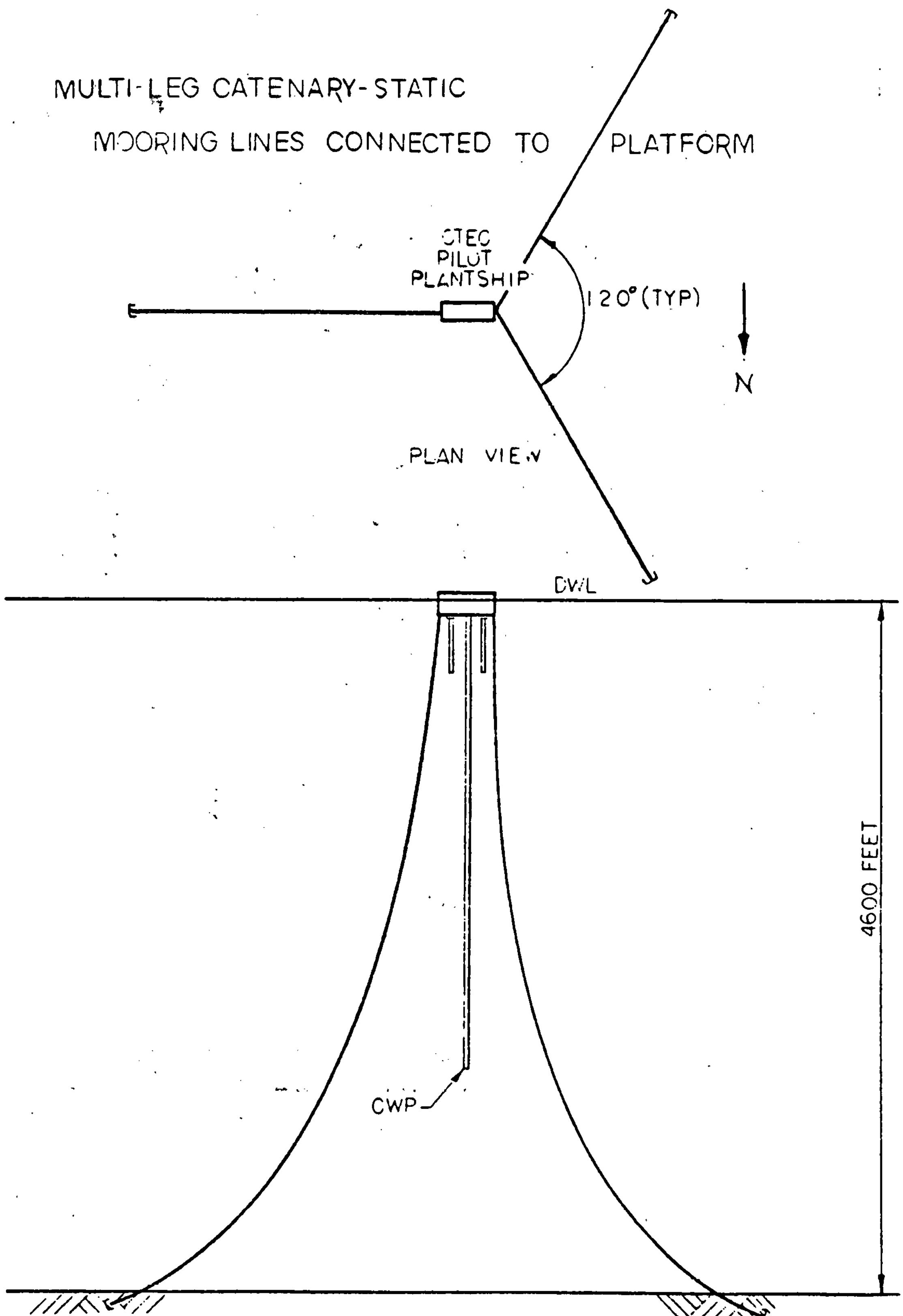
FIGURE 19



DETAIL "B" TYP. PIPE SECTION

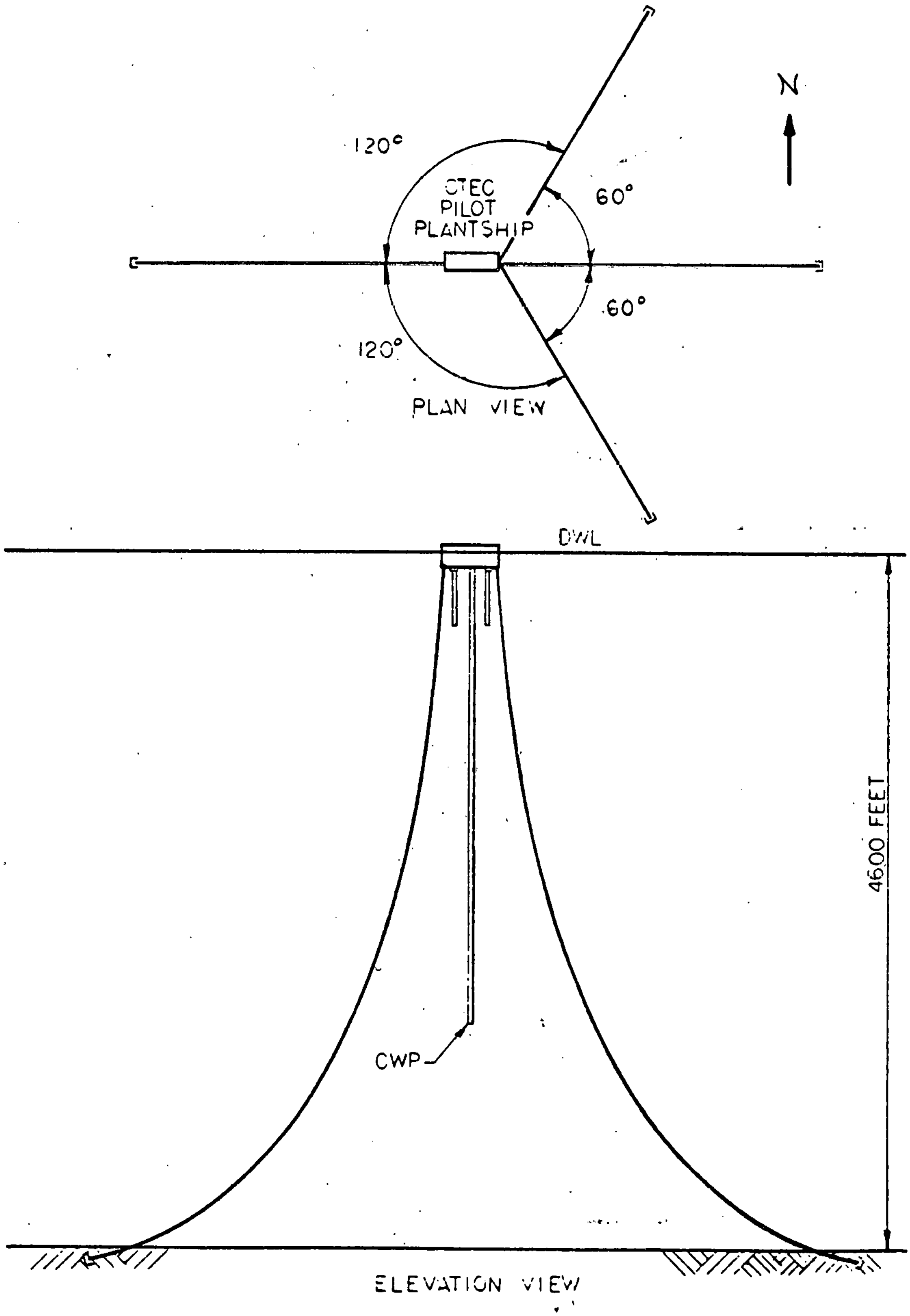
1/8" = 1'-0"

FIGURE 19-A



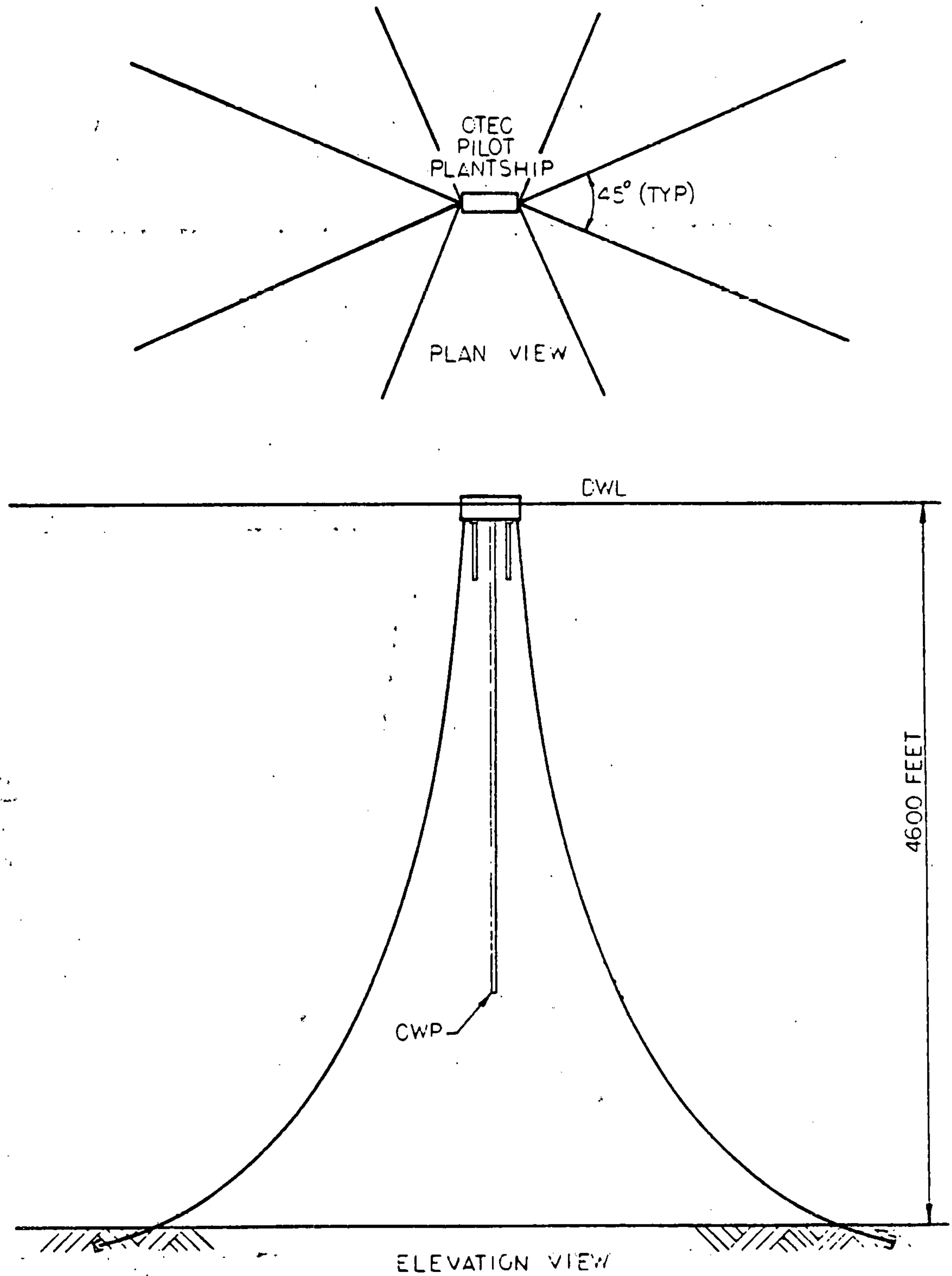
3 LEG SYMMETRICAL SPREAD MOORING

FIGURE 20



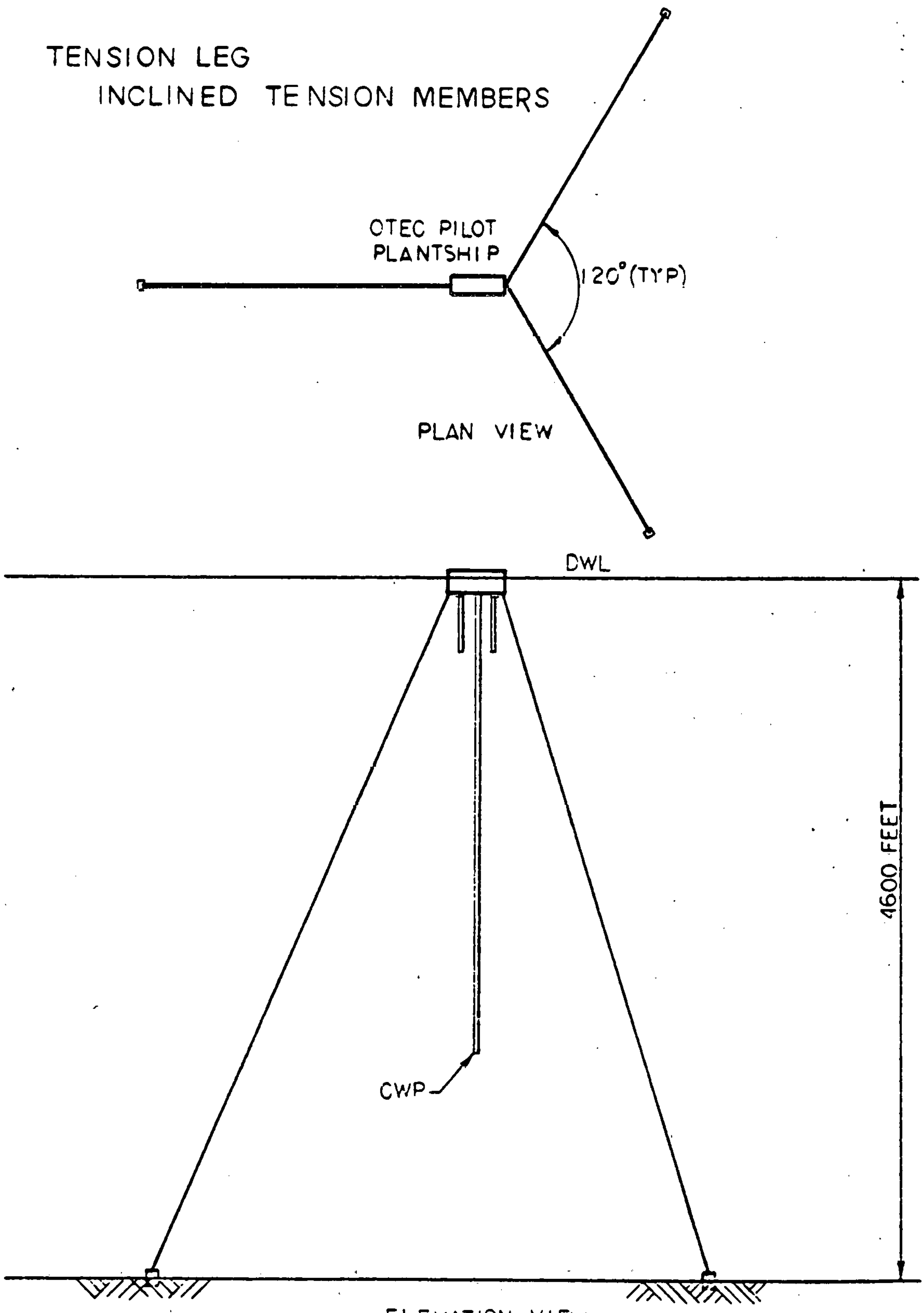
4 LEG SYMMETRICAL SPREAD MOORING

FIGURE 21



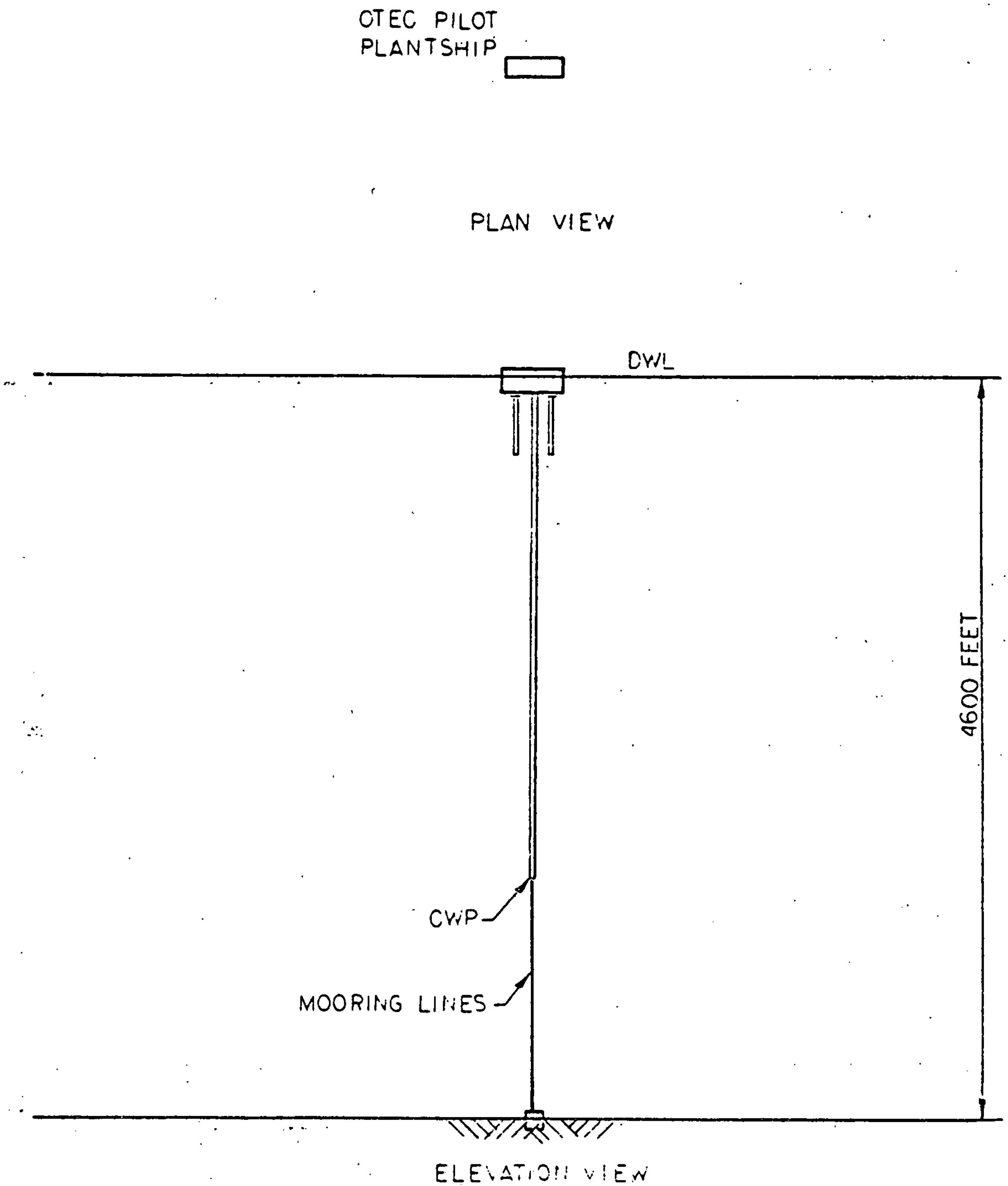
8 LEG SYMMETRICAL SPREAD MOORING

FIGURE 22



3 LEG SYMMETRICAL INCLINED VERTICAL MOORING

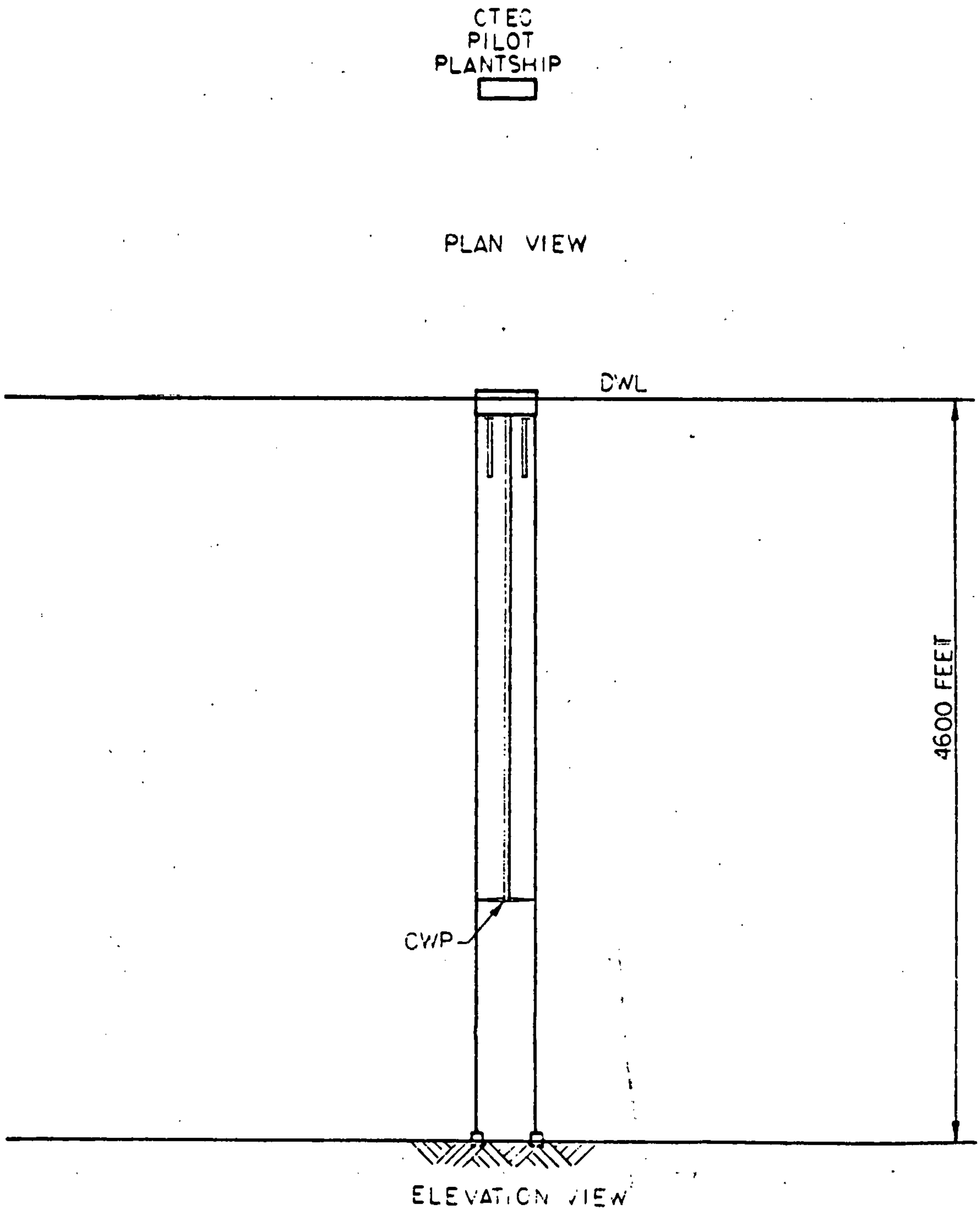
FIGURE 23.



VERTICAL MOORING WITH COLD WATER PIPE AS TENSION MEMBER

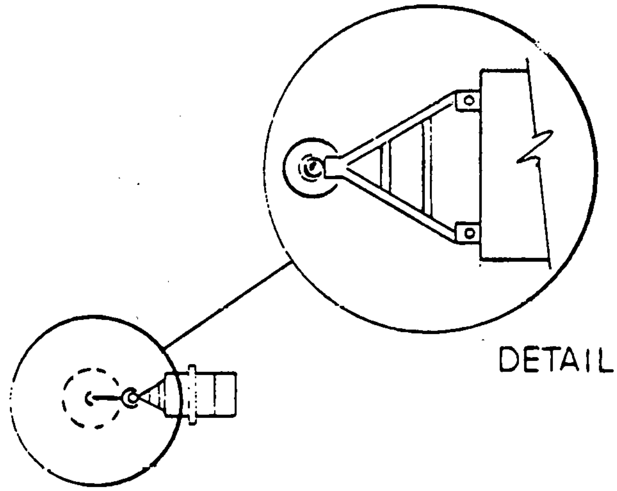
FIGURE 24

VERTICAL TENSION MEMBERS



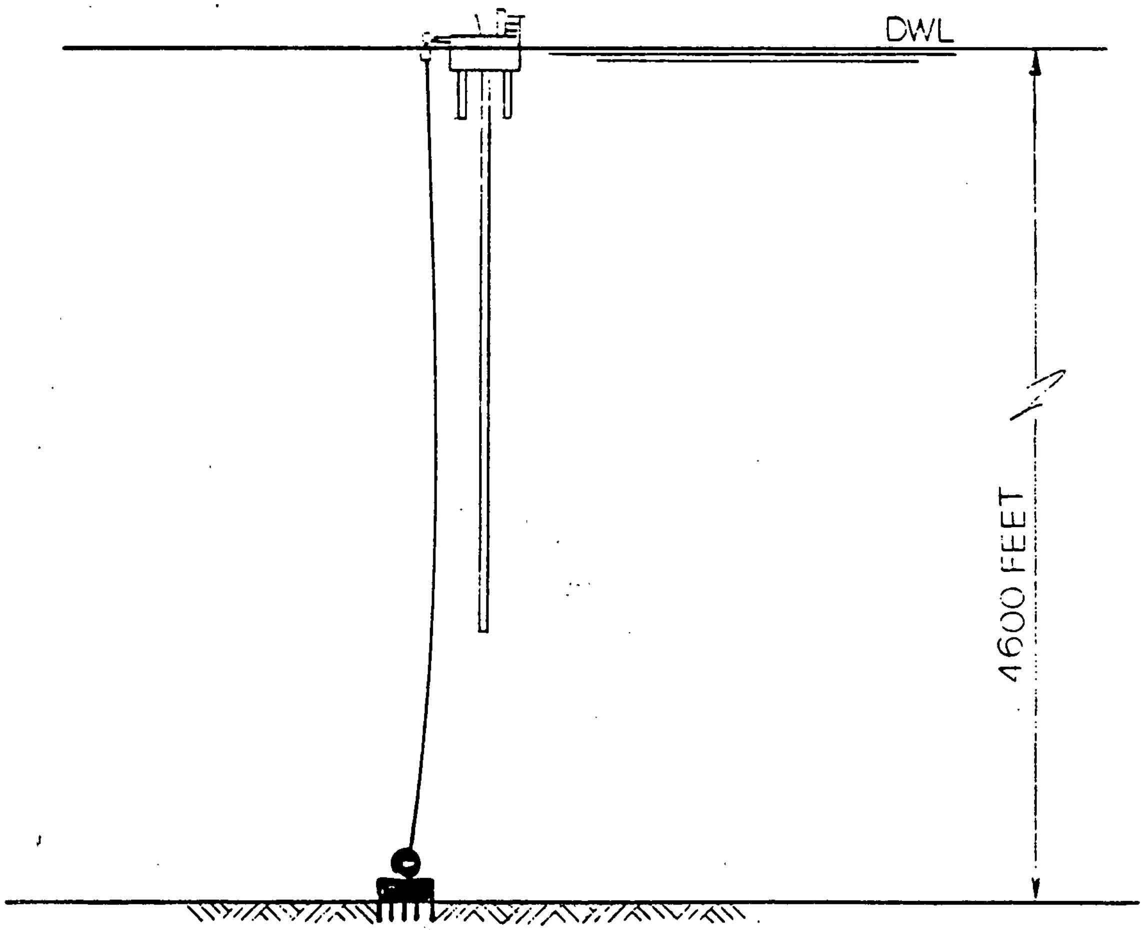
VERTICAL MOORING GUIDED AT COLD WATER PIPE

FIGURE 25



PLAN VIEW

MOORING LINE CONNECTED TO BARGE PLATFORM



ELEVATION VIEW

SINGLE POINT MOORING

FIGURE 26

4.6 Evaluation Matrix of Conceptual Design Candidates

4.6.1 SPAR Platform

TABLE 9

Initial Matrix for Evaluation - SPAR SKSS

Concepts

Generic Type	Symmetric Mooring Array	Mooring Legs: #Segments	Mooring Legs: Leg Types	Anchor Type
Catenary	4 Leg	2	HCL	Deadweight
Catenary	4 Leg	2	HCL & Chain	Deadweight
Catenary	4 Leg	3	Wire Rope, HCL & Chain	Deadweight
Catenary	8 Leg	3	HCL & Chain	Deadweight
Catenary	8 Leg	3	Kevlqr & Chain	Deadweight
Catenary	8 Leg	1	Kevlqr	Deadweight
Catenary	8 Leg	1	HCL	Deadweight
Catenary	8 Leg	2	Wire Rope & Chain	Drag Embedment or Deadweight
Catenary	8 Leg	3	Wire Rope & Chain	Drag Embedment or Deadweight
Catenary	12 Leg	2	HCL & Chain	Deadweight
Vertical Tension	3 Leg	1	Tension Rod	Deadweight
Short Tension	3 Leg	1	Tension Rod	Deadweight
Vertical Tension	1 Leg (Inside CWP)	1	HCL	Deadweight

4.6.2 Barge Platform

TABLE 10

Initial Matrix for Evaluation - Barge SKSS Concepts

Generic Type	Symmetric Mooring Array	Mooring Legs: #Segments	Mooring Legs: Leg Types	Anchor Type
Catenary	4 Leg	1	HCL or Solid Bar	Deadweight
Catenary	4 Leg	2	HCL or Solid Bar	Deadweight
Catenary	8 Leg	3	HCL & Chain	Deadweight
Single Leg Mooring	1 or 3 Legs	1	HCK or Solid Bar	Deadweight

5.0 PLATFORM LOADINGS AND MOTIONS

5.1 Quasi-Static Drag Forces and Oscillatory Loads

The problem of computing external loads from the environment and the resisting anchor line reactions is complicated due to the non-linear nature of the problem. The moored structure may be regarded as a mass-spring system with a total load imposed on it by environmental forces. The environmental load consists of oscillating wave forces and of wind, current and wave drift forces which vary at a frequency much lower than the wave frequency. Studies have indicated that mooring-leg forces are generally smaller than the first order oscillatory wave forces [18]. The main purpose of the SKSS is to hold the platform on a desired average position, so the almost steady or quasi-static low frequency wind, current and wave drift forces generally govern the SKSS design.

The almost steady wind, current and wave drift forces cause a shift in the equilibrium position of the platform around which the first order oscillations due to waves occur. This causes a change in the spring constant and consequently in the dynamic response. Generally, resonance at the wave frequency is avoided since the natural frequency of the horizontal motion of the moored platform is much smaller than the wave frequency even after an increase in the spring constant.

Since the wind, current and wave drift forces are slowly fluctuating forces, the risk exists that resonance may occur at very low frequencies at which these forces oscillate. Low frequency oscillations in the horizontal plane have been observed in model experiments as well as in full scale tests. This phenomenon is generally believed to be attributed to the slowly varying wave drift force as the result of varying wave height in an irregular sea.

In the present conceptual design stage, the quasi-static wind, current and wave drift forces are treated as constant forces although the average wave drift forces are multiplied by a factor to account for extreme loads. The first order wave forces which lead to oscillatory motion of the platform are considered by adding their amplitude to the static displacement or excursion of the platform and then computing the mooring line reaction forces for this total displacement. An SKSS concept is considered feasible if it is strong enough to withstand extreme loads in the survival condition, environmental state 12, and stiff enough in the operational condition, environmental state 8, to prevent exceedance of the allowable excursion limit. In the preliminary designs, the time varying wind and wave drift forces will be considered along with the effect of the mooring lines by the use of a time domain program. In this manner, the effect of these slowly varying forces on the mooring line loads will also have been accounted for.

5.2 Computation of Wind Drag

Wind is a time dependent phenomenon which is characterized by large fluctuations in its velocity and direction. The variation in mean velocity is very slow compared with the wave period. Although the fluctuation of velocity about the mean value will impose dynamic forces. for conceptual designs, these fluctuations may be neglected in comparison with the magnitude and time variation of hydrodynamic forces when considering the dynamic behavior of the platform [19]. (See Appendix B for wind drag calculations.

The pressure drag due to wind force is computed from the standard equation

$$Fw = 1/2 \; \rho_A \; Vw^2 \; Ap \; C_D$$

where Fw = Wind pressure drag force

ρ_A = Density of air

Vw = Wind velocity

Ap = Projected area normal to the wind direction

C_D = Wind drag coefficient

The drag coefficient for the BARGE was found from [20] which gives values for longitudinal and transverse coefficients for several ship types. A cargo ship with the superstructure aft and a deck crane amidships and a tanker with superstructure aft most closely approximate the barge platform configuration. A wind drag coefficient of 0.8 was used for both the head to and beam to conditions.

The drag coefficient for the SPAR was treated differently since data was not available for this type of platform. The wind force was computed by dividing the platform into three elementary sections: the rectangular superstructure, the cylindrical access trunk, and the miscellaneous structure and equipment on the top deck of the superstructure. The wind drag coefficient for the total SPAR platform was determined to be 0.86, as shown in the calculations of Appendix B.

5.3 Computation of Current Drag

The variation in current velocity and direction is considered to occur at much too low a frequency to be of importance for its effect on the platform dynamic response [19] Thus the current drag force is considered a constant force both in the conceptual and preliminary design stages.

The current drag for the submerged portion of the SPAR hull is found by considering separate hull components using drag coefficients for elementary shapes from reference [21]. Since the lowest Reynolds numbers applicable to the cases and configurations being studied were in the fully developed turbulent flow regine, a drag coefficient of 0.34 was used for all cylindrical elements of the SPAR hull. For the submerged portion of the BARGE hull a cross-flow drag coefficient of 0.6 was used based on experimental data of a similar barge form. The current loading was approximated as a linear variation of current velocity versus depth.

The procedure used for determination of current drag on the cold water pipe is the same for both the BARGE and the SPAR platforms. The mean drag force is found using the relationship:

$$Fc = 1/2 \quad \rho_w \quad b \quad Vc^2 \quad C_d$$

where Fc = Current drag per unit length of CWP

ρ_w = Density of salt water

b = Diameter of the CWP

Vc = Current velocity

C_d = Drag Coefficient

The Reynolds number ranges from 2.0×10^6 to 1.08×10^7 so the values for drag are predominantly in the critical regime. At Reynolds numbers exceeding 3×10^6, the mean drag coefficient becomes independent of Reynolds No. and becomes dependent on the relative roughness ratio K/d where K is the height of the roughness and d is the pipe diameter. Steel plates generally have a roughness in the order of 10^{-3} pipe diameters and ocean biofouling is estimated to produce roughnesses of 10^{-3} to 10^{-2} pipe diameters [22]. A value of

$K/d = 10^{-3}$ was used in this study. If resonance occurs at twice the vortex shedding frequency, the drag loads may be amplified by a factor of two to three. Since a cold water pipe structure operating in this resonant condition is not considered feasible, the CWP structure is assumed to be designed to avoid this condition. With this assumption, the drag coefficient fluctuations about the mean are known to be small and are conservatively covered by increasing the mean drag coefficient by 20 percent (equivalent to 3 times the standard deviation). The mean drag coefficient for a relative roughness of 10^{-3} is 0.95 and with the allowance for vortex shedding, the design drag coefficient is 1.14.

Unsteady pressure forces developed from vortex shedding lead to oscillatory lift forces which act normal to the crossflow direction. The Reynolds numbers R_{e_k} corrected for roughness yield values in excess of 500. An appropriate RMS lift coefficient for design would then be 0.27. The lift coefficient has been found to be normally distributed in time. Even using extreme values for lift coefficients (about 70% of the drag coefficient) and considering the worst loading case for the SPAR, the total platform load increases by only a few percent. The actual load increase on the SKSS would most likely be even smaller so the effect of the lift force has been neglected.

5.4 Computation of Mean Wave Drift Forces

The second order drift force due to waves is found by means of a hydrodynamic analysis based upon the scattered waves associated with the presence of a floating body in an oncoming ambient wave system. The scattered wave system includes the waves due to diffraction of the oncoming waves, as well as the radiated waves due to the motion of the platform. In regular waves, a steady drift force is generated resulting in a static shift of position of the moored vessel. For irregular waves, a varying sequence of drift forces arises in correspondence to changes in wave height and period.

For the case of the barge type platform, the drift force in beam seas is the maximum value and is found by evaluating the reflected wave associated with diffraction effects and the radiated wave due to the motions of heave, sway and roll (yaw and pitch effects are generally negligible in the present case). The analysis provides a pseudo-transfer function operator relating the average lateral drift force to the square of the wave amplitude as a function of wave frequency, i.e., $\frac{Yd}{a^2}(\omega)$. This function is then combined with each particular wave spectrum to provide the mean drift force in that particular seaway by the operation:

$$\bar{Y}_{MEAN} = 2 \int_0^\infty \frac{Yd}{a^2}(w)\, S_n(w)\, dw$$

where Sn(w) is the wave spectrum. A Bretschneider sea spectrum was used based on the stated significant height and an average wave period calculated from the modified wave period histograms developed by Glenn and Associates. This analysis requires the initial determination of the first order motions of the vessel, from which the drift force is determined by quadratic operations involving sums of first order motions and wave properties.

Computations of wave drift forces for the BARGE in head seas were also carried out. The method used for this case is somewhat questionable since the platform was approximated as a barge with a higher L/B ratio. This may be reasonable since the barge form is basically that of a rectangular box and lacks the fineness of a conventional ship form.

The drift force for the SPAR, which is essentially symmetrical about a vertical axis, is determined in a manner similar to that for the Barge. The "transfer function" relating the average force in a regular sinusoidal wave to the square of the incident wave amplitude is found from the scattered wave appropriate for the SPAR shape.

The values for average wave drift are multiplied by a factor of three to give the extreme loads used for the conceptual designs for lack of any reliable existing data.

Note: It was found during the preliminary design studies in the next phase of this project that the maximum wave drift forces did exceed three times the mean value of the wave drift forces. However, drift forces didn't increase the line tensions in the same proportion but, rather, by a factor of approximately 1.3. (See Volume III, Table 6, pages 3-29).

5.5 Summation of Platform Loadings

Tables 11 through 13 provide a breakdown of the various external load components and their summation for the total load for each invironmental state. As discussed in Section 2.2, the environmental state No. 8 is used as the design environmental state for the operating condition and condition number 12 as the design extreme environmental state for the survival condition.

5.6 Platform Motions

The first order oscillatory wave forces are considered indirectly by adding the surge and heave motion amplitudes to the static displacement resulting from the quasi-static forces. The increase in mooring line tensions is then readily found. Platform motions data were obtained from Applied Physics Laboratory and Gibbs & Cox, Inc. for use in the conceptual design phase. In the preliminary design phase, the time domain program of Oceanics will be used to obtain the platform motions with the effect of the mooring legs. As discussed in section 6.0, the first order wave forces have relatively little effect on mooring line loadings for a deep water catenary mooring and their effects can be minimized by proper design for a tension leg mooring.

Loading on OTEC Barge in Beam Seas vs. Sea State

Environmental State	H_s (ft.)	F_{wind} (LT)	$F_{current}$ (LT)	F^*_{drift}	Total (LT)	Total (KIPS)
1	2	1.47	193.59	4.08	199.14	446.07
3	6	4.25	202.85	54.6	261.7	586.21
4	8	5.88	206.77	102.3	314.95	705.49
6	15	10.72	226.41	354.6	591.74	1325.5
8	25	23.51	253.04	802.17	1078.72	2416.2
10	35	93.93	379.51	1259.1	1732.54	3880.8
12	45	129.91	467.11	2256.9	2853.92	6392.7

Loading on 40 MW OTEC Spar vs. Sea State

Environmental State	H_s (ft.)	F_{wind} (LT)	$F_{current}$ (LT)	F^*_{drift}	Total (LT)	Total (KIPS)
1	2	0.83	209.35	0.57	210.75	472.08
3	6	2.36	217.28	4.08	223.72	501.13
4	8	3.24	220.52	6.09	229.85	514.86
6	15	5.93	238.13	11.49	255.55	572.4
8	25	12.99	268.90	18.75	300.64	673.4
10	35	52.0	298.95	27.57	478.52	1071.8
12	45	71.78	492.43	32.97	597.18	1337.6

* Assumed 3 times the calculated mean wave drift force.

TABLE 11: SPAR PLATFORM LOADINGS

Loading on OTEC Barge in Head Seas vs. Sea State

Environmental State	H_s (ft.)	F_{wind} (LT)	$F_{current}$ (LT)	F^*_{drift}	Total (LT)	Total (KIPS)
1	2	.99	165.26	2.55	168.8	378.11
3	6	2.86	171.10	36.87	210.83	472.26
4	8	3.95	173.60	71.64	249.19	558.19
6	15	7.21	186.36	268.5	462.07	1035.04
8	25	15.80	207.39	647.01	879.2	1949.25
10	35	63.14	300.73	1046.1	1409.97	3158.3
12	45	87.32	375.71	1341.42	1804.45	4041.97

*Assumed 3 times the mean wave drift force.

Breakdown of Current Forces (LT) on Barge vs. Sea State

H_s	CWP	Discharge Pipe (4)	Hull (beam seas)	Hull (head seas)
2	110.64	41.28	41.67	13.34
6	112.02	44.13	46.70	14.95
8	112.58	45.4	48.79	15.62
15	116.04	51.47	58.90	18.85
25	125.10	60.79	67.15	21.50
35	163.38	100.25	115.88	37.10
45	214.84	117.83	134.44	43.04

TABLE 12 : BARGE PLATFORM LOADINGS

TABLE 13

Breakdown of Current Forces (LT) on Spar vs. Sea State

H_s	CWP	Evaporators (4)	Condensers (4)	Main Body
2	99.62	34.18	26.47	49.08
6	99.86	36.16	27.84	53.42
8	99.96	36.96	28.39	55.21
15	101.10	41.34	31.49	64.20
25	107.25	49.23	37.66	74.76
35	132.27	80.23	61.00	125.45
45	179.12	94.57	72.06	146.68

6.0 ANALYSIS OF SKSS LOADS AND STRESSES

6.1 Analytical Procedures

6.1.1 Catenary Moorings

A straightforward static analysis was used in the conceptual design approach. A hand calculation procedure was first employed to eliminate the most impractical SKSS concepts. The generalized catenary equations for a segment of the mooring line catenary are presented in Appendix A.

A program titled "CALMS" developed by Exxon Production Research Company [14] was used in the later stages of conceptual design to analyze the more complex catenary mooring systems consisting of composite lines with clump weights and spring buoys. This program computes anchor line tensions, suspended line lengths, anchor loads, and total horizontal restoring force as functions of assumed horizontal offsets. CALMS was selected because of its low cost which permitted analysis of numerous SKSS concepts and because the program has seen extensive use by the offshore industry. Results obtained with CALMS have reportedly been verified by field tests.

Several assumptions have been made in using the static analysis approach.

- All mooring lines are assumed to be attached at a single point at the center of the vessel. This is not very significant since the platform dimensions are small relative to the depth.

- o Only motions in the horizontal plane are considered. Roll, pitch and heave motions have little effect on line reactions for a deep water catenary mooring.

- o Current and wave forces acting on the mooring lines are neglected.

- o A uniform density is assumed within a segment of the catenary.

- o The ocean bottom slope is assumed to be constant and the bottom topography regular (a flat inclined plane). For the most part, this is true but some mooring lines are not in the same plane as the others. The effect on the computation of line loading is not considered large but the computed line lengths in some cases may have some error.

6.1.2 Tension Leg Moorings

A properly designed tension leg system should minimize the wave excitation forces and the overall platform motions. In addition to evaluating the mooring leg reactions resulting from static loads and excursions, the effect of oscillatory wave loads must be considered and the structural natural frequencies must be outside those of the energy intensive wave spectra.

The total line tension is comprised of a static component resulting from pretension and static excursion and a time varying portion from wave forces and surge motions. This total tension must never equal zero at any time and the maximum line tension must not exceed the tensile capacity of the cable. The elasticity of the lines must also be considered which permits some heave motions. Line tensions are computed by considering inclined legs to form a catenary and considering the excursion resulting from static loads. Forces from surge excursion and buoyancy changes from incident waves are added to the static case. Vertical tension moorings are treated similarly but the inclination angles of the legs are small enough that they can be considered as straight. The interaction between the CWP and mooring leg is also considered.

The natural frequency of the mooring system is checked for surge and heave. Where a resonant condition is found to exist suitable changes in pretension or cable spring stiffness are made.

6.2 Results of Catenary Mooring Calculations

Significant problems exist in the development of a catenary mooring system in a water depth of 5400 feet and holding force requirements in excess of 1,000 kips. As stated in Section 2.0, these conditions mark the limits of the current state-of-the-art for catenary systems and the results of our study support this position. Other problems aside from deep water and high holding capacity requirements are:

- High line pretension levels are required to avoid exceedance of the excursion limit.

- o Anchors must be placed very far from the platform to obtain a zero or small mooring line slope at the anchor.
- o Bottom slope considerations limit the mooring line lengths and anchor positions.
- o Cost considerations limit mooring line lengths.

The above considerations lead to a catenary system which typically has large mooring line slopes at the anchor and a very shallow catenary shape yielding a "stiff" mooring system. Appendix B provides sample output from the CALMS program runs and tables and graphs which summarize the results of the catenary computations.

6.2.1 SPAR Catenary Studies

Table 14 summarizes the characteristics of and the results for all feasible catenary mooring concepts that were developed. These are:

- o A 4 leg composite segment line of HCL links and chain
- o An 8 leg composite line of wire and chain
- o A 4 leg single segment solid bar link.

A drag type anchor may be used with the wire-chain system but for the others deadweight anchors are required.

6.2.2 Barge Catenary Studies

Table 15 summarizes the feasible concepts for barge catenary moorings. These consist of:

- o A 4 leg HCL single segment line with riser buoy
- o A 4 leg single segment solid bar link
- on 3 leg single segment solid bar link.

Beam sea drag loading is considered for all of these cases.

6.3 Results of Tension Leg Mooring Calculations

As seen in Table 14 three different types of tension leg moorings were considered.

The slant leg mooring is seen to be extremely effective in limiting excursion but the leg sizes required are quite large and deballasting must be used to prevent leeward line slacking in extreme conditions.

The 3 leg vertical tension mooring with the legs running outside the cold water pipe is the most attractive mooring system. The interference of the CWP with the mooring lines was considered but the 10" DIA. leg sizes are still significantly less than 16.25" DIA. for the slant leg. The biggest problem for the vertical tension leg mooring is that the mooring system appears to be in a resonant condition. A more rigorous analysis is required to determine the magnitude of this problem but larger leg sizes may be required to increase the mooring stiffness so the natural frequency is above the region of maximum wave energy.

Another concept is a mooring leg running down the center of the cold water pipe. This concept was not analyzed in detail since the three leg mooring would appear to be more desirable from the standpoint of reliability and relative ease of maintenance, and deployment procedures. However, the single leg mooring does appear to be technically feasible.

As noted in Section 4, a tension leg mooring is not feasible for the barge platform although the single leg mooring concept with a separate buoy in tension is somewhat similar. This concept could work well from the standpoint of SKSS performance; however the electrical transmission configuration and its connection to the platform may be complicated.

Careful consideration of the "platform-mooring buoy-riser cable buoy" interface will be necessary in a preliminary design if a single leg/buoy mooring concept is selected for the barge platform.

TABLE 14 MATRIX OF FEASIBLE SKSS CONCEPTS FOR "SPAR"

Mooring System										Computed Results								
	Legs	Material	Breaking Strength Kips	Factor of Safety	Allowable Strength Kips	Length ft	Wet Weight #/ft	Clump/Buoy Force K	Bottom Slope	Hori. Dist. to Anchor λ - ft	Operating Condi. e - ft	Operating Condi. T_{max} - kips	Operating Condi. Pull on Anchor Hori - kips	Operating Condi. Pull on Anchor Vert - kips	Survival Condi. e - ft	Survival Condi. T_{max} - kips	Survival Condi. Pull on Anchor Hori - kips	Survival Condi. Pull on Anchor Vert - kips
CATENARY	4	SL			5400	6500	400		0.095	3382	164	3950	1135	1047	246	5100	2004	2607
				PRETENSION = 3000 K.														
	8	5" WR	2156	2/3	1078 / 719	1000	38.4	0/50K	0.095	7919	455	710	181	0	835	1065	669	8
		"	"	"	"	6000	"	100/0										
		4" CHN	1632	2	816	3200	132											
				PRETENSION = 400 K.														
	4	HCL				1000	49	0/100	0.095	7880	370	1330			840	1935		
		HCL				6000	49	500/0										
		CHN				3200	49											
				PRETENSION = 700 K.														
TENSION LEG	SLANT 3	TR				4400	614			508	-	-	-	-	270	13174	2355	12965
	VERT 3	TR				4400	219			0	-	-	-	-	450	13799		
	VERT 1					4400				0	-	-	-	-	460	18460	1801	13681
				PRETENSION = 12085 K														

TABLE 15 MATRIX OF FEASIBLE SKSS CONCEPTS FOR "BARGE"

MOORING SYSTEM										COMPUTED RESULTS								
	LEGS	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	WET WEIGHT #/FT	CLUMP/BUOY FORCE K	BOTTOM SLOPE	HORI. DIST. TO ANCHOR λ - FT	OPERATING CONDI. e - FT	OPERATING CONDI. T_{MAX} - KIPS	OPERATING CONDI. PULL ON ANCHOR HORI - KIPS	OPERATING CONDI. PULL ON ANCHOR VERT - KIPS	SURVIVAL CONDI. e - FT	SURVIVAL CONDI. T_{MAX} - KIPS	SURVIVAL CONDI. PULL ON ANCHOR HORI - KIPS	SURVIVAL CONDI. PULL ON ANCHOR VERT - KIPS
Catenary	4	HCL			12096	1000	400	/200	0.095	4510	626	5100	2464	1623	717	12000	7000	6400
		HCL			12096	6500												
			PRETENSION = 2606 K.															
	4	SL			12500	1000	920	--	0.095	4510	600	5100			700	12500		
		SL				6500	920											
			PRETENSION = 4000 K.															
	8	SL			11500	7500	860	--	0.095	4557	274	7300	2273	297	568	9400	3817	1809
			PRETENSION = 6400 K.															
SLM	1	SL			28000	4650	1524	--	--	--	--	--	--	--	673	27640		27340
	P5 3			PRETENSION = 1505 K.														

7.0 EVALUATION AND COMPARISON OF FEASIBLE SKSS CANDIDATES

7.1 Performance - Effectiveness

At the conceptual design level, the performance - effectiveness considerations are necessarily partially subjective.

At this point, only the operating and survival conditions are considered. In the operating condition the platform must not exceed an excursion radius equal to 10 per cent of the depth. In the survival condition, the allowable leg tension must not be exceeded. The feasible concepts discussed in section 6 either meet these requirements or come close enough so that with more detailed design they can be expected to meet these requirements.

Reliability assessment is qualitative. It takes into account system redundancy, past experience with similar designs, state of the art of component development and number of possible modes of failure. Handling of the components during deployment and maintenance operations must also be considered since different loads and possibly different modes of failure could be experienced.

The SKSS systems which display the lowest excursion at the least cost with greatest reliability are the best or most effective candidates. The differences between various systems are quite significant. Costs are presented separately in section 7.2 and the final overall evaluation of candidates is made in section 7.7.

7.1.1 SPAR SKSS Performance

All of the SPAR SKSS candidates meet the excursion requirements quite easily for the operating condition. In the case of the 4 leg solid link catenary concept, the pretension level should be reduced which would bring the excursion distance up to that of the other two catenary concepts. This would reduce the leg tension level to some degree and increase the distance to the anchor.

The tension-leg moorings all show spectacular excursion performance staying within the 10% depth limitation even in the survival conditions.

If necessary, the excursion radius could be reduced even further by increasing leg pretension but this, of course, would lead to an increase in the system cost.

The eight leg wire rope and chain catenary has an adequate allowable strength for the tension developed in the survival condition. This however is only possible with the use of a clump weight and a riser buoy on each leg. The design factors of safety discussed in Section 2.1 for wire rope (two for survival, three for operating conditions) have been employed. It's expected that careful selection of slightly larger line segment sizes and lengths will permit elimination of the riser buoy and perhaps even the clump weight. The factors of safety can also be increased in this manner.

The tension leg systems appear to be structurally sound assuming the problem of heave response can be avoided.

Fatigue life has not been computed for the HCL or solid bar link legs at this stage in the design cycle, but the extreme stress level is fairly close to the fatigue limit of the material considered. Any increase in material tensile strength properties or leg sizes to provide an adequate fatigue life is expected to be small.

The life of wire rope however is generally governed by fatigue failure. The fatigue life for a design factor of safety of 4 is about five years. Chain failure from fatigue is not common if factors of safety of 2 to 2.5 are used.

7.1.2 SPAR SKSS Reliability

The system with the highest reliability is the wire-chain system which has had considerable field experience and uses standard type drag anchors. The eight leg array will provide high reliability in case of one leg failure. The tension rod concept has not been previously used for this type of application, but it is currently under serious consideration by some offshore companies.

Tension rod is within the current state-of-the-art for fabrication; the required level of quality control can be achieved. The biggest problem facing the tension rod systems is that in the current configuration one leg failure would most likely lead to failure of the remaining legs. The addition of one or two more legs may be required to obtain the minimum desired reliability level.

The four leg solid link system will probably be able to sustain a one-leg failure although further computations are required to confirm this. The link itself should be quite reliable because of its simple construction and minimal required welding. The critical part of the link is the joint connection which changes the direction of link rotation.

The least reliable system is the HCL four-leg catenary system. This system has the same modes of failure as the solid link catenary system. In addition there is the possibility of link collapse or leakage which would degrade the strength of the entire leg. The quality control levels for welding and fabrication processes of the link connections must be much more stringent.

7.1.3 Barge Platform SKSS Performance

Two of the feasible barge SKSS concepts fail to meet the excursion requirement of 10% of depth at site. The excursion limits actually attained are 11.5% but this could be lowered to the acceptable limit by either increasing pretension or by adding more legs. Aside from the excursion consideration, the 4 and 8 leg catenary systems provide adequate strength and would be satisfactory for the OTEC operation. The single leg concept has excursion characteristics which are quite different from the catenary concepts since the platform is free to rotate 360 degrees about the mooring point. The radius of excursion is about the same as for the catenary systems although this now has little meaning since it is assumed that the riser cable moves with the mooring system.

7.1.4 Barge Platform SKSS Reliability

The discussion in 7.1.2 for the 4 leg catenary HCL or solid bar link for the SPAR platform would also apply to the BARGE platform. The eight leg solid link concept clearly provides greater reliability in the case of one leg failure as compared to the four leg system but, as seen in section 7.2, at much greater cost. If further analysis demonstrates that the reliability of the four leg SKSS is inadequate, then additional legs could be provided to increase redundancy.

For the single leg mooring concept, three legs closely spaced together have replaced the single leg, principally to facilitate fabrication and deployment of the legs but also to provide some redundancy for one leg failure. Maintenance and repair operations are also facilitated by using the three leg system.

7.2 COST ESTIMATES

7.2.1 DATA BASE

In order to develop a data base for the life cycle costing of SKSS candidates initial, annual operating, and major repair and replacement costs must be determined. The basic cost items for each category are listed in Table 16.

Referring to this table, cost items No. 1 and 6 thru 8 under initial costs are not included in the cost estimates.

Item No. 8 under initial costs and items No. 3 and 4 under annual operating costs would be covered under a seperate WBS* group for the complete OTEC plant.

Routine maintenance costs which are substantial enough to warrant a quantitative study apply only to the 8-leg wire-chain system for reasons stated in Section 7.4. Operating Personnel costs are taken into account for the active systems only. Support Services specific to the SKSS would be covered in the maintenance costs as would the costs for additional personnel for major repairs, and replacements.

In the computation of average annual costs, the formula presented in [23] is used with following assumptions:

- o Interest rate : 9%
- o N = 5 years from initial start-up
- o Scrapping and/or resale costs neglected

A complete description of cost calculations can be found in Volume IV of this report

* Work Breakdown Structure

A. Initial Costs

1. System research and development
2. Engineering -- preliminary, contract and detail
3. Fabrication of system components
4. Off-the-shelf hardware and equipment
5. Installation and deployment of SKSS
6. Industrial facilities
7. Special test facilities
8. Initial training of operating personnel.

B. Annual Operating Costs

1. Routine Maintenance
2. Operating Personnel
3. Additional personnel training
4. Insurance
5. Support Services for the SKSS

C. Major Repairs and Replacement Costs

1. Replacement of hardware and equipment with an expected life less than the total SKSS life.
2. Major repair and replacement operations. This would include cost of restoring the power cable hook-ups at the time of failure including active repair time and logistic time.
3. Additional personnel for major repair and replacement operations.

TABLE 16

In developing the data base, the following sources were used:

- All off-the shelf equipment costs were obtained from the manufacturers, either directly or through MR&S' subcontractors. Where large quantities of material were required to fabricate an item, such as the solid link or HCL mooring legs, wholesale steel suppliers were contacted and given details of the design before price quotes were received.

- The costs for welding, flame cutting, rolling, and rigging, etc. were estimated on the basis of past experience for pricing any non-standard items to be fabricated.

- For deployment and transportation costs, the following list of charter rates were used:

	$/day
2000-3000 hp tugs	3000
5000 hp tugs	5000
200 Ton crane barge w/tugs	15,000
Large derrick barges	50,000 - 75,000
15000 hp tugs	15,000
Large barge	3,000

These rates are on a daily basis and it should be noted that if any equipment is required for a full week or month during the actual installation, lower rates may be applicable.

All mobilization and demobilization rates are assumed to be about half of the above.

Towing speeds are assumed to be 5 mph and mobilization speeds 8-12 mph.

Special deployment equipment and instrumentation costs were estimated on the basis of deployment scenarios developed on Section 7.3.

For the contract and detail design engineering costs, 2% and 5% respectively of the total SKSS acquisition cost (consisting of deployment / installation, fabrication and construction costs) were assumed.

7.2.2 COST BREAKDOWN

Tables 17 thru 25 exhibit the cost breakdwon used for this analysis and cover the cost items discussed in 7.2.1.

7.2.3 OVERALL COST ESTIMATES

Table 26 summarizes the overall costs for the feasible SKSS candidates.

SKSS COST ESTIMATE - WBS GROUP 3.1.2

BARGE PLATFORM: SKSS CONCEPT: SINGLE LEG LINK, TENSION

WBS No.		WBS Item	Fabrication/Construction Costs: Tooling	Material & Other	Total
3.1.2.1	0	Anchors			
	1	Deadweight	5,287	4,865	10152
	2	Drag			
	3	Pilings			
3.1.2.2	0	Mooring Legs			
	1	Segments			
	1	1 Links		16,519	16519
	1	2 Wire			
	1	3 Chain			
	1	4 Kevlar			
	2	Clump Weights			
	3	Buoy	3,234	717	3951
	4	Support Arm	76	25	101
	5	Fittings		150	150
	6	Biofouling and Abrasion Prevention			
3.1.2.3	0	Deck Equipment			
	1	Winches, Foundations		3.600	3,600
	2	Hawse Pipe			
	3	Fairleads, Guides			
3.1.2.4	0	Control System		2,000	2,000
3.1.2.5	0	Thrusters		6,000	6,000
		Subtotal	8,597	33,876	42,473

Total Acquisition Cost Summary

($ x10^{-3})	
Fabrication/Constr	42,473
Deployment/Inst.	5,221
Contract Design	954
Detail Design	2,385
Test/Operation	
Total	51,033

TABLE 17

SKSS COST ESTIMATE - WBS GROUP 3.1.2

BARGE PLATFORM: SKSS CONCEPT: 4 LEG, HCL CATENARY

WBS No.		WBS Item	Tooling	Material & Other	Total
			FABRICATION/CONSTRUCTION COSTS		
3.1.2.1	0	Anchors			
	1	Deadweight	13,556	12,485	26,041
	2	Drag			
	3	Pilings			
3.1.2.2	0	Mooring Legs			
	1	Segments			
	1	1 Links		123,341	123,341
	1	2 Wire			
	1	3 Chain			
	1	4 Kevlar			
	2	Clump Weights			
	3	Buoy			
	4	Support Arm			
	5	Fittings		150	150
	6	Biofouling and Abrasion Prevention			
3.1.2.3	0	Deck Equipment			
	1	Winches, Foundations		7,200	7,200
	2	Hawse Pipe			
	3	Fairleads, Guides			
3.1.2.4	0	Control System			
3.1.2.5	0	Thrusters			
		Subtotal	13,556	143,176	156,732

Total Acquisition Cost Summary

($ x10^{-3})	
Fabrication/Constr	156,732
Deployment/Inst.	14,295
Contract Design	3,421
Detail Design	8,551
Test/Operation	
Total	182,999

TABLE 18

SKSS COST ESTIMATE - WBS GROUP 3.1.2

SPAR PLATFORM: SKSS CONCEPT: 8-LEG, CHAIN-WIRE CATENARY

WBS No.		WBS Item		Fabrication/Construction Costs: Tooling	Material & Other	Total
3.1.2.1	0	Anchors				
	1	Deadweight				
	2	Drag			880	880
	3	Pilings				
3.1.2.2	0	Mooring Legs				
	1	Segments				
	1	1	Links			
	1	2	Wire		3,984	3,984
	1	3	Chain		2,007	2,007
	1	4	Kevlar			
	2	Clump Weights			69	69
	3	Buoy		90	30	120
	4	Support Arm				
	5	Fittings			80	80
	6	Biofouling and Abrasion Prevention				
3.1.2.3	0	Deck Equipment				
	1	Winches, Foundations			5,280	5,280
	2	Hawse Pipe			1,064	1,064
	3	Fairleads, Guides			67	67
3.1.2.4	0	Control System			2,000	2,000
3.1.2.5	0	Thrusters				
		Subtotal		90	15,461	15,551

Total Acquisition Cost Summary

($ x10^{-3})	
Fabrication/Constr	15,551
Deployment/Inst.	2,190
Contract Design	355
Detail Design	887
Test/Operation	
Total	18,983

TABLE 19

SKSS COST ESTIMATE - WBS GROUP 3.1.2

SPAR PLATFORM: SKSS CONCEPT: 3-LEG, SLANT TENSION MOORING

WBS No.		WBS Item	Fabrication/Construction Costs: Tooling	Material & Other	Total
3.1.2.1	0	Anchors			
	1	Deadweight	6,044	5,524	11,568
	2	Drag			
	3	Pilings			
3.1.2.2	0	Mooring Legs			
	1	Segments			
	1	1 Links		17,484	17,484
	1	2 Wire			
	1	3 Chain			
	1	4 Kevlar			
	2	Clump Weights			
	3	Buoy			
	4	Support Arm			
	5	Fittings		150	150
	6	Biofouling and Abrasion Prevention			
3.1.2.3	0	Deck Equipment			
	1	Winches, Foundations		5,400	5,400
	2	Hawse Pipe		399	399
	3	Fairleads, Guides		27	27
3.1.2.4	0	Control System			
3.1.2.5	0	Thrusters			
		Subtotal	6,044	28,984	35,028

Total Acquisition Cost Summary

($ x10^{-3})	
Fabrication/Constr	35,028
Deployment/Inst.	5,803
Contract Design	817
Detail Design	2,042
Test/Operation	896
Total	44,586

TABLE 20

SKSS COST ESTIMATE - WBS GROUP 3.1.2

SPAR PLATFORM: SKSS CONCEPT: 3-LEG, VERTICAL TENSION MOORING

WBS No.			WBS Item	Fabrication/Construction Costs: Tooling	Material & Other	Total
3.1.2.1	0		Anchors			
	1		Deadweight	2,059	1,879	3,938
	2		Drag			
	3		Pilings			
3.1.2.2	0		Mooring Legs			
	1		Segments			
	1	1	Links		6,779	6,779
	1	2	Wire			
	1	3	Chain			
	1	4	Kevlar			
	2		Clump Weights			
	3		Buoy			
	4		Support Arm			
	5		Fittings		150	150
	6		Biofouling and Abrasion Prevention			
3.1.2.3	0		Deck Equipment			
	1		Winches, Foundations		5,400	5,400
	2		Hawse Pipe		399	399
	3		Fairleads, Guides		27	27
3.1.2.4	0		Control System			
3.1.2.5	0		Thrusters			
			Subtotal	2,059	14,634	16,693

Total Acquisition Cost Summary

($ x10^{-3})	
Fabrication/Constr	16,693
Deployment/Inst.	5,162
Contract Design	437
Detail Design	1,093
Test/Operation	896
Total	24,281

TABLE 21

SKSS COST ESTIMATE - WBS GROUP 3.1.2

SPAR PLATFORM: SKSS CONCEPT: 4-LEG, LINK CATENARY

WBS No.		WBS Item	Fabrication/Construction Costs: Tooling	Material & Other	Total
3.1.2.1	0	Anchors			
	1	Deadweight			
	2	Drag	4,726	4,353	9,079
	3	Pilings			
3.1.2.2	0	Mooring Legs			
	1	Segments			
	1	1 Links		18,600	18,600
	1	2 Wire			
	1	3 Chain			
	1	4 Kevlar			
	2	Clump Weights			
	3	Buoy			
	4	Support Arm			
	5	Fittings			
	6	Biofouling and Abrasion Prevention			
3.1.2.3	0	Deck Equipment			
	1	Winches, Foundations		3,600	3,600
	2	Hawse Pipe		533	533
	3	Fairleads, Guides			
3.1.2.4	0	Control System			
3.1.2.5	0	Thrusters			
		Subtotal	4,726	27,086	31,812

Total Acquisition Cost Summary ($ x10^{-3})	
Fabrication/Constr	31,812
Deployment/Inst.	10,708
Contract Design	850
Detail Design	2,126
Test/Operation	
Total	45,496

TABLE 22

SKSS COST ESTIMATE - WBS GROUP 3.1.2

PLATFORM: SPAR   SKSS CONCEPT: HCL-CHAIN CATENARY -- 4-LEG

WBS No.			WBS Item	FABRICATION/CONSTRUCTION COSTS Tooling	Material & Other	Total
3.1.2.1	0		Anchors			
	1		Deadweight	711	656	1,367
	2		Drag			
	3		Pilings			
3.1.2.2	0		Mooring Legs			
	1		Segments			
	1	1	Links		30,492	30,492
	1	2	Wire			
	1	3	Chain		1,004	1,004
	1	4	Kevlar			
	2		Clump Weights			
	3		Buoy			
	4		Support Arm			
	5		Fittings			
	6		Biofouling and Abrasion Prevention			
3.1.2.3	0		Deck Equipment			
	1		Winches, Foundations		2,640	2,640
	2		Hawse Pipe		533	533
	3		Fairleads, Guides			
3.1.2.4	0		Control System			
3.1.2.5	0		Thrusters			
			Subtotal	711	35,325	36,036

Total Acquisition Cost Summary ($ x10^{-3})	
Fabrication/Constr	36,036
Deployment/Inst.	10,708
Contract Design	935
Detail Design	2,337
Test/Operation	
Total	50,016

TABLE 23

SKSS COST ESTIMATE - WBS GROUP 3.1.2

BARGE PLATFORM: SKSS CONCEPT: 8-LEG LINK CATENARY

WBS No.		WBS Item	FABRICATION/CONSTRUCTION COSTS		
			Tooling	Material & Other	Total
3.1.2.1	0	Anchors			
	1	Deadweight			
	2	Drag	13,500	12,500	26,000
	3	Pilings			
3.1.2.2	0	Mooring Legs			
	1	Segments			
	1	1 Links		91,977	91,977
	1	2 Wire			
	1	3 Chain			
	1	4 Kevlar			
	2	Clump Weights			
	3	Buoy			
	4	Support Arm			
	5	Fittings		300	300
	6	Biofouling and Abrasion Prevention			
3.1.2.3	0	Deck Equipment			
	1	Winches, Foundations		10,828	10,828
	2	Hawse Pipe			
	3	Fairleads, Guides			
3.1.2.4	0	Control System			
3.1.2.5	0	Thrusters			
		Subtotal	13,500	115,605	129,105

Total Acquisition Cost Summary

($ x10^-3)	
Fabrication/Constr	129,105
Deployment/Inst.	19,760
Contract Design	2,997
Detail Design	7,443
Test/Operation	
Total	159,285

TABLE 24

SKSS COST ESTIMATE - WBS GROUP 3.1.2

BARGE PLATFORM: SKSS CONCEPT: 4-LEG, LINK CATENARY

TABLE 25

WBS No.		WBS Item	Fabrication/Construction Costs: Tooling	Fabrication/Construction Costs: Material & Other	Fabrication/Construction Costs: Total
3.1.2.1	0	Anchors			
	1	Deadweight	13,556	12,485	26,041
	2	Drag			
	3	Pilings			
3.1.2.2	0	Mooring Legs			
	1	Segments			
	1	1 Links		49,104	49,104
	1	2 Wire			
	1	3 Chain			
	1	4 Kevlar			
	2	Clump Weights			
	3	Buoy			
	4	Support Arm			
	5	Fittings		150	150
	6	Biofouling and Abrasion Prevention			
3.1.2.3	0	Deck Equipment			
	1	Winches, Foundations		7,200	7,200
	2	Hawse Pipe			
	3	Fairleads, Guides			
3.1.2.4	0	Control System			
3.1.2.5	0	Thrusters			
		Subtotal	13,556	68,939	82,495

Total Acquisition Cost Summary ($ $\times 10^{-3}$)	
Fabrication/Constr	82,495
Deployment/Inst.	14,295
Contract Design	1,936
Detail Design	4,839
Test/Operation	
Total	103,565

Overall SKSS

Cost Summary

($000) 1980$

	Platform & SKSS Concept	Initial Costs	Average Annual Costs	Present Value
* 1	Spar - 8 Leg Wire - Chain Catenary	18,983	3,560	22,850
* 2	Spar - 3 Leg Vertical Tension Rod	24,281	4,054	26,020
3	Spar - 3 Leg Slant Tension Rod	44,586	7,587	48,700
4	Spar - 4 Leg Solid Link Catenary	45,496	7,666	49,204
5	Spar 4 Leg HCL - Chain Catenary	50,016	8,670	55,648
* 6	Barge w/Buoy Solid Link 1 Leg Tension	51,033	9,022	57,908
* 7	Barge - 4 Leg Solid Link Catenary	103,564	17,480	112,195
8	Barge - 8 Leg Solid Link Catenary	159,285	26,039	167,452
9	Barge - 4 Leg HCL Catenary	182,999	31,579	202,692

TABLE 26

* Final Candidates

7.3 Deployment Scenarios

7.3.1 General

The deployment processes and their sequences are considered in this section for the ten feasible SKSS concepts for Modular Experiment platforms listed in Tables 14 and 15 of Section 6.0.

To repeat, these are:

- o For the SPAR
  - Catenary, 4-leg, Solid Link
  - Catenary, 4-leg, HCL and Chain
  - Catenary, 8-leg, Wire Rope and Chain
  - Tension, 3-leg, Slant
  - Tension, 3-leg, Vertical

- o For the BARGE
  - Catenary, 4-leg, Solid Link
  - Catenary, 4-leg, HCL
  - Catenary, 8-leg, Solid Link
  - Tension, SLM with Buoy

All deployment operations are based on transportation from New Orleans to Puerto Rico. It is assumed that surveying of the bottom soil conditions at the deployment site has been completed and conditions evaluated prior to the arrival of the platform and SKSS components at the site.

Four deployment scenarios are developed to cover the above-mentioned SKSS concepts, as follows:

- o 4 Leg Solid Link Catenary
- o 8 Leg Wire Rope & Chain Catenary
- o 3 Leg, Slant Tension Mooring
- o SLM with Tension Buoy,

The top three of these scenarios are applicable to the SPAR platform. For the BARGE platform, only the first and fourth deployment scenarios are applicable.

The scenario for the 4 leg HCL catenary concept would be similar to the solid link scenario described in 7.3.2 (b). The deployment operations for all deadweight anchors would be the same as outlined in 7.3.3 (a) steps 1 through 4. However, the connection of mooring legs to the anchor will differ for the SPAR tension leg concepts from that for other concepts.

7.3.2 Deployment Scenarios for Catenary Mooring Concepts

a. Eight Leg Wire-Chain Catenary

Usually, the wire rope can be manufactured up to a certain practical length based on the weight of the entire string. With the size of ropes we are talking about the practical limit will be about 3000 ft. Hence, since we need around 7,000 ft. of rope per mooring line we will assume that each mooring line will come in one 3000 ft. section, two 1500 sections stored on storage drums, and one 1500-2000 foot section stored in the drum of the mooring winch onboard the OTEC. Prior to installation, arrangements will be made for the 1500-2000 sections to be spooled on the OTEC mooring winches, and the storage reel holding the 3000 foot sections and one 1500 foot section to be onboard a work boat. The remaining 1500 foot sections are on the barge with the chain and anchors. Prior to the arrival of the mooring equipment, the area would have been surveyed, the anchor locations would have been marked and the anchor and chain drag line installation would have begun.

The drag anchor and chain drag and wire line installations are visualized to proceed following the steps below, (See Figures 27 thru 34.):

1. The chain, wire, and drag anchors arrive on location on a barge.
2. A crane barge with a minimum capacity of 200 tons is already there or arrives simultaneously.
3. The crane picks up the anchor(s) with the chain already attached to them and lowers it in the water.
4. The barge starts paying out chain from its chain lockers. The barge is equipped with a high load capacity chain windlass that can control the descent of 3200 ft. of chain plus 1500 ft. of wire with the anchor at the end. It is estimated that the capacity of this windlass should be

around one million pounds.

5. The chain end comes carefully off the windlass. Before this is done special pelican hooks, attached with wire rope to bollards on the barge, secure the chain against an accident. This operation is critical since the entire chain with the anchor can be lost. Now the chain end is laying freely on the barge deck.
6. The 1500 foot section of wire is connected to the chain with shackles and the paying out continues.
7. When the anchor touches bottom, a tug boat starts pulling the barge slowly towards the OTEC vessel which is held on location either by its own power or by assisting tugs.
8. The crane barge follows the barge under its own power or by assisting tugboats.

   Note: The barge and crane barge could be combined into one vessel, if such a vessel could be found with the crane and chain lockers available. The chain windlass will have to be made anyway.
9. A triplate is installed at the end of the 1500 foot wire section.
10. The attachment of 1500' wire section to the triplate and simultaneously to the pendant line with a buoy and the 3000' wire section is performed.
11. Step 9 is performed with the aid of a work boat carrying the 3000 foot wire rope storage reel which approaches the barge and passes one end of the wire rope. This is the end that gets connected to the free end of the triplate.
12. With the triplate connection still on the barge the work boat takes off towards the OTEC vessel unspooling rope continuously. The procedure continues until the second segment of the wire rope runs out.

13. Meanwhile another tug boat approaches the OTEC vessel, picks up the free end of the rope stored on the mooring winch onboard the OTEC vessel and starts pulling towards the work boat with the free end of the two long segments. Sufficient rope is unspooled so the tug boat does not have to have very high bollard pull.

14. When the tug boat and work boat approach each other, a line is thrown on the tug boat from the work boat. This line is attached to the wire rope coming from the OTEC vessel. The tug boat pulls out of the way and the work boat now holds the two ends of the wire rope mooring line. The two ends are pulled together and joined with shackles. The entire mooring line is now connected. The triplate/wire rope interface is on the barge and the wire rope/wire rope interface is on the work boat.

15. The crane barge approaches first the work boat, picks up the wire rope - wire rope connection, lowers it in the water and releases it.

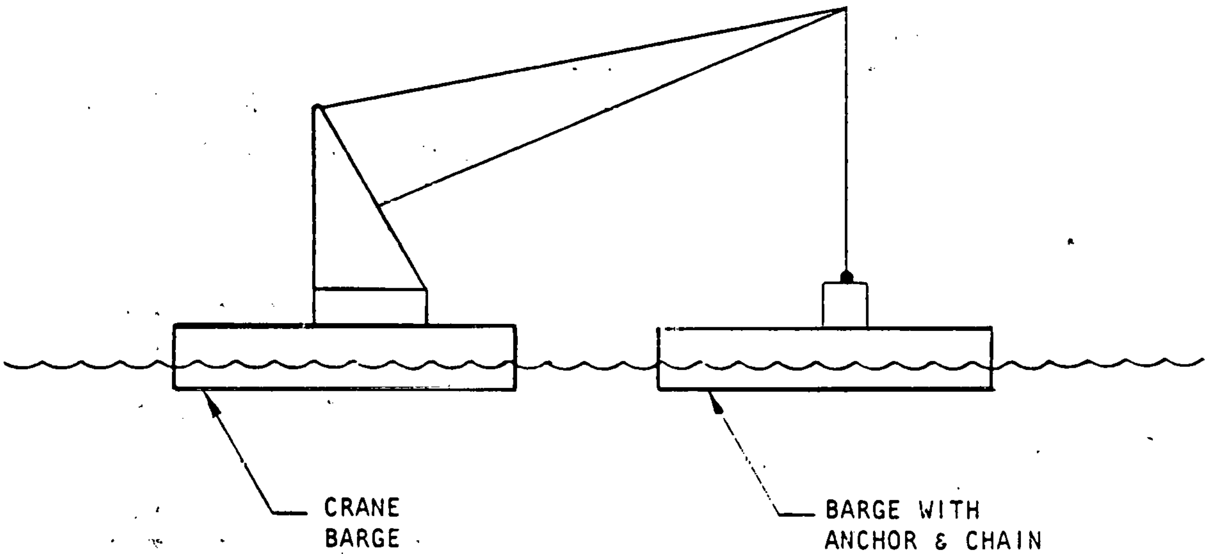
16. Next, the crane barge approaches the barge and picks up the triplate wire rope connection, lowers it in the water and releases it again. Now the entire mooring line is in place without any tension.

    Note: The crane barge is used in the last two steps simply because of the great weights involved. The release of the lines once in the water is achieved through special hooks triggered from the crane barge.

When all the mooring lines are installed, the OTEC vessel with its own mooring winches tensions the lines to the prescribed pretension. The SKSS is installed and operational.

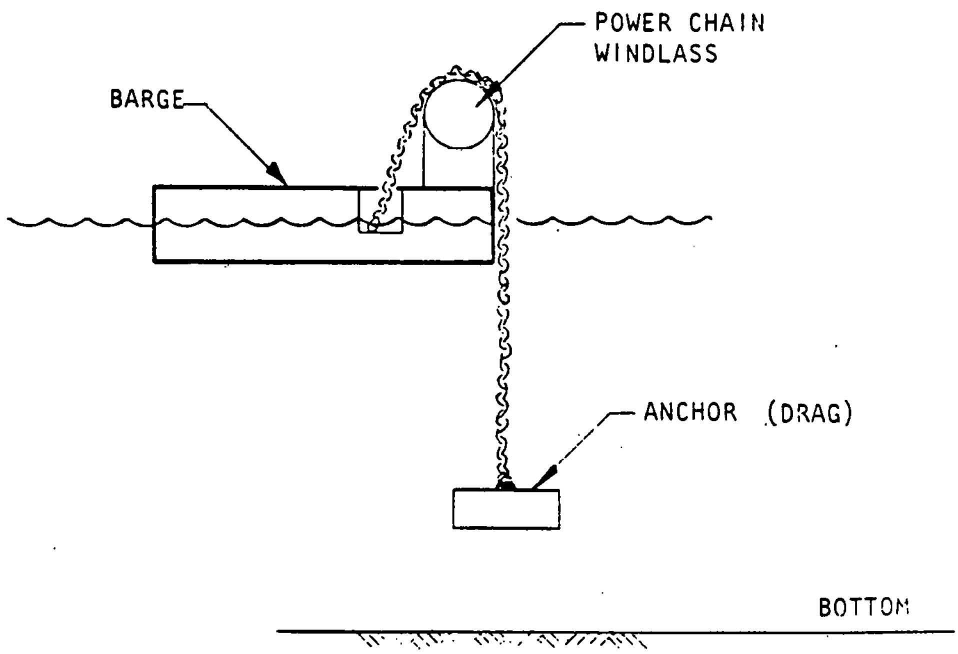
Equipment used

1. One 200 ton crane barge self propelled or with two assisting tugs around 2,000 hp each.
2. One barge with large chain lockers together with two tugs, one for pulling (say 5,000 hp) and one for maneuvering (say 2,000 hp).
3. One tug boat for pulling wire rope line from OTEC vessel to work boat. Fairly good bollard required, say 5,000 hp.
4. One work boat with large deck area and powered wire rope windlass. Good bollard capacity is required, say 5,000-6,000 hp.
5. Work boat windlass with large storage drum and termination point for tying wire rope end. Two catheads required with good pulling capacity.
6. Two large powered storage drums for storing pendant lines and paying them out.
7. Assortment of pelican hooks, slings, chain pieces, etc. for handling and securing heavy mooring equipment.
8. Complete communications gear such as walkie-talkie special band radios, etc. for coordinating all the activities.



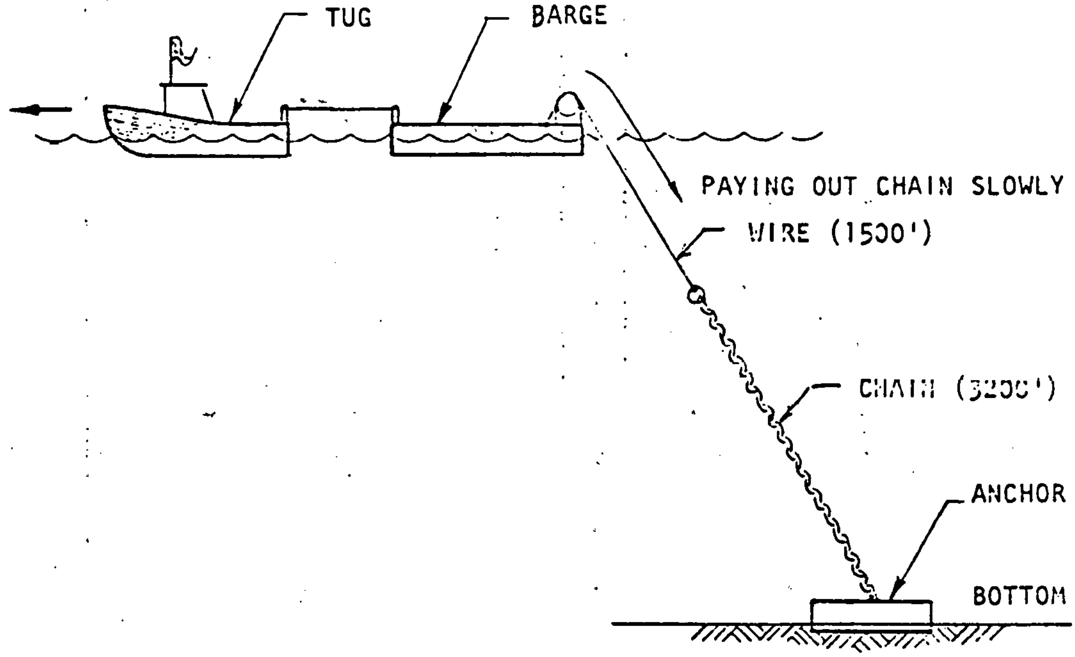
STEP 3

FIGURE: 27



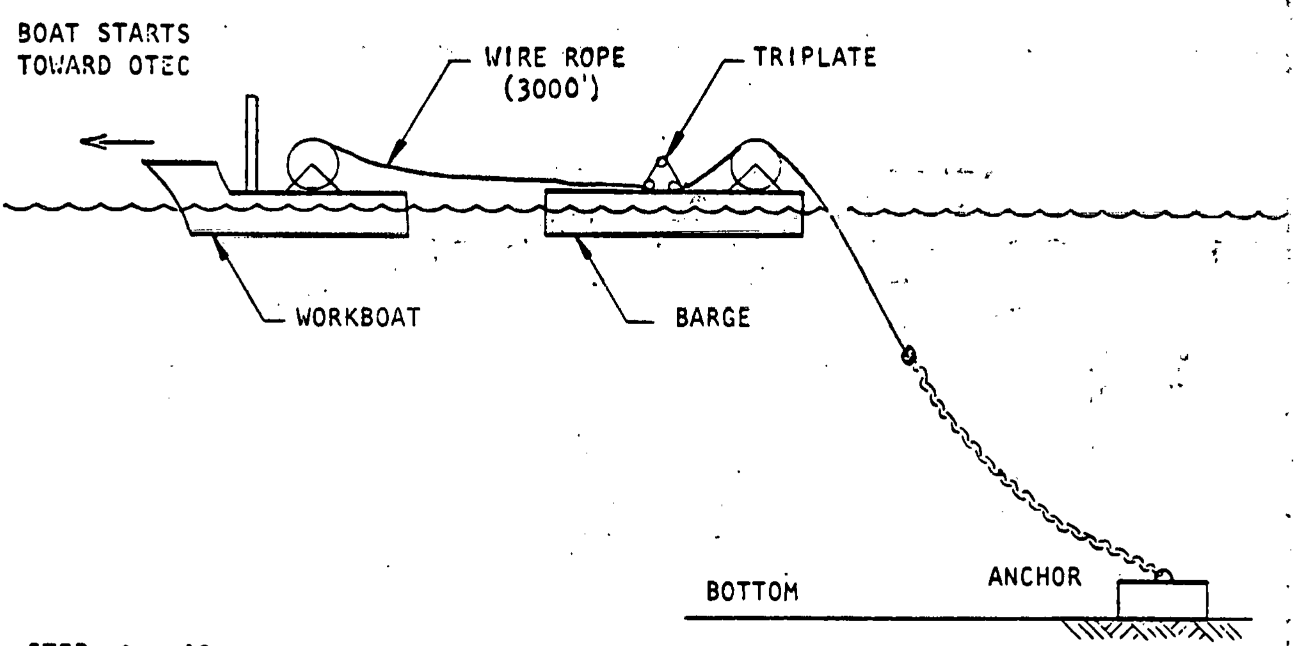
STEP 4

FIGURE: 28



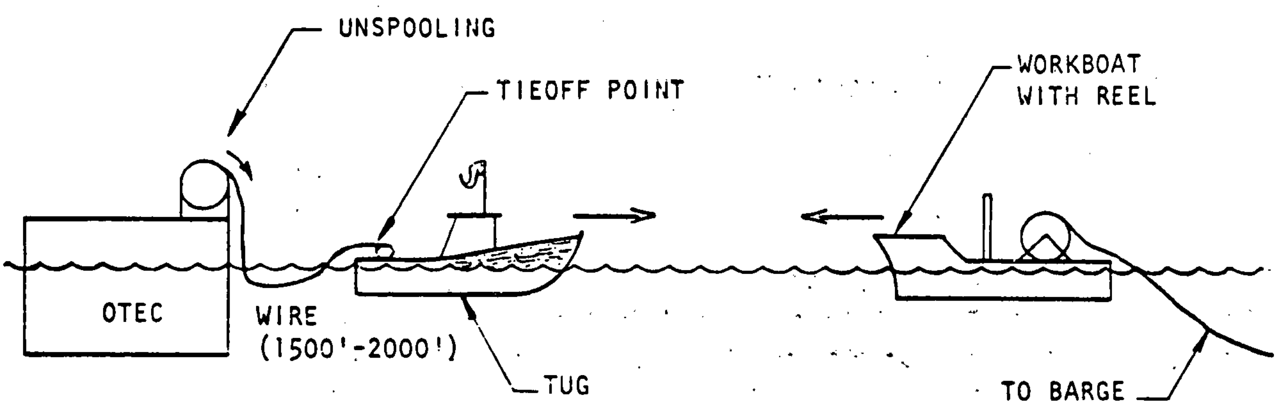
STEP 5-8

FIGURE:29



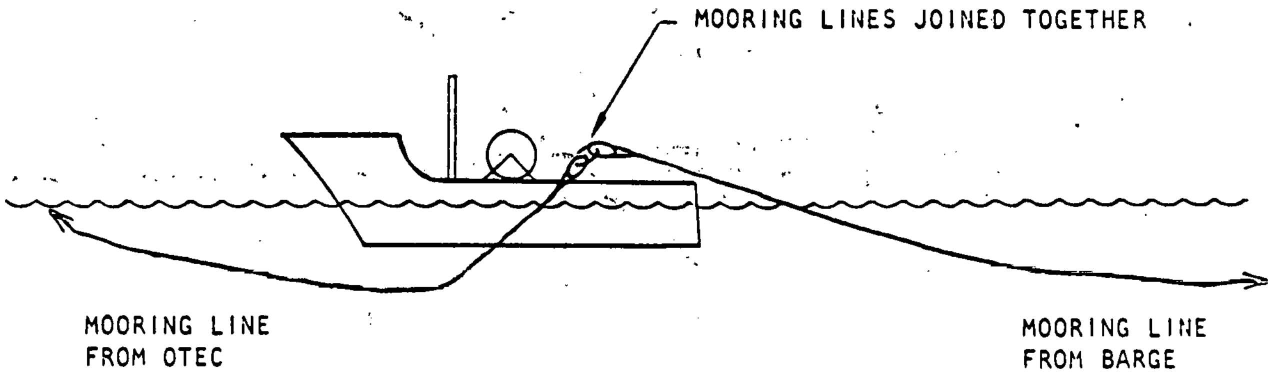
STEP 9 - 12

FIGURE: 30



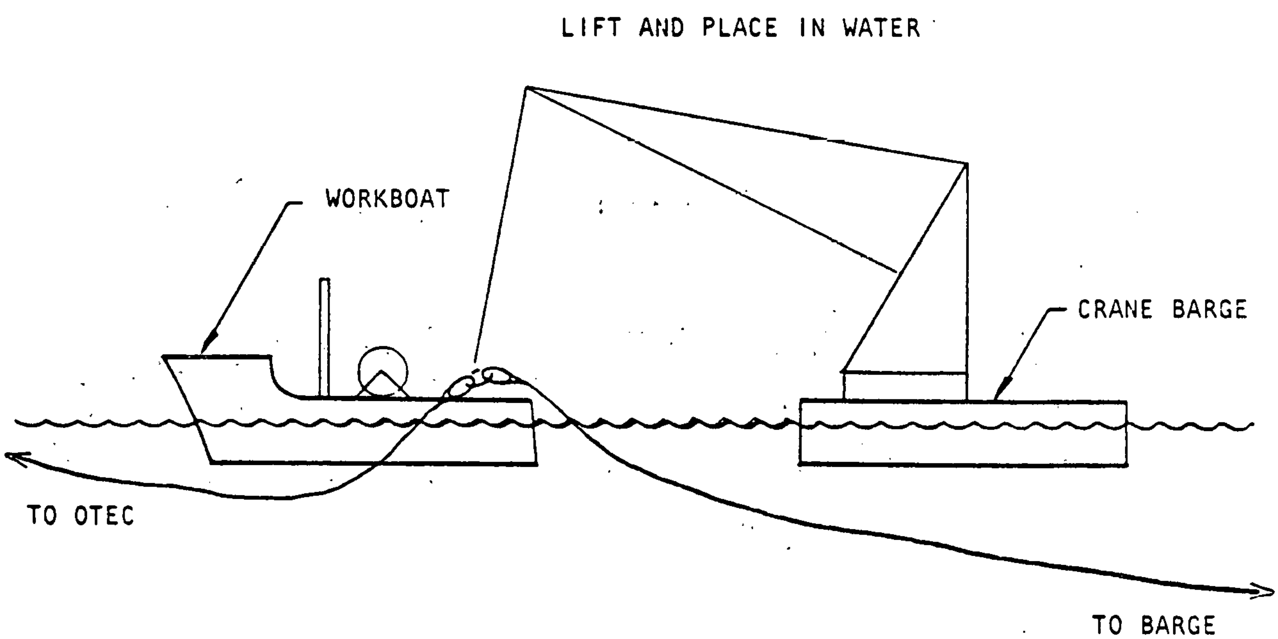
STEP 13

FIGURE: 31



STEP 14

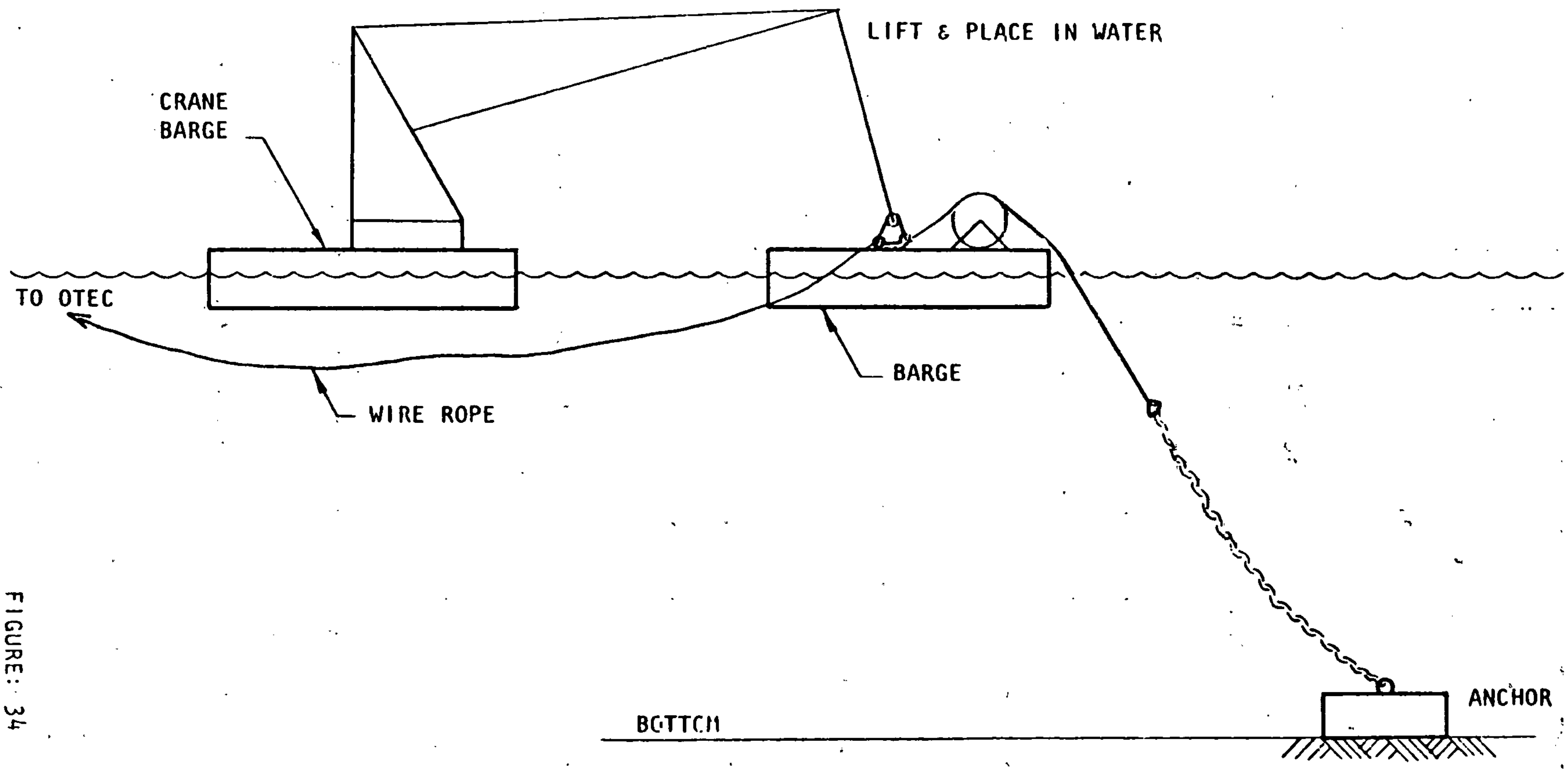
FIGURE: 32



STEP 15

FIGURE: 33

M. ROSENBLATT & SON, Inc.



STEP 16

FIGURE: 34

b. Four Leg Solid Link Catenary (Spar and Barge)

Follow steps 1-4 from section 7.3.3 (a) for the anchor deployment. Due to the wet steel weight of the anchor for the barge system, the use of four workboats will be necessary to lower the anchor.

The deployment of the solid links is visualized to proceed as follows for the first one of the four legs.

STEP 5.

A derrick barge (1200 ton capacity) and hoisting equipment arrives on site simultaneously and pulls buoys with attached guidelines to anchors and connects them on board, see Figures 35 and 38

STEP 7.

The anchor connecting system is rigged up, the frame is attached and the links are hoisted aboard from the barge.

STEP 8.

Links are connected and lowered until they reach the anchor connection, see Figures 35, 36; 38, 39.

STEP 9.

Simultaneously the OTEC platform (which has equipment similar to those shown in Figure 35) develop a link line which must be long enough to reach the derrick barge, see Figures 36 and 39.

STEP 10.

Divers connect a wire line from the derrick barge to the links coming from the OTEC platform and the hoisting equipment is used to bring this line to the derrick barge, see Figures 36 and 39.

STEP 11.

The two link lines are connected and the hoisting equipment lowers the catenary until it lays slack in the water. The guide-lines to the anchor are severed and recovered, See Figures 37 and 40.

Steps 1-11 are repeated for legs No. 2-4.

Required Equipment

1. (a) Barge with derrick and hoisting equipment.

   (b) Barge has two wire rope guideline terminating equipment (no tensioners needed due to great depth). Wire rope guidelines are those used to lower the anchor.

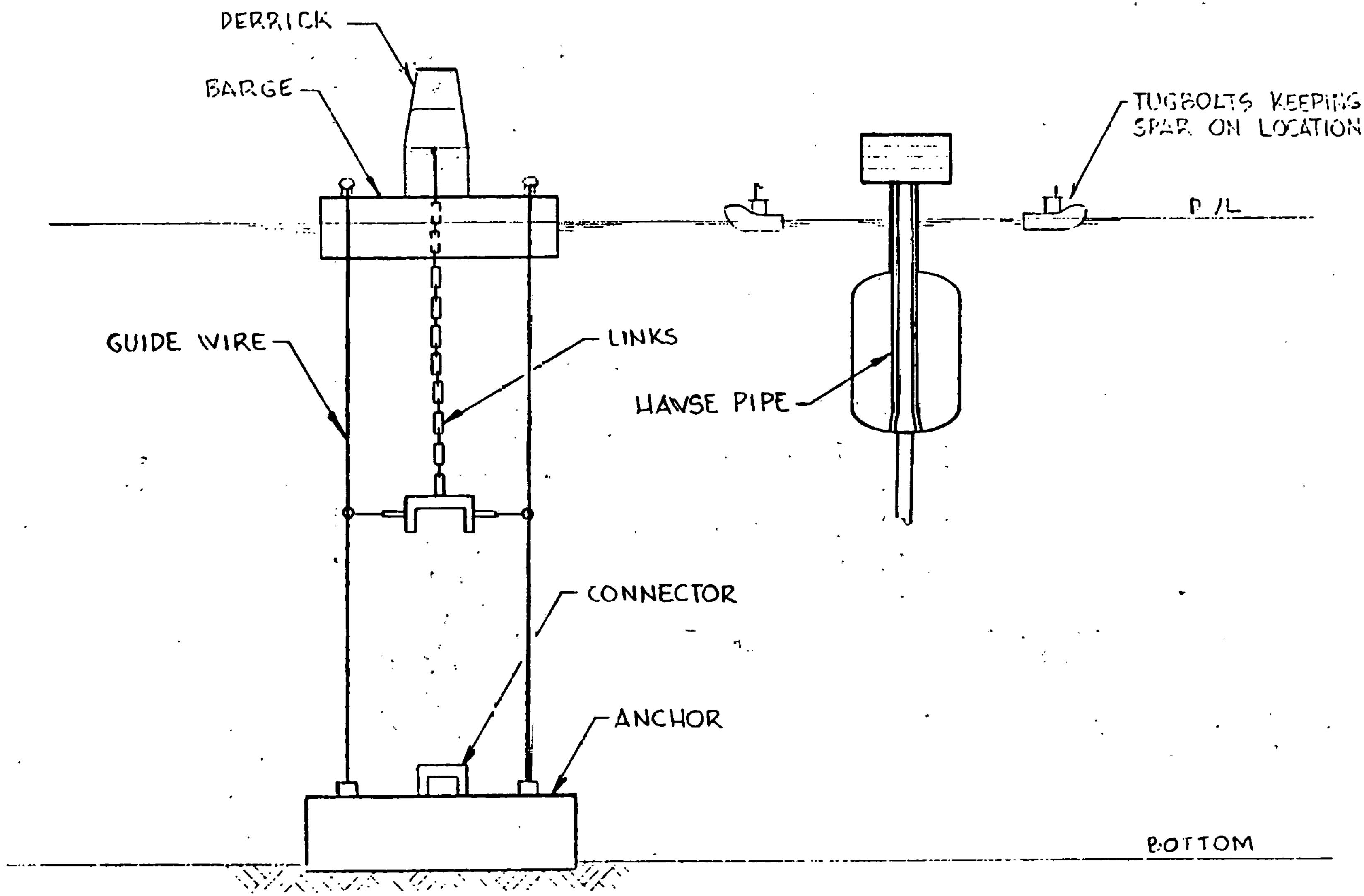
   (c) Hoisting equipment for hoisting link line from OTEC to barge.

2. Three (3) 3000 HP tug-boats for keeping barge on location.

3. Five 4000 to 5000 HP tug boats for SPAR, and seven for BARGE, (of the 4,000-5,000 hp variety) for maintaining OTEC platform on location.

4. A set of divers, say 3 with wetsuit equipment for connecting lightweight line from end of link line at OTEC to surface, so that the two lines, i.e., at the barge and the OTEC platform can be pulled together & connected.

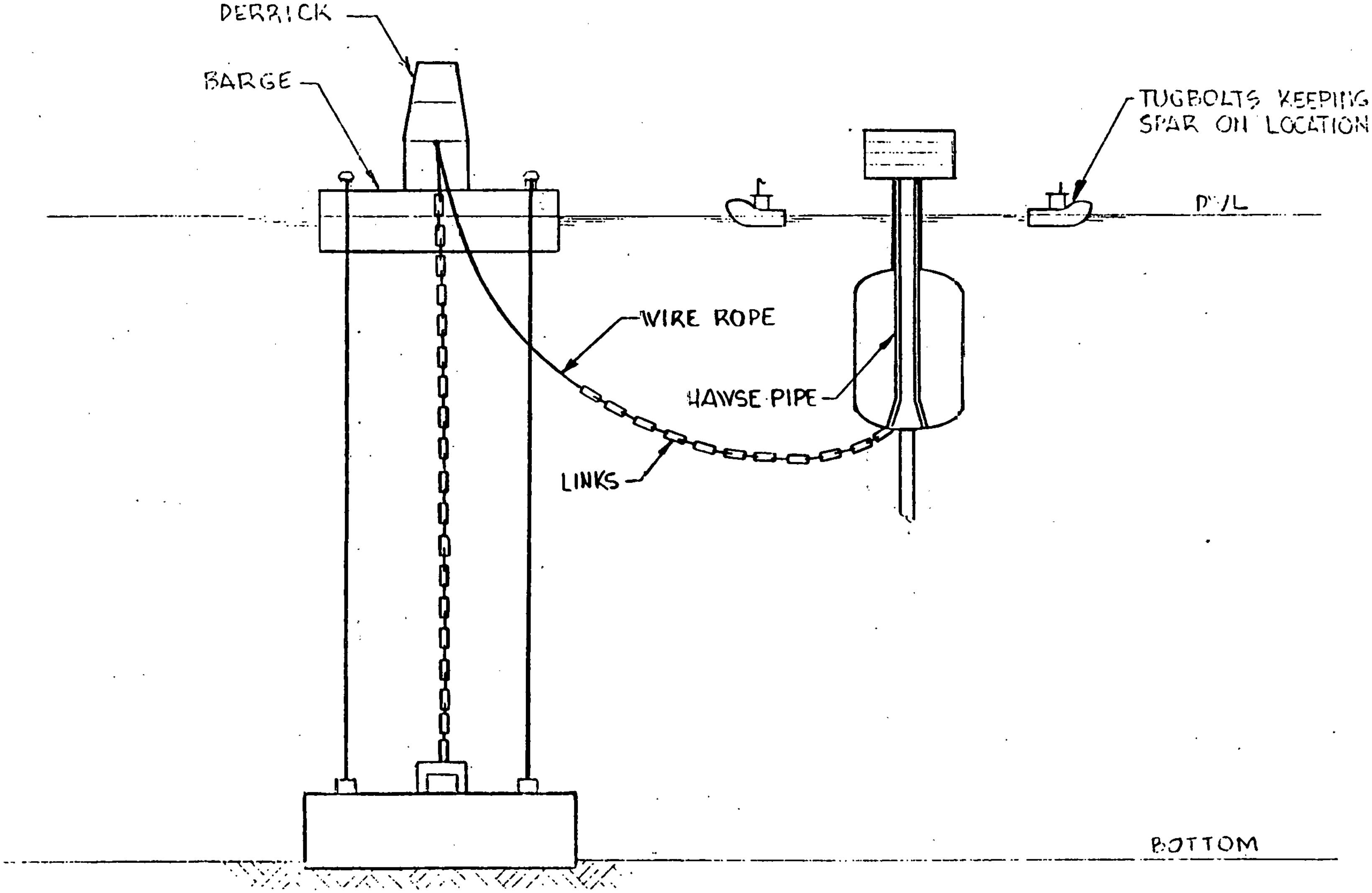
5. Barge with links accompanied by tugs.



INSTALLATION OF 1 MOORING LEG

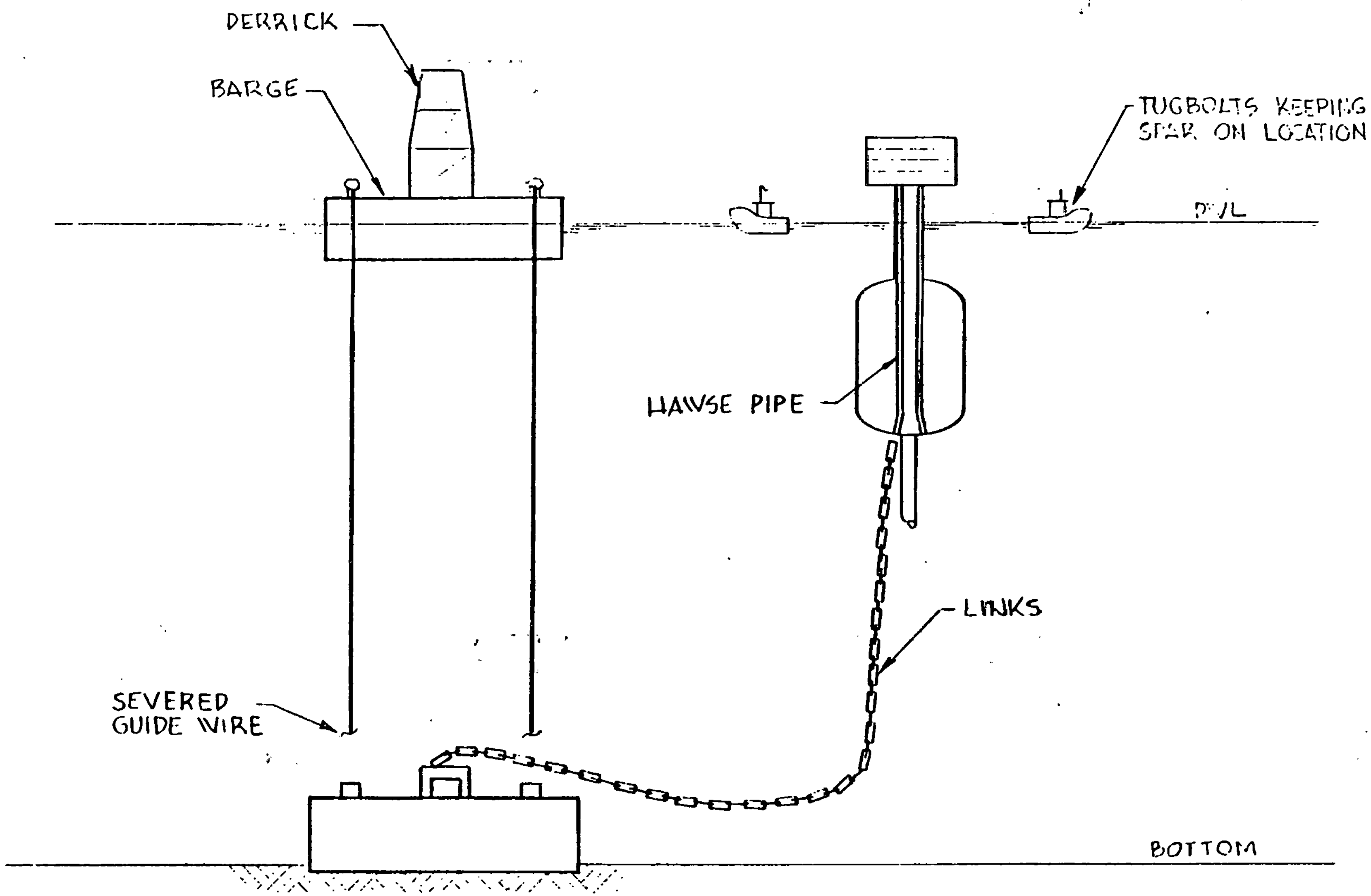
FIGURE 35

M. ROSENBLATT & SON, INC.



CONNECTION TO SPAR

FIGURE 36



INSTALLATION OF 1 LEG COMPLETE

FIGURE 37

M. ROSENBLATT & SON, Inc.

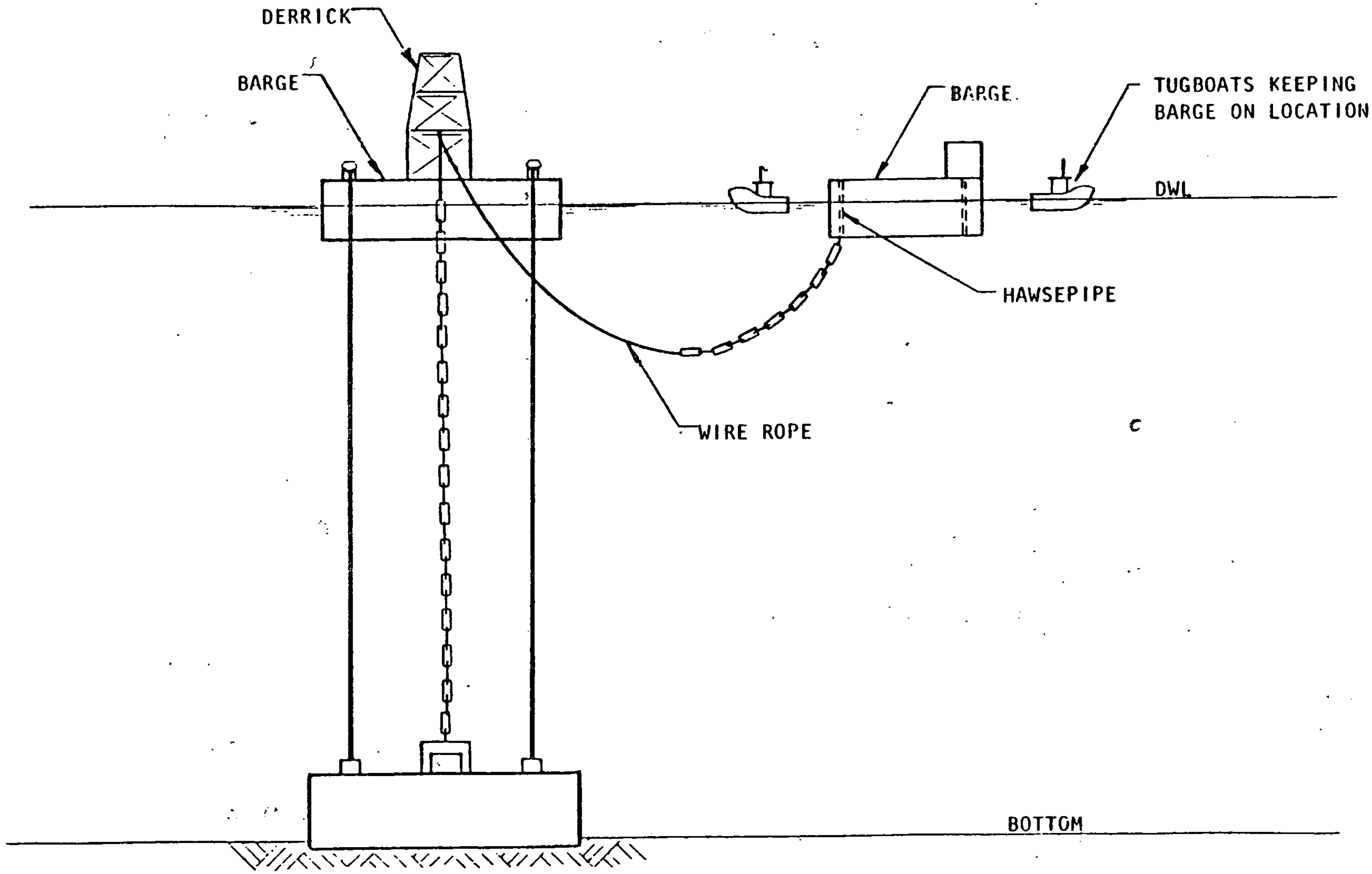
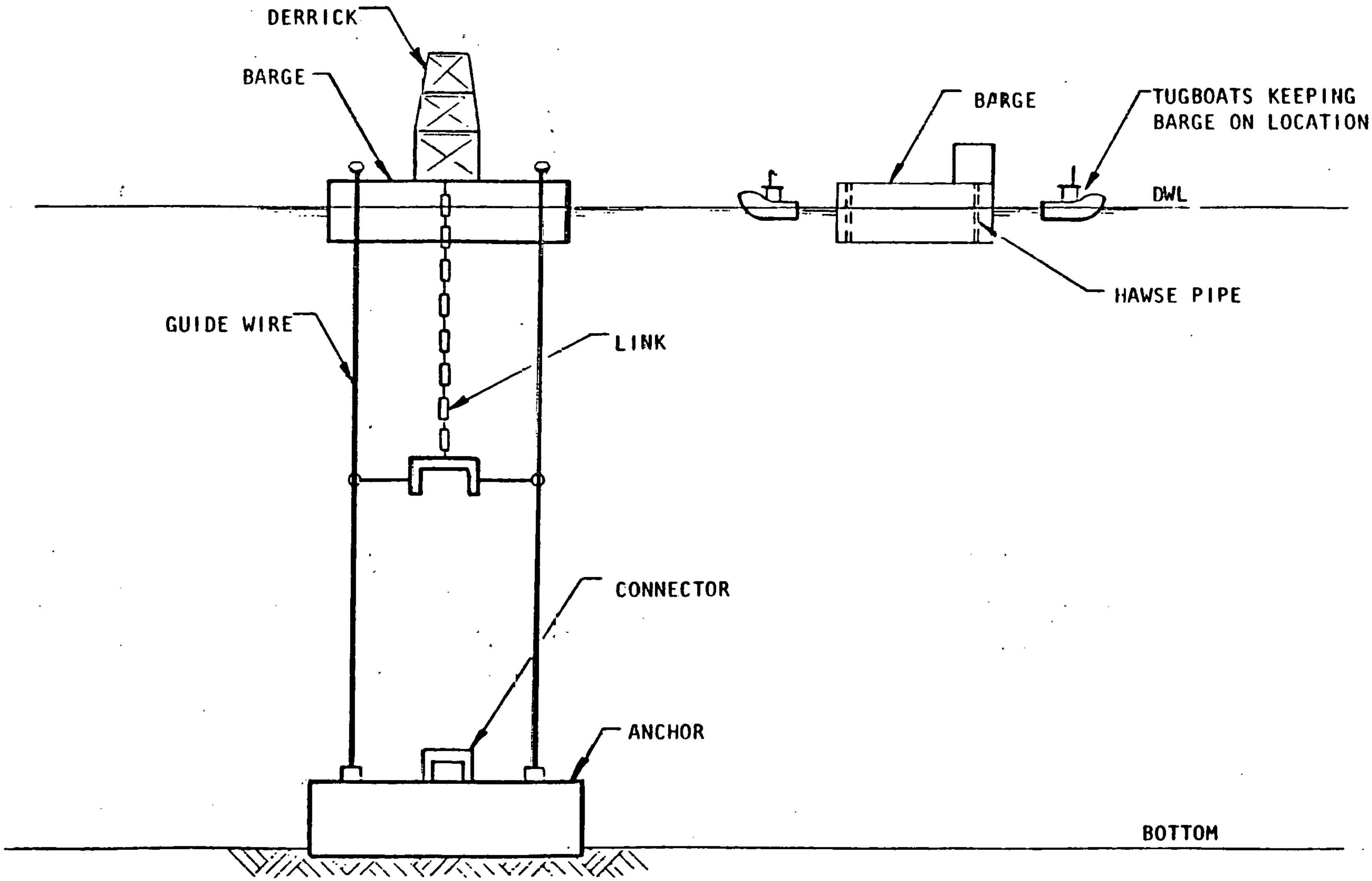


FIGURE 38

CONNECTION TO BARGE



INSTALLATION OF 1 MOORING LEG

FIGURE 39

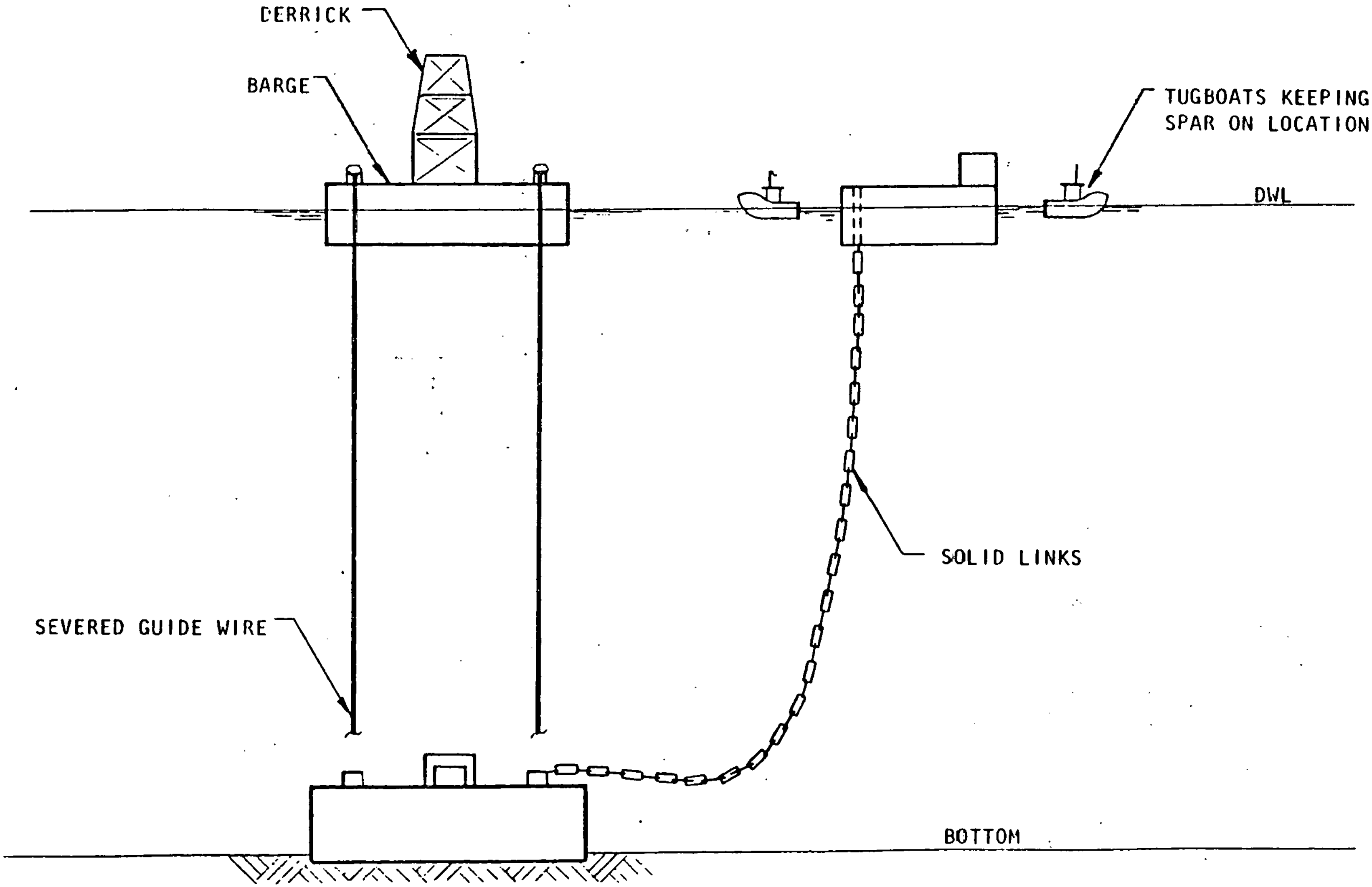


FIGURE 40

INSTALLATION OF ONE LEG COMPLETE

7.3.3 Deployment Scenarios for Tension Leg Mooring Concepts

a. SLANT LEG MOORING SYSTEM

DEPLOYMENT PLAN

STEP 1.

TOW FIRST GRAVITY ANCHOR TO LOCATION. ANCHOR IS 15' DEEP BY 94' DIAMETER AND WEIGHTS 1050 KIPS WHEN SUBMERGED AND FLOODED. VOLUME IS 10500 CU. FT. IT IS TOWED IN BUOYANT CONDITION USING 2000 HP TUG.

STEP 2.

AT SITE, THREE 165 FT. WORK BOATS WORK TOGETHER TO DEPLOY ANCHOR. WORK BOATS ARE EQUIPPED WITH SPECIAL WINCHES WHICH ACCOMMODATE 5000 FT. OF 3" IWRC WIRE ROPE. ONE BOAT IS EQUIPPED WITH POSITIONING EQUIPMENT AND INSTRUMENTATION INCLUDING DEPTH SENSOR, OUT OF LEVEL SENSOR, POSITION INDICATOR AND TV SYSTEM. SENSORS ON THE ANCHOR RELAY SIGNALS VIA AN UMBILICAL WHICH IS STORED ON THE INSTRUMENT LINE WINCH.

ALL WORK LINES ARE SECURED TO THE ANCHOR AND THE ANCHOR IS FLOODED VIA THE REMOTELY OPERATED FLOOD VALVES.

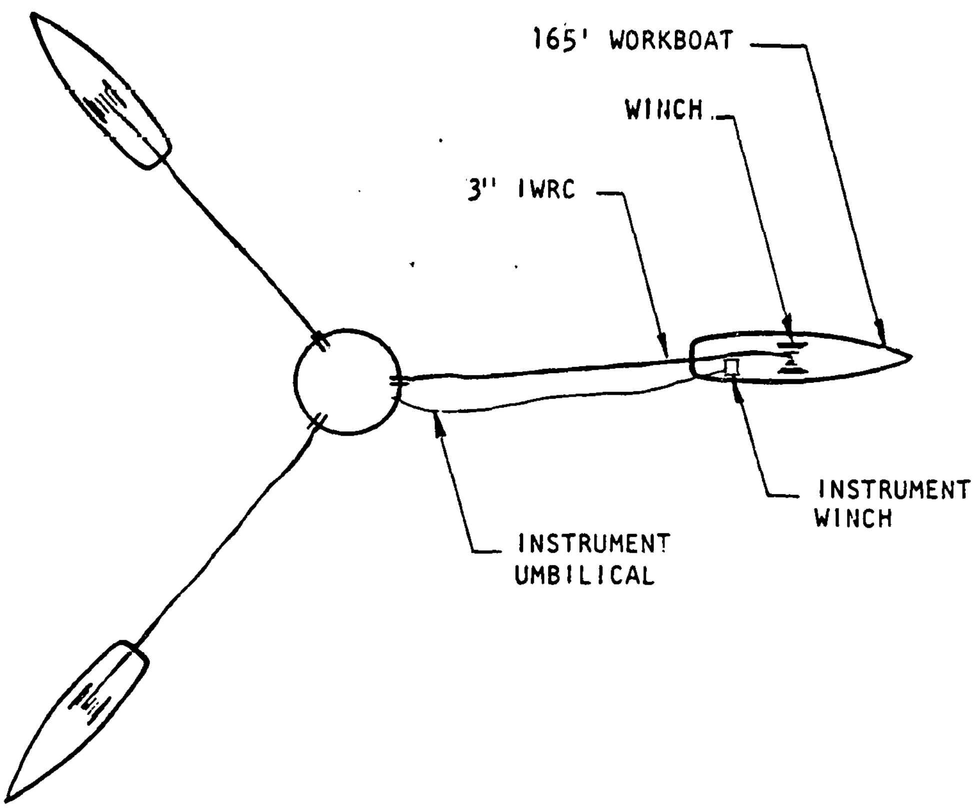


FIGURE: 41

STEP 3.

WORK BOATS LOWER ANCHOR TO SEA FLOOR. POSITIONING EQUIPT ABOARD THE LEAD BOAT (LORAN OR WHATEVER) ALLOWS ACCURATE POSITIONING. ACOUSTIC POSITIONING SYSTEM ON THE ANCHOR INDICATES ANCHOR POSITION RELATIVE TO THE LEAD BOAT. ANCHOR IS POSITIONED TO SET ON BOTTOM. WORK BOATS STAY WIDELY SPACED DURING LOWERING TO PREVENT ANCHOR FROM ROTATING & WINDING UP PENDANTS. ONCE ON BOTTOM PENDANT LINES ARE DISCONNECTED AT THE ANCHOR BY REMOTE DISCONNECTS ACTUATED BY UMBILICAL. PENDANTS ARE DISCONNECTED ONE AT A TIME & RECOVERED TO THE WORK BOATS.

STEP 4.

GRAVITY ANCHORS 2 & 3 ARE DEPLOYED AS IN STEPS 1, 2, & 3.

STEP 5.

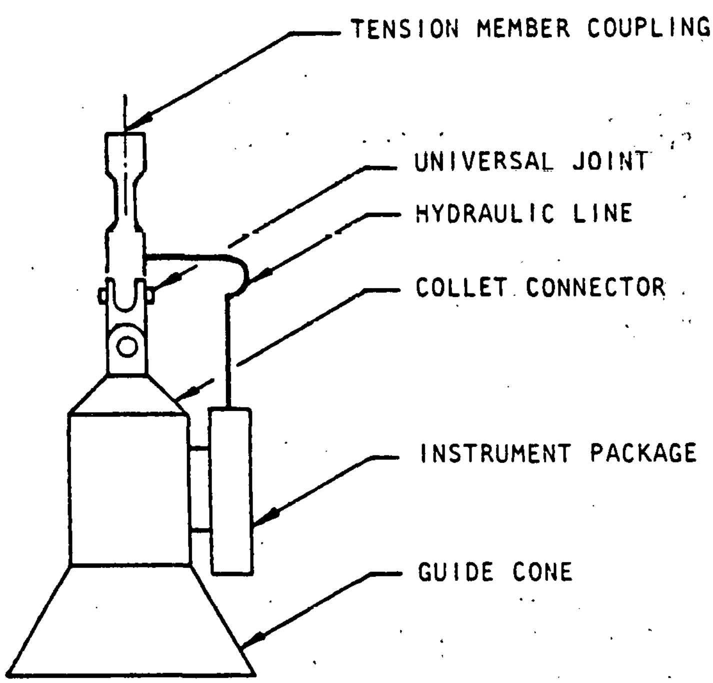
SPAR IS TOWED TO SITE USING 3 15000 HP TUGS. SPAR ARRIVES CARRYING AN EQUIPMENT NECESSARY FOR RUNNING MOORING LEGS INCLUDING ACOUSTIC POSITIONING EQUIPMENT, SUBSEA TV, AND SIDE SCAN SONAR.

13650 FT OF TENSION LEG MEMBERS ARE TRANSPORTED TO THE SITE ON A WORK BARGE & ARE TRANSFERRED TO THE SPAN USING PEDESTAL CRANE ON THE CRANE BARGE.

STEP 6.

THE NUMBER 1 ANCHOR CONNECTOR ASSEMBLY IS PICKED UP & POSITIONED OVER THE NUMBER 1 MOORING PIPE. THE ANCHOR CONNECTOR IS A HYDRAULICALLY ACTUATED COLLET CONNECTOR SIMILAR TO A WELLHEAD CONNECTOR. IT IS RATED AT 13,200,000 LBS CAPACITY. SEE FIGURE 42.

ALSO INCLUDES A DOUBLE PIN UNIVERSAL JOINT, HYDRAULIC CONTROL MANIFOLD, AND INSTRUMENTATION INCLUDING TV, LIGHTS, SONAR, ACOUSTICS, ETC. HYDRAULIC POWER IS PROVIDED THROUGH THE TENSION LEG MEMBERS. HYDRAULIC CONTROL IS VIA PRESSURE PULSE SEQUENCING.



ANCHOR CONNECTOR ASS'M

STEP 7.

NUMBER 1 ANCHOR CONNECTOR ASSEMBLY IS RUN TO THE BOTTOM MAKING UP JOINTS OF TENSION LEG MEMBER. THE SPAR IS POSITIONED OVER ANCHOR NUMBER ONE BY TWO 25000 HP TUGS. AT THE PROPER HEIGHT ABOVE THE BOTTOM, THE UNIVERSAL AND GUIDE LINK AND SPACE OUT JOINTS ARE MADE UP IN THE TENSION MEMBER STRING.

FIGURE: 42

STEP 8.

THE NUMBER I ANCHOR CONNECTOR IS GUIDED ONTO THE LATCH PREP ON ANCHOR NO. I. HYDRAULIC PRESSURE IS APPLIED TO THE TOP OF THE TENSION MEMBER STRING TO ACTUATE THE ANCHOR CONNECTOR COLLET.

STEP 9.

THE CONNECTION IS INSPECTED VIA TV AND TESTED BY PULLING 80% OF THE WET WEIGHT OF THE ANCHOR.

STEP I0.

ADDITIONAL TENSION MEMBERS ARE ADDED TO THE STRING AS THE SPAR IS PULLED TOWARD ANCHOR NO. 2 POSITION BY 2 I5000 HP TUGS.

STEP II.

STEPS 6 THROUGH I0 ARE REPEATED FOR ANCHORS 2 AND 3.

STEP I2.

THE SPAR IS PULLED TO THE CENTER OF THE MOORING PATTERN BY REMOVING EXTRA TENSION MEMBERS AND TENSIONING ALL LINES UP EQUALLY.

NOTE: WHILE THE SPAR IS MANEUVERED BETWEEN ANCHOR POSITIONS, A TENSION EQUAL TO THE WET WEIGHT OF THE STRING IS MAINTAINED. THE TOP OF THE STRING IS THEREFORE NEARLY STRAIGHT UP SO THERE IS NO BINDING IN THE MOORING PIPE OR IN THE TENSION MEMBER STRING AT THE ENTRANCE TO THE MOORING PIPE.

ALL THREE TENSION MEMBER STRINGS ARE TENSIONED TO 60% OF THE WET WEIGHT OF THE ANCHORS.

STEP 13.

BY HYDRAULIC SEQUENCING, VALVING IS CONNECTED TO THE TENSION MEMBER STRING FROM ANCHOR BALLAST COMPARTMENTS.

STEP 14.

LARGE MULTISTAGE CENTRIFUGAL PUMPS ARE USED TO PUMP BALLAST SLURRY DOWN THE TENSION MEMBER STRINGS INTO THE ANCHOR BALLAST SPACE. THE BALLASTING OPERATION IS SUPPORTED BY A SPECIALLY OUTFITTED "CEMENTING" BARGE, SEE FIGURE 43.

STEP 15.

TENSION MEMBER STRINGS ARE PRETENSIONED, LEVELED, & SECURED.

STEP 16.

SEVEN 15000 HP TUGS ARE USED TO TEST MOORING. THE SPAR IS DISPLACED IN THE DIRECTION WHICH PUTS THE MOST LOAD ON ANCHOR NUMBER 1. A BOLLARD PULL OF 1990 IS APPLIED AND HELD FOR 5 MINUTES. ANCHORS 2 & 3 ARE SIMILARLY TESTED.

NOTE: IF SIGNIFICANT CURRENT & WIND ARE PRESENT DURING TESTING A PRESCRIBED DISPLACEMENT CORRESPONDING TO A 1990 KIP LOAD MUST BE MEASURED & APPLIED INSTEAD OF THE 1990 KIP BOLLARD PULL.

OPERATIONAL PROCEDURES

FOR

TENSION LEG MEMBERS

1. MAST & TRAVELLING ASS'M IS USED TO LOWER TENSION LEG STRING THROUGH MOORING PIPE.

2. EACH JOINT IS SET IN SLIPS IN TENSIONING YOKE WHILE THE SUBSEQUENT JOINT IS STAGGED & TORQUED UP.

3. THE TOP JOINT (UPPER MOST JOINT BELOW HULL) IS A SPACE OUT JOINT AND ALLOWS ADJUSTING STRING LENGTH FOR EXACT WATER DEPTH.

4. A UNIVERSAL JOINT DIRECTLY BELOW THE HULL PROVIDES FOR ANGULAR DEFLECTION AND DIRECTS SIDE LOAD INTO LOCALLY REINFORCED LOWER HULL.

5. THE TENSIONING YOKE IS SUPPORTED BY 4 500 TON HYDRAULIC RAMS. AFTER THE STRING IS RUN AND SECURED TO THE ANCHOR, THE SPAR IS DEBALLASTED TO OBTAIN THE REQUIRED TENSION LEG PRELOAD. THEN THE RAMS CAN BE STROKED AS REQUIRED TO LEVEL THE SPAR AND DISTRIBUTE LOAD EQUALLY AMONG THE MOORING LEGS.

6. REMOVEABLE SHIMS ARE USED TO SPACE OUT THE RAMS. WHEN THE HYDRAULIC PRESSURE BLEEDS DOWN, TENSION LEG LOAD IS REACTED BY THE TENSIONING YOKE THROUGH THE SHIMS TO THE TENSIONING FOUNDATION.

EQUIPMENT REQUIRED

1. ONE 2000 HP TUG I ANCHOR
2. THREE L65' WORK BOATS
3. SPECIAL WINCHES
4. DEPTH SENSOR, OUT OF LEVEL SENSOR
5. INRC
6. MISC. FITTINGS, ETC.
7. PEDESTAL CRANE BARGE WITH TWO SMALL TUGS
8. ACOUSTIC POSITIONING EQUIPMENT, SUBSEA TV, SIDE SCAN SONAR
9. SEVEN 15,000 HP TUGS
10. CEMENTING BARGE WITH TUGS
11. PUMPS, MIXING EQUIPMENT

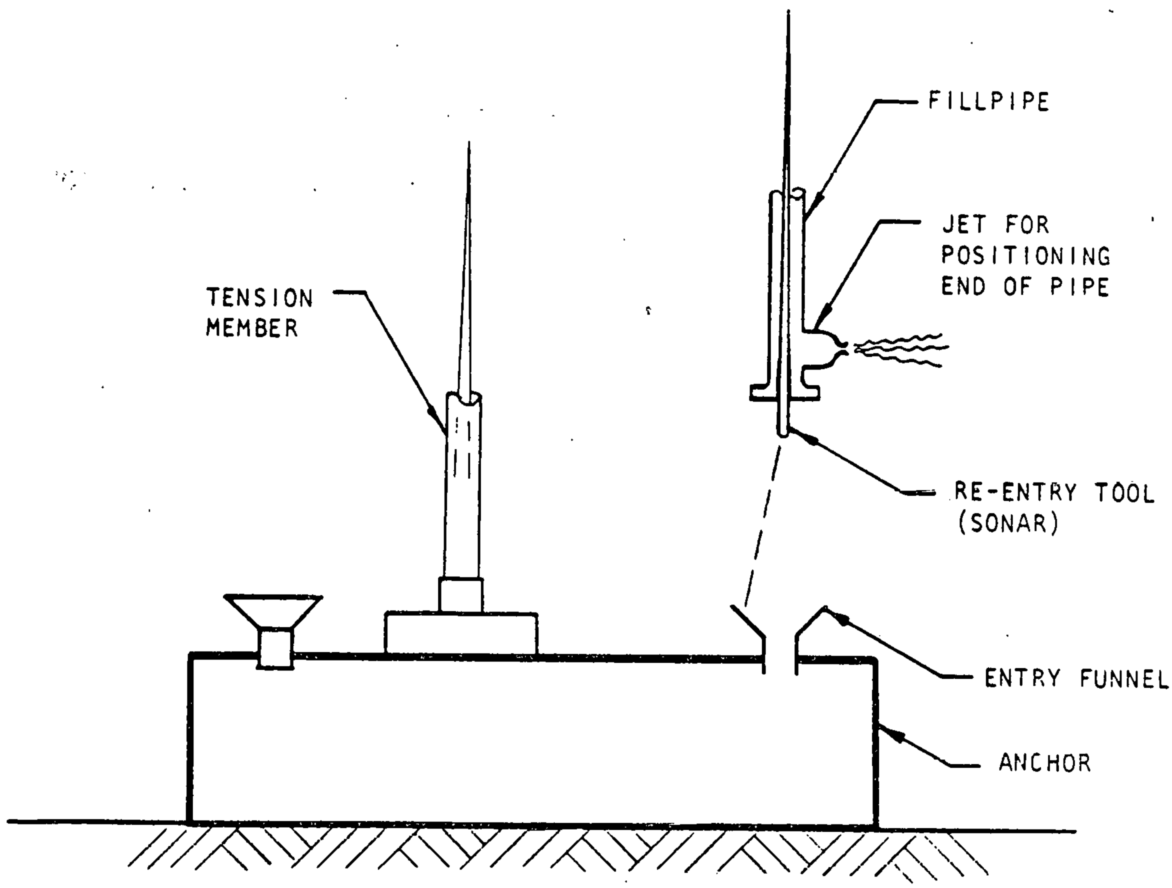

FILLPIPE
JET FOR POSITIONING END OF PIPE
TENSION MEMBER
RE-ENTRY TOOL (SONAR)
ENTRY FUNNEL
ANCHOR

FIGURE: 43

b. SLM Rotary Mooring with Buoy

See 7.3.2 (b) for steps #1 thru 4.

STEP 5.

A large crane barge arrives at the site with the 3 links of the buoy legs on board.

STEP 6.

The Buoy simultaneously arrives at the site with the running and retrieving system on a deck inside the buoy. The top deck of the buoy is open for the most part. The small buoys attached to the anchor guidelines are pulled aboard and secured. See Figure 44.

STEP 7.

The links are continuously placed aboard the buoy; connected and lowered until they reach the anchor connection, see Figure 44.

Steps 1-8 are repeated for legs number 2 and 3.

STEP 9.

The barge arrives on site with a hatch on deck to be placed and secured to the top of the buoy. This hatch incorporates the universal joint connection which is to be connected to the support arm from the barge to the buoy, see Figure 45.

STEP 10.

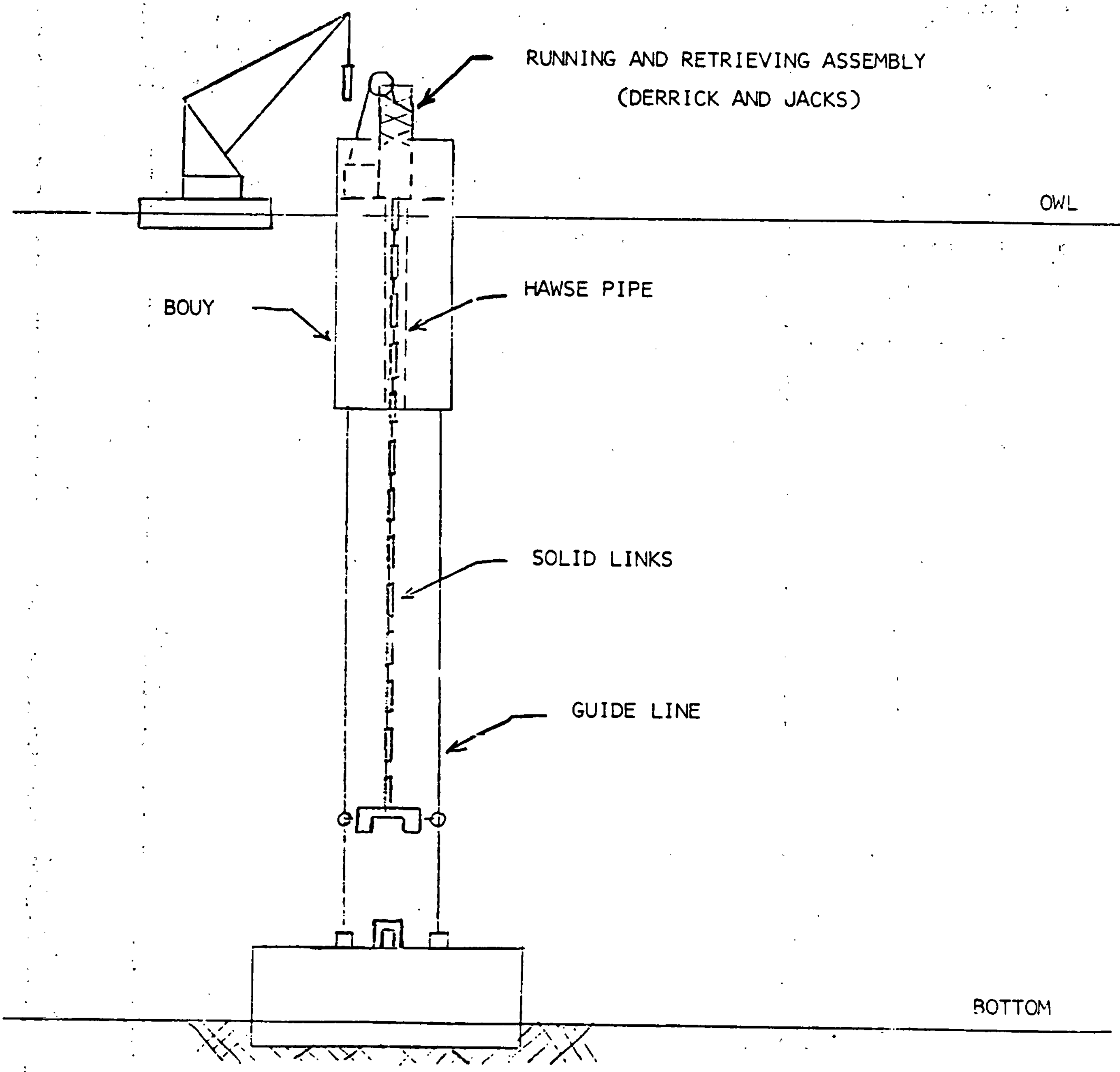
The support arm is already connected to the barge and is held in a vertical position while the barge is towed to site. After the hatch is placed on the buoy, the support arm is allowed to pivot down to the horizontal position and connected to the buoy universal joint, see Figure 45.

The crane barge will assist in the installation of the buoy hatch and support arm.

The mooring system is now completely deployed.

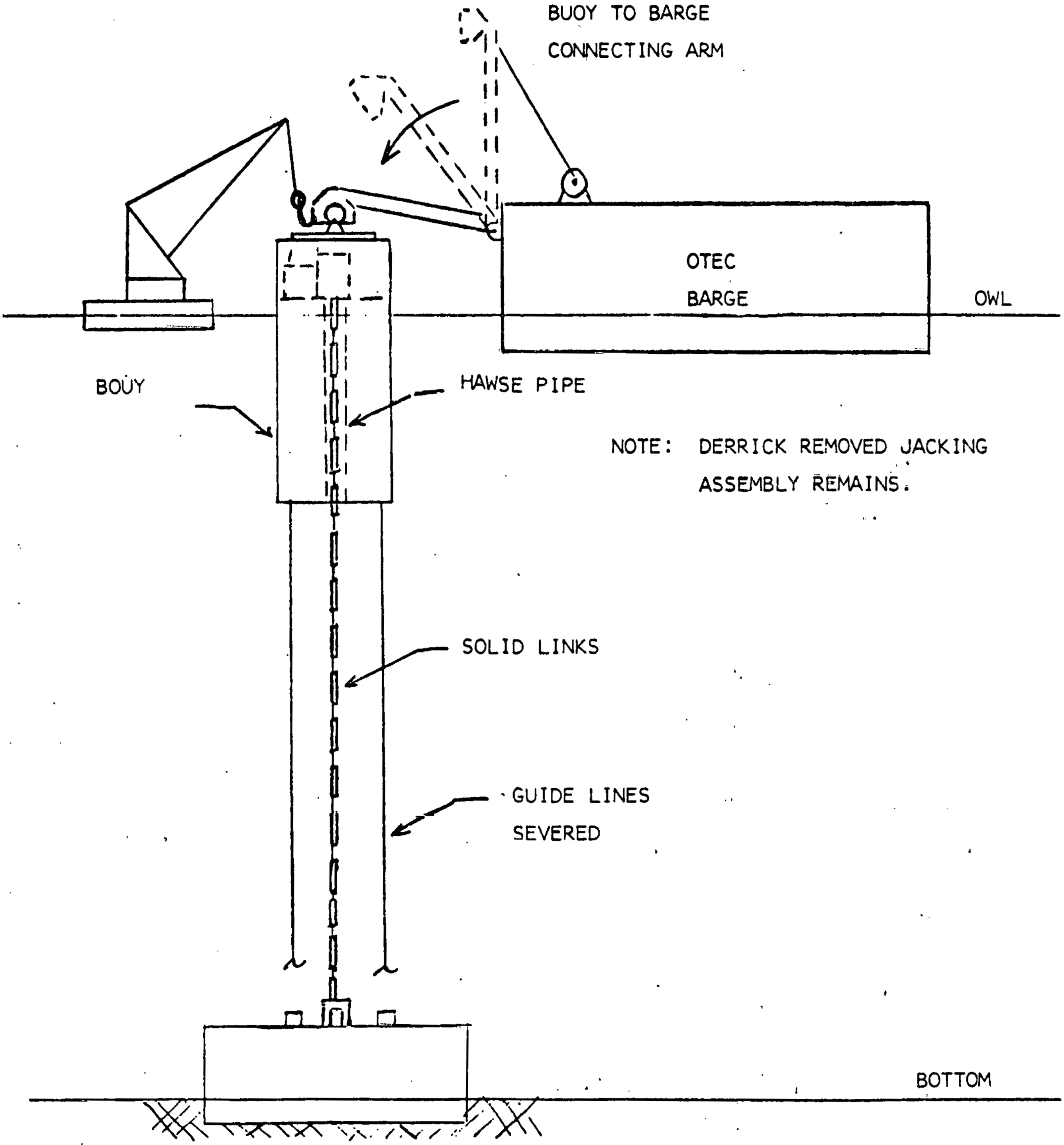
Equipment Required

1. 180' x 65' Dia. Buoy with running and retrieving system intact.
2. Large crane barge with Tugs with the links on board.
3. Three 5000 hp Tugs to keep buoy in position.
4. Seven 5000 hp Tugs to keep barge in position
5. Barge to Buoy support arm.
6. Hatch for the Buoy.
7. Wire rope guideline terminating equipment installed on the deck of the buoy.



NOTE; THERE ARE ACTUALLY 3 SETS OF CONNECTIONS, LINKS, GUIDE WIRES 7 HAWSE PIPES.

FIGURE : 44



NOTE: THERE ARE ACTUALLY 3 SETS OF CONNECTIONS, LINKS, GUIDE WIRES & HAWSEPIPES.

FIGURE : 45

7.4 Maintenance, Repair, and Replacement Scenarios

The general maintenance/repair, and major replacement scenarios for the 7 individual mooring configurations are presented in this section.

It is assumed that the anchors for all mooring concepts will not need maintenance nor will they be subject to structural failure. More than one anchor line connections will be provided on each DWT type anchor to permit their replacement during original installation or when a new line must be installed due to failure of the existing line.

All mooring systems except the 8 leg wire-chain (Spar) concept will be designed for a 10 year life with allowance for the replacement, due to failure, of one leg in 10 years. Therefore, the only routine maintenance and replacement would be performed on the wire component of the wire-chain (Spar) system. This is due to the difficult and costly process of removing for inspection the legs of any of the other systems. It should be noted that the slant and vertical tension leg concepts would be more practical than the catenary systems with regard to removal for inspection; the platforms can be held in place in calm conditions with tugs while the legs are released, raised, inspected and lowered directly back down on the anchor. All of these operations can be done by the platform itself instead of using support equipment as would be the case for other systems. Accordingly, the maintenance and replacement sceanrio that follows describes the general maintenance and routine replacement of the wire and the replacement due to failure of the chain for the 8 leg wire-chain system (Spar);

for the remaining systems, replacement of the legs due to failure only is considered.

For the wire rope-chain mooring system there is previous experience as far as its life is concerned, and that is approximately five years. However, this experience derives from the offshore oil industry where mooring systems are deployed and picked up every 2-3 months; hence, there is an opportunity to lubricate the wire rope and at least visually inspect the chain.

In the case of the OTEC SKSS this opportunity will not exist. Therefore, if we assume that the wire rope-chain system will be replaced after five years of operation, a periodic maintenance program should be set up at shorter intervals. Particular attention should be paid to the splash zone area.

Therefore, approximately once in six months a visual examination should be made of the wire rope in the drum and the splash zone. This can be achieved by slacking lines off on one side and tensioning them up on the other side, thus effectively changing the position of the vessel slightly. Then the splash zone section of the rope can be examined and lubricated. If it is necessary, divers can be used around the vessel for examination of the underwater fairleaders.

If there is great concern about a particular mooring line, then at the half-point interval, that is two and half years after installation, a crane barge could be brought in during an expected weather window. The pendant line buoy is then used to pick up the pendant line and the mooring line. This assumes that all mooring lines have been first completely slacked off. Then the entire wire rope section can be completely examined and/or lubricated.

Also a part of the chain can be examined or ultrasonically tested. The anchor will not be picked up unless severer than expected deterioration of the chain has occurred.

Regarding the replacement of the wire rope after 5 years, Figures 46 and 47 demonstrate how relatively simple it may be to do this. A work boat containing the new wire rope line with a tracing loop on the end deploys the new line by moo ing away from the platform in line with the old mooring line until the tracing loop passes over the latching barb. Then the work boat proceeds in the opposite direction which completes the latching procedure. The new line is connected to the Spar and the replacement is complete.

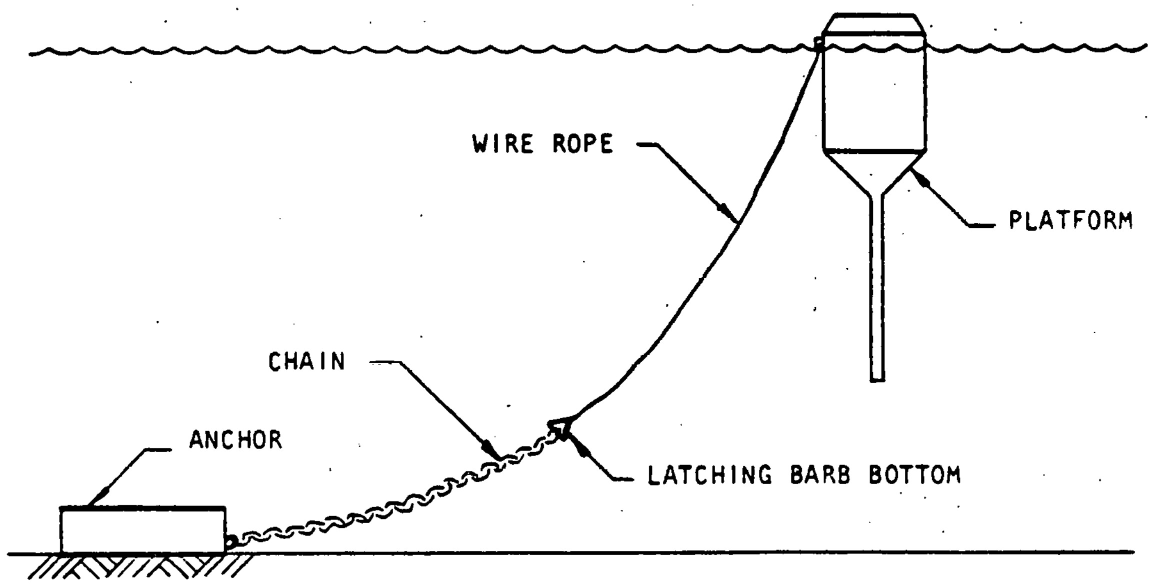


FIGURE: 46

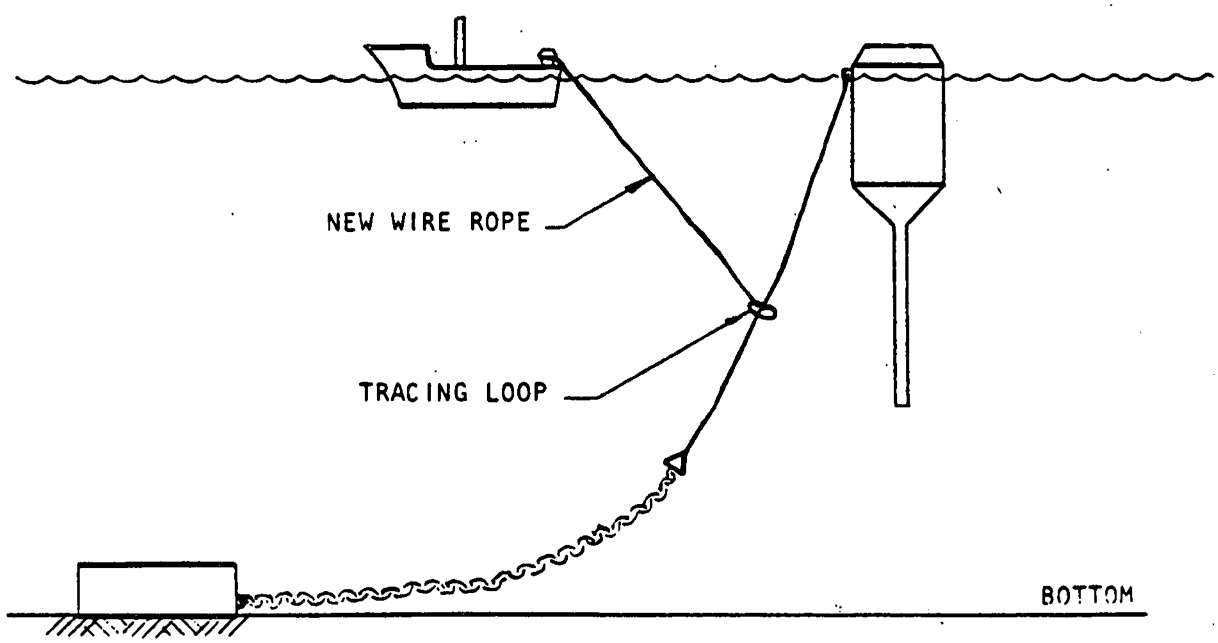


FIGURE: 47

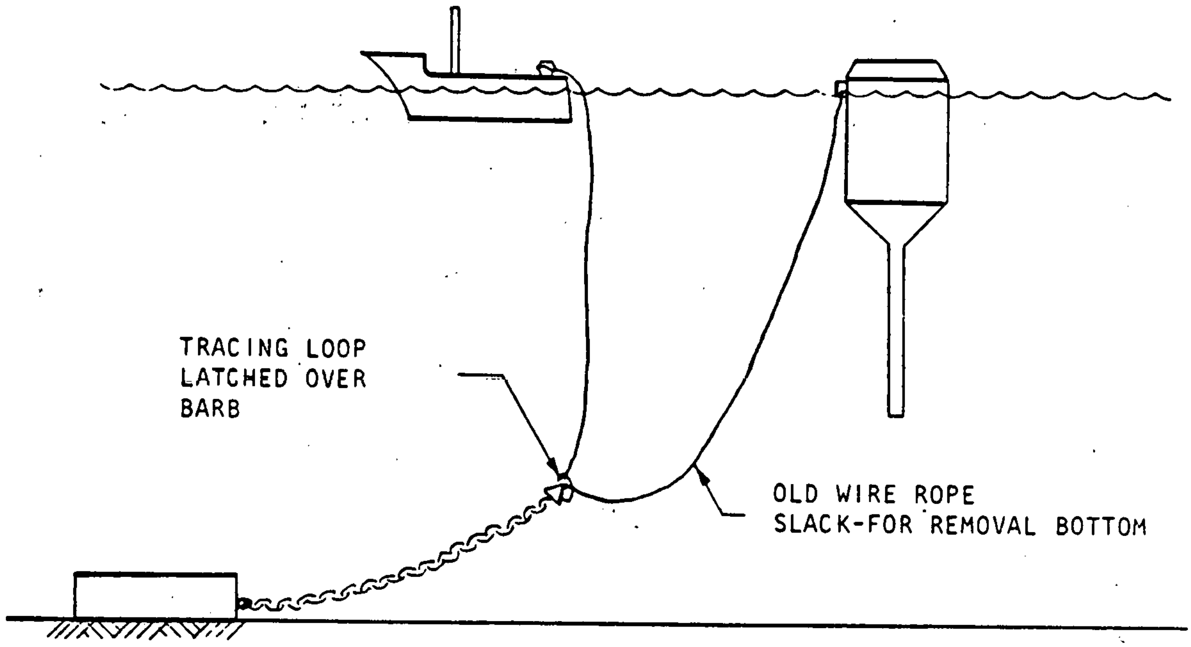

TRACING LOOP
LATCHED OVER
BARB
OLD WIRE ROPE
SLACK-FOR REMOVAL BOTTOM

FIGURE: 48

7.5 Time Schedules

The dominant factors in the development of time schedules for the realizations, from preliminary design initiation to physical deployment at site, of the SKSS concepts will be the following:

-Research and development time required for components beyond current state-of-the-art (if any).

-Fabrication and testing of prototypes, if required, for any components.

-Manufacturing time for components which are not off-the-shelf items.

-Deployment

  -Maximum environmental states during which phases of deployment operations can be performed.

  -Expected weather windows at the designated site for these environmental states.

-Probability of completing deployment operations within expected weather windows.

Above factors are considered for major components of the feasible SKSS concepts in a qualitative manner for this conceptual study. More detailed quantitative analysis will be necessary for the preliminary design studies.

The basis used in the development of time schedules was the most recent "OTEC Ocean Engineering Program" as established by the Department of Energy.*

According to this program:

-SKSS preliminary designs would be completed in Fiscal year 1980.

*Department of Energy OTEC objectives and Status Conference. Volume 3: Long Range Research and Summary, pages 55-4 and 55-5, Jan. 23-25, 1979.

-A Contract would be awarded for the development of an SKSS "Analytical Model".

-The deployment of the 10/40 MW Modular Experiment OTEC platforms would take place in the third quarter of 1984.

Following assumptions are made in the development of time schedules:

-A "Systems Integration" type of contract will be awarded for the Modular Experiment Platform development covering all ocean systems including the SKSS for the detail design, contruction/installation, deployment, and operation stages.

-Six months after the completion of SKSS Analytical Model, a contract design will be ready.

-The Systems Integration Contractor will start detail design and construction efforts immediately after the contract design work is complete for individual components.

In order to identify and present the case for SKSS as it ties to the complete platform system development, time schedules are considered separately for major SKSS components that may affect the schedule. These major items are:

-Wire Rope and Chain WC of required sizes

-Solid Link type mooring legs (SL)

-Hollow Cylindrical Links (HCL)

The deadweight or drag type anchors, mooring winches, anchor and line connectors, and the control systems are considered to require minimal development and therefore assumed to have no appreciable influence on time schedules.

The time schedule presented in Figure 49 is accordingly based on the development of mooring legs only. The date needed is estimating the time required to fabricate and deploy these mooring legs were obtained from existing or probable manufacturers of these items.

Following considerations apply:

-Wire rope and chain type mooring legs are state-of-the-art; a nominal design period is nevertheless allowed for the development of complete systems and accurate deterioration of line loads using the analytical model. The design time for this mooring line development also includes allowance for the design of mooring winches required.

-The development of hollow cylindrical links will require the longest design and manufacturing time.

-Solid links will fall somewhere between the HCL and WC alternatives as far as development times are concerned.

-Tension bars or rools are presently being used in a few offshore oil drilling rig applications. Their development time requirements will be approximately equal to the solid link concept.

-The construction periods estimated for the HCL and solid link type mooring legs, as shown in Figure 49, are very flexible. Actual construction times may vary considerably depending on the degree of automation the prospective manufacturers may employ.

-A two month deployment period is estimated to be necessary on the basis of practical considerations derived from offshore industry experience from comparable operations.

-The present offshore industry practice in deployment operations is to have all deployment equipment and vehicles in a "ready-to-commence" status, and to await calm sea conditions. Reportedly, for the Puerto Rico area, the months of May and June appear to provide a suitable weather window.

In the preliminary design studies, the possibility of defining a maximum environmental state suitable for deployment operations without interruption will be investigated. The probability of such an environmental state prevailing for the duration of deployment operations can then be predicted using the historical data available in the SSMO[] publications for the region.

In general, it can be said that all candidate mooring leg systems can be developed to become ready for use by the OTEC platform, and therefore the SKSS, deployment date of 1984.

MODULAR SKSS DESIGN, CONSTRUCTION, AND DEPLOYMENT TIME SCHEDULE

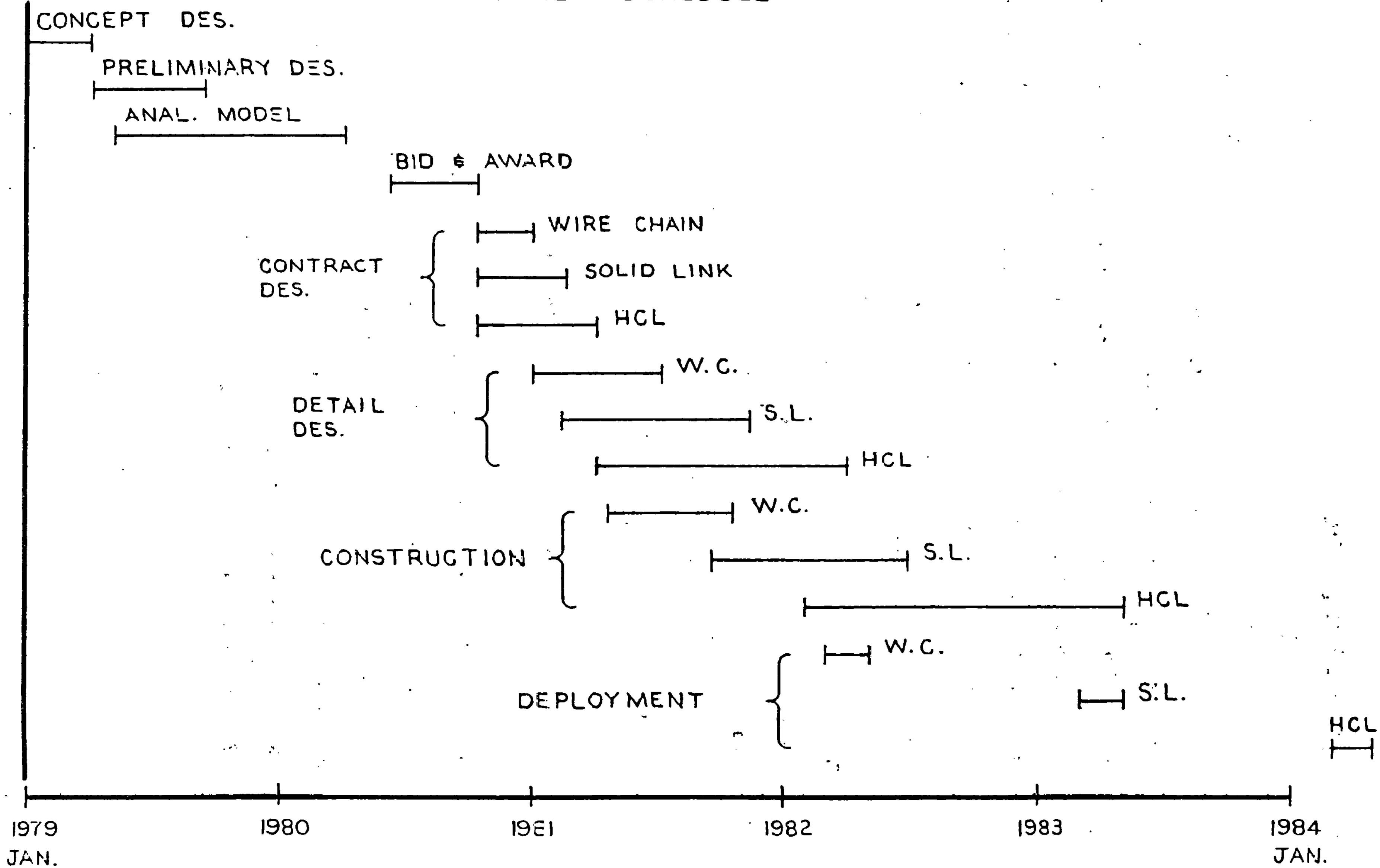


FIGURE: 49

7.6 Interface Considerations

7.6.1 Platform Hull

a. SPAR Platform

All of the SKSS concepts call for leading the lines from the bottom of the SPAR hull. The wire rope-chain catenary system mooring legs could be led either up through the access trunk of the SPAR through hawsepipes or else along the outside of the SPAR and led through additional fair-leads at the top of the hull to terminate at winches in the deckhouse. It would probably be most convenient to locate the winches on the upper deck of the superstructure but a lower deck could be used if necessary.

The other SKSS concept involving solid bar links, HCL links or tension rod pose greater interface difficulties since they must be led vertically upwards from the take-off point at the bottom of the platform. Presently this is accomplished by running the legs through hawsepipes of about 2 feet diameter through the main hull. An alternative arrangement would be to run up the outside of the hull although this would present some structural difficulties for the bottom of the main hull and the superstructure.

b. Barge Platform

The barge platform posed few interface problems because space is already allocated for thrusters (only two are required) and legs for the catenary system may be led vertically through hawsepipe to jack-up tensioning devices on the main deck. The single leg mooring system provides the least interference with the barge hull since virtually all of the mooring equipment is contained on a separate buoy.

7.6.2 Cold Water Pipe

a. SPAR Platform

There is no intererence with the cold water pipe from the catenary moorings or the tension leg mooring. Later calculations may show that the tension leg mooring indirectly assist the cold water pipe by greatly reducing the heave response of the platform. The vertical tension mooring definitely impacts the cold water pipe design as the lower end of the pipe is braced by a rigid support to each mooring leg. This effectively keeps the CWP parallel to the upper portion of the mooring legs. The reaction force of the mooring leg on the CWP at the bottom is approximately 400 kips from deadweight and current forces.

b. Barge Platform

The catenary SKSS concepts do not impact the cold water pipe or discharge pipes directly but previous studies indicate that bending stresses for the CWP hull connection for the barge in beam seas is excessive. The rotary mooring permits the barge to head into the wind and waves so this problem is avoided; however there was concern that a storm which is rapidly shifting its direction could cause the barge to over run the mooring cable. Calculations show that this could not occur even in environmental state 6 with a significant wave height of 15 feet and wind speed of 27 knots.

7.6.3 Riser Cable

a. SPAR Platform

None of the feasible SKSS concepts for the SPAR adversely affect the riser cable system. From the standpoint of this subsystem interface the vertical tension mooring system would be preferred since the platform motions would be minimized and the excursion limit is not.

b. Barge Platform

As previously discussed the excursion radius for the two four leg catenary systems exceeds the allowable limit of 10% but this can be readily corrected by pretension adjustment. The single leg mooring presents a special problem of power transmission over a pivot point connection. If this problem can be resolved at a reasonable cost then other interface characteristics would appear quite favorable.

7.7 Results of Overall Evaluation

7.7.1 SPAR Platform

Table 27 summarizes the trade-off considerations for the overall evaluation of the SPAR SKSS candidates. The two best candidates are considered to be:

1) The eight leg catenary mooring concept comprised of wire rope and chain with drag anchors

2) The 3 leg vertical tension mooring concept using tension rod and deadweight anchors.

The eight leg catenary system is attractive because it involves the use of state-of-the-art components which significantly increase its reliability compared to other systems. It also has the lowest cost.

It is anticipated that the design factors of safety used in the conceptual designs will yield more reliable SKSS in the preliminary designs.

The deployment and maintenance sequence and operations for this concept have been actually performed in the past so that new and untest techniques are not employed.

The vertical tension leg mooring concept displays excellent excursion characteristics and is the next lowest cost candidate.

It must be noted however that there may be a potential resonance problem with this mooring concept. If any additional provisions to offset the resonance problem and to increase the system reliability should result in higher SKSS costs, the trade-off may have to be repeated and its competitiveness compared to other concepts established.

For all concepts, the impact of the reaction force on the cold water pipe structure was also considered in the evaluation.

The proposed tension rod system has not been previously deployed. It is, however, similar enough in concept to the present offshore drilling practice that it can therefore still be considered state-of-the-art in terms of required technological development.

7.7.2 BARGE Platform

Table 28 summarizes the trade-off considerations for the overall evaluation of BARGE SKSS candidates.

The best SKSS candidate appears to be the single leg mooring concept which has excellent excursion characteristics and the lowest cost relative to other candidates. The most important trade-off consideration is the advantage gained by the weathervaning action of the platform which eases the cold water pipe design problem. As a disadvantage of this concept, one can cite the increased difficulties imposed on the riser cable design.

The four leg solid bar link concept is the next lowest cost candidate which has higher reliability than the four leg HCL design. The excursion level of the present design is somewhat excessive but this can be corrected by a modest increase in pretension. This design will intensify the cold water pipe design problems since the platform must now operate in beam seas also.

The riser cable design problem, however, will be simplified as compared with the single leg mooring concept.

TABLE 27 SPAR PLATFORM OVERAL EVALUATION OF SKSS CANDIDATES

SKSS Candidate Description	Watch Circle Radius	Reliability	Cost $M	Deployment	Maintenance Repair Replacement	Time Schedules	Interface
Catenary 4 Legs Solid Bar Links	Good Exceeds 10% limit in survival condition	Good Solid bar links have not been previously used Pin joints critical	49	Fair *Requires much chartered equipment, timely	Fair *Reqires much chartered equipment, timely	Good	Good
Catenary 8 Legs 5" wire rope & 4" Chain	Good but requires use of clump wgt. & riser buoy Exceeds 10% limit in survival condition	Excellent Extensive Field Experience & state-of-art components I Leg failure OK	23	Good Procedure has been used before, fast	Good - Fast However wire must be replaced every 5 years	Excellent Off the Shelf Hardware	Excellent Winches take up little space Legs can be run up access trunk
Catenary 4 Legs HCL & Chain	Good but requires use of clump wgt. & riser buoy Exceeds 10% limit in survival condition	Fair Possibility of failure due to cylinder collapse, leakage - Fin joint failure - Quality control is stringent	55	Fair *	Fair *	Fair HCL use causes the most extensive design & construction. 1984 date possible	Good
Slant Leg tension 3 Legs Tension Rod	Excellent Stays within 10% limit in survival conditions	Fair 1 Leg failure probably leads to total failure	49	Fair to good Deploy. from Platform	Fair to good Require tugs to re-set	Good	Good Platform motions might be reduced
Vertical Leg Tension 3 Legs Tension Rod	Excellent Stays within 10% limit in survival conditions	Fair I Leg failure probably leads to total failure	26	Good Deploy. from Platform	Good Leg lifts straight up and down	Good	Fair Significant Interferance with CWP
Vertical Leg Tension I Leg (Inside CWP) HCL	Excellent Stays within 10% limit in survival conditions	Poor Same proglems as HCL, no leg redundanct	(G&C Est.)	Difficult	Poor Maintenance, Repair Extremely Difficult	Fair	Good Apparently CWP design is assisted by mooring

TABLE 28 BARGE PLATFORM OVERALL EVALUATION OF SKSS CANDIDATES

SKSS CANDIDATE DESCRIPTION	WATCH CIRCLE RADIUS	RELIABILITY	COST $M	DEPLOYMENT	M & R AND REPLACEMENT	TIME SCHEDULES	INTERFACE
Catenary 4 Legs HCL Clump Wgt.	FAIR Higher pretension required to limit excursion Limit exceeded in survival condition	FAIR Possibility of failure due to cylinder collapse, leakage, pin joint failure Stringent quality control required	243	POOR to FAIR * Heavy Legs	POOR to FAIR * Heavy Legs	FAIR	FAIR For Riser Cable POOR For CWP since Barge will encounter beam seas
Catenary 4 Legs Solid Bar Links	FAIR Higher pretension required to limit excursion Limit exceeded in survival condition	GOOD Pin joint connections are critical	112	POOR Heavy Anchors and Legs *	POOR to FAIR *	GOOD	FAIR For Riser Cable POOR For CWP since Barge will encounter beam seas
Catenary 8 Legs Solid Bar Links	GOOD Pretension could be lowered for operating condition Excursion requirement nearly met for survival condition	EXCELLENT 1 leg failure can be tolerated Pin joints are critical Reliability gain is costly	167	POOR * Very timely	FAIR *	GOOD	GOOD For Riser Cable Excursion limited
Single Leg Mooring 3 Legs Closely Spaced Solid Bar Links	EXCELLENT Assuming riser cable can be run along mooring line	GOOD 1 or 2 add'l legs may be added to assure redundancy in case of leg failure	58	FAIR to GOOD Deploy. from Buoy	GOOD Legs lift straight up and down self sufficient	GOOD	EXCELLENT For Hull, very little interference Motions minimized FAIR For riser cable Power transfer difficult

8.0 CONCEPTUAL SKSS DESIGNS FOR THE SPAR PLATFORM

The two concept designs for the station-keeping subsystems of the SPAR Modular OTEC plant are described in the following sections:

8.1 - 8 leg wire/chain catenary

8.2 - 3 leg vertical tension mooring

Components and Materials

Platform: Spar

8.1. Mooring Concept: 8 Leg wire-chain catenary

1. Winch (8)
   - 1000Kip Holding Force
   - 1500'-2000' of Wire Capacity Drum
   - Fossil Fuel

2. Hawse Pipe (4)
   - Steel
     - 300 feet long
     - 2' Dia. X 1 1/2" t
   - Fair lead (16, 2 each end of H.P.)

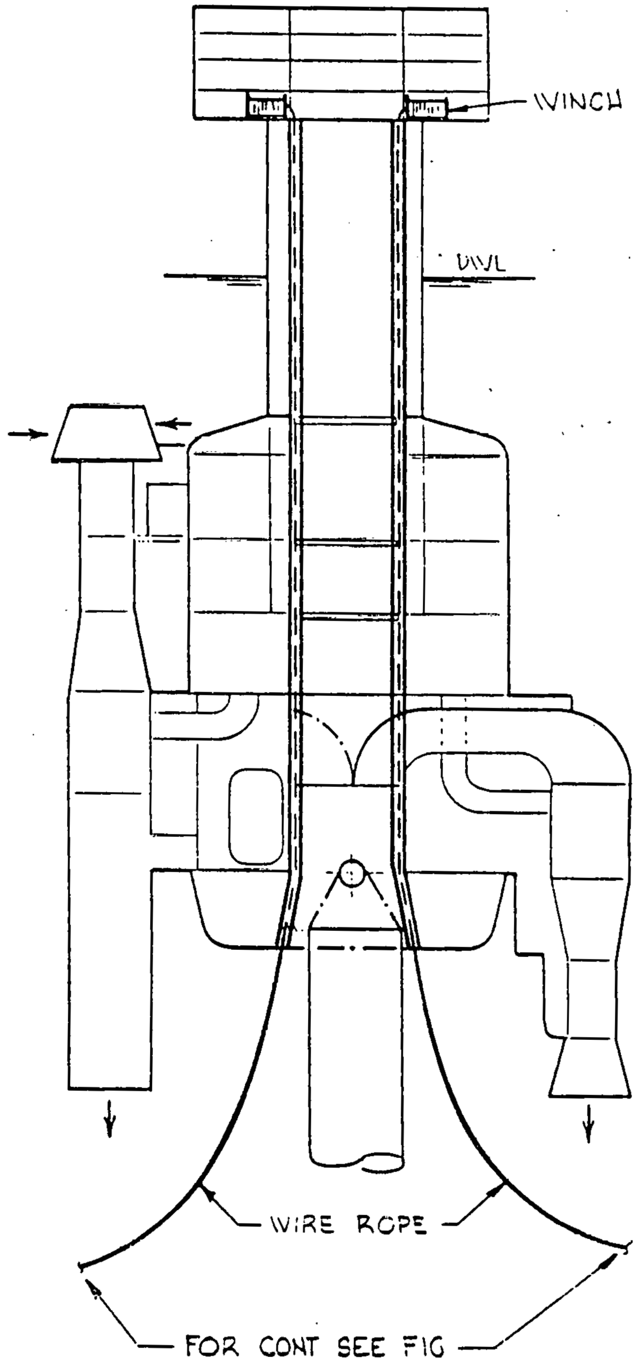
3. Wire (8)
   - 5"
   - 7500'-8000' (1500'-2000' on the winch, 2X1500' on drums, 1X3000' on a drum)
   - Shackles (16)
   - Triplate (8)

4. Chain (8)
   - 4"
   - 3200'

5. Drag Anchor (8)
   - wt. = 60 Kips
   - High Holding Power = 1500 Kips
   - Shackles (8)

6. Riser Buoy (8)
   - Steel Cylinder w/wire
   - 50 Kips of buoyancy

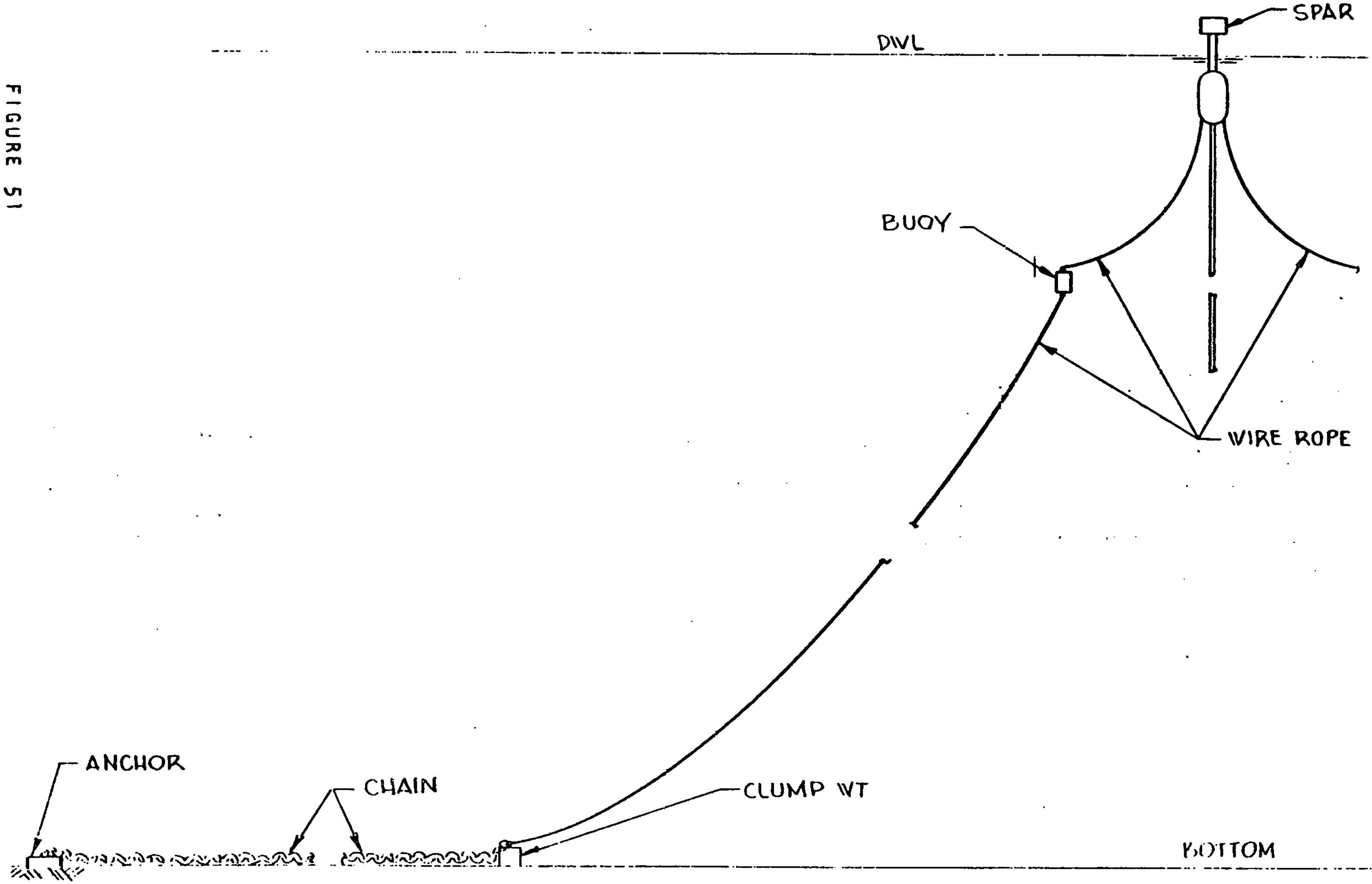
7. Clump Weight (8)
   - 100 Kips of Reinforced Concrete ea.
   - Eye Bolt



SPAR - 8 LEG WIRE & CHAIN CATENARY

FIGURE 50

FIGURE 51



TYPICAL ARR OF 8 LEG WIRE & CHAIN CATENARY
MOORING LINE FOR SPAR

M. ROSENBLATT & SON, INC.

Platform: Spar

8.2 Mooring Concept: 3 Leg Vertical Tension Rod

1. Running and Retrieving Assembly (3)
   4500 Kip Holding Force
   Applies to Derrick and
   Jacking System

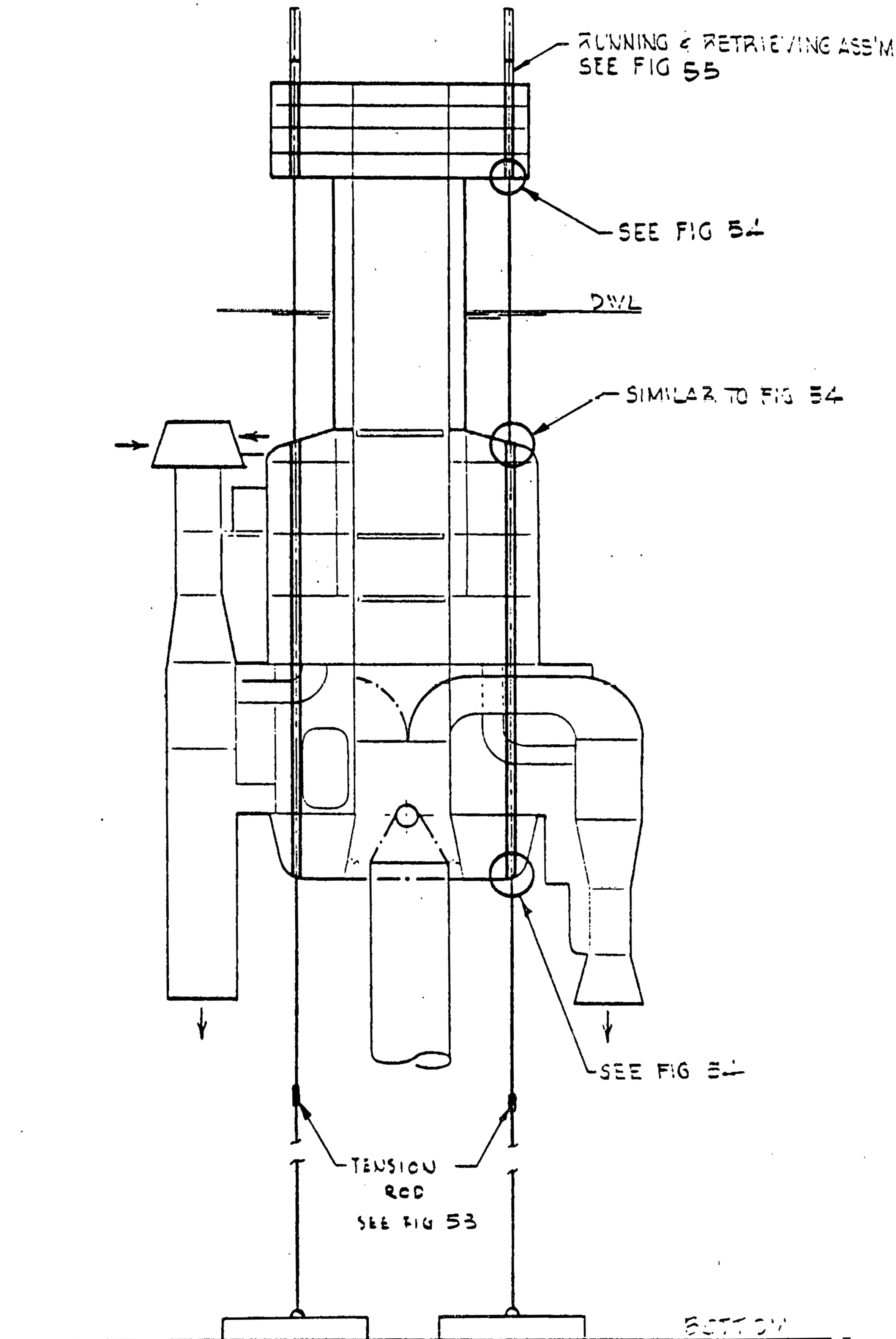
2. Hawse Pipe (3)
   Steel
   300 feet long
   2' Dia X 1 1/2" t

3. Tension Rod (3)
   High Yield Steel
   30' X 11" OD, 5" ID ea. Rod
   4400' total
   Universal & Guide Link (3)
   Space Out Joint
   Couplings

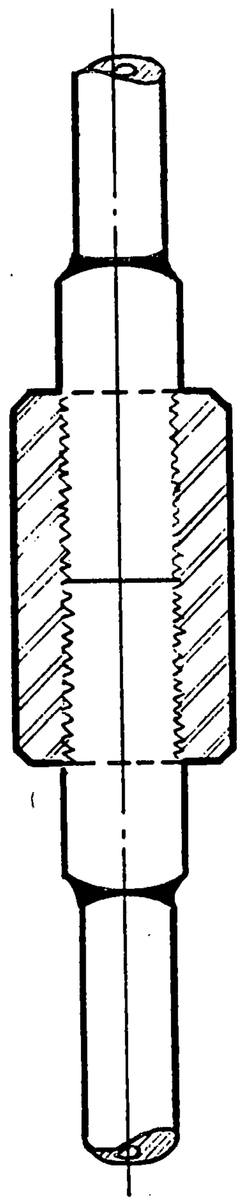
4. Side Thrust Framing at Bottom of Hawse Pipe

5. Anchor Connecting Assembly (3)
   Hydraulic tine (runs inside the Rod)
   Instrument Package (Subsea sonar, TV, etc.
   Universal Joint (3)

6. DWT Steel Anchor (3)
   800 Kips Steel Wt. (Dry)
   7200 Kips Ballast Filler (Dry)

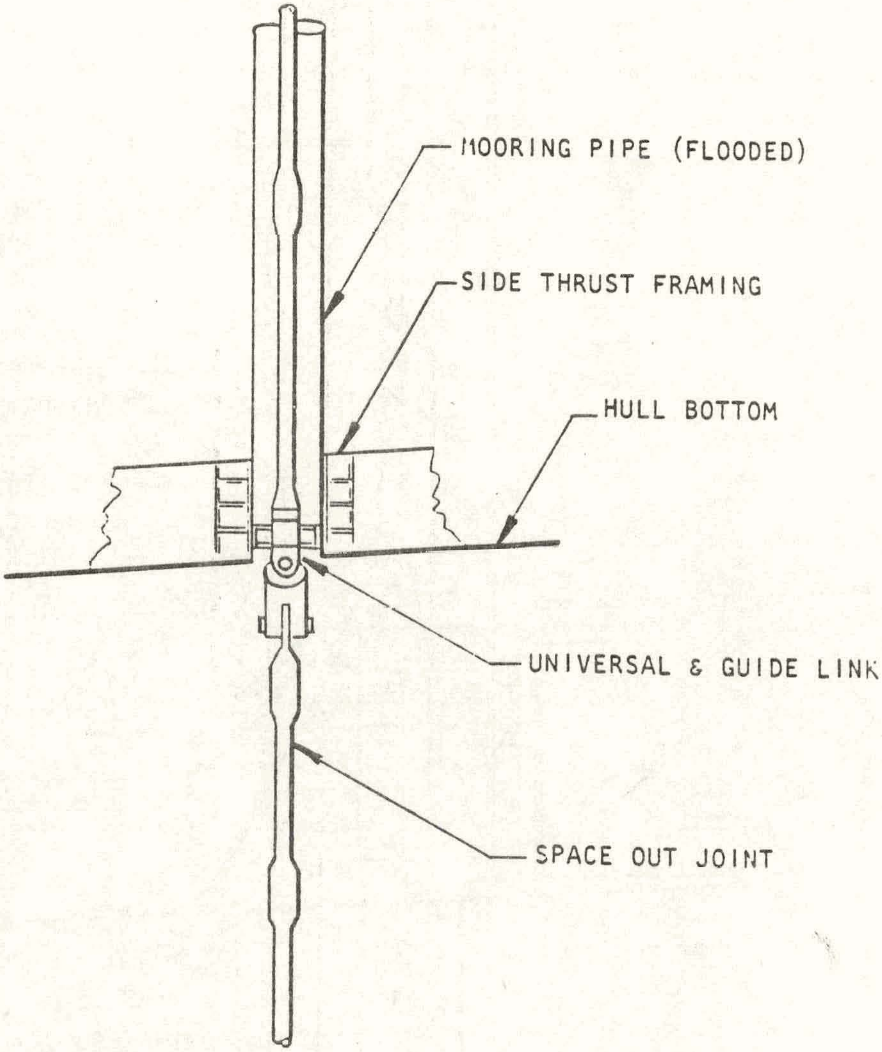


SPAR- 3 LEG VERTICAL TENSION MOORING FIGURE 52



CONNECTING COUPLING DEVICE
FOR 3 LEG TENSION MOORING LINE OF SPAR

FIGURE 53

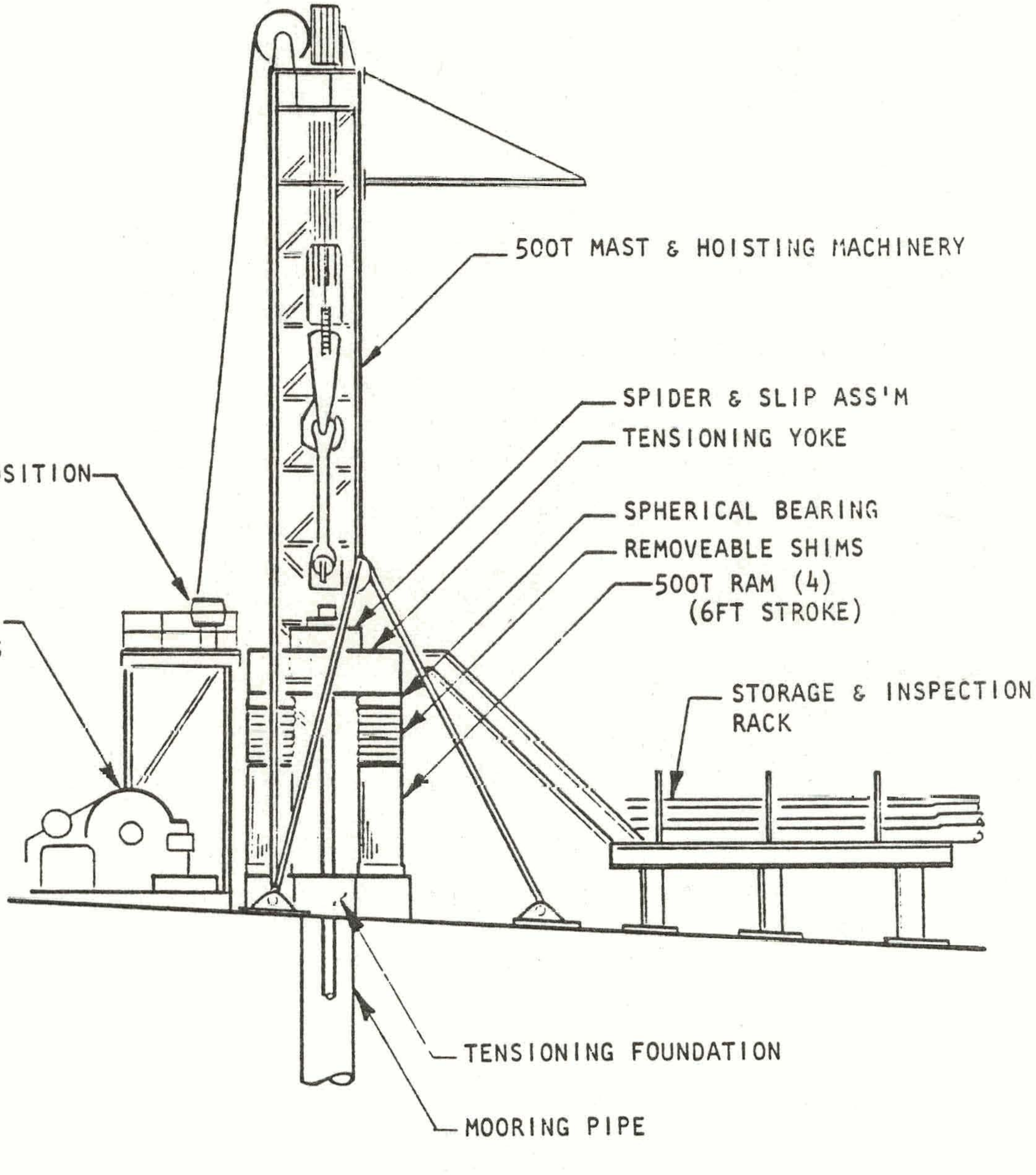


LOWER HULL PENETRATION

FOR

TENSION LEG MEMBERS

FIGURE: 54



RUNNING & RETRIEVING ASS'M

FOR

TENSION LEG MEMBERS

FIGURE: 55

9.0 CONCEPTUAL SKSS DESIGNS FOR THE BARGE PLATFORM

The basic descriptions for the two concept designs for the 10/40 MW_e Modular OTEC Barge platform are given in the following sections:

9.1 - 4 Leg Solid Link Catenary

9.2 - Single Buoy Mooring

Platform: Barge

9.1 Mooring Concept: 4 Leg Solid Link Catenary

1. Running and Retrieving Assembly (4)
   12,500 Kip Holding Force
   Applies to Derrick and Jacking System

2. Hawse Pipe(4)
   Mild Steel
   80' long
   4' Dia X 1 1/2" t

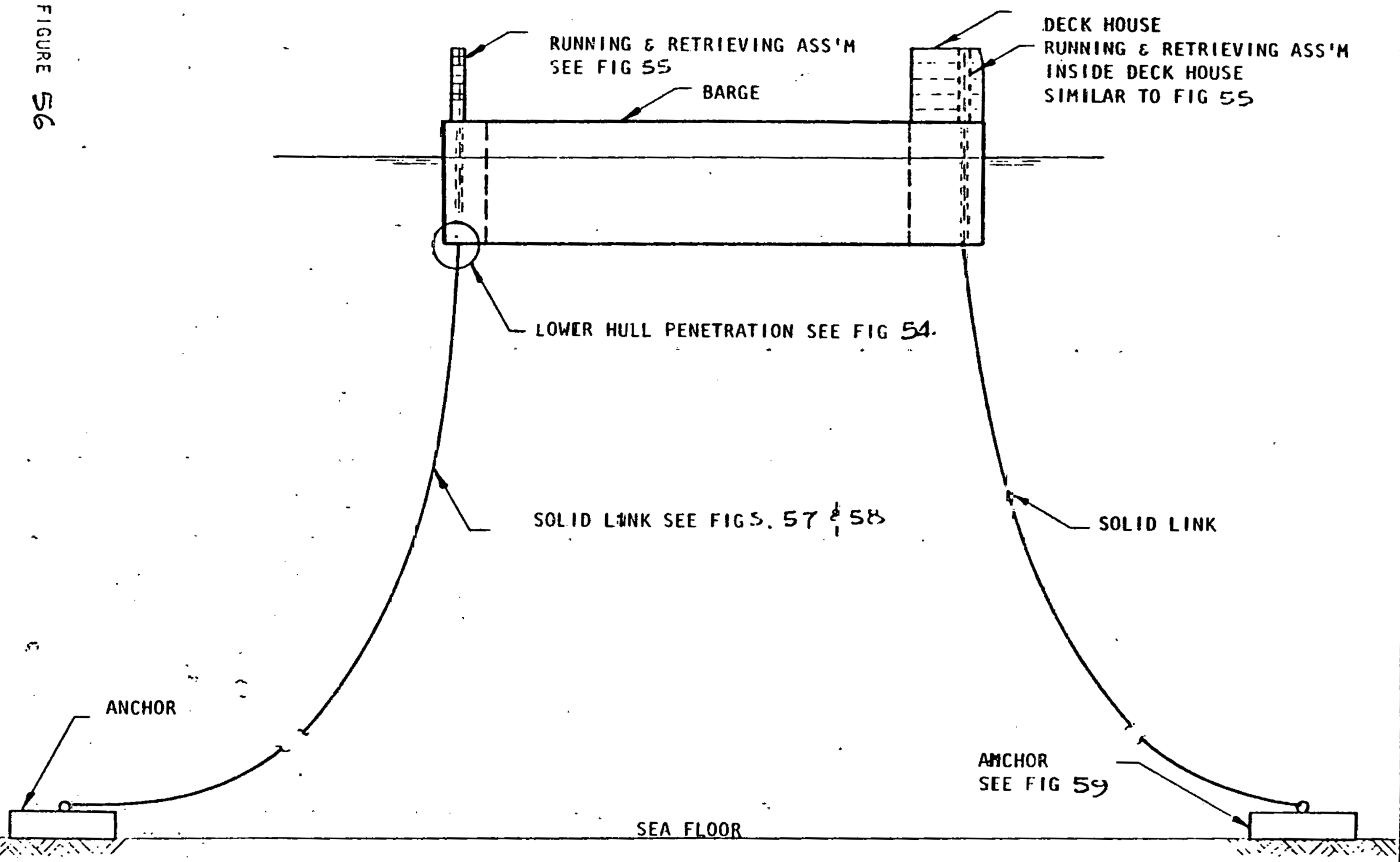
3. Solid Ling (4)
   High Yield Steel
   7500' / leg
   920 lb/ft Wet Weight
   Universal Link at Hull/Water Interface
   Pin Connections

4. Side Thrust Framing at Bottom of Hawse Pipe

5. Anchor Connecting Assembly (4)
   Hydraulic Line
   Universal Joint

6. DWT Steel Anchor (4)
   4000 Kips Steel Wt (Dry)
   36000 Kips Ballast Filler (Dry)

FIGURE 56



BARGE - 4 LEG SOLID LINK CATENARY

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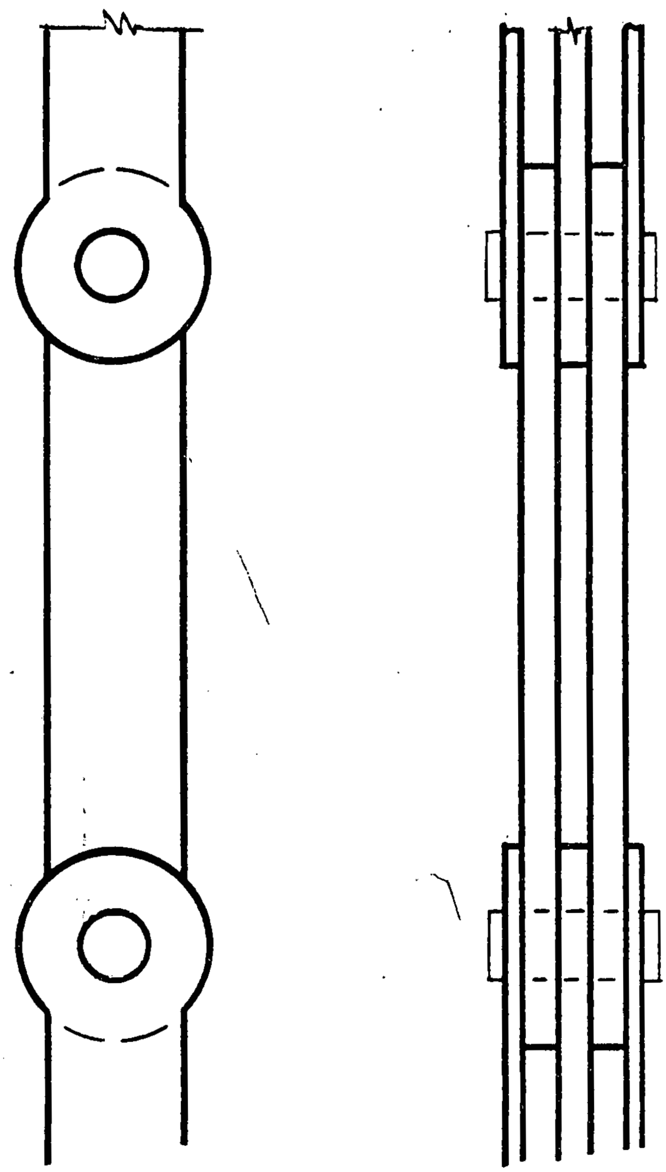
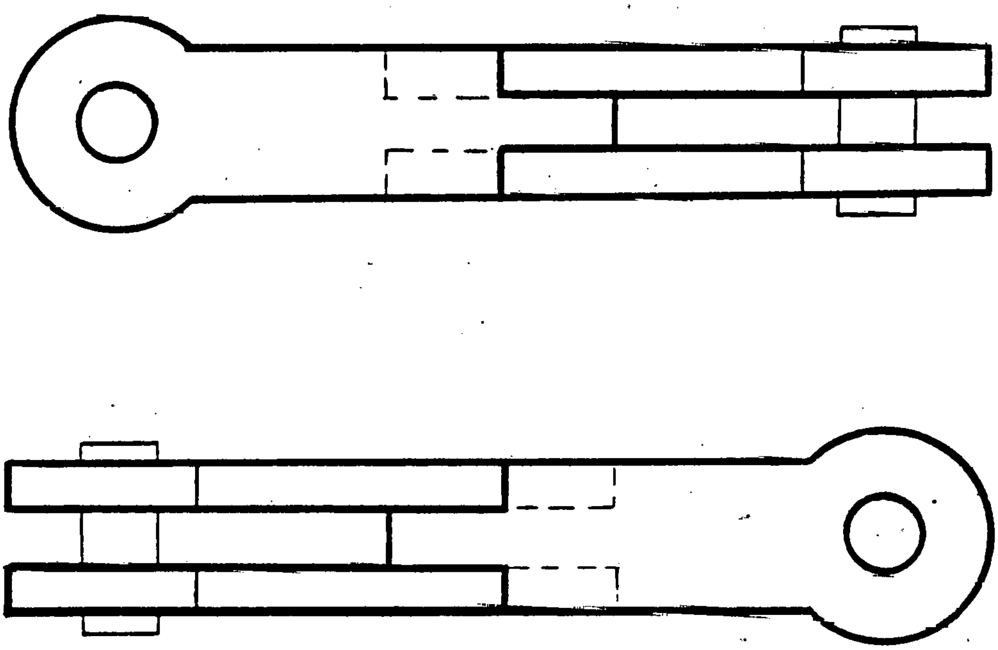


FLAT PLATE LINK

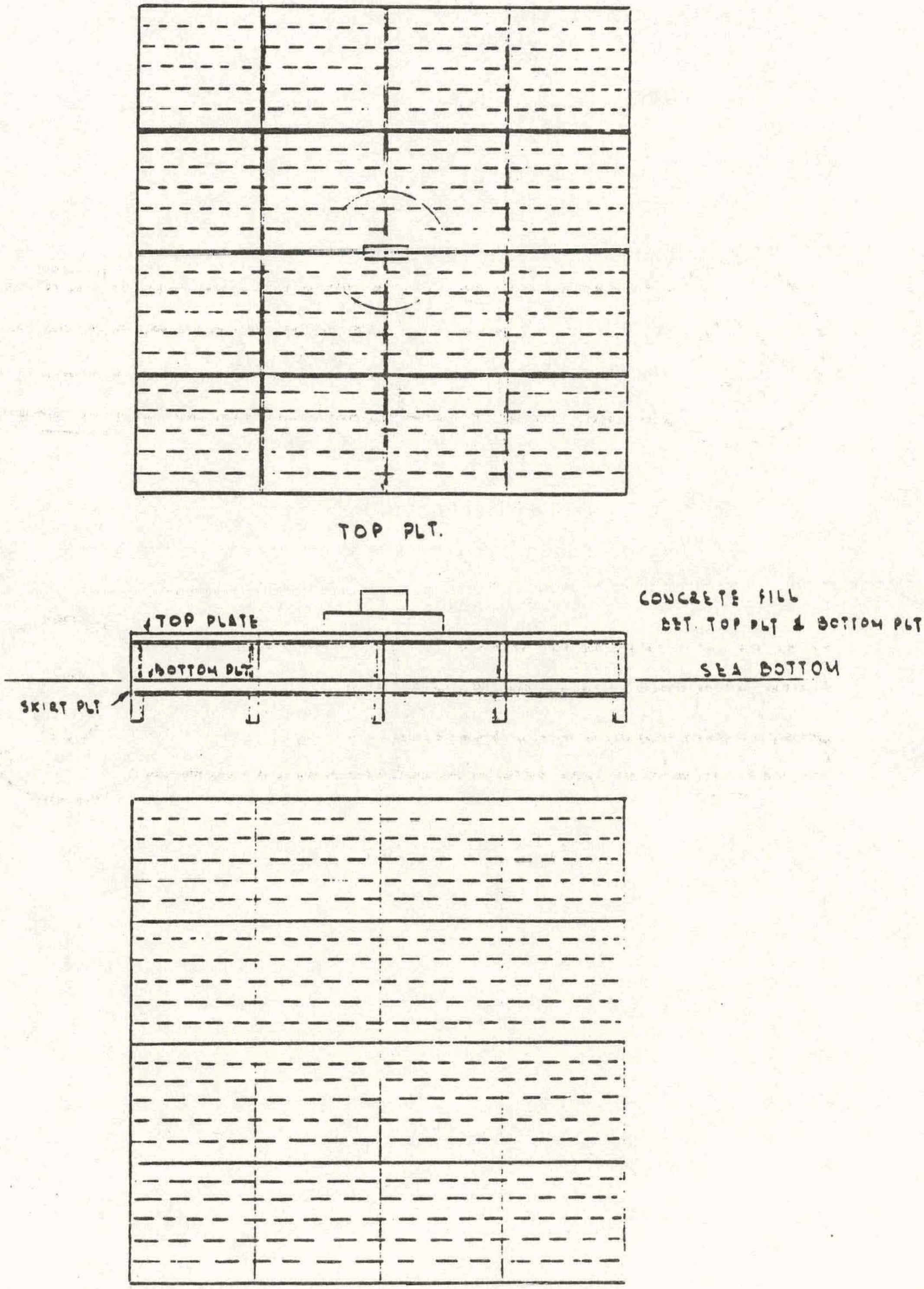
FIGURE 57



FLAT PLATE LINK

FIGURE 58

FIGURE , TYPICAL DEAD WT. ANCHOR



BOTTOM PLT

FIGURE 59

Platform: Barge

9.2 Mooring Concept: Single Point Tension Barge with Buoy

1. Buoy to Barge Support
   Arm
   - Universal Joint
   - Steel
   - Box Girder Design

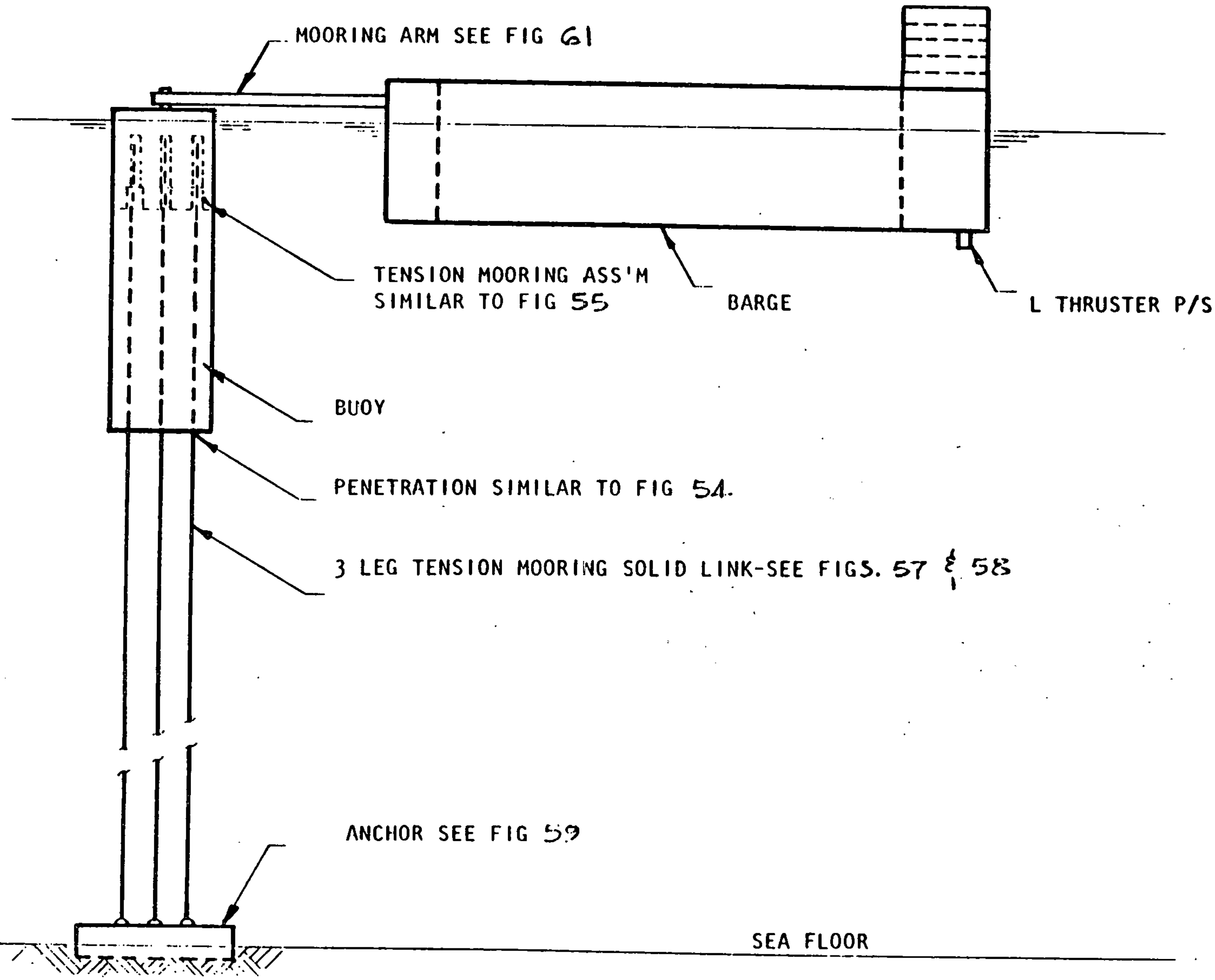
2. Buoy
   - Steel
     - 200' X 70' Dia
   - Structural Deck
   - Inside and Hawsepipe

3. Running and Retrieving
   Assembly (1)
   - 36000 Kip Holding Force
   - Jacks Inside Buoy
   - Derrick on Top, Removable

4. Solid Link (1 or 3)
   - 680 in cross section
   - Area Req'd
   - 4550'/leg
   - Pin Connections

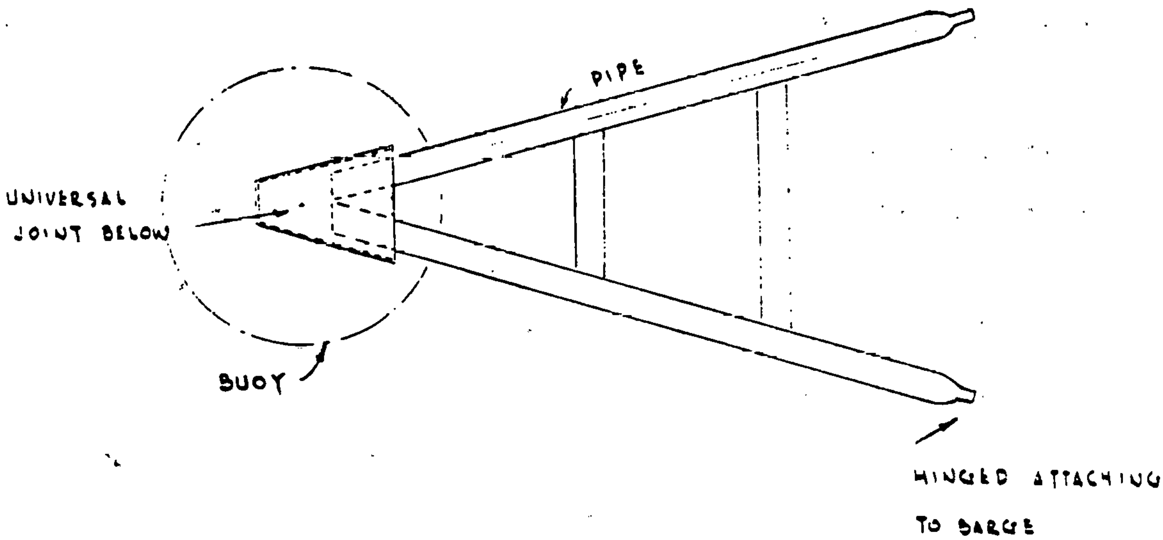
5. Anchor Connecting (1 or 3)
   Assembly
   - Hydraulic Line
   - Universal Joint

6. DWI Steel Anchor (1 or 3)
   - 6200 Kips, Steel Wt (dry)
   - 56000 Kips, Ballast
   - Filler (dry)



MOORING ARM SEE FIG 61
TENSION MOORING ASS'M
SIMILAR TO FIG 55
BARGE
L THRUSTER P/S
BUOY
PENETRATION SIMILAR TO FIG 54.
3 LEG TENSION MOORING SOLID LINK-SEE FIGS. 57 & 58
ANCHOR SEE FIG 59
SEA FLOOR

FIGURE 60



ARM FOR SINGLE MOORING WITH BUOY

FIGURE 61

10.0 APPLICABILITY OF SELECTED CONCEPTS TO COMMERCIAL PLANT SKSS DESIGNS

As stated in Ref. 24, the Modular Experiment OTEC Platforms will be the "forerunners" of larger commercial OTEC plants. The conceptual and preliminary SKSS designs for the Modular SPAR and BARGE platforms may therefore be the forerunners of commercial plant SKSS designs as well, if this is found to be feasible.

In assessing the applicability of Modular plant SKSS designs to commercial plants, the following essential differences in the requirements for the two plants must be taken into consideration:

- Modular plants are much smaller in plant capacity, and therefore in platform size, than the commercial plants:
  - The net electrical output capacity of the modular plant is 10/40 MW while the commercial plant output, as foreseen at this stage, is 400 MW_e.
  - The operating displacements for the Modular SPAR and BARGE platforms are 54,300 and 67,900 Long Tons, respectively, while the commercial plant operating displacements will probably reach the 300,000 to 500,000 Long Ton range. Corresponding physical sizes for the "surface ship" or "barge" platform are 380' overall length and 120' beam versus 620' length and 300' beam, respectively, for the modular and commercial plants.
- The life expectancy of the modular plant SKSS is specified to be 10 years while the commercial plant is envisioned to be operational for a life period of 40 years.
- The diameter of the cold water pipe attached to the modular plat-

form is nominally 30' while the commercial plant will probably require cold water pipe diameters in the 80 to 100' range.

- o The deployment site for the Modular plant is specified to be the Punta Tuna area in the south eastern coastline of Puerto Rico. The commercial plant may also be deployed in any one of the other four DOE sites, i.e., West coast of Florida, Hawaii, New Orleans, and Brazil.

- o The modular plant will probably be constructed and operated as a single unit. The scenario for the commercial plant, on the other hand, is to deploy a number of individual OTEC platforms in one site to form an OTEC Energy Park.

- o The shapes of the platform hulls selected for the modular plant are the submerged SPAR with outboard heat exchangers and the surface BARGE. The eventual hull shape to be selected for the commercial plants may be of a different configuration.

All of the differences discussed above will influence the applicability of modular SKSS designs to commercial plants:

- o The large increase in the physical size of the platform will result in much higher drag and wave drift forces; therefore the loads and stresses acting on the mooring or tension legs will be proportionally higher. This may rule out the use of one or the other leg members or their configurations selected for the modular plant.

- o The ensuing larger reaction forces will result in higher anchor holding power requirements and will therefore influence anchor designs; this may even necessitate the use of conbination deadweight-pile driven anchors.

- The changing environmental conditions for various other OTEC sites will require a reassessment of the spectrum of wind, wave, and current characteristics for the specific site, and will cause the adoption of more (or less) severe environmental states for the operational and extreme conditions.

- The interface of the much larger diameter cold water pipe with the SKSS components will probably present different problems and thereby require changes in hull passages, connections, etc.

- The costs of SKSS components for the commercial platforms will probably benefit from the series production possibilities afforded by quantity production.

Without an equally developed conceptual design for the commercial platforms, it is difficult to perform a quantitative determination of the influences inflicted upon modular SKSS designs regarding their applicability to commercial plants. Nevertheless, for the two SKSS conceptual designs selected as being the most feasible and cost effective candidates for each of the two modular platforms, qualitative discussions are presented in the following sections.

10.1 SPAR Platform

The eight leg catenary with wire rope and chain concept most likely will not be feasible for the commercial plant. Even for the modular plant, the design factors of safety are marginal; it is hard to see how this system could be used for higher drag applications at least using currently available sizes of wire rope and chain. If the platform could be located in an area with a flat ocean bottom where very large line lengths could be used and the number of legs were increased to 12 then this might be considered for the commercial platform. Drag type anchors would have to be replaced by deadweight anchors.

The three leg vertical mooring probably would have to be modified to an eight leg mooring in order to withstand the higher drag loadings. This concept is quite sensitive to the waterplane area of the platform. Use of tension rods may not be feasible but these could be replaced by HCL or solid bar links.

10.2 BARGE Platform

The four leg solid bar link catenary would probably fail to keep the platform within a 10% depth excursion limit so the number of legs would probably be increased to eight or more. This would also keep the leg size down to reasonable dimensions.

The single leg mooring concept could probably be made to work for the commercial size plant although the leg sizes would obviously be very much larger.

11.0 CONCLUSIONS AND RECOMMENDATIONS FOR THE MODULAR PLANT SKSS PRELIMINARY DESIGNS

Of the many different SKSS concepts considered for application to Modular Experiment OTEC platforms, the two best candidates are established, in Section 7.7, to be the following:

- o For the SPAR
  - 8 leg catenary with wire rope and chain
  - 3 leg vertical tension mooring
- o For the BARGE
  - Single leg mooring with buoy and support arm
  - Four leg catenary with solid links.

A close comparison was made of these alternatives on the basis of the following criteria (Tables 27 and 28):

- o excursion performance
- o reliability
- o cost effectiveness
- o ease of deployment procedures
- o maintenance and replacement procedures
- o time schedules
- o interface with the other OTEC subsystems

By carefully studying the results summarized in the above-mentioned two tables for the SPAR and BARGE platforms, the most feasible SKSS candidates for each platform are selected, and the basic rationale for the selection given, below:

- o For the SPAR platform, the "Eight Leg Wire Rope/Chain Catenary Mooring Concept" is selected and recommended for use as baseline in the preliminary design stage for the following reasons:

- Lowest cost
- Highest reliability
  - Little research and development necessary
  - All components state-of-the-art
  - Actual experience exists in the offshore industry for all deployment, maintenance, and replacement operations.
- Can meet excursion requirements and time schedules with reasonable certainty.

o For the BARGE platform, the "Single Leg Mooring Concept with a Tension Moored Buoy and Support Arm" is selected and recommended for use as baseline in the preliminary design stage for the following reasons:

- Lowest cost
- Best excursion performance
- Attractive weathervaning capability
- Reliability comparable to 4 leg catenary.

12.0 OVERVIEW ON CONCEPTUAL DESIGN STUDIES

The results of all conceptual design studies were orally presented to the Department of Commerce (National Oceanic and Atmospheric Administration) and the Department of Energy (Ocean Systems Branch of Division of Central Solar Technology), in a review meeting held in Rockville, Maryland on April 25, 1979.

The concensus reached as a result of comments and discussions by DOE/DOC authorities, as well as representatives of other OTEC contractors who attended the meeting, was that the recommended SKSS for the SPAR Modular platform would be endorsed. Accordingly, for the SPAR platform preliminary designs a catenary SKSS with the state-of-the-art components was specified.

For the Barge platform, the two recommended SKSS concepts, admittedly, were not quite state-of-the-art. Some of the mooring components, such as solid bar links for catenary mooring and electrical swivels for the single buoy mooring concepts, called for considerable development efforts. In view of this, and the general desire to develop a mooring system consisting completely of readily available or easily producible components, the project team was asked to present the details of a wire rope/chain catenary configuration, or other state-of-the-art approach, for the Barge platform SKSS.

A subsequent quasi-static analysis was performed and it was found that, aided by a reduction in the operational and survival environmental conditions as reported in reference (25) by C. L. Bretschneider, by increasing the number of mooring legs and utilizing the largest wire rope and chain sizes, a catenary mooring concept could be obtained for the Barge platform as well. As a result, the project team was directed to use multipoint catenary mooring concepts as baseline for both the Barge and the SPAR platform SKSS preliminary designs.

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APPENDIX A

CATENARY EQUATIONS

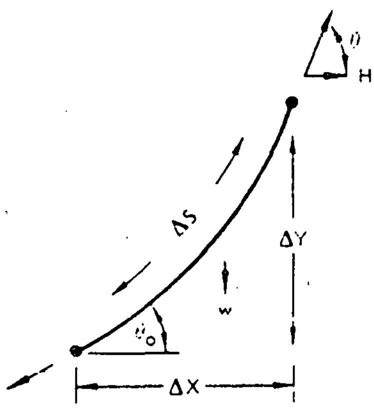
Any segment of a catenary may be described mathematically by the equations:

$$\Delta Y = \frac{H}{w}(\Delta \sec\theta),$$

$$\Delta S = \frac{H}{w}(\Delta \tan\theta), \text{ and}$$

$$\Delta X = \frac{H}{w}\ln\left[\frac{\tan\left(\frac{\pi}{4}+\frac{\theta}{2}\right)}{\tan\left(\frac{\pi}{4}+\frac{\theta_o}{2}\right)}\right]$$

This geometry is described in the following diagram, in which H is the horizontal component of the tension in the leg, and w is the weight per unit length of the segment.



Expressed as above, or in any of the variations which have been optimized for particular applications, these relationships are sufficient to calculate the geometry and static tension in any mooring line, whether a simple, compound, or double catenary.

Wire rope is the usual component used in the remainder of the leg. Since the length of the wire-rope section of the leg is unknown, calculation to determine its shape must include the remaining depth of water to be traversed as the controlling parameter. Thus

$$\Delta Y_{wr} = D - \Delta Y_c$$

where D is the depth of the water at the anchor position. The angle at the buoy or moored structure is then determined by

$$\theta_b = \sec^{-1}\left(\sec\theta_1 + \frac{\Delta Y_{wr} w_{wr}}{H}\right)$$

The total scope of the wire rope may then be calculated from

$$S_{wr} = \frac{H}{w_{wr}}\left(\tan\theta_b - \tan\theta_1\right)$$

and the following equation will define the horizontal extension:

$$X_{wr} = \frac{H}{w_{wr}} \ln\left[\frac{\tan\left(\frac{\pi}{4} + \frac{\theta_b}{2}\right)}{\tan\left(\frac{\pi}{4} + \frac{\theta_1}{2}\right)}\right]$$

When a clump is included at the juncture of the chain and the wire rope, the calculation of the configuration of the wire rope is modified by the substitution of θ_1' for θ_1, in which case:

$$\theta_1' = \tan^{-1}\left(\tan\theta_1 - \frac{W}{H}\right)$$

where W is the weight of the clump in water.

The primary criterion, of course, is the holding power of the leg, H; this parameter, representing the horizontal component of tension, is a constant throughout the catenary.

To assure that the anchor line at the anchor remains horizontal, or nearly so, a heavy chain is normally attached to the anchor as the first portion of the scope of the leg. The length of this chain, S_c, and thus its total weight, $S_c w_c$, are therefore selected to provide the necessary mass to restrain the anchor shank. (In some cases a clump, or concentrated mass, is added at the upper end of the chain to reduce chain pickup by the overall tension in the leg.)

Since the length of the chain is known, calculation of its configuration begins by assuming an initial shank angle equal to the bottom slope, θ_0. Small anchor shank angles may be involved in certain cases, and $\theta_0 + \theta$ would then be the initial chain angle. For the specific length of chain, S_c, the angle at its upper end, θ_1, may be calculated from

$$\theta_1 = \tan^{-1}\left(\tan\theta_0 + \frac{S_c w_c}{H}\right),$$

wherein w_c is the weight per unit length of the chain in water. The vertical rise, ΔY_c, of the chain is then

$$\Delta Y_c = \frac{H}{w_c}\left(\sec\theta_1 - \sec\theta_0\right)$$

and the horizontal extension, ΔX_c, is

$$\Delta X_c = \frac{H}{w_c}\ln\left[\frac{\tan\left(\frac{\pi}{4} + \frac{\theta_1}{2}\right)}{\tan\left(\frac{\pi}{4} + \frac{\theta_0}{2}\right)}\right]$$

APPENDIX B - SUMMARY CALCS. & ANALYSIS

B. I SPAR - CATENARY

4 - LEG MOORING SYSTEM

HCL & HCL

HCL & CHAIN

WIRE ROPE, HCL & CHAIN

HCL, HCL & CHAIN

8 - LEG MOORING SYSTEM

STEEL ROD

KEVLAR

HCL, HCL & CHAIN

WIRE ROPE & CHAIN

WIRE ROPE, WIRE ROPE & CHAIN

KEVLAR, KEVLAR & CHAIN

12 - LEG MOORING SYSTEM

HCL & CHAIN

MOORING SYSTEM										SPAR							
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA / (WET) #/FT	CLUM / BUOY #	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR Δ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI. - KIPS	VERT - KIPS
4									MAX.								
DIR. e = 15°	HCL				4,200	/48.9		0.095	9962	756	1,030			OUT OF RANGE .			
	CHAIN				8,000	3.31/90.4											
(ε-1)	PRETENSION 670 KIPS																
4	HCL				4,200			0.095	9,962	770	OUT OF RANGE			OUT OF RANGE			
DIR. e = 105°	CHAIN				8,000												
(ε-1a)	PRETENSION 670 KIPS																
4									MAX.								
DIR. e = 15°	HCL				4,200		20K/0	0.095	9,880	810	1,600			OUT OF RANGE			
	CHAIN				8,000												
(ε-2)	PRETENSION 670 KIP																
									MAX								
4	HCL				4,200	/48.9		0	10,447	475	1,159			OUT OF RANGE			
DIR. e = 105°	CHAIN				8,000	3.31/90.4											
	PRETENSION = 700 KIPS																
	TO COMPARE T159 CALCULATION																
(ε-4)																	

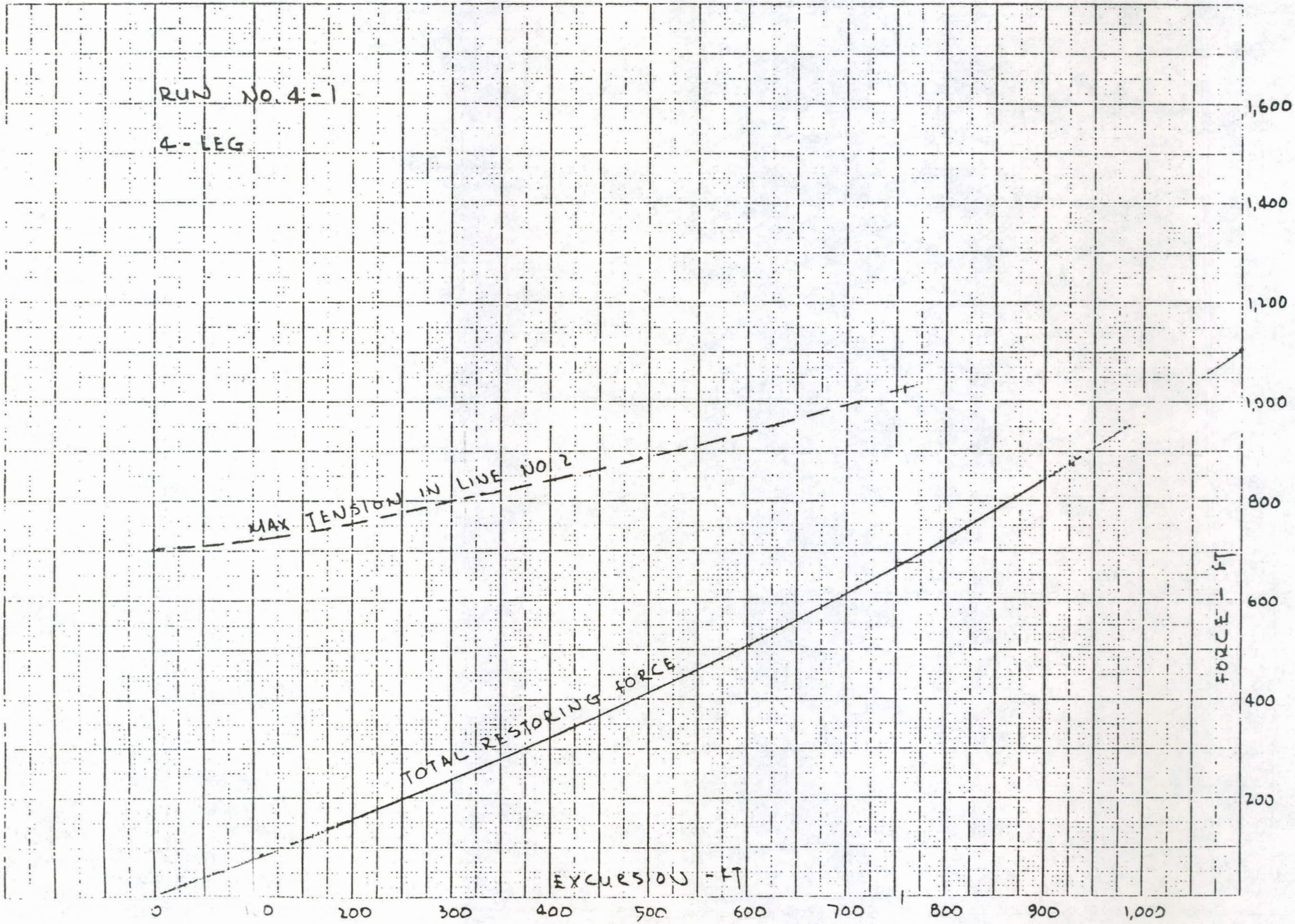
MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA/#/FT	CLUM/BODY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS
4	HCL				1,000	/48.9	0/100K										
DIR e = 105°	HCL				4,200	/48.9	100K/0	0.095	11,529	467.4	1,345			747.	1,717.0		
	CHAIN				8,000	3.31/90.4	—										
(4-5)		PRETENSION =			1,000 KIPS												
4	HCL				1,000	/48.9	0/200K										
DIR. e = 105	HCL				4,200	/48.9	200/0	0.095	11,300	501.0	1,345			894	1,721.0		
	CHAIN				8,000	3.31/90.4	—										
(4-6)		PRETENSION			= 1000 KIPS												
4	HCL				1,000	/48.9	0/50K										
	HCL				4200	/48.9	100K/0	0.95	11512	412	1,345			752	1715.0		
DIR e = 105	CHAIN				8000	3.31/90.4	—										
(4-7)		PRETENSION =			1,000 KIPS												
4	HCL				1000	/48.9	0/250										
	HCL				6000	/48.9	500/0	0.95	10875	200	1110			765	1515.0		
	CHAIN				6200	4"/132	—										
DIR e = 105 (4-8)		PRETENSION =			700 KIPS												

MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS.				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA/(WET) #/FT	CLUMP/BUOY	SLOPE AT BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{MAX} - KIPS	HORI. - KIPS	VERT. - KIPS	e - FT	T_{MAX} - KIPS	HORI. - KIPS	VERT. - KIPS
									MAX.								
4	HCL		2		1,000	/50	0/250	0.095	4,636	603	1,170			604	1,420		
DIR. e = 60°	HCL		2		6,500	/50	0/0										
(B-1B)	PRETENSION = 325.8 KIPS																
									MAX.								
4	HCL		2		1,050	/50	0/200	0.095	3,674	120	2,000	8,342	14,987	134	3,400	14,861	27,762
DIR. e = 60°	HCL		2		5,500	/50	0/0										
(B-1)	PRETENSION = 450 KIPS																

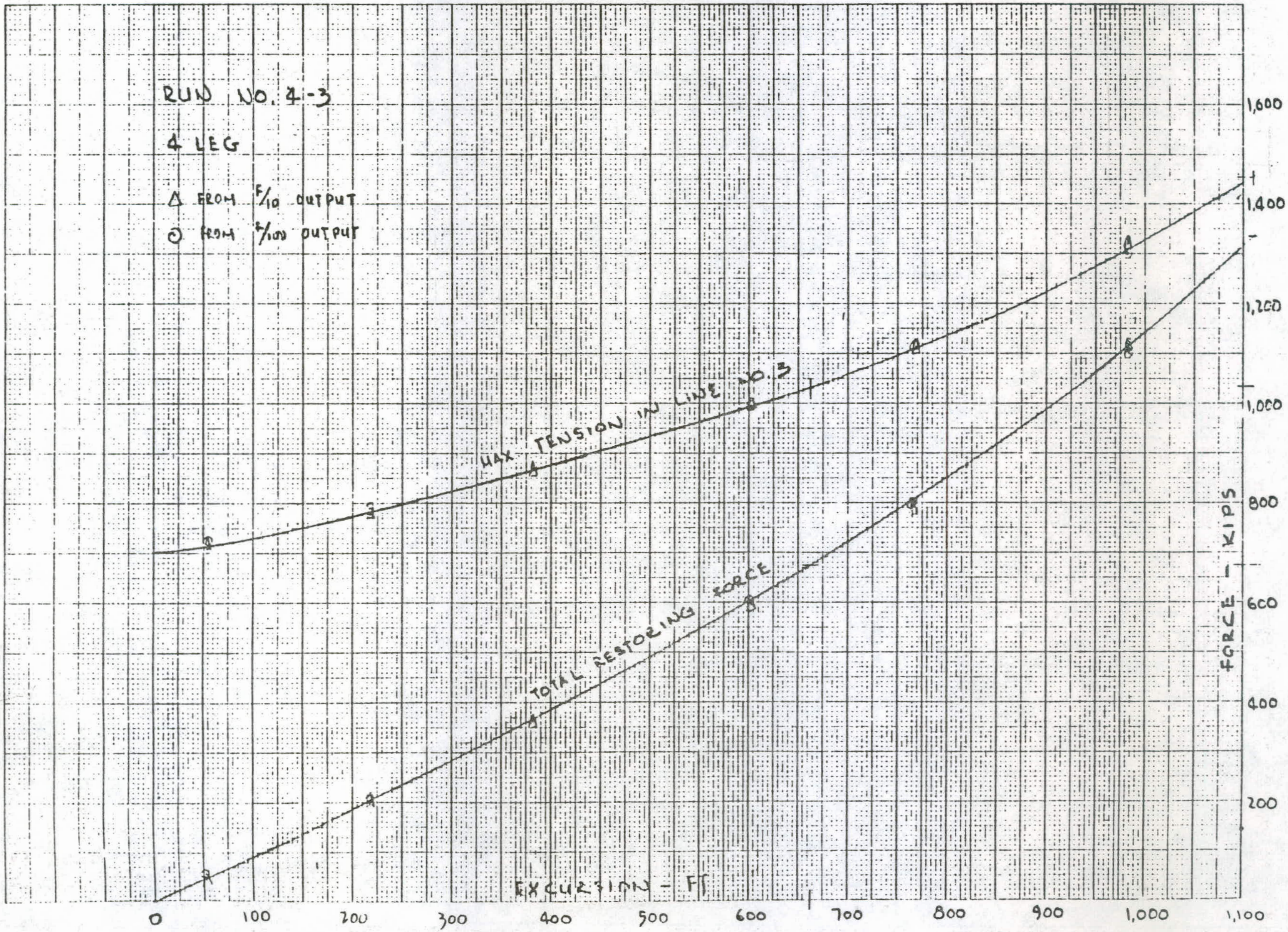
3/20/1979

MOORING SYSTEM									SPAR								
										OPERATING CONDI 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA."/(WET) #/FT	CLUMP KIPS	BUOY KIPS	HORI DIST. TO ANCHOR λ - FT	e - FT	T_MAX - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_MAX - KIPS	HORI - KIPS	VERT - KIPS
4	HCL	4,200	2	2,100	1,000	30"/48.91	—	100									
:IR e = 60°	HCL	↓	↓	↓	6,000	↓	500	—	LINE 1&2 7,880	379	1,330	582	0	840	1,939	1,274	131
:UNNO 4-11)	CHAIN	1,632	2	816	3,200	4"/152	—	—	LINE 2&3 7,177								

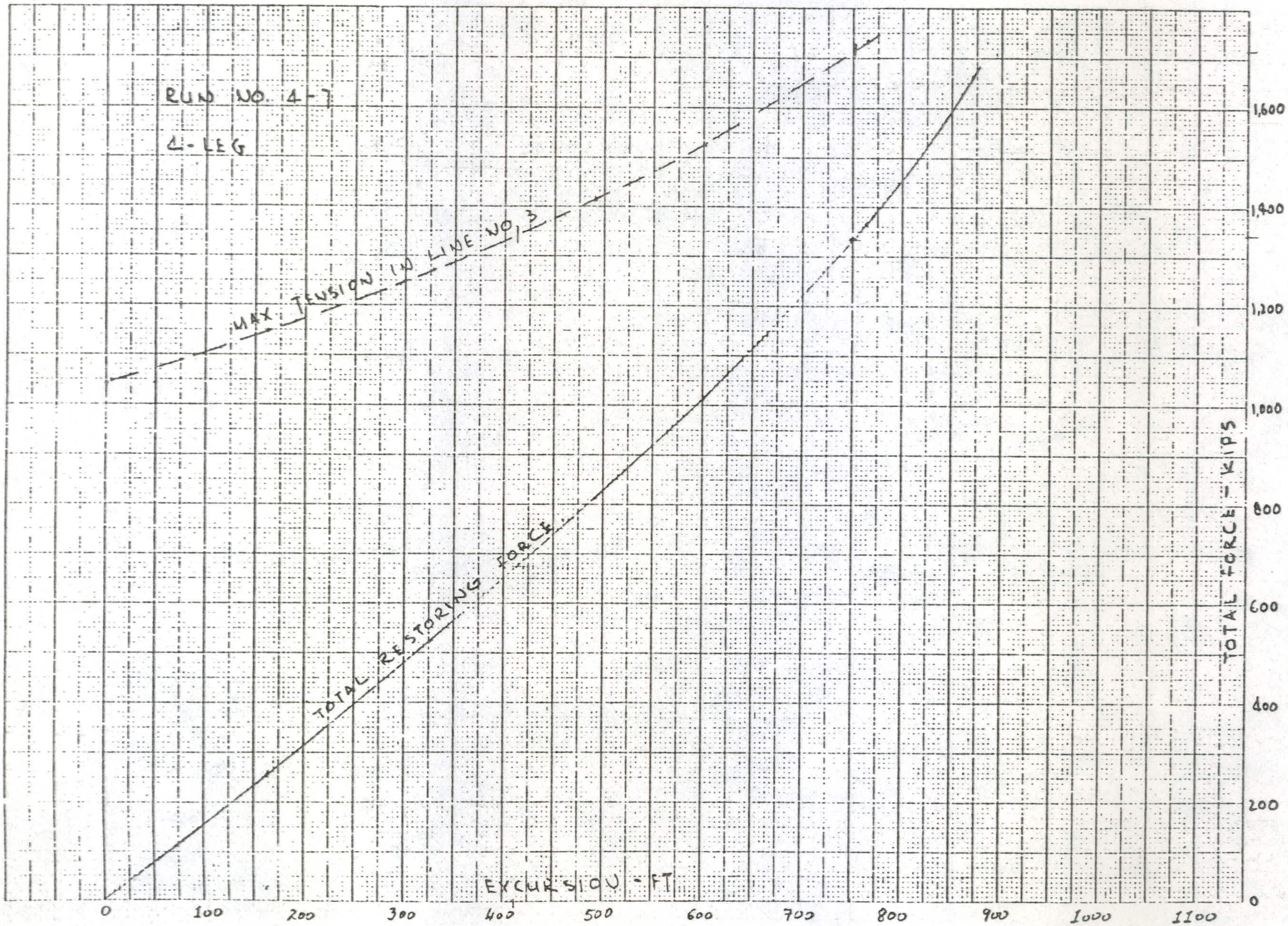
MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA. / (WET) #/FT	CLUMP / BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS
4	WIRE ROPE				1000	4½"/3104	0/20K		MAX								
DIR. e	HCL				4,200	/48.9	20K/0	0.095	11,153	662	1,018			1,110	14,550		
=15°	CHAIN				8,000	3.31/904	—										
(4-3)			PRETENSION = 700 KIPS														

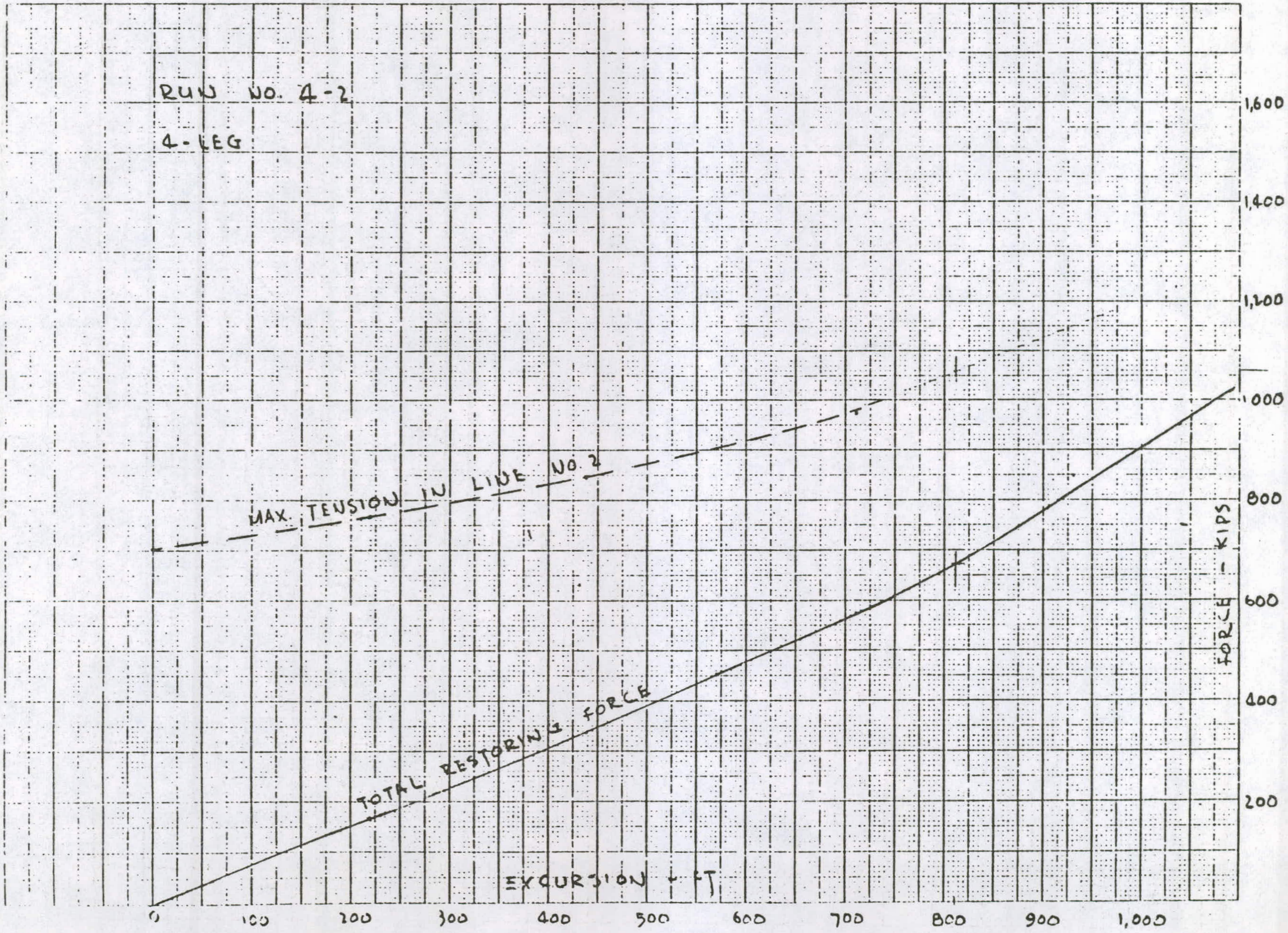

RUN NO. 4-1
4-LEG
MAX TENSION IN LINE NO. 2
TOTAL RESTORING FORCE
EXCURSION - FT
FORCE - FT
1,600
1,400
1,200
1,000
800
600
400
200
0
1.0
200
300
400
500
600
700
800
900
1,000

MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS.			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA./(WET) #/FT	CLUMP/BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS
1	HCL				1,500	/48.9	0/100K		MAX.								
DIR e	HCL				6,500	/48.9	500/0	0.095	7,880	197.0'	1,115			722'	1,515		
105°	CHAIN				3,200	4/132	—										
(1-9)	PRETENSION 700KIPS																
1	HCL				↓	↓	↓	↓	MAX.								
DIR e	HCL								7,880	272.0'	1,170			818'	1,565		
15°	CHAIN																
(1-17)																	
4	HCL								MAX.								
DIR e	HCL								7,880	370.0	1,330			840	1,935		
60°	CHAIN																
(4-11)																	
4	HCL								MAX.								
DIR e	HCL								7,880	239.0'	1,205			724'	1,595		
150°	CHAIN																
(2-11)																	
1	HCL								MAX.								
DIR e	HCL								7,880	145.0	1,050			6850	1,435		
195°	CHAIN				↓	↓	↓	↓									
(1-14)																	
4	HCL				1,500	/48.9	0/100K		MAX.								
DIR e	HCL				6,000	/48.9	500/0	0.095	7,922	241	1,321			666	1,934		
60°	CHAIN				3,200	4/132	—										
(4-14)	PRETENSION 700 KIPS																

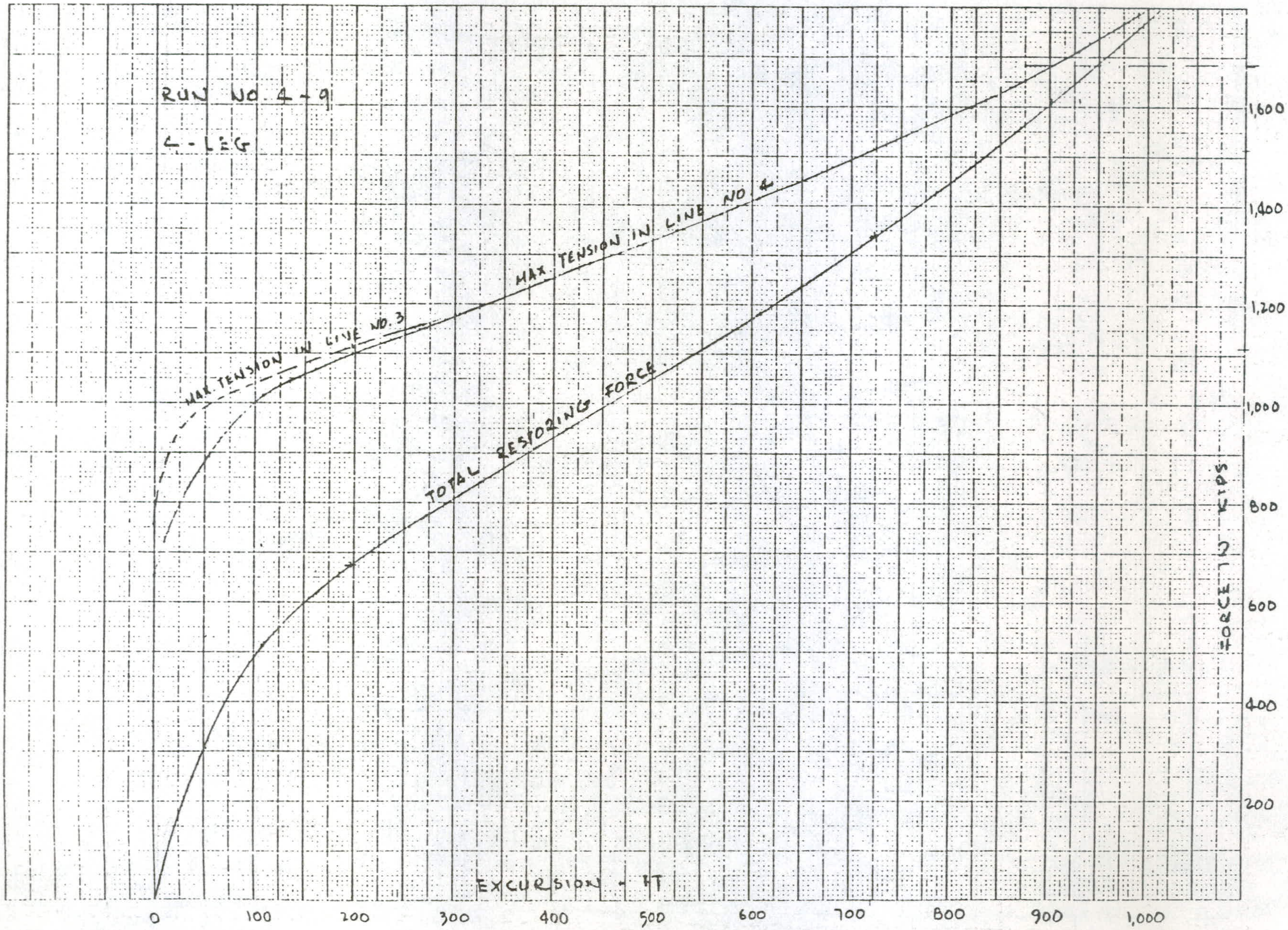

RUN NO. 4-3
4 LEG
Δ FROM F/10 OUTPUT
⊙ FROM F/100 OUTPUT
MAX TENSION IN LINE NO. 3
TOTAL RESTORING FORCE
EXCURSION - FT
FORCE - KIPS
0
100
200
300
400
500
600
700
800
900
1,000
1,100
200
400
600
800
1,000
1,200
1,400
1,600

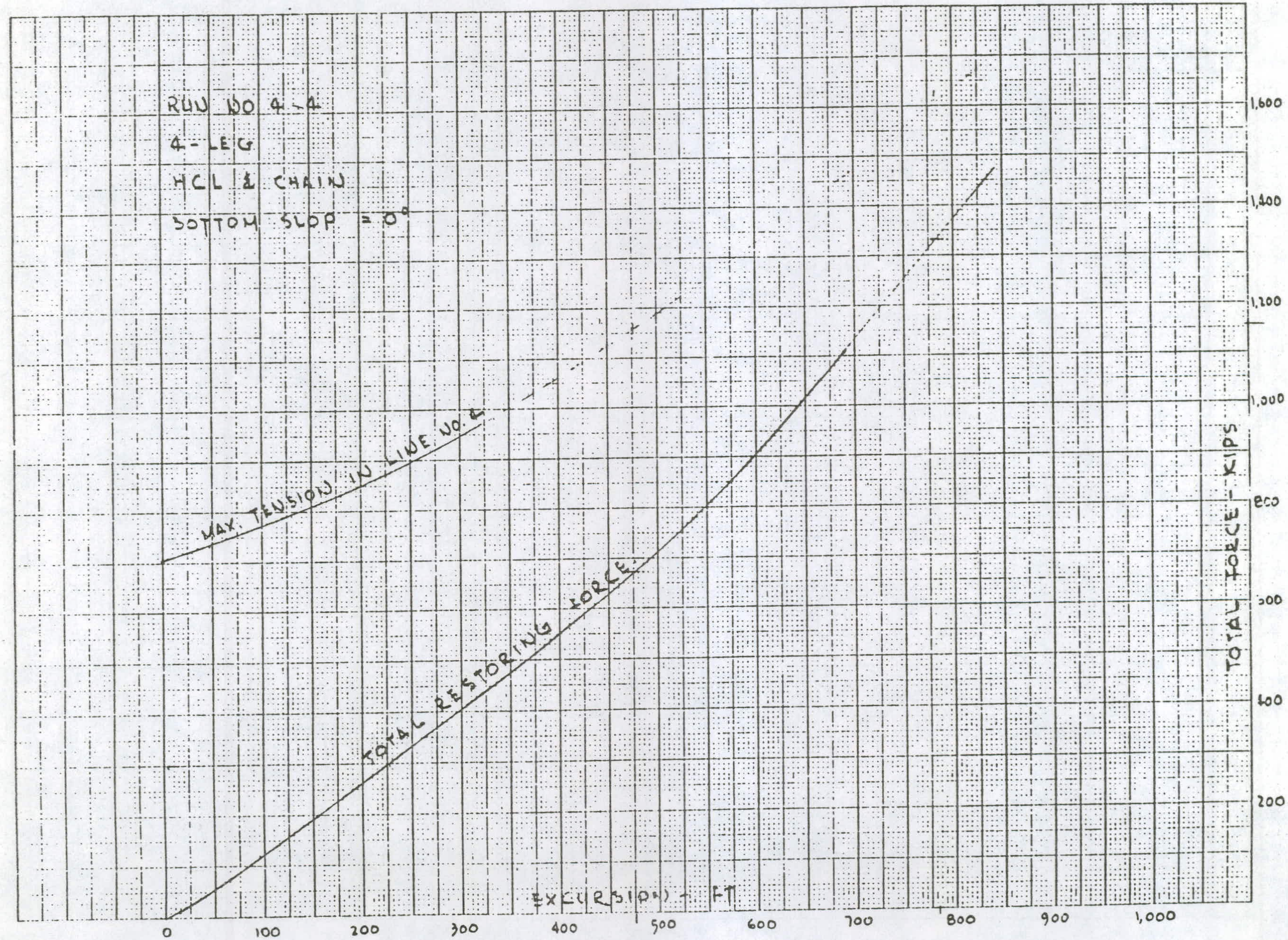
MOORING SYSTEM										SPAR							
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA "/ #/FT	CLUMP/ BUOY	SLOPE AT BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS
4	HCL				7,500	/450	0/0	0.095	MAX. 3,382	164	3,950	1,135	1,047	246	5,100	2,004	7,001
DIR. of e=60°																	
(x-1G)	PRETENSION = 3,000 KIPS																
4 DIR of e=60°	HCL				1,000	/400	0/200	0.095	MAX 4,510	300	3,100	1,129	713	500	3,800	1,602	676
	HCL				6,500	/400	0/0										
(x-1E)	PRETENSION = 2,606 KIPS																

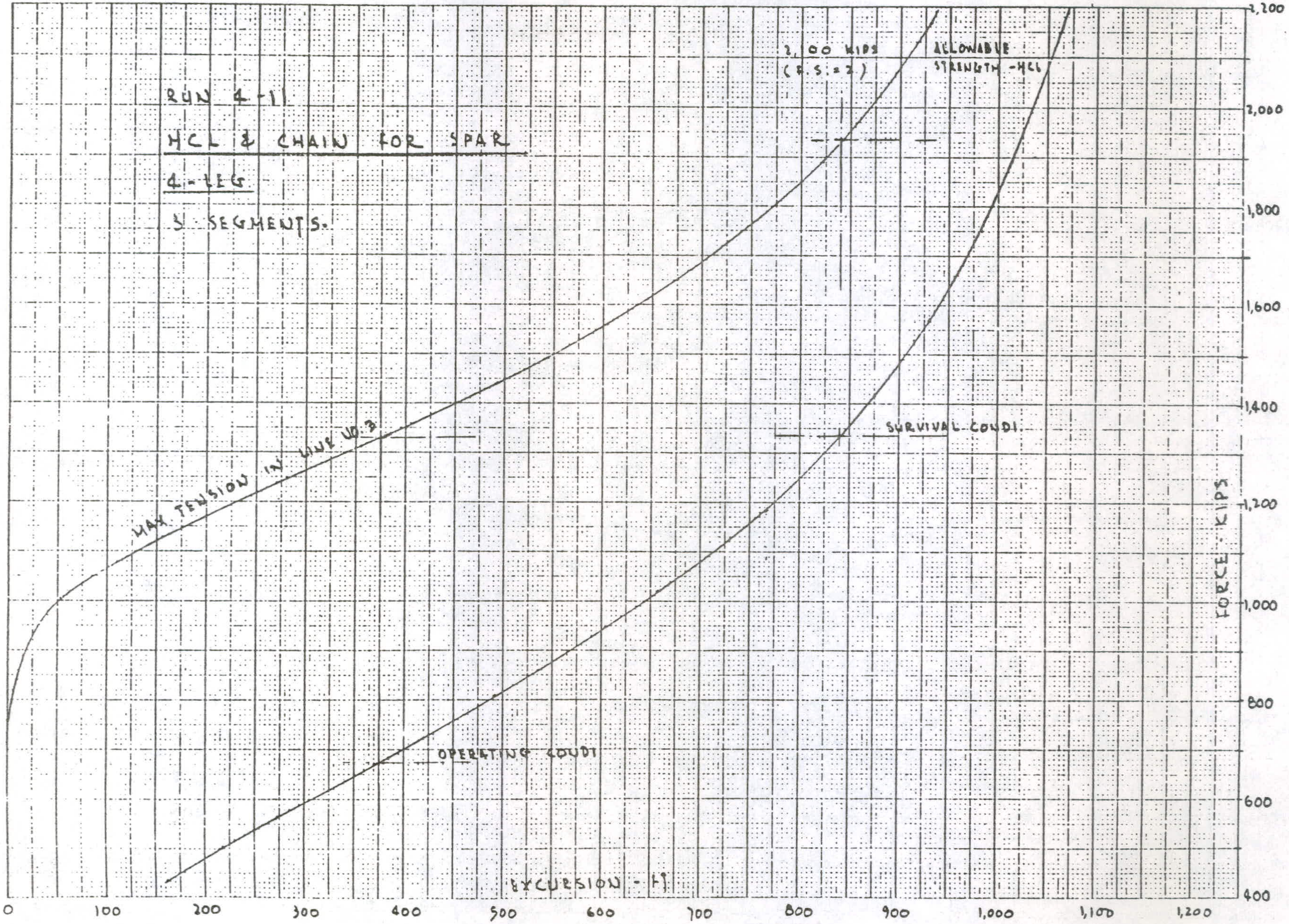

RUN NO. 4-7
4-LEG
MAX TENSION IN LINE NO. 3
TOTAL RESTORING FORCE
EXCURSION - FT
TOTAL FORCE - KIPS
0
100
200
300
400
500
600
700
800
900
1000
1100
200
400
600
800
1,000
1,200
1,400
1,600



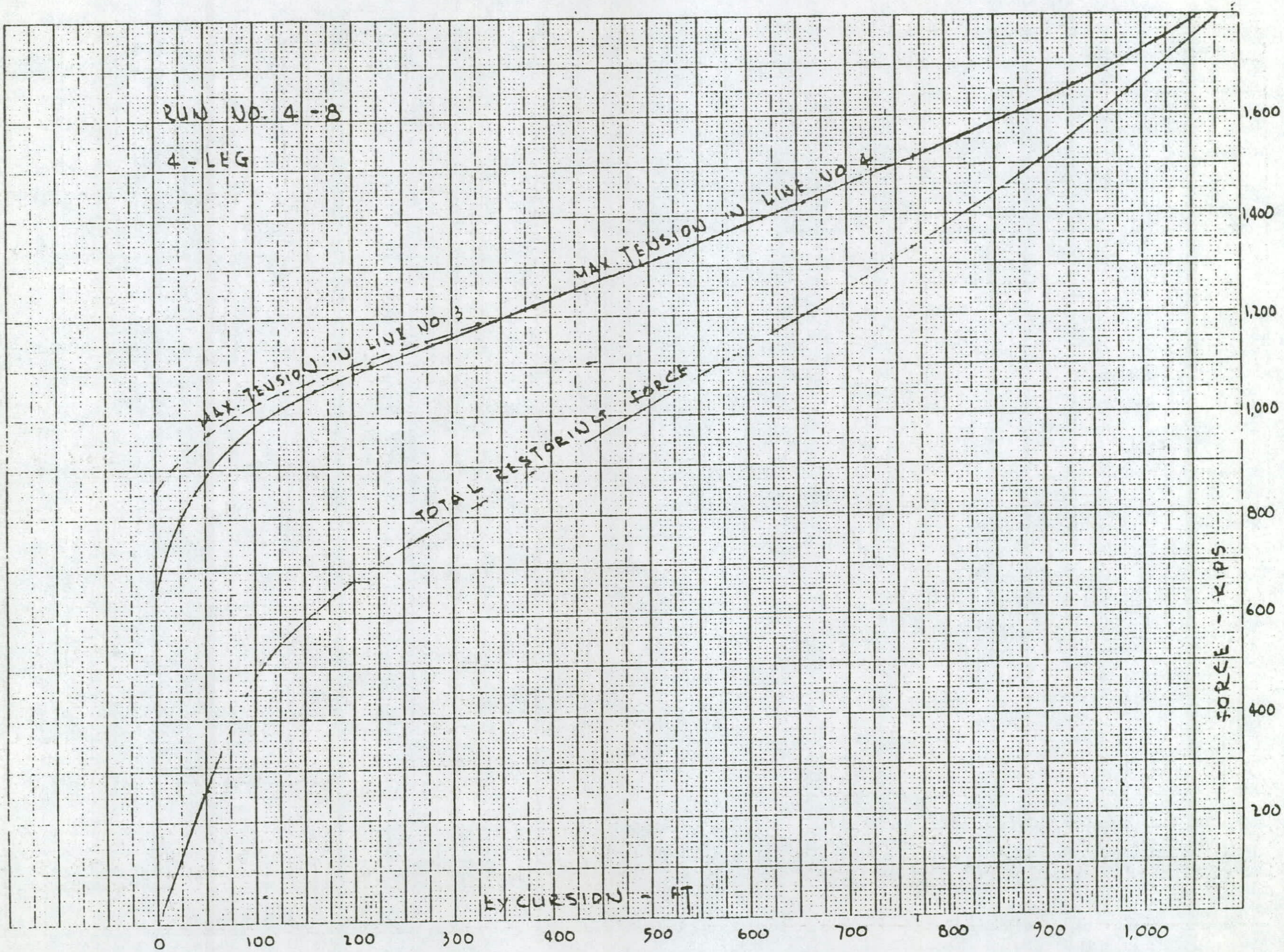
RUN NO. 4-2
4-LEG
MAX. TENSION IN LINE NO. 2
TOTAL RESTORING FORCE
EXCURSION - FT
FORCE - KIPS
0
100
200
300
400
500
600
700
800
900
1,000
200
400
600
800
1,000
1,200
1,400
1,600


RUN NO. 4-9
4-LEG
MAX. TENSION IN LINE NO. 4
MAX. TENSION IN LINE NO. 3
TOTAL RESTORING FORCE
EXCURSION - FT
FORCE IN KIPS
0
100
200
300
400
500
600
700
800
900
1,000
200
400
600
800
1,000
1,200
1,400
1,600


RUN NO 4-4
4-LEG
HCL & CHAIN
BOTTOM SLOP = 0°
MAX. TENSION IN LINE NO.
TOTAL RESTORING FORCE
EXCURSION - FT
TOTAL FORCE - KIPS
0
100
200
300
400
500
600
700
800
900
1,000
200
400
600
800
1,000
1,200
1,400
1,600

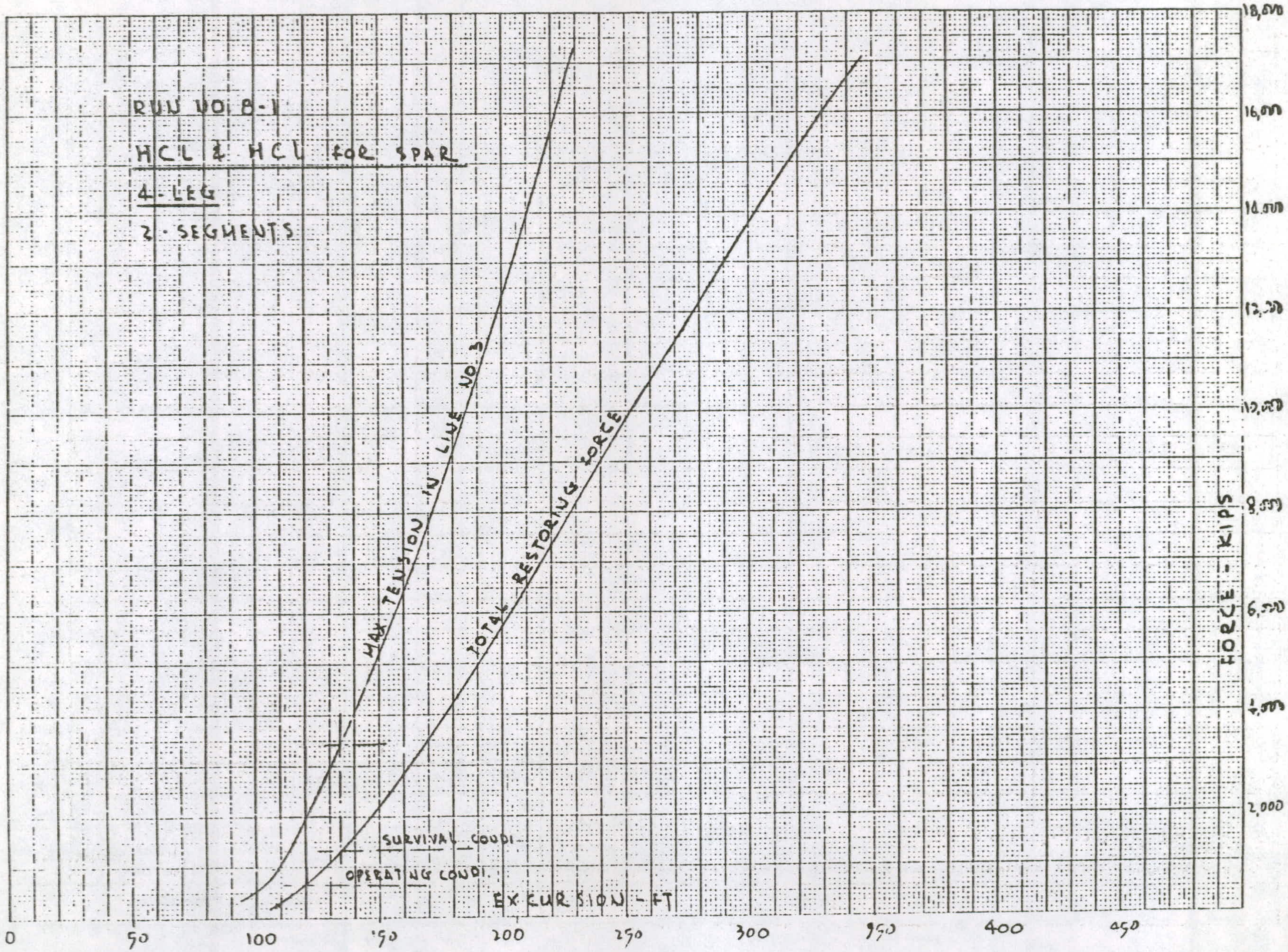


RUN 4-11
HCL & CHAIN FOR SPAR
4-LEG
3 SEGMENTS.
2,100 KIPS
(F.S.=2)
ALLOWABLE
STRENGTH -HCL
MAX. TENSION IN LINE NO.3
SURVIVAL CONDI.
OPERATING CONDI
EXCURSION - FT
FORCE - KIPS
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200



RUN NO. 4 - 8
4 - LEG
MAX TENSION IN LINE NO 4
MAX TENSION IN LINE NO 3
TOTAL RESTORING FORCE
EXCURSION - FT
FORCE - KIPS
0
100
200
300
400
500
600
700
800
900
1,000
200
400
600
800
1,000
1,200
1,400
1,600

MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA." / (WET) #/FT		BOTTOM SLOPE FT/FT	HORI DIST. TO ANCHOR λ - FT	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS
8	KEVLAR		5		1,2,3,7,8: 5,600; 4,5,6: 5,800	6"/4		0	1,2,3,7,8: 1,184; 4,5,6: 1,875	64.5	2,760	772	2,179	73.0	3,680	1,196	3,383
DIR. OF e = 15°																	
RUN-2-1	PRETENSION ON LINES 57,860 TO 81,710# (70,000#)																
8	KEVLAR		5		6,500	6"/4 REVISED SEE 2-3B		0.095	1: 3,972; 2&8: 3,821; 3&7: 3,464; 4&6: 3,125; 5: 2,992	43.0	1,420	595	1,298	51.8	2,280	878	1,924
DIR OF e = 5°																	
RUN 2-2	PRETENSION ON LINES 62,240 TO 79,290# (70,000#)																
8	KEVLAR		5		7,800	6"/4		0.095	1: 5,969; 2&8: 5,929; 3&7: 5,126; 5: 4,994	81.0	1,580	977	1,723	93.5	2,330	1,386	1,670
DIR OF e = 15°																	
RUN 2-3	PRETENSION ON LINES 64,330 TO 76,490# (70,000#)																
8	KEVLAR		5		6,500	6"/4		0	3,463	56.0	900			70.0	1,950		
DIR OF e = 15°																	
RUN 2-4	PRETENSION 76,000#																


RUN NO B-1
HCL & HCL FOR SPAR
4-LEG
2-SEGMENTS
MAX TENSION IN LINE NO 3
TOTAL RESTORING FORCE
SURVIVAL CONDI.
OPERATING CONDI.
EXCURSION - FT
FORCE - KIPS
0
50
100
150
200
250
300
350
400
450
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000

3/20/79

MOORING SYSTEM									SPAR								
										OPERATING CONDI 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA / #/FT	CLUMP KIPS	BUOY KIPS	HORI DIST TO ANCHOR λ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS
									LINE 1 8,020								
3	HCL	4200	2	2100	1000	30/48.71	—	100	LINE 2 & 8 7,880								
D R OF = ± 5° 240 DO. :-1)	HCL	↓	2	↓	6,000	↓	500	—	LINE 3 & 7 7,931	81	1,060	174	0	330	1,290	487	0
	CHAIN	1632	2	8160	3200	4"/152	—	—	LINE 4 & 6 7,177								
		PRETENSION = 700 KIPS							LINE 5 7,031								

MOORING SYSTEM									SPAR								
									HORI. DIST. TO ANCHOR	OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA/(WET) #/FT	CLUMP/BUOY	SLOPE OF BOTTOM	λ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS
8																	
DIR. e	WIRE ROPE				1,000	4.50/21.04	0/20k		MAX								
353°	WIRE ROPE				4,197	4.50/31.04	20/0	0.095	10,536	770	650			1,230	945		
	CHAIN				8,000	331/9046	0										
(6-79)	DEPTH = 5471'				PRETENSION = 359 KIPS												
8																	
DIR. e	WIRE ROPE	2,156	2/3	1078/719	1000	5"/38.35	0/50k		MAX.								
15°	WIRE ROPE	2,156	2/3	1078/719	6,000	5"/38.35	100/0	0.095	7,919	455	710	181	0	835	1,065	669	8
	CHAIN	1,632	2	816	3,200	4"/132											
(6-9)	DEPTH = 5,471'				PRETENSION = 400 KIPS												
8									MAX.								
DIR. e	WIRE ROPE	3156	2/3	1,078/719	1,000	5"/38.35	0/50k		7,919	454	679			831	995		
= 353°	WIRE ROPE	2,156	2/3	1,078/719	6,000	5"/38.35	100/0	0.095									
	CHAIN	1.632	2	816	3,200	4"/132											
(6-10)	DEPTH = 5,471'				PRETENSION = 400 KIPS.												

APRIL 2, 1979

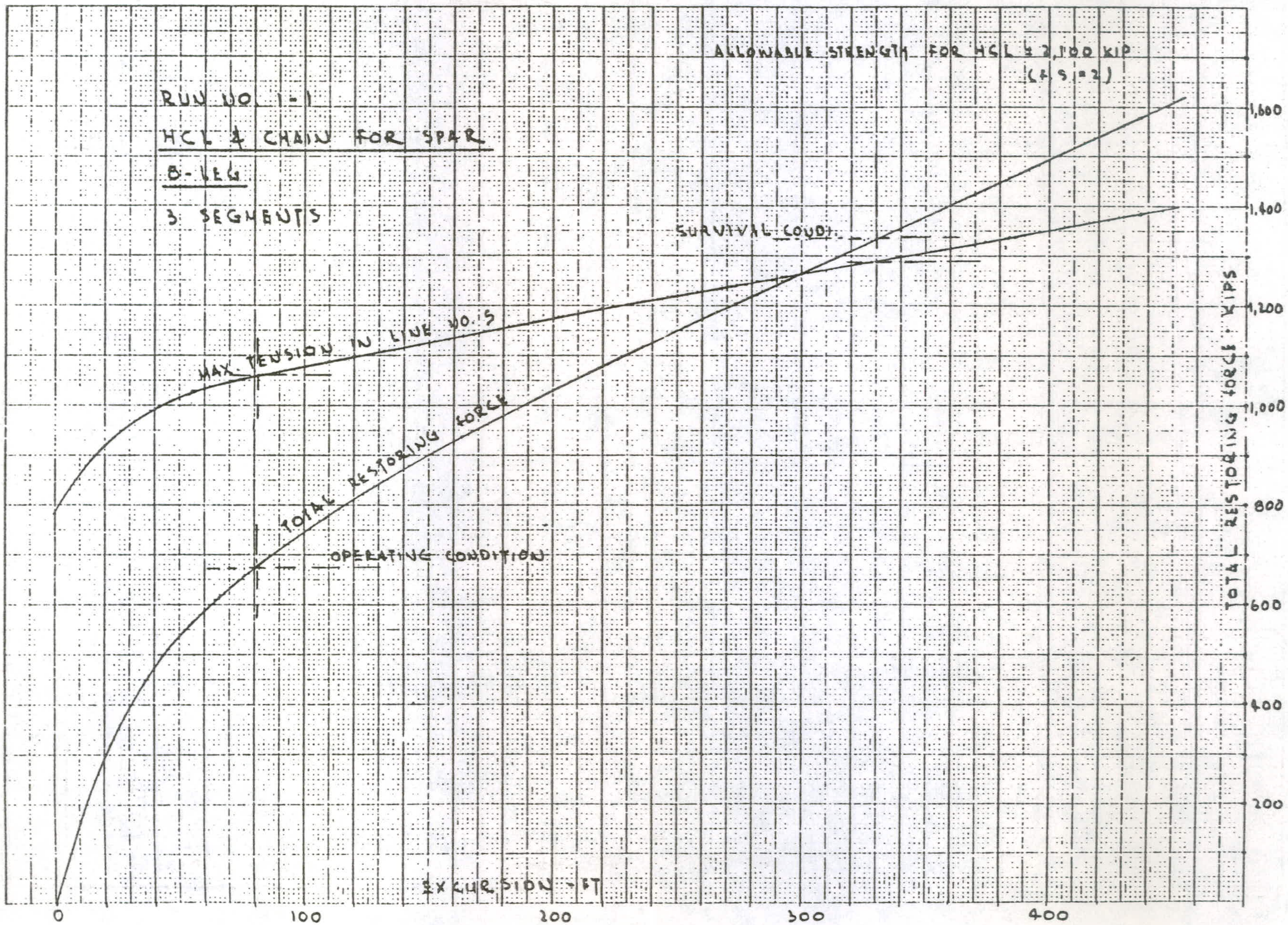
MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA/(WET) #/FT	CLUMP/BUOY	SLOPE AT BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS
8 DIR. OF θ = 60° (2-2B)	KEVLAR	(SAME AS RUN NO. 2-2)							SAME AS RUN 2-2	42.0	1,120		≈	56.0	2,340		
8 DIR OF θ = 15° (2-2C1)	KEVLAR		5		7,500	9.55/10		.095	MAX. 4,982	443.0	1,061			450.0	2,103		
	PRETENSION = 90 KIPS																

MOORING SYSTEM									
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA/(WET) #/FT	CLUMP/BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT
8 DIR. θ = 172°	WIRE ROPE				4,197	4.50/31.04	0/0	0	MAX 9,845
	CHAIN				8000	3.31/90.4			
(6-1)	DEPTH = 4,600'				PRETENSION = 359 KIPS				
8 DIR θ = 172°	WIRE ROPE				4,197	4.50/31.04	0/0	0.095	MAX 10,143
	CHAIN				8,000	3.31/904	0/0		
(6-2)	DEPTH = 4,600'				PRETENSION = 359 KIPS				
8 DIR θ = 353°	WIRE ROPE				↓	↓	↓	↓	MAX
	CHAIN								10,143
(6-4)									
8 DIR θ = 353°	WIRE ROPE				4,197	4.50/31.04	20K/0	0.095	MAX.
	CHAIN				8,000	3.31/904	0/0		10,014
(6-6)	DEPTH 4600'				PRETENSION = 359 KIPS				
8 DIR θ = 353°	WIRE ROPE				1,000	4.50/31.04	0/20K		MAX.
	WIRE ROPE				4,197	4.50/31.04	20K/0	0.095	11,450
	CHAIN				8,000	3.31/904	0/0		
(6-7)	DEPTH 4600				PRETENSION = 359 KIPS				

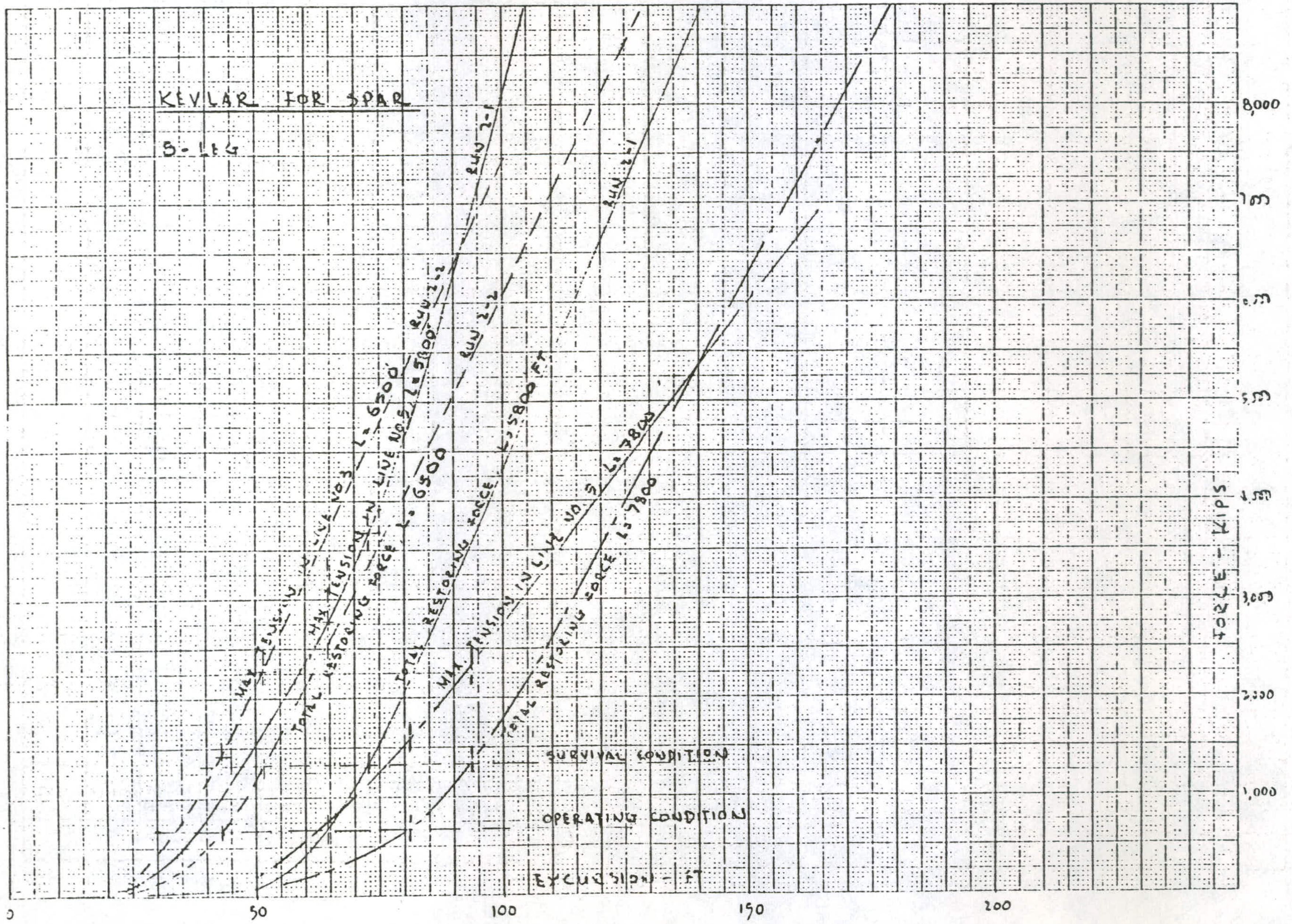
LEG	SPAR: OPERATING CONDI. 673.4 KIPS — e - FT	OPERATING — T_{MAX} - KIPS	OPERATING — PULL ON ANCHOR HORI - KIPS	OPERATING — PULL ON ANCHOR VERT - KIPS	SURVIVAL CONDI. 1,337.6 KIPS — e - FT	SURVIVAL — T_{MAX} - KIPS	SURVIVAL — PULL ON ANCHOR HORI - KIPS	SURVIVAL — PULL ON ANCHOR VERT - KIPS
8 DIR. θ = 172° (6-1)	635	595.0			OUT OF RANGE.			
8 DIR θ = 172° (6-2)	310	928.0			OUT OF RANGE.			
8 DIR θ = 353° (6-4)	615	640.0			990	917		
8 DIR θ = 353° (6-6)	675	640			1,082	960		
8 DIR θ = 353° (6-7)	460	630			770	930		

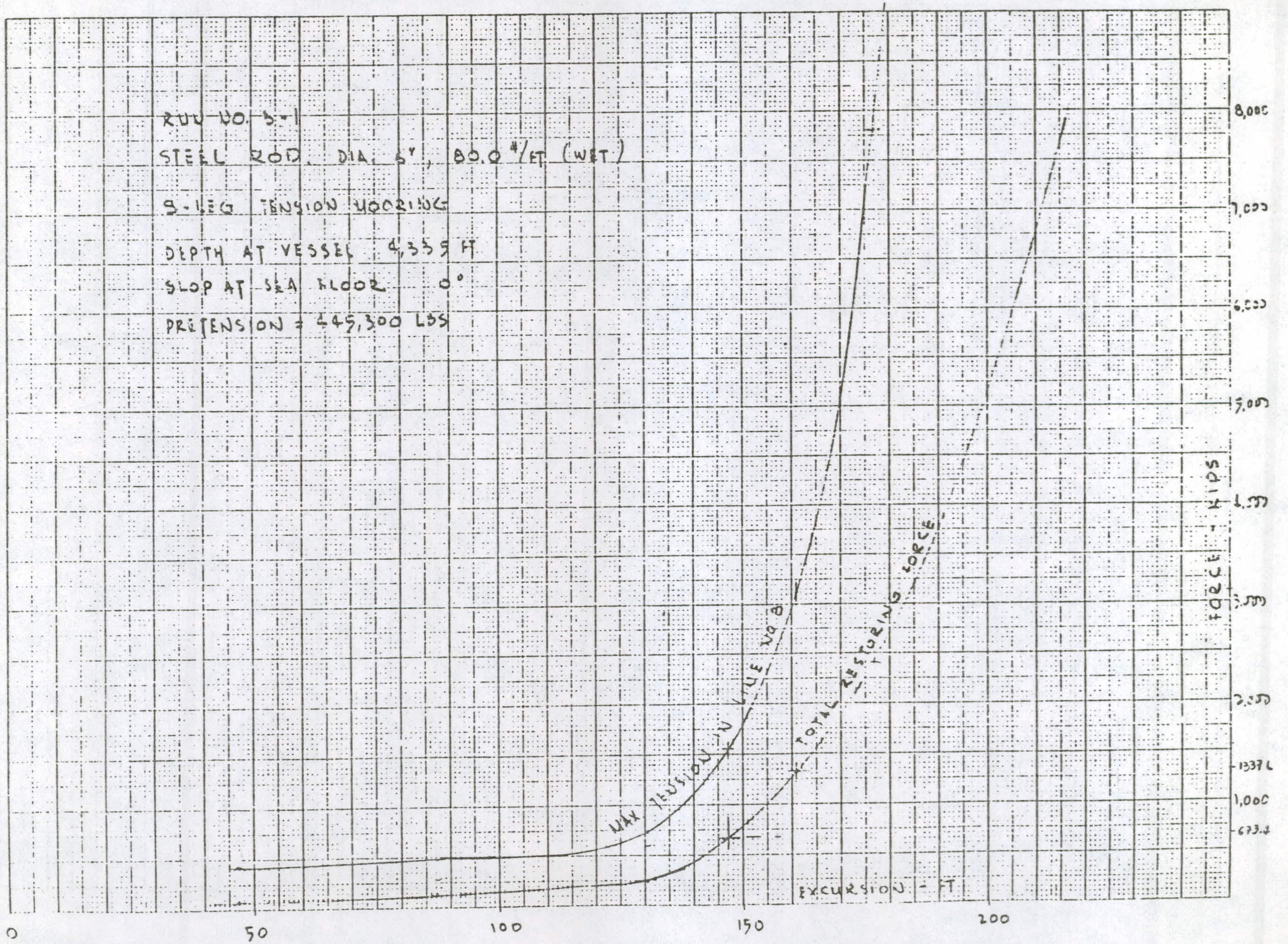
K-E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

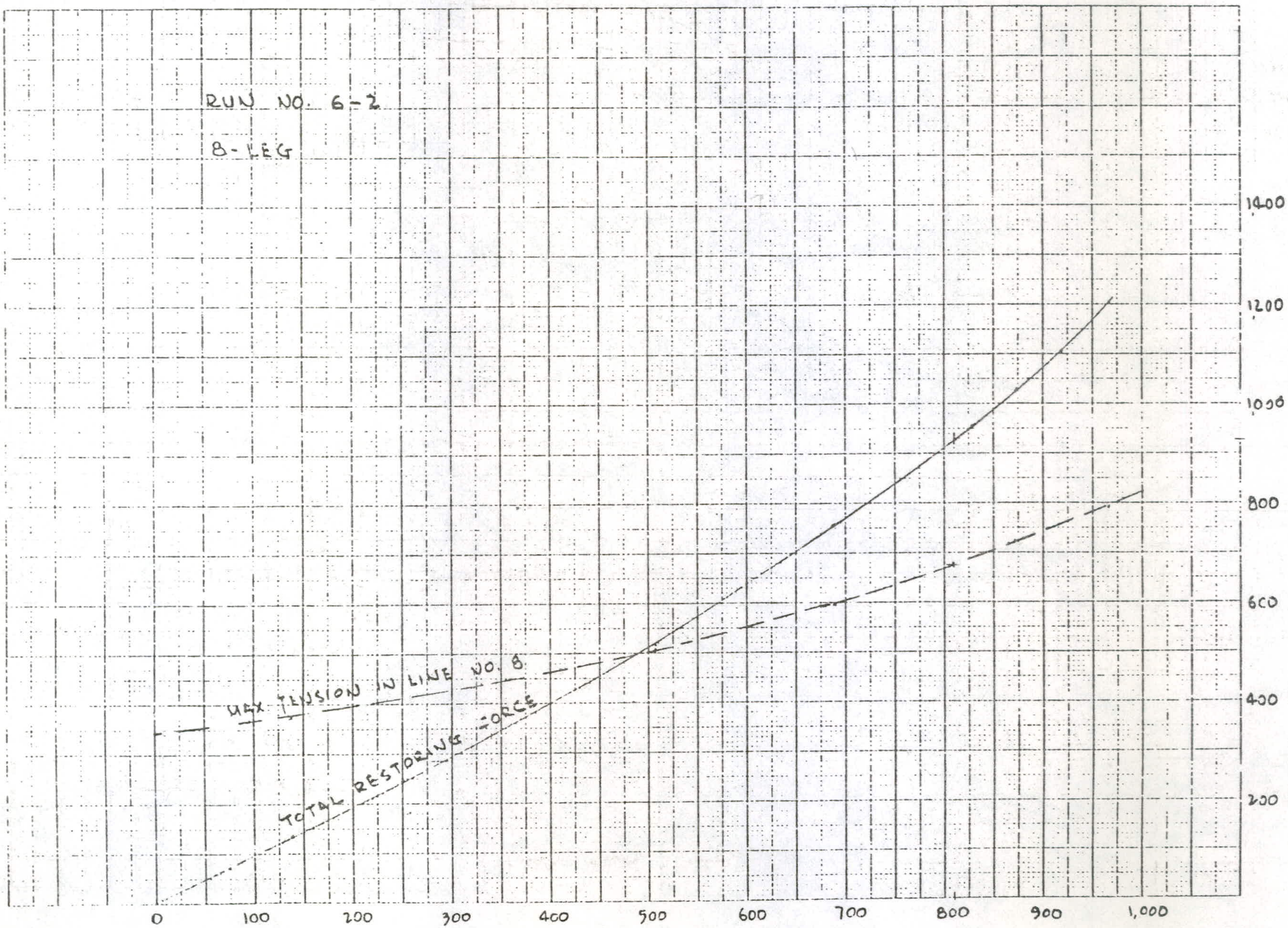
46 1512

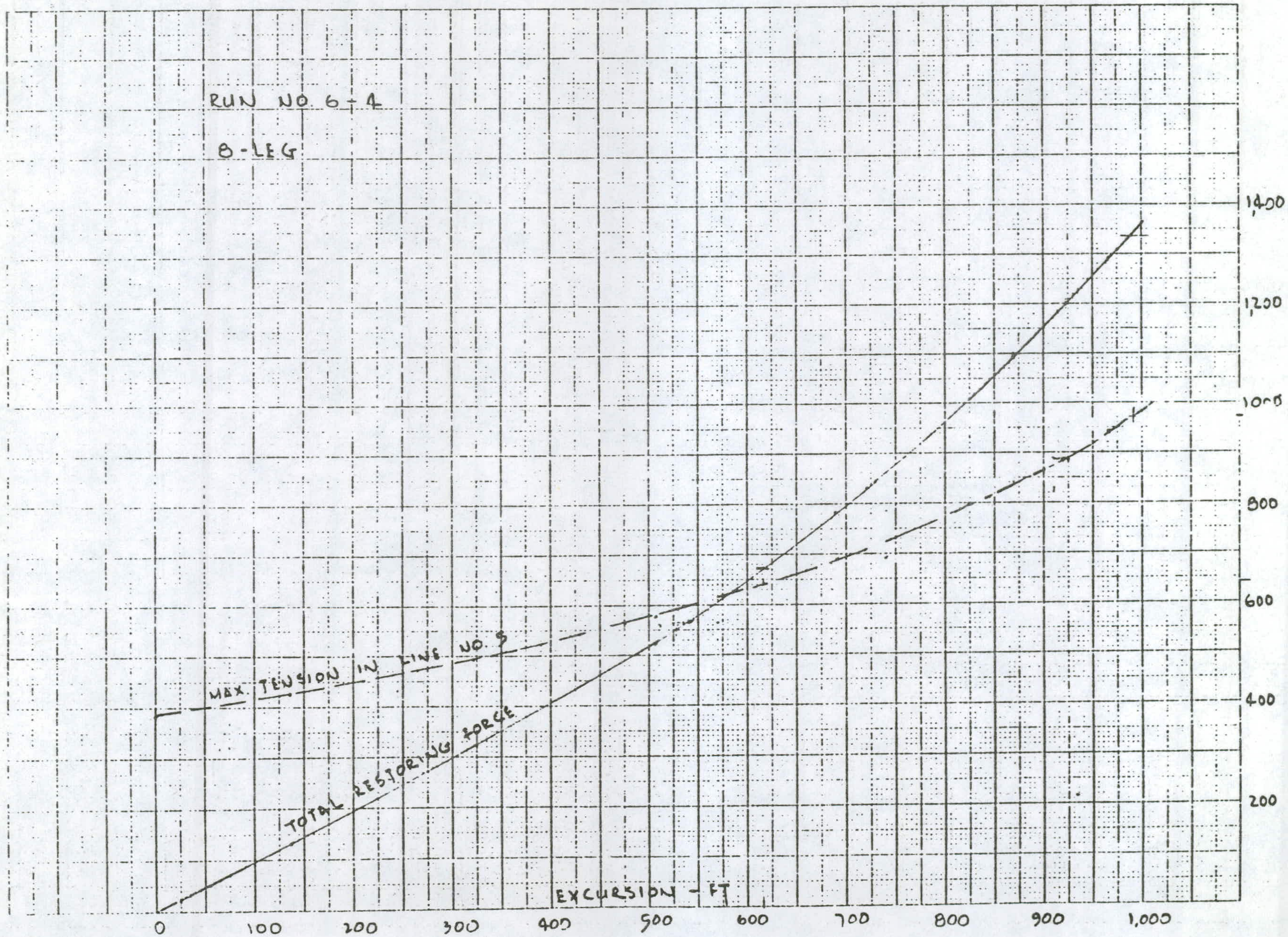


MOORING SYSTEM									SPAR								
										OPERATING CONDI. 673.4 KIPS				SURVIVAL CONDI. 1,337.6 KIPS.			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA/(WET #/FT)	CLUMP/BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS
8	KEVLAR				1,000	6"/-2.1	0/20K		MAX								
DIR θ	KEVLAR				6,000	6"/-2.1	20/0	0.095	12,976	711	446			1,047	808		
= 353°	CHAIN				8,550	3.31/90.4											
(6-8)				PRETENSION = 80 KIPS													


KEVLAR FOR SPAR
3-LEG
RUN 2-1
RUN 2-2
RUN 2-2
RUN 2-1
MAX TENSION IN LINE NO 3 L = 6300'
MAX TENSION IN LINE NO 3 L = 5800'
TOTAL RESTORING FORCE L = 6300
TOTAL RESTORING FORCE L = 5800 FT
MAX TENSION IN LINE NO 3 L = 7800
TOTAL RESTORING FORCE L = 7800
SURVIVAL CONDITION
OPERATING CONDITION
EXCURSION - FT
FORCE - KIPS
0
50
100
150
200
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000

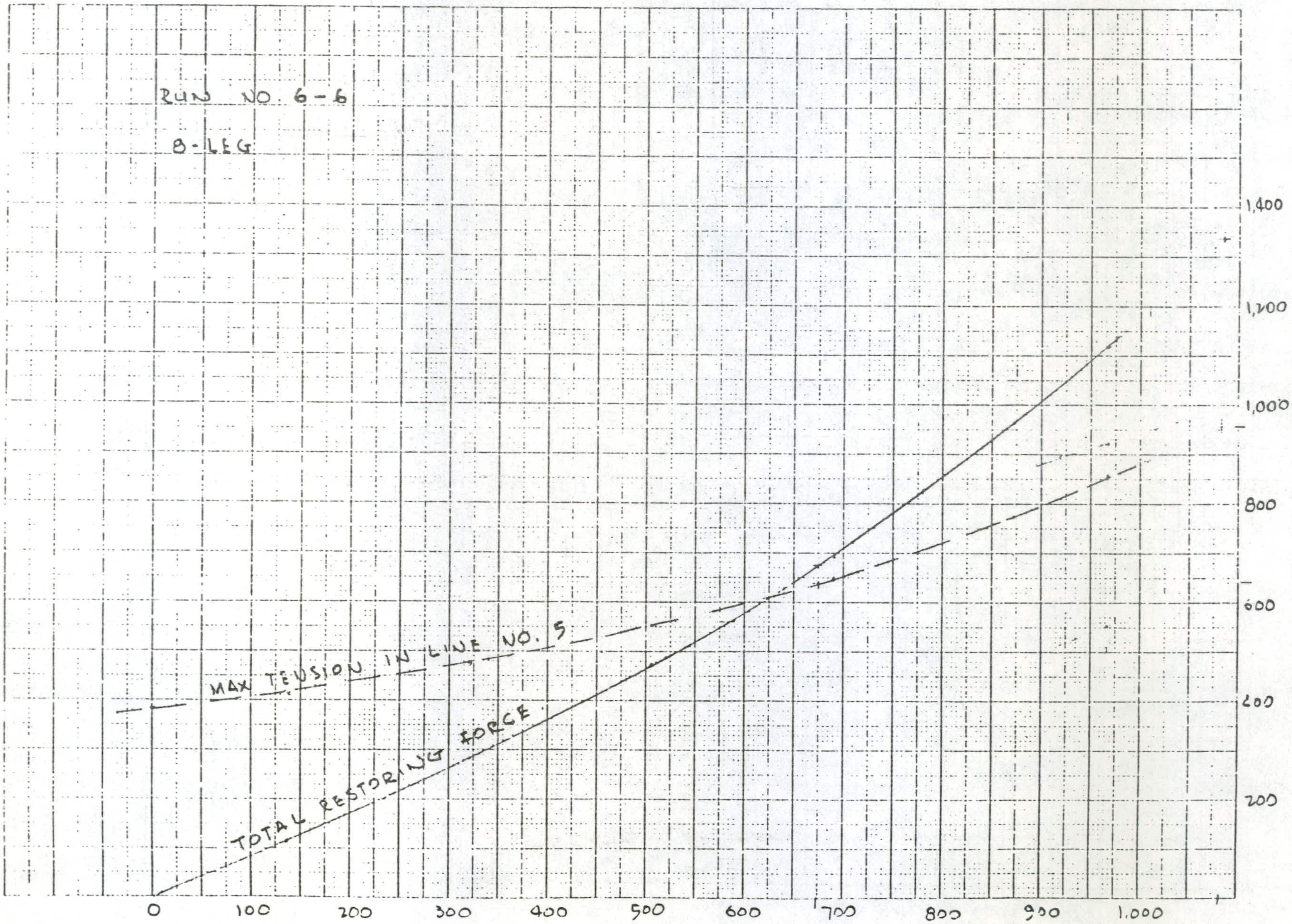

RUN NO. 3-1
STEEL ROD, DIA. 5", 80.0 #/FT (WET)
9-LEG TENSION MOORING
DEPTH AT VESSEL 4,335 FT
SLOP AT SEA FLOOR 0°
PRETENSION = 445,300 LBS
MAX TENSION IN LINE NO. 8
TOTAL RESTORING FORCE
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1337.6
1,000
673.4
FORCE - KIPS
EXCURSION - FT
0
50
100
150
200

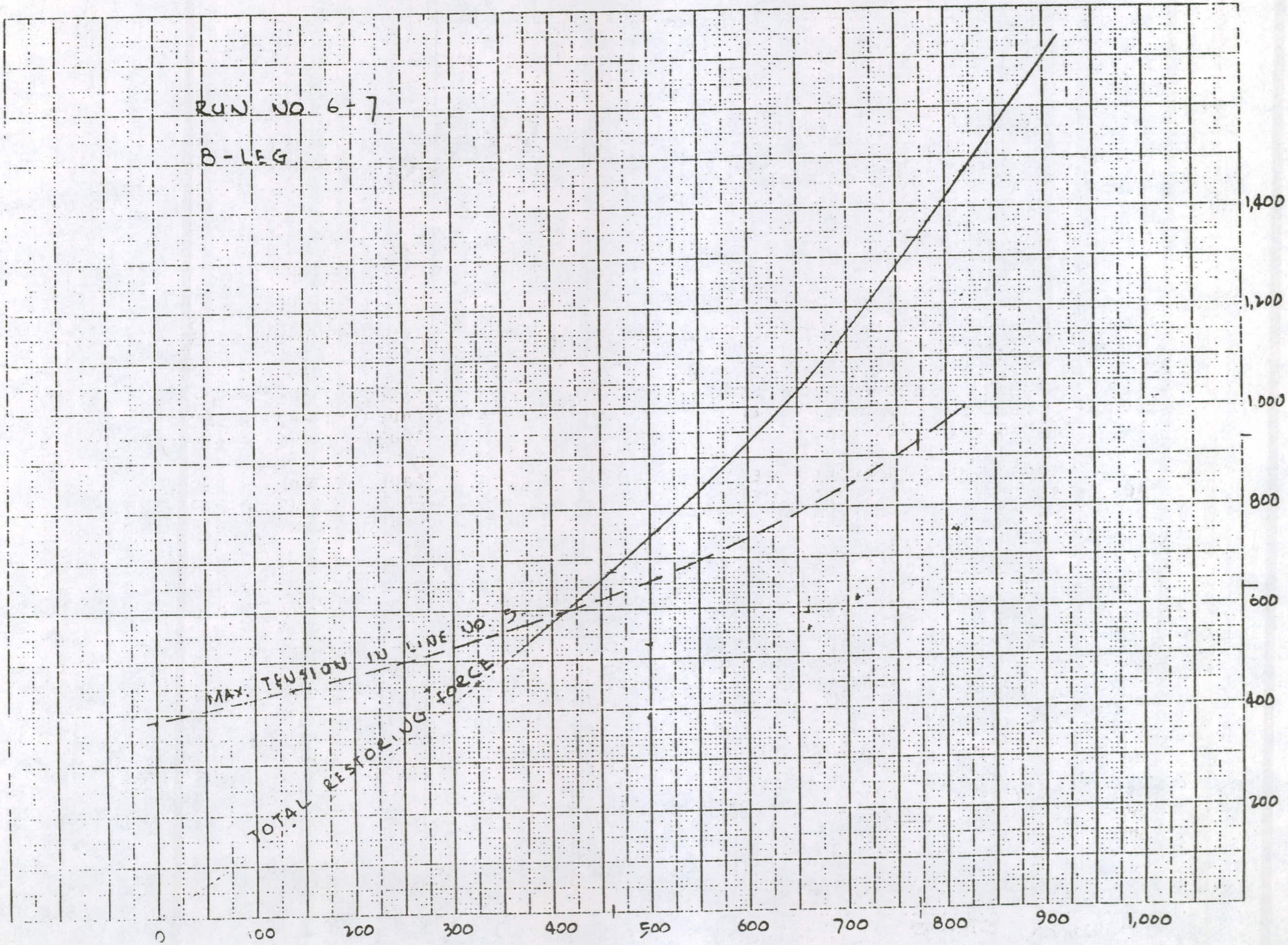

RUN NO. 6-2
8-LEG
MAX TENSION IN LINE NO. 8
TOTAL RESTORING FORCE
1400
1200
1000
800
600
400
200
0
100
200
300
400
500
600
700
800
900
1,000


RUN NO. 6-4
8-LEG
MAX. TENSION IN LINE NO. 5
TOTAL RESTORING FORCE
EXCURSION - FT
0
100
200
300
400
500
600
700
800
900
1,000
200
400
600
800
1000
1,200
1,400

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1512





RUN NO 6-7
B-LEG
MAX. TENSION IN LINE NO 5
TOTAL RESTORING FORCE
1,400
1,200
1,000
800
600
400
200
0
100
200
300
400
500
600
700
800
900
1,000

SPAR – 8 LEG WIRE–CHAIN

NO. 6208
-OTEC-
NO. 6-9 03/13/79 (1/10)

LINE	DIR (DEG)		TYPE	LENGTH (FT)	DIA (IN)	WT IN AIR (LB/FT)	WT SUBMERGED (LB/FT)	ELASTIC MODULUS (LB/IN²)	STRETCH COEFFIC (LB-FT/FT)	CLUMP WEIGHT (LB)	LIFT OR BUOY (LB)
1	15.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
2	60.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
3	105.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
4	150.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
5	195.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
6	240.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
7	285.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.
8	330.	SEG 1	CHAIN	3200.	4.00	15.2	13.2	2900000.	18235200.		
		SEG 2	CABLE	6000.	5.00	4.62	3.83	1500000.	17662500.	10000.	
		SEG 3	CABLE	1000.	5.00	4.62	3.83	1500000.	17662500.		5000.

DEPTH AT VESSEL 5471. FT
SLOPE OF SEA FLOOR .0950 FT/FT
DIRECTION OF SLOPE 195. DEG
DIRECTION OF DISPLACEMENT 15. DEG

NO. 6-9

LINE NO.	DEPTH AT ANCHOR (FT)	HORIZONTAL DISTANCE TO ANCHOR (FT)	SLOPE (FT/FT)	INITIAL TENSION (LB)
1	4713.	7919.	-.0950	36591.
2	4945.	7791.	-.0672	37591.
3	5470.	7478.	-.0000	40099.
4	5949.	7168.	.0672	42692.
5	6133.	7043.	.0950	43771.
6	5949.	7168.	.0672	42692.
7	5470.	7478.	-.0000	40099.
8	4945.	7791.	-.0672	37591.

RESULT OF VESSEL OFFSET

MOST LOADED LINE (1/10)

OFFSET (FT)	LINE NO.	TENSION (LB)	HORIZONTAL FORCE (LB)	LENGTH SUSPENDED (FT)	PULL ON ANCHOR HORIZONTAL (LB)	PULL ON ANCHOR VERTICAL (LB)	TOTAL RESTORING FORCE (LB)
0.0	5	43771.	18750.	7360.	0.0	0.0	0.
54.7	5	46630.	20741.	7513.	0.0	0.0	10264.
109.4	5	49406.	22735.	7657.	0.0	0.0	18660.
164.1	5	52274.	24839.	7803.	0.0	0.0	26757.
218.8	5	55249.	27068.	7951.	0.0	0.0	34403.
273.5	5	58374.	29444.	8103.	1953.6	0.0	41581.
328.2	5	61687.	32004.	8261.	6359.9	0.0	48886.
382.9	5	65224.	34773.	8426.	11159.4	0.0	56427.
437.6	5	68958.	37729.	8597.	16307.6	0.0	64113.
492.3	5	73049.	41016.	8779.	21926.9	0.0	72076.
547.1	5	77303.	44454.	8967.	27761.2	0.0	80326.
601.8	5	82053.	48353.	9169.	34245.4	0.0	89072.
656.5	5	87102.	52531.	9380.	41118.1	0.0	98442.
711.2	5	92471.	57006.	9600.	48406.1	0.0	108181.
765.9	5	98433.	62036.	9837.	56458.7	0.0	118823.
820.6	5	104871.	67511.	10067.	64843.5	253.7	130207.
875.3	5	112185.	73739.	10200.	72537.8	2191.8	142689.
930.0	5	121305.	81455.	10200.	79713.6	6782.6	156893.
984.7	5	133689.	91813.	10200.	89335.5	13059.1	174152.
1039.4	5	151397.	106461.	10200.	102928.5	22094.8	195996.
1094.1	5	178592.	128728.	10200.	123567.8	36066.3	226086.
1148.8	5	222036.	163986.	10200.	156218.7	58520.1	269538.

No. 6-9

OFFSET (FT)	LINE 1	2	3	4	5	6	7	8
	TENSION (LB)							
0.0	36591.	37591.	40099.	42692.	43771.	42692.	40099.	37591.
54.7	32980.	34908.	40113.	44826.	46630.	44826.	40113.	34908.
109.4	30961.	32899.	40154.	46832.	49406.	46832.	40154.	32899.
164.1	28942.	31316.	40221.	48847.	52274.	48847.	40221.	31316.
218.8	27875.	29741.	40316.	50935.	55249.	50935.	40316.	29741.
273.5	26852.	28871.	40438.	53081.	58374.	53081.	40438.	28871.
328.2	25829.	28085.	40587.	55238.	61687.	55238.	40587.	28085.
382.9	25151.	27302.	40763.	57587.	65224.	57587.	40763.	27302.
437.6	24648.	26525.	40966.	59991.	68958.	59991.	40966.	26525.
492.3	24145.	25919.	41197.	62467.	73049.	62467.	41196.	25919.
547.1	23642.	25550.	41449.	65190.	77303.	65190.	41449.	25550.
601.8	23139.	25183.	41678.	67924.	82053.	67924.	41678.	25183.
656.5	22724.	24819.	41928.	70943.	87102.	70943.	41928.	24819.
711.2	22393.	24457.	42200.	74048.	92471.	74048.	42200.	24457.
765.9	22062.	24097.	42493.	77380.	98433.	77380.	42493.	24097.
820.6	21730.	23740.	42808.	80900.	104871.	80900.	42808.	23740.
875.3	21399.	23385.	43144.	84638.	112185.	84638.	43144.	23385.
930.0	21068.	23164.	43501.	88616.	121305.	88615.	43501.	23164.
984.7	20753.	22947.	43880.	92866.	133689.	92866.	43880.	22947.
1039.4	20515.	22731.	44280.	97342.	151397.	97342.	44280.	22731.
1094.1	20277.	22517.	44702.	102218.	178592.	102218.	44702.	22517.
1148.8	20039.	22305.	45144.	107323.	222036.	107323.	45144.	22305.

V0.6-9 OFFSET (FT)	LINE 1	2	3	4	5	6	7	8
	HORIZONTAL COMPONENT OF TENSION (LB)							
0.0	18750.	18750.	18750.	18750.	18750.	18750.	18750.	18750.
54.7	15966.	16743.	18759.	20238.	20741.	20238.	18759.	16743.
109.4	14338.	15212.	18788.	21697.	22735.	21697.	18788.	15212.
164.1	12709.	13983.	18836.	23163.	24839.	23163.	18836.	13983.
218.8	11784.	12761.	18903.	24721.	27068.	24721.	18903.	12761.
273.5	10891.	12042.	18989.	26350.	29444.	26350.	18989.	12042.
328.2	9998.	11384.	19094.	27988.	32004.	27988.	19094.	11384.
382.9	9370.	10729.	19218.	29818.	34773.	29818.	19218.	10729.
437.6	8876.	10077.	19361.	31701.	37729.	31701.	19361.	10077.
492.3	8361.	9553.	19524.	33651.	41016.	33651.	19523.	9553.
547.1	7887.	9204.	19703.	35836.	44454.	35836.	19703.	9204.
601.8	7393.	8858.	19874.	38030.	48353.	38030.	19874.	8858.
656.5	6977.	8513.	20062.	40491.	52531.	40491.	20062.	8513.
711.2	6637.	8171.	20266.	43032.	57006.	43032.	20266.	8171.
765.9	6297.	7831.	20486.	45785.	62036.	45785.	20486.	7831.
820.6	5956.	7493.	20722.	48715.	67511.	48714.	20722.	7493.
975.3	5616.	7158.	20975.	51848.	73739.	51848.	20974.	7158.
930.0	5275.	6935.	21243.	55206.	81455.	55206.	21243.	6935.
984.7	4952.	6716.	21527.	58821.	91813.	58821.	21527.	6716.
1039.4	4706.	6499.	21828.	62647.	106461.	62647.	21828.	6499.
1094.1	4459.	6283.	22144.	66852.	128728.	66852.	22144.	6283.
1148.8	4212.	6069.	22476.	71265.	163986.	71265.	22476.	6069.

NO. 6-9 OFFSET (FT)	LINE 1	2	3	4	5	6	7	8
	SUSPENDED LINE LENGTH (FT)							
0.0	7065.	7102.	7195.	7309.	7360.	7309.	7195.	7102.
54.7	7000.	7028.	7195.	7425.	7513.	7425.	7195.	7028.
109.4	7000.	7000.	7197.	7531.	7657.	7531.	7197.	7000.
164.1	7000.	7000.	7201.	7638.	7803.	7638.	7201.	7000.
218.8	7000.	7000.	7206.	7745.	7951.	7745.	7206.	7000.
273.5	7000.	7000.	7212.	7854.	8103.	7854.	7212.	7000.
328.2	7000.	7000.	7219.	7963.	8261.	7963.	7219.	7000.
382.9	6980.	7000.	7228.	8077.	8426.	8077.	7228.	7000.
437.6	6951.	7000.	7238.	8194.	8597.	8194.	7238.	7000.
492.3	6922.	6996.	7249.	8312.	8779.	8312.	7249.	6996.
547.1	6893.	6986.	7262.	8439.	8967.	8439.	7262.	6986.
601.8	6863.	6977.	7274.	8566.	9169.	8566.	7274.	6977.
656.5	6812.	6967.	7288.	8702.	9380.	8702.	7288.	6967.
711.2	6739.	6958.	7303.	8842.	9600.	8842.	7303.	6958.
765.9	6666.	6949.	7319.	8988.	9837.	8988.	7319.	6949.
820.6	6593.	6939.	7336.	9140.	10067.	9140.	7336.	6939.
875.3	6521.	6930.	7354.	9299.	10200.	9299.	7354.	6930.
930.0	6448.	6884.	7374.	9464.	10200.	9464.	7374.	6884.
984.7	6378.	6837.	7395.	9638.	10200.	9638.	7395.	6837.
1039.4	6322.	6791.	7417.	9819.	10200.	9819.	7417.	6791.
1094.1	6266.	6745.	7440.	10011.	10200.	10011.	7440.	6745.
1148.8	6210.	6699.	7464.	10190.	10200.	10190.	7464.	6699.

SPAR : 4-LEG SOLID LINK

U0 6208
-OTEC SPAR- (1/30)
04704779

NO. 8-1G

LINE	DIR (DEG)		TYPE	LENGTH (FT)	DIA (IN)	WT IN AIR (LB/FT)	WEIGHT SUBMERGED (LB/FT)	ELASTIC MODULUS (LB/IN²)	STRETCH COEFFIC. (LB-FT/FT)
1	60.	SEG 1	CABLE	6500.	1.19	4.8	4.0	29600000.	19742700.
2	150.	SEG 1	CABLE	6500.	1.19	4.8	4.0	29600000.	19742700.
3	240.	SEG 1	CABLE	6500.	1.19	4.8	4.0	29600000.	19742700.
4	330.	SEG 1	CABLE	6500.	1.19	4.8	4.0	29600000.	19742700.

CABLE = HCL

DEPTH AT VESSEL 5471. FT
SLOPE OF SEA FLOOR .0950 FT/FT
DIRECTION OF SLOPE 195. DEG
DIRECTION OF DISPLACEMENT 60. DEG

NO.3-1G

LINE NO.	DEPTH AT ANCHOR (FT)	HORIZONTAL DISTANCE TO ANCHOR (FT)	SLOPE (FT/FT)	INITIAL TENSION (LB)
1	5238.	3382.	-.0672	28756.
2	5661.	2902.	.0672	31538.
3	5661.	2902.	.0672	31538.
4	5238.	3382.	-.0672	28756.

RESULT OF VESSEL OFFSET

(1/100)

	MOST LOADED LINE						TOTAL
OFFSET (FT)	LINE NO.	TENSION (LB)	HORIZONTAL FORCE (LB)	LENGTH SUSPENDED (FT)	PULL ON ANCHOR HORIZONTAL (LB)	PULL ON ANCHOR VERTICAL (LB)	RESTORING FORCE (LB)
0.0	2	31533.	7596.	6500.	7270.5	4083.3	0.
54.7	3	33124.	8595.	6500.	8175.0	5395.0	1834.
109.4	3	35545.	10036.	6500.	9471.5	7402.2	3999.
164.1	3	39237.	12138.	6500.	11353.1	10469.1	6827.
218.8	3	46590.	16110.	6500.	14886.9	16592.6	11462.
273.5	3	69434.	27833.	6500.	25249.5	35657.1	23783.
328.2	3	246033.	115170.	6500.	102081.9	183259.2	111725.
382.9	3	575548.	277212.	6500.	244525.3	458730.6	274381.
437.6	3	912529.	442847.	6500.	390117.6	740448.0	440595.
492.3	3	*******	608715.	6500.	535913.1	********	607034.

HORIZONTAL DISTANCE TO THE ANCHOR EXCEEDS TABLE RANGE, ON OFFSET = 547.1

NO B-1G — TENSION (LB)

OFFSET (FT)	LINE 1	LINE 2	LINE 3	LINE 4
0.0	28756.	31538.	31538.	28756.
54.7	28091.	31553.	33124.	28763.
109.4	27592.	31590.	35545.	28782.
164.1	27094.	31672.	39237.	28815.
218.8	26609.	31777.	46590.	28861.
273.5	26379.	31911.	63434.	28920.
328.2	26079.	32074.	246033.	28992.
382.9	25761.	32267.	575548.	29077.
437.6	25497.	32489.	912524.	29175.
492.3	25254.	32740.	*******	29286.

NO. B-1G — HORIZONTAL COMPONENT OF TENSION (LB)

OFFSET (FT)	LINE 1	LINE 2	LINE 3	LINE 4
0.0	7596.	7596.	7596.	7596.
54.7	7027.	7600.	8595.	7602.
109.4	6571.	7634.	10036.	7618.
164.1	6115.	7681.	12138.	7645.
218.8	5727.	7747.	16110.	7683.
273.5	5408.	7831.	27933.	7731.
328.2	5084.	7934.	115170.	7791.
382.9	4770.	8050.	277212.	7861.
437.6	4493.	8195.	442947.	7941.
492.3	4235.	8354.	608715.	8033.

NO. B-1G — SUSPENDED LINE LENGTH (FT)

OFFSET (FT)	LINE 1	LINE 2	LINE 3	LINE 4
0.0	6500.	6500.	6500.	6500.
54.7	6500.	6500.	6500.	6500.
109.4	6500.	6500.	6500.	6500.
164.1	6500.	6500.	6500.	6500.
218.8	6485.	6500.	6500.	6500.
273.5	6455.	6500.	6500.	6500.
328.2	6426.	6500.	6500.	6500.
382.9	6396.	6500.	6500.	6500.
437.6	6349.	6500.	6500.	6500.
492.3	6293.	6500.	6500.	6500.

B.2 BARGE — CATENARY

4-LEG MOORING SYSTEM

KEVLAR

HCL

HCL & HCL

8-LEG

STEEL ROD

KEVLAR

HCL, HCL & CHAIN

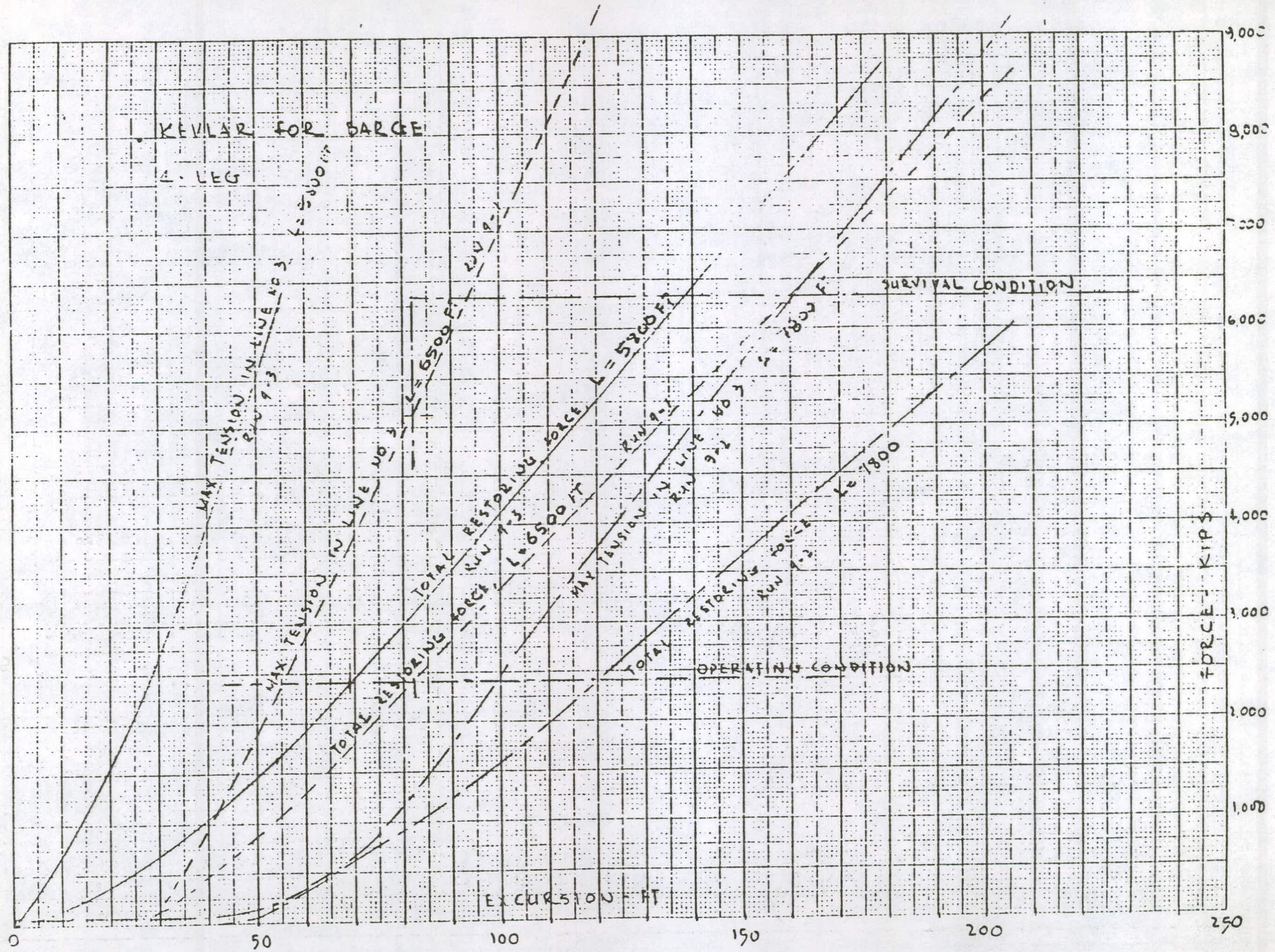
MOORING SYSTEM										BARGE							
										OPERATING CONDI. 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH K.PS	LENGTH FT	DIA	(WET) #/FT	BOTTOM SLOPE FT/FT	HORI DIST. TO ANCHOR λ - FT	e - FT	TMAX - KIPS	HORI - KIPS	VERT - KIPS	e - FT	TMAX - KIPS	HORI - KIPS	VERT - KIPS
4	KEVLAR		5		6,450'			0.095	1 & 4 3,731 2 & 3 3,034	32.0	5,130			160.0	13,400		
CON 4-1	PRETENSION				64,330# TO 77,110#												
4	KEVLAR		5		7,700			0.095	1 & 2 1,686 2 & 3 4,996	120.0	3,760			213.0	9,630		
CON 4-2	PRETENSION				65,860# TO 74,620#												
4	KEVLAR		5		1 & 4 5,500 2 & 3 5,850			0.095	1 & 4 1,859 2 & 3 1,571	69.0	8,150			138.0	OUT OF CHART		
CON 4-3	PRETENSION				68,460# TO 71,610#												

MOORING SYSTEM									BARGE								
										OPERATING CONDI. 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA. / (WET) #/FT	CLUMP / BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS
4 DIR. θ = 60° (7-1)	HCL		2		7,800	/50		0.095	MAX 5,316	471	3,892			540	9,801	6,420	7,011
					PRETENSION = 450 KIPS												
4 DIR. θ = 60° (7-3)	HCL		2		6,500	/50		0.095	MAX. 3,449	298	5,218			352	13,375	APPROX. 7,500	APPROX. 14,500
					PRETENSION = 450 KIPS												

APRIL 2, 1979

MOORING SYSTEM										BARGE							
										OPERATING CONDI. 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA / (WET) #/FT	CLUMP / BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{MAX} - KIPS	HORI - KIPS	VERT - KIPS
						EQU DIA = 6"			MAX.								
4	HCL		2		1,000	/50	0/200	0.095	3,674	193	5,900	23,708	45,099	207	13,650	57,862	93,580
DIR θ = 60°	HCL		2		5,000	/50	0/0										
	PRETENSION = 450 KIPS																
(8-1)																	
						EQU. DIA = 26.2"				CORRECTED EQUIVALENT DIAMETER LARGER MADE LINE MORE STIFF							
4	HCL		2		1,000	/50	0/200		MAX	THIS MADE TENSION JUMP. PUTTING T OUT OF LIMIT OF OUTPUT							
DIR θ = 60°	HCL		2		5,500	/50	0/0	0.095	3,495	ORIGINAL D HCL = 6" } equivalent							
										Corrected D HCL = 26.2"							
(8-1A)	PRETENSION = 375.8 KIPS																
									MAX								
4	HCL		2		1,000	/50	0/200	0.095	4,636	608	3,843			620	9,914		
DIR θ = 60°	HCL		2		6,500	/50	0/0										
(8-1B)	PRETENSION = 325.8 KIPS.																
									MAX								
4	HCL		2		1,000	/200	0/200	0.095	4,508	680	4357			679	10,446		
DIR θ = 60°	HCL		2		6,500	/200	0/0										
(8-1C)	PRETENSION = 1,300 KIPS.																
									MAX								
4	HCL		2		1,000	/600	0/200	0.095	4,508	510	5,752			690	11,682		
DIR θ = 60°	HCL		2		6,500	/600	0/0										
(8-1D)	PRETENSION = 3,900 KIPS																

MOORING SYSTEM									BARGE								
										OPERATING CONDI. 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA./(WET) #/FT	CLUM/BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS	e - FT	T_{max} - KIPS	HORI - KIPS	VERT - KIPS
									MAX								
4	HCL		2		1,000	/400	0/200	0.095	4,510	626	5,100.5			712	11,023		
DIR θ = 60°	HCL		2		6,500	/400	0/0										
(9-1E)		PRETENSION = 2,606 KIPS															


KEVLAR FOR BARGE
4 - LEG
SURVIVAL CONDITION
OPERATING CONDITION
MAX TENSION IN LINE NO 3 RUN 9-3 L=5800 FT
MAX TENSION IN LINE NO 3 L=6500 FT
TOTAL RESTORING FORCE L=5800 FT RUN 9-3
TOTAL RESTORING FORCE L=6500 FT RUN 9-1
MAX TENSION IN LINE NO 3 RUN 9-2 L=1800 FT
TOTAL RESTORING FORCE RUN 9-2 L=1800
EXCURSION - FT
FORCE - KIPS
0
50
100
150
200
250
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000

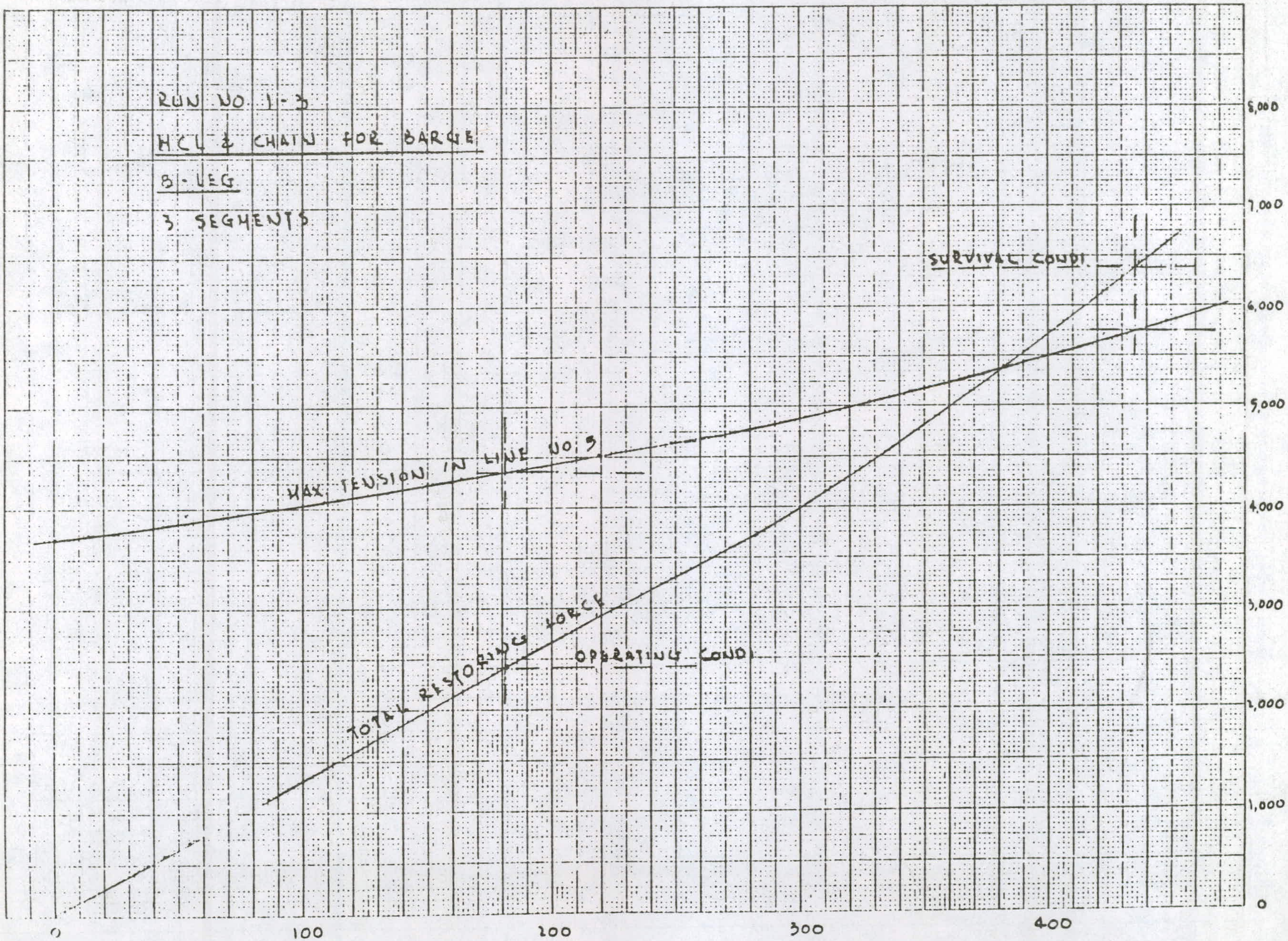
MOORING SYSTEM									BARGE								
										OPERATING CONDI. 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA / WET #/FT		BOTTOM SLOPE	HORI. DIST. TO ANCHOR λ - FT	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS
8	KEVLAR		5		1,2,3,7,8 : 5,600' ; 4,5,6 : 5,850	6"/4 #/FT		0	1,2,3,7,8 : 1,184 ; 4,5,6 : 1,875	83.0	5,150	17,398	1,387	118.0	11,620	3,683	?
RUN 2-1	PRETENSION ON LINES = 57,860# TO 61,710#																
8	KEVLAR		9		6,500 (70000)	6"/4 #/FT		0.095	1 : 3,972 ; 2,8 : 3,821 ; 3,7 : 3,462 ; 4,6 : 3,125 ; 5 : 2,992	63.5	3,560	1,351	2,968	103.0	7,770	2,947	6,496
RUN 2-2	PRETENSION ON LINES : 62,220# TO 79,890#																
8	KEVLAR		9		7,850 (73000 lb)	6"/4 #/FT		0.095	1 : 5,962 ; 2,8 : 5,829 ; 3,7 : 5,606 ; 5 : 5,446	108.0	3,280	1,859	4,222	150.1	6,050	3,390	4,112
RUN 2-3	PRETENSION ON LINES : 64,330 TO 76,490#																

3/20/79

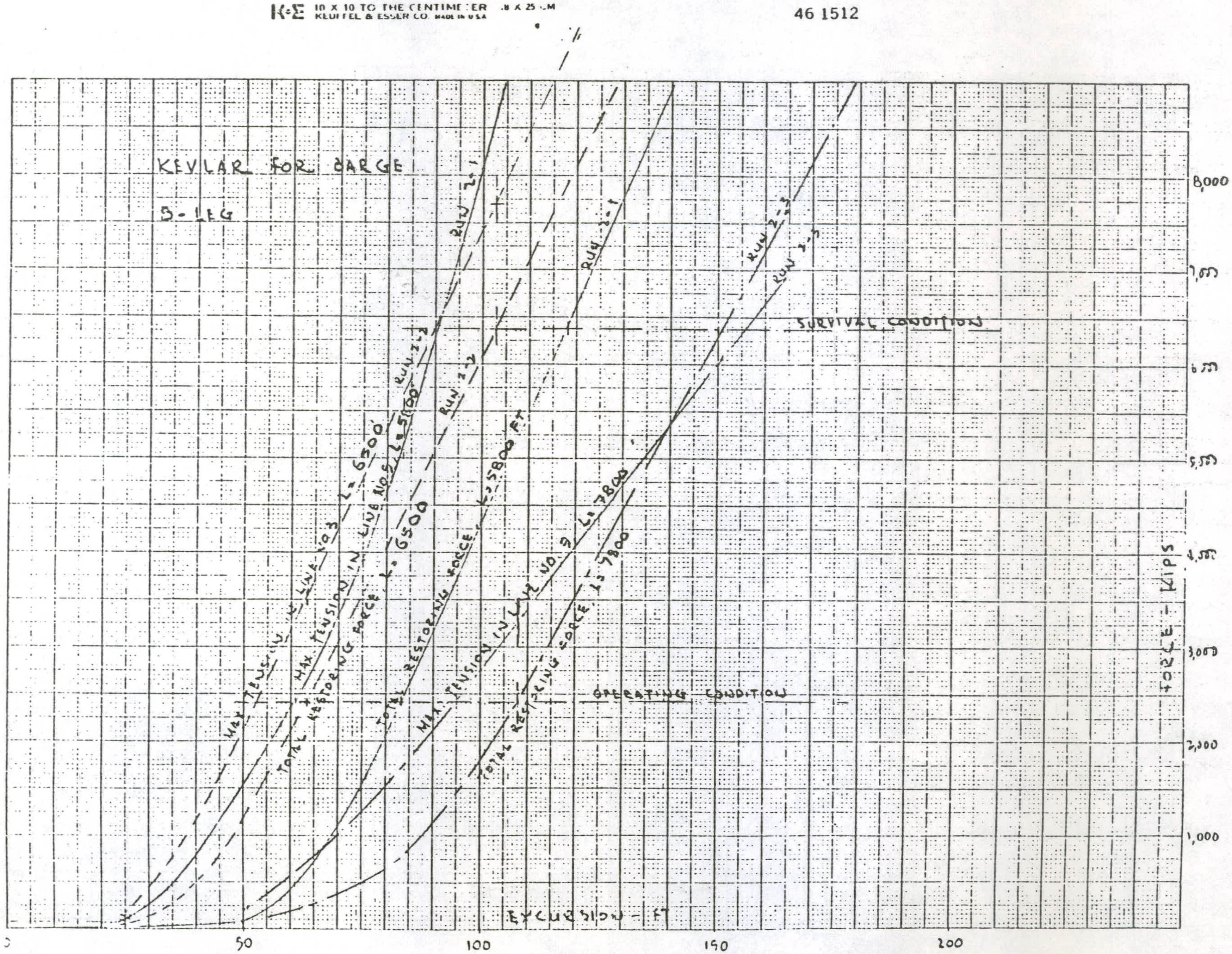
MOORING SYSTEM									BARGE								
										OPERATING CONDI 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
												PULL ON ANCHOR				PULL ON ANCHOR	
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT		CLUMP KIPS	BUOY KIPS	HORI DIST. TO ANCHOR λ - FT	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS	e - FT	Tmax - KIPS	HORI - KIPS	VERT - KIPS
					TOO LONG				LINE 1 16,146								
8	HCL		2		1,000		—	300	LINE 2&8 16,036								
(DIR OF α = 15°	HCL		2		8,000		900	—	LINE 3&7 15,729	181	4,350	3,370	43	435	5,750	4,666	355
RUN NO	CHAIN		2		3,000		—	—	LINE 4&6 15,368								
1-3)	PRETENSION 1,500 KIPS.								LINE 5 15,209								
8	HCL		2		1,000		—	300	ABOUT					OVER THE			
(DIR OF α = 15°	HCL		2		5,000		900	—	6,000	600	2,000			OUTPUT LIMIT			
RUN NO	CHAIN		2		3,200		—	—						(REVISED USE RUN 1-3)			
1-2)	PRETENSION 1,500KIPS																

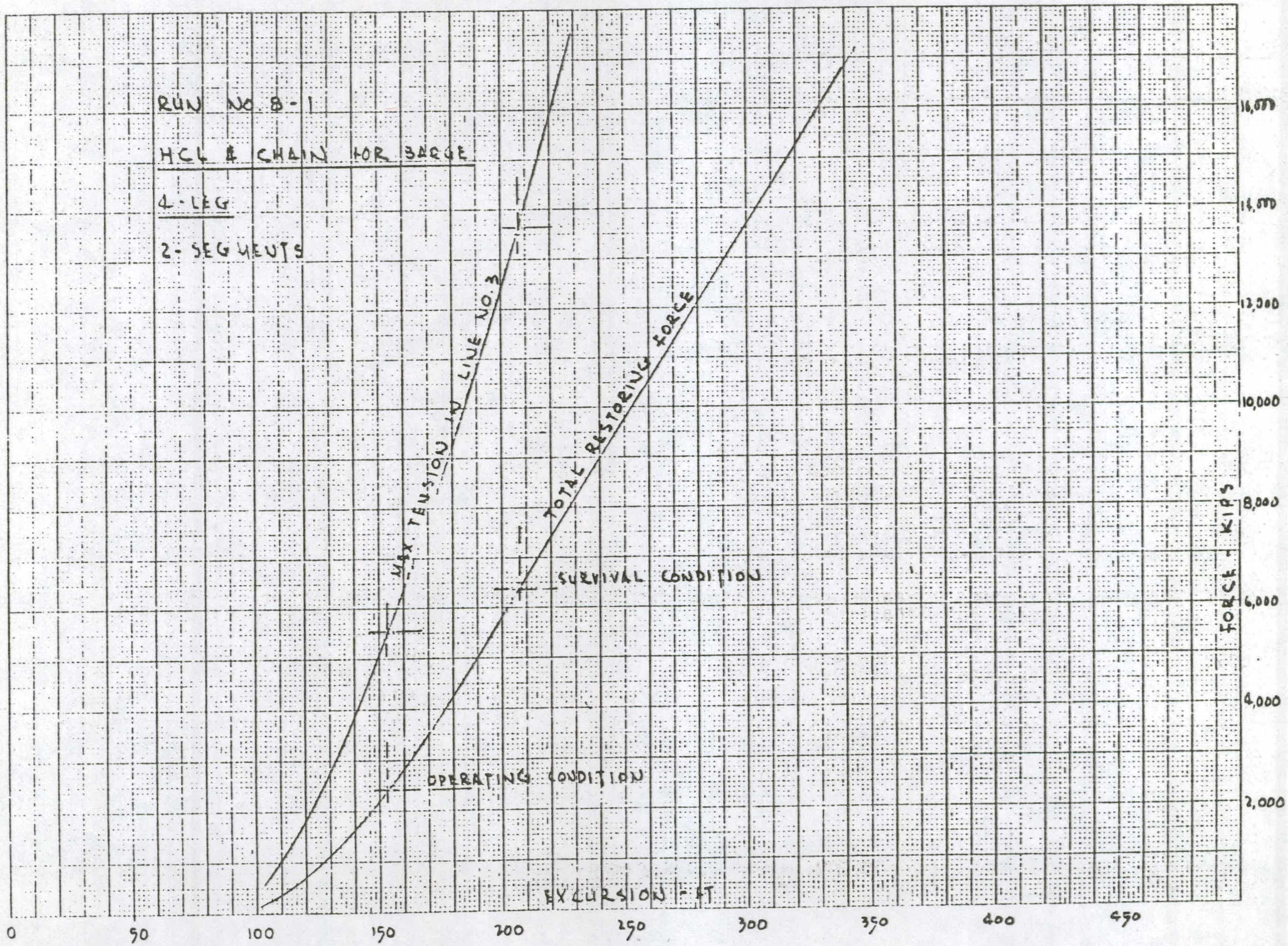
4/9/79

MOORING SYSTEM									BARGE								
LEG	MATERIAL	BREAKING STRENGTH KIPS	FACTOR OF SAFETY	ALLOWABLE STRENGTH KIPS	LENGTH FT	DIA./(WT) #/FT	CLUM/BUOY	SLOPE OF BOTTOM	HORI. DIST. TO ANCHOR λ - FT	OPERATING CONDI. 2,416.3 KIPS				SURVIVAL CONDI. 6,392.7 KIPS			
										e - FT	Tmax - KIPS	PULL ON ANCHOR HORI - KIPS	PULL ON ANCHOR VERT - KIPS	e - FT	Tmax - KIPS	PULL ON ANCHOR HORI - KIPS	PULL ON ANCHOR VERT - KIPS
4	HCL		2		1,000	/400	0/200	0.095	MAX 4,510	626	5,100.5	2,464	1,623	717	12,000	7,000	6,400
DIR. E = 60°	HCL		2		6,500	/400	0/0										
(3-1E)		PRETENSION = 2,606 KIPS															
8	HCL		2		7500	/[illegible]	0/0	0.095	4557	274	[illegible]	2,273	297	568	9400	3,817	1,801
DIR. C = 60°																	
[illegible]		[illegible]		[illegible] = 6400 kips													



RUN NO. 1-3
HCL & CHAIN FOR BARGE
8-LEG
3 SEGMENTS
SURVIVAL COND.
MAX. TENSION IN LINE NO. 5
TOTAL RESTORING FORCE
OPERATING COND.
0
100
200
300
400
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0


K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1512
KEVLAR FOR BARGE
3-LEG
RUN 2-1
RUN 2-1
RUN 2-2
RUN 2-2
RUN 2-3
RUN 2-3
SURVIVAL CONDITION
OPERATING CONDITION
MAX TENSION IN LINE NO 3 L= 6500'
MAX TENSION IN LINE NO 3 L= 5800
TOTAL RESTORING FORCE L= 6500
TOTAL RESTORING FORCE L= 5800 FT
MAX TENSION IN LINE NO 3 L= 7800
TOTAL RESTORING FORCE L= 7800
EXCURSION - FT
FORCE - KIPS
0
50
100
150
200
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000


RUN NO. 8-1
HCL & CHAIN FOR BARGE
4-LEG
2-SEGMENTS
MAX TENSION IN LINE NO. 3
TOTAL RESTORING FORCE
SURVIVAL CONDITION
OPERATING CONDITION
EXCURSION - FT
FORCE - KIPS
0
50
100
150
200
250
300
350
400
450
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000

BARGE 4 LEG HCL (400 #/FT)

NO. 6208

-OTEC-

NO. 9-1 E 03/31/77 (1/100)

LINE	DIR. (DEG)		TYPE*	LENGTH (FT)	DIA. (IN)	WT. IN AIR (LB/FT)	WT SUBMERGED (LB/FT)	ELASTIC MODULUS (LB/IN²)	STRETCH COEFFIC (LB-FT/FT)	LIFT OF BUOY (LB)
1	60.	SEG 1	CABLE	6500.	2.62	4.8	4.0	29600000.	95700719.	
		SEG 3	CABLE	1000.	2.62	4.82	4.00	29600000.	95700719.	2000.
2	150.	SEG 1	CABLE	6500.	2.62	4.8	4.0	29600000.	95700719.	
		SEG 3	CABLE	1000.	2.62	4.82	4.00	29600000.	95700719.	2000.
3	240.	SEG 1	CABLE	6500.	2.62	4.8	4.0	29600000.	95700719.	
		SEG 3	CABLE	1000.	2.62	4.82	4.00	29600000.	95700719.	2000.
4	330.	SEG 1	CABLE	6500.	2.62	4.8	4.0	29600000.	95700719.	
		SEG 3	CABLE	1000.	2.62	4.82	4.00	29600000.	95700719.	2000.

*CABLE = HCL

DEPTH AT VESSEL 5471. FT

SLOPE OF SEA FLOOR .0950 FT/FT

DIRECTION OF SLOPE -195. DEG

DIRECTION OF DISPLACEMENT 60. DEG

NO. 8-1E

LINE NO.	DEPTH AT ANCHOR (FT)	HORIZONTAL DISTANCE TO ANCHOR (FT)	SLOPE (FT/FT)	INITIAL TENSION (LB)
1	5159.	4510.	-.0672	25000.
2	5738.	4100.	.0672	27119.
3	5738.	4100.	.0672	27119.
4	5159.	4510.	-.0672	25000.

RESULT OF VESSEL OFFSET

MOST LOADED LINE (1/100)

OFFSET (FT)	LINE NO.	TENSION (LB)	HORIZONTAL FORCE (LB)	LENGTH SUSPENDED (FT)	PULL ON ANCHOR HORIZONTAL (LB)	PULL ON ANCHOR VERTICAL (LB)	TOTAL RESTORING FORCE (LB)
0.0	2	27119.	8009.	7340.	7321.1	0.0	0.
54.7	3	27629.	8472.	7429.	8131.3	0.0	1096.
109.4	3	28271.	9055.	7455.	8793.7	341.4	2314.
164.1	3	29443.	9648.	7477.	9444.6	709.0	3509.
218.8	3	29546.	10241.	7499.	10095.6	1076.6	4662.
273.5	3	30522.	11093.	7500.	10897.9	1783.5	6075.
328.2	3	31667.	11957.	7500.	11707.7	2507.3	7502.
382.9	3	33125.	13107.	7500.	12781.6	3523.9	9191.
437.6	3	34791.	14400.	7500.	13988.2	4688.3	10987.
492.3	3	37255.	16236.	7500.	15695.0	6419.9	13328.
547.1	3	40699.	18729.	7500.	18007.7	8850.1	16329.
601.8	3	46315.	22664.	7500.	21649.4	12832.8	20774.
656.5	3	57095.	29996.	7500.	28415.5	20515.7	28566.
711.2	3	95485.	55277.	7500.	51677.2	48032.0	54312.
765.9	3	736663.	468762.	7500.	431362.4	509632.6	468270.

OF HORIZONTAL DISTANCE TO THE ANCHOR EXCEEDS TABLE RANGE, ON OFFSET = 820.6

NO. 8-1E OFFSET (FT)	LINE 1	2	3	4
			TENSION (LB)	
0.0	25000.	27119.	27119.	25000.
54.7	24575.	27122.	27620.	25002.
109.4	24151.	27132.	28271.	25010.
164.1	23769.	27147.	28933.	25023.
218.8	23412.	27172.	29596.	25041.
273.5	23064.	27202.	30622.	25064.
328.2	22716.	27239.	31667.	25092.
382.9	22394.	27282.	33125.	25125.
437.6	22111.	27332.	34791.	25164.
492.3	21828.	27388.	37255.	25207.
547.1	21545.	27451.	40699.	25256.
601.8	21264.	27521.	46315.	25310.
656.5	21036.	27597.	57096.	25368.
711.2	20808.	27687.	95485.	25432.
765.9	20580.	27805.	736663.	25503.

HORIZONTAL COMPONENT OF TENSION (LB)

NO 8-1E OFFSET (FT)	1	2	3	4
0.0	8009.	8009.	8009.	8009.
54.7	7580.	8013.	8472.	8012.
109.4	7150.	8022.	9055.	8020.
164.1	6753.	8037.	9648.	8033.
218.8	6399.	8059.	10241.	8051.
273.5	6045.	8086.	11093.	8075.
328.2	5691.	8120.	11957.	8103.
382.9	5363.	8160.	13107.	8137.
437.6	5074.	8200.	14400.	8176.
492.3	4784.	8258.	16236.	8220.
547.1	4495.	8316.	18729.	8269.
601.8	4208.	8381.	22664.	8324.
656.5	3973.	8451.	29996.	8383.
711.2	3739.	8533.	55277.	8447.
765.9	3504.	8635.	468762.	8519.

NO 3-1E	OFFSET (FT)	SUSPENDED LINE LENGTH (FT) 1	2	3	4
	0.0	7053.	7340.	7340.	7053.
	54.7	6969.	7341.	7429.	7053.
	109.4	6885.	7343.	7455.	7055.
	164.1	6807.	7346.	7477.	7057.
	218.8	6735.	7350.	7494.	7061.
	273.5	6663.	7355.	7500.	7065.
	328.2	6592.	7362.	7500.	7071.
	382.9	6524.	7369.	7500.	7077.
	437.6	6463.	7378.	7500.	7085.
	492.3	6402.	7388.	7500.	7093.
	547.1	6341.	7399.	7500.	7103.
	601.8	6281.	7411.	7500.	7114.
	656.5	6229.	7425.	7500.	7125.
	711.2	6178.	7436.	7500.	7138.
	765.9	6127.	7440.	7500.	7152.

APPENDIX C

METHODS FOR PREDICTION OF MEAN ENVIRONMENTAL FORCES AFFECTING OTEC MODULAR PLANT SKSS

The major forces affecting the design of the SKSS for the OTEC modular plant are, just as in the case of any floating system, those forces that act in the horizontal plane. They primarily arise from the second order drift forces due to waves, as well as the forces due to the action of wind and current. In order to arrive at an assessment of the mean values of these horizontal plane forces, as a first step in establishing the level of forces that would be countered by a mooring system design, an analytical study is presently being carried out by Oceanics for that purpose. These values can then be provided to designers of proposed mooring systems so that they can use such information as a preliminary means of establishing a range of possible system designs. The procedures used in evaluating these mean values are described below.

The second order drift force due to waves is found by means of a hydrodynamic analysis based upon the scattered waves associated with the presence of a floating body in an oncoming ambient wave system. The scattered wave system includes the waves due to diffraction of the oncoming waves, as well as the radiated waves due to the motion response of the body.

For the case of the barge type platform the drift force in beam seas is the maximum value, and that is found by means of evaluating the reflected wave associated with diffraction effects and the radiated wave due to the motions of heave, sway and roll (yaw and pitch effects are generally negligible in the present case). The analysis provides a (pseudo) "transfer function" operator relating the average lateral drift force to the square of the wave amplitude, as a function of wave frequency, i.e., $\frac{Y_d}{a^2}(\omega)$. This function is then combined with each particular wave spectrum to provide the mean drift force in that particular seaway by means of the operation

$$\overline{Y}_{mean} = 2 \int_0^{\infty} \frac{Y_d}{a^2}(\omega) S_{\eta}(\omega) d\omega \qquad (1)$$

where $S_{\eta}(\omega)$ is the wave spectrum.

The analysis above requires the initial determination of the first order motions of the vessel, from which the drift force is determined by quadratic operations involving sums of first order motion and wave properties. The same basic procedure applies to the case of the spar-type platform, which is described below. The general procedure for finding the drift forces is basically similar to the method outlined by Maruo [1], with special techniques applied by Oceanics to find the various required constituent elements.

For the spar, which is assumed to be essentially symmetric about a vertical axis, the drift force is also determined in a manner similar to that for the ship. The "transfer function" relating the average force in a regular sinusoidal wave to the square of the incident wave amplitude is found from a scattered wave appropriate to that shape vehicle. The operation given by Eqn. (1), applied to that force representation, provides the mean drift force for each particular wave spectrum condition of interest.

The wind force is found, for each case, in terms of the above-water projected area for any particular wind direction. The basic force is represented by

$$F_W = \frac{\rho_a}{2} V_W{}^2 A_p \cdot C_D \qquad (2)$$

where ρ_a = air density, F_w = wind speed component, A_p = projected area, etc., with the main problem being an estimation of the drag coefficient C_D. This can be found from any available measured data for the particular vessel, or by means of a reference handbook source such as Hoerner [2].

A similar type of analysis is applied to determine the force due to water current action, using the appropriate water density, current magnitude, etc. Again the major problem is determining the appropriate cross-flow drag coefficient value, which may be known from specific model tests or from published data such as that in [2].

REFERENCES

1. Maruo, H.: "The Drift of a Body Floating in Waves," Journal of Ship Research, Vol. 4, No. 3, Dec. 1960.

2. Hoerner, S. F.: Fluid-Dynamic Drag, published by the author, 1958.

Prepared by Dr. Paul Kaplan

16 January 1979

APPENDIX D

DETAIL DATA ON ENVIRONMENTAL STATES

ENVIRONMENTAL WAVE, WIND, CURRENT STATES, AND PROBABILITIES OF EXCEEDANCE: APPROXIMATELY 17°57'N, 65°52'W: OFFSHORE PUNTA TUNA, PUERTO RICO

INTRODUCTION

This report presents results of an analysis of certain environmental wave, wind, and current states, and their probabilities of exceedance at a site off Punta Tuna, Puerto Rico, in an approximate chart depth of 1200 meters. The site is described as follows:

Location 1: Approximately 17°57'N, 65°52'W, approximate chart depth (Mean Low Water depth) 1200 meters, offshore Punta Tuna, southeast Puerto Rico

The data herein were developed for use in analysis of the effect of the selected environmental wave, wind, current states on an OTEC facility (Ocean Thermal Energy Conversion facility) proposed for the site.

Reference is made to two previous meteorological-oceanographic reports on this site, as follows:

1. Bretschneider, C. L., Final Report, Design Wave and Current Criteria For Potential OTEC Sites, 1977

2. Evans-Hamilton, OTEC Demonstration Plant Environmental Package, 1978

The specifications of this report stipulated that the results herein be consistent with reference (1) above, insofar as possible, and where it appeared that the results of this analysis differed to a significant extent with those of reference (1), comment to that effect would be included herein.

In references (1) and (2) use is made of both the English and metric systems. To permit convenient direct comparison between this report, and references (1) and (2), the same units are used for each parameter (i.e., wave height in feet, wind speed in knots, current speeds in centimeters/second, ...etc.)

This report consists of the following section:

1. Environmental Wave, Wind, Current States, and Probabilities of Exceedance

ENVIRONMENTAL WAVE, WIND, CURRENT STATES, AND PROBABILITIES OF EXCEEDANCE

Tables 1 through 35 summarize results of the analysis of environmental wave, wind, current states and their probabilities of exceedance.

Three wave directions (direction from which waves move) are considered herein, ...northeast, east, and southeast. These wave directions account for more than 92 percent of all wave directions occurring at the site because of the strongly prevailing easterly winds ("trade winds") of the Puerto Rico area.

Significant wave height, Hs, is the average height of the highest 33 1/3% of the waves. The waves are observed consecutively and all waves are considered (that is, no differentiation between a "sea" or "wind wave", and a "swell" is made). An actual measurement of significant wave height usually involves a 10 to 20 minute continuous recording of a wave gage.

Significant wave period, Ts, is the average period of the highest 33 1/3% of the waves, ...the same waves considered in the determination of the significant wave height.

The wind speed is stated (reference 2) as a maximum 10 minute average and is given in knots (nautical miles per hour).

The still water depth at the site is specified as approximately 1200 meters. Because of the considerable depth at the site, storm tides are small (a few feet in the case of severe hurricanes). The astronomical tide range is also small (2 feet or less). The possible tidal variation of several feet, at the most, has negligible effect on the wave profile or wave forces in a water depth of approximately 1200 meters. For this reason, storm tides and astronomical tides are not considered herein.

The percentages of waves in period groups are summarized in the tables. The waves at the site are predominately short period, locally generated wind waves, but some swell reaches the site. The wave period distributions of reference (1) were adjusted to include some longer period wave action, since longer period wave action is present at this site and is important with respect to vessel motion problems.

Current speeds in centimeters per second are summarized for 100 meter depth intervals in the tables. The currents summarized are the vector totals of the geostrophic, tidal, and wind driven currents in the direction of motion of the waves.

The probability of exceedance of the environmental state is the percentage of time the environmental state (combined wave, wind, and current) in the specified direction, is exceeded. Thus an exceedance of 1% indicates that the environmental state in the specified direction is exceeded 3.6525 days total time per year.

TABLE 1: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	2.0 Ft.
Significant Wave Period, T_s	4.0 Secs.
Wind Speed[1]	10. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	12.5
2.5 - 4.4	63.5
4.5 - 6.4	15.8
6.5 - 8.4	4.5
8.5 - 10.4	1.9
10.5 - 12.4	0.9
12.5 - 14.4	0.5
14.5 - 16.4	0.2
16.5 - 18.4	0.1
18.5 Plus	0.1

Current Speed Versus Depth, Meters	
0	78 Cm/Sec
100	67
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

38.07 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 2: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	4.0 Ft.
Significant Wave Period, T_s	4.7 Secs.
Wind Speed[1]	14. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	7.9
2.5 - 4.4	48.7
4.5 - 6.4	31.1
6.5 - 8.4	7.0
8.5 - 10.4	3.1
10.5 - 12.4	1.1
12.5 - 14.4	0.6
14.5 - 16.4	0.3
16.5 - 18.4	0.1
18.5 Plus	0.1

Current Speed Versus Depth, Meters	Cm/Sec
0	80
100	67
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

21.88 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 3: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	6.0 Ft.
Significant Wave Period, T_s	5.4 Secs.
Wind Speed[1]	17. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	4.7
2.5 - 4.4	33.8
4.5 - 6.4	44.6
6.5 - 8.4	9.6
8.5 - 10.4	4.6
10.5 - 12.4	1.4
12.5 - 14.4	0.7
14.5 - 16.4	0.4
16.5 - 18.4	0.1
18.5 Plus	0.1

Current Speed Versus Depth, Meters	
0	83 Cm/Sec
100	67
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

12.41 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 4: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	8.0 Ft.
Significant Wave Period, T_s	6.1 Secs.
Wind Speed[1]	20. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	2.9
2.5 - 4.4	22.5
4.5 - 6.4	46.3
6.5 - 8.4	18.5
8.5 - 10.4	6.4
10.5 - 12.4	1.8
12.5 - 14.4	0.9
14.5 - 16.4	0.4
16.5 - 18.4	0.2
18.5 Plus	0.1

Current Speed Versus Depth, Meters	
0	85 Cm/Sec
100	67
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

6.09 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 5: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	10.0 Ft.
Significant Wave Period, T_s	6.8 Sec.
Wind Speed[1]	22. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	1.7
2.5 - 4.4	16.1
4.5 - 6.4	36.3
6.5 - 8.4	32.1
8.5 - 10.4	8.8
10.5 - 12.4	3.0
12.5 - 14.4	1.2
14.5 - 16.4	0.4
16.5 - 18.4	0.2
18.5 Plus	0.2

Current Speed Versus Depth, Meters	Cm/Sec
0	88
100	67
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

3.38 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 7: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	20.0 Ft.
Significant Wave Period, T_s	9.7 Secs.
Wind Speed[1]	31. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.7
2.5 - 4.4	4.0
4.5 - 6.4	13.3
6.5 - 8.4	27.5
8.5 - 10.4	29.8
10.5 - 12.4	18.4
12.5 - 14.4	4.8
14.5 - 16.4	0.8
16.5 - 18.4	0.4
18.5 Plus	0.3

Current Speed Versus Depth, Meters	
0	100 Cm/Sec
100	70
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.124 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 8: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	25.0 Ft.
Significant Wave Period, T_s	10.4 Secs.
Wind Speed[1]	40. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.5
2.5 - 4.4	3.0
4.5 - 6.4	10.5
6.5 - 8.4	22.7
8.5 - 10.4	27.5
10.5 - 12.4	22.9
12.5 - 14.4	10.1
14.5 - 16.4	1.8
16.5 - 18.4	0.6
18.5 Plus	0.4

Current Speed Versus Depth, Meters	
0	110 Cm/Sec
100	76
200	62
300	52
400	44
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.0131 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 9: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	30.0 Ft.
Significant Wave Period, T_s	11.0 Secs.
Wind Speed[1]	60. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.4
2.5 - 4.4	2.2
4.5 - 6.4	8.5
6.5 - 8.4	19.1
8.5 - 10.4	26.2
10.5 - 12.4	24.2
12.5 - 14.4	13.8
14.5 - 16.4	4.1
16.5 - 18.4	0.9
18.5 Plus	0.6

Current Speed Versus Depth, Meters	Cm/Sec
0	123
100	85
200	62
300	50
400	42
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.000637 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 10: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	35.0 Ft.
Significant Wave Period, T_s	11.7 Secs.
Wind Speed[1]	80. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.3
2.5 - 4.4	1.6
4.5 - 6.4	7.0
6.5 - 8.4	14.4
8.5 - 10.4	25.0
10.5 - 12.4	24.1
12.5 - 14.4	17.5
14.5 - 16.4	7.6
16.5 - 18.4	1.7
18.5 Plus	0.8

Current Speed Versus Depth, Meters	
0	132 Cm/Sec
100	94
200	64
300	48
400	40
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.0000159 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE II: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	40.0 Ft.
Significant Wave Period, T_s	12.4 Secs.
Wind Speed[1]	89. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.2
2.5 - 4.4	1.1
4.5 - 6.4	5.7
6.5 - 8.4	12.0
8.5 - 10.4	21.7
10.5 - 12.4	22.7
12.5 - 14.4	20.7
14.5 - 16.4	11.0
16.5 - 18.4	3.6
18.5 Plus	1.3

Current Speed Versus Depth, Meters	
0	138 Cm/Sec
100	99
200	67
300	48
400	40
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.00000327 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 12: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	45.0 Ft.
Significant Wave Period, T_s	13.0 Sec.
Wind Speed[1]	94. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.1
2.5 - 4.4	0.7
4.5 - 6.4	4.8
6.5 - 8.4	9.9
8.5 - 10.4	19.8
10.5 - 12.4	21.4
12.5 - 14.4	21.6
14.5 - 16.4	13.9
16.5 - 18.4	5.6
18.5 Plus	2.2

Current Speed Versus Depth, Meters	
0	142 Cm/Sec
100	103
200	69
300	48
400	40
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.00000143 Percent

Note: [1]Direction from which waves move or wind blows.

TABLE 13: ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY 17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO, APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION[1]

Significant Wave Height, H_s	50.0 Ft.
Significant Wave Period, T_s	13.7 Secs.
Wind Speed[1]	99. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods	Percentage of Waves in Period Group
0 - 2.4 Secs.	0.0
2.5 - 4.4	0.4
4.5 - 6.4	3.9
6.5 - 8.4	8.6
8.5 - 10.4	16.6
10.5 - 12.4	20.0
12.5 - 14.4	21.2
14.5 - 16.4	17.2
16.5 - 18.4	8.3
18.5 Plus	3.8

Current Speed Versus Depth, Meters	
0	145 Cm/Sec
100	105
200	71
300	48
400	40
500	37
600	32
700	29
800	27
900	25
1000	24

Probability of Exceedance of Environmetal State

0.000000633 Percent

Note: [1]Direction from which waves move or wind blows.

APPENDIX E

ANCHOR TYPES FOR PROBABLE USE IN SKSS DESIGNS

The four probable types of anchors which may be used in SKSS designs were mentioned in Section 3.2.4.

Selection of a specific type of anchor will depend on the required holding power of an anchor or system of anchors and the reasibility of its successful installation. The quantitative data must be generated for estimated soil conditions based on an evaluation of available information. It is recommended that the soil conditions at the site be determined by drilling a soil boring and by obtaining appropriate soil samples from the soil boring for field and laboratory testing. The required depth of the boring below the seafloor will depend to some extent on the type of anchor to be used.

The cases for the four different types of anchors are discussed separately in the following pages.

1. Drag Type - LWT, Danforth, etc.

   Design criterion is anchor holding power given by:

   $$AHP = DW_a^b \qquad \text{(Reference \# 13)*}$$

   where:
   - AHP = anchor holding power in pounds
   - W_a = anchor weight in pounds
   - C,b = soil constants, dimensionless, determined by tests

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* Numbers refer to the listing at the end of Section 3.0 of the main text.

Typical values of C and b are given in [13] for various bottom conditions:

	C	b
Sands	65 - 110	.82 - .76
Mud	37	.91
Clays	2.6 - 98	1.15 - .82

The actual soil conditions for the designated site at Punta Tuna are estimated to be predominantly calcareous oozes (see Section 2.3).

The holding power of drag anchors installed in a calcareous ooze depends on several variables including weight and configuration of anchor components (i.e., fluke area, fluke-shank angle) and depth of embedment. No published data is available for the holding power of anchors in a calcareous ooze; we can estimate the holding power to range between that for clay and sand conditions. The holding power ratio of a 15 kips Danforth anchor ranges from 2 to 12[14], the former value is lower limiting value for clays and the latter value is upper limiting value for sands. Assuming a holding power ratio of 5 for the largest commercially advertised anchor of 100 kips [14], the anchor will have a holding power of 500 kips. We anticipate the following problems during the installation of drag anchors at the site:

(1) The anchors must be dragged 10 to 50 ft. or more in order to embed about 2 to 10 ft. below seafloor and develop the rated holding power. The anchors require a near horizontal mooring line at the seafloor. Large scopes of line and other connective gear are required, with the associated surface operational problems in handling the immense amounts of line and in maintaining correct position and course of work barges during placement of anchors.

(2) The near horizontal mooring line at the seafloor can be achieved only by supplying sufficient deadweight ahead of the anchors to balance the vertical load component in the mooring line to the platform. This dead weight has to be provided in the form of heavy chains or clamp weights.

(3) The anchors are able to resist maximum loads only from the direction in which they are dragged during installation. Forces from other directions may greatly reduce their holding power.

2. <u>Direct Embedment Anchors</u>

Direct embedment anchors are installed by imparting energy directly to anchors at seafloor by several means including a gun or a vibratory hammer. The anchor may be (1) a conventional drag anchor, (2) a solid steel shaft shaped as a projectile with outward opening flukes, or (3) a steel plate with keying flaps. During installation, the conventional drag anchor or steel shaft is driven with the flukes and shaft aligned parallel to each other until adequate embedment is achieved, then the flukes are keyed or rotated by mechanical linkages to a position in which the anchor will provide a maximum area to resist load. A steel plate is driven edgewise and then keyed to the desired position. The holding power of direct embedment anchors installed in a calcareous ooze may vary over a wide range, depending on the surface area available for resisting load, and depth of embedment, e.g., steel plates 5 ft. x 5 ft. and 10 ft. x 10 ft. installed 10 ft. below seafloor in the calcareous ooze will have uplift holding capacity of 30 and 80 kips, respectively.

The following problems are foreseen in the use of direct embedment anchors at the designated OTEC site:

(1) Operational problems were frequently encountered in the driving of small anchors with low energy hammers for water depths up to 6000 ft. [15]. Efficient high energy hammers are needed to drive the large plates, such as 10 ft. x 10 ft.

(2) The keying operation of the flukes reduces their embedment depth. Further, the rotation of flukes forces the overlying soil to move with it, thus leaving a void beneath the flukes that may be partially filled with the caved-in material from the surrounding soil. This effect is more pronounced for a steel plate compared to the other types.

3. Pile Anchors

Piles to resist mooring line loads may be installed in a sea bed by either driving or grouting piles in predrilled holes. Presently, piles have been driven in a maximum water depth of about 1000 ft. To drive piles in 4000 to 4500 ft. of water, high pressure technology is needed that to our knowledge is not yet developed. The only other means of installing piles at the site is by grouting piles in holes predrilled by the deep sea drilling project drill ship "Glomar Challenger." The diameter of predrilled holes is generally 6 in. larger than that of the pile and the annular space is filled with a cement grout delivered under pressure. Drilling mud may be required during drilling to provide a stable hole and to prevent caving-in of the loose near-seafloor material.

Analyses of the performance of pipe piles subjected to lateral loads can be made for known values of pile size, pile thickness, and pile penetration. The soil resistance-pile deflection data can be generated for the calcareous ooze and then used to compute deflection of the pile at the seafloor for given lateral loads. For example, a 50-ft. long 3-ft.-diameter pipe pile (0.6 in. wall thickness) grouted in a 3.5-ft.-diameter predrilled hole at the site will experience deflections at the seafloor of about 1 in. and 20 in. for lateral loads of 50 kips and 250 kips, respectively, assuming that the mooring line is nearly horizontal at the seafloor and is connected to the top of the anchor pile. The problems associated with the use of pile anchors at the site may include non-applicability of the concepts developed for installation of grouted piles in shallow water to deeper waters and the construction problems resulting therefrom.

A procedure for designing piles is given in [16]. The general factors of safety recommended by this reference are 2.0 based on normal operating condition maximum loads and 1.5 based on extreme condition maximum loads.

4. Gravity Anchors.

Gravity or deadweight anchors derive their lateral holding power from friction on the sides and bottom in the direction of potential motion and passive resistance on the side pushing the soil outward. Both the friction and passive resistance depend on the depth of embedment of the anchor. The anchor embeds if the bearing pressure at the base of the anchor exceeds the ultimate bearing capacity of the valcareous ooze. The ultimate bearing capacity of a circular anchor may be estimated from:

$$q_u = {}_yD(N_q - 1) + 0.3yBN_y$$

where y is buoyant unit weight of soil, D is embedment, N_q is 6.4 and N_y is 5.39 for an angle of internal friction of the calcareous ooze of 20^o, and B is diameter of the anchor.

For example, a solid concrete block with B = 50 ft., height = 10 ft., D = 0 ft., y = 40 pcf will have an ultimate bearing capacity of 3234 psf as computed from the above equation. The bearing pressure at the base of the block is (150 - 64) x 10 = 860 psf. The anchor block won't penetrate the seafloor.

The ultimate frictional resistance equals 0.268 times the average effective stress on the side and bottom. The ultimate passive resistance equals 2 times the average effective stress on the appropriate side. For the example cited above, the only resistance available is from friction at the base of the block and equals 1963.5 x 860 x 0.268 lb = 453 kips.

Gravity anchors can fail in four ways:

a) Foundation bearing failure

b) Overturning due to lateral loads

c) Horizontal sliding due to lateral loads

d) Inadequate weight.

Factors of safety to be used are those recommended by API [16] which are 210 for normal operating loads and 1.5 for maximum storm loads.

The force at the anchor is the vector sum of the anchor weight and the tensile force in the mooring line at its resultant angle off vertical. Since the lateral portion of the anchor force may be a controlling factor, the safety factors are <u>not</u> based on the weight of the anchor alone. Rather, they are based on a ratio of the anchor force that will cause a failure to the expected force of the anchor for the maximum design condition.

The gravity anchors may be constructed as cellular reinforced concrete units that can be subsequently ballasted, and may be provided with shear keys at the base to improve the development of frictional resistance. The anchors may be installed in the seafloor by either controlled lowering or free fall. The controlled lowering can be affected by temporarily adding buoyancy using air filled pressure hulls or be increasing the drag on the anchor by adding drogue buoys. Both the controlled lowering and free fall methods need to be developed in the field for accurate deployment of the anchors.

APPENDIX F

PROPERTIES OF SKSS MATERIALS

APPENDIX # F.1

STEELS -- Category 1 - Structural Steel

ASTM A-36

This is the most common steel used in structural design. It is a carbon steel and is available in types of structural shapes, plates and bars.

Yield strength	36,000 psi
Tensile strength	58,000 psi

Allowable loads are computed according to the specifications of AISC and for as already specified in the General Design Criteria.

Fatigue strength is not exactly known, but a conservative estimate is 40 - 50% of the tensile strength.

Welding characteristics are excellent.

Corrosion Resistance -- It rusts by oxygen and water. Rate of attach increases sharply as pH goes above 4, decreasing below pH of 8. Salt solutions increase corrosion rate. It is attached by acids but it is resistant to alkalis.

STEELS -- Category 2 - High Strength, Low Alloy Steel

ASTM A-440

This is a typical high strength, low alloy steel used whenever savings in weight are important.

Yield strength	42 - 50,000 psi
Tensile strength	63 - 70,000 psi

Allowable loads are computed according to the specifications of AISC and/or as alreadyspecified in the General Design Criteria.

The steel is available in all structural shapes and plates up to 4 inches.

Welding and fabricating characteristics are excellent and welding procedures are the same as those for carbon steel.

The atmospheric corrosion resistance of this steel is approximatoly twiee that of rebular carbon steel.

AISI 4140

This is a typical low alloy steel used in mechanical applications.

Yield strength	100 - 241,000 psi
Tensile strength	117 - 290,000 psi

Allowable loads are computed according to the specifications of AISC and/or as already specified in the General Design Criteria.

This steel is available in all standard mill forms.

Fatigue strength data or stress vs. cycles curves are readily available, as it is a very widely used steel.

Weldable by all procedures. Depending on the applications preheating and/or postheating is sometimes necessary.

Corrosion resistance is the same or slightly better than that of carbon steel.

STEELS -- Category 3 - Stainless Steels

AISI 316

This is the primary stainless steel employed in marine work.

Yield strengths	30, 36 & 42,000 psi
Tensile strengths	80, 82 & 84,000 psi
Modulars of elasticity	28×10^6 psi

Allowable loads are computed according to specifications of the AISC and/or as already specified in the General Design Criteria.

This steel is available as sheet, bar, plate, wire or tubing.

Weldability is excellent and machinability is good.

Corrosion resistance to sea water and other corrosive media causing pitting type of corrosion is good.

APPENDIX F.2

1. KEVLAR 29 and 49 (DuPont Registered Trademarks)

	Kevlar 29	Kevlar 49
Tenacity (grams/denier)*	21.7	21.7
Tenacity (i.e., breaking strength) psi	400,000	400,000
Modulus of elasticity (psi)	12×10^6	19×10^6
Density (grams/cc)	1 - 44	1 - 44
Elongation to break (dry)		
% of original length	4.0	2 - 4

Chemical resistance of Kevlar is good except in strong acids and bases.

Thermal stability for temperature range in mooring applications is excellent. There is no loss of tensile strength.

There is concern that Kevlar may be subject to degradation on exposure to ultraviolet light. However, the problem diminishes as rope diameter increases due to the self-screening of the material. Jacketing is recommended whenever prolonged exposure is anticipated.

* denier is the weight in grams of 9.000 meters of yarn.

2. Nylon 66 (High Tenacity)

	Nylon 66
Tenacity (grams/denier) - dry	5.9 - 8.8
Tenacity (grams/denier) - wet	5.1 - 7.6
Breaking strength (psi)	86,000 - 128,000
Modulus of Elasticity (psi)	$.8 \times 10^6$
Density (grams/cc)	1.14
Elongation to break % - dry	18 - 28
Elongation to break % - wet	21 - 32

Chemical resistance -- Nylon dissolves in strong acids and ultimately disintegrates in weak acids. It is substantially inert to strong and weak alkalis. Thermal stability for temperature range in mooring applications is good.

Nylon is weakened with prolonged exposure to sunlight. Quantitative gifures are not available.

5. DACRON (High Tenacity)

	DACRON
Tenacity (grams/denier) - dry	6 - 7
Tenacity (grams/denier) - wet	6 - 7
Breaking strength - (psi)	106,000 - 123,000
Modulus of elasticity (psi)	2×10^6
Density (grams/cc)	1.38
Elongation to break % - dry	9 - 11
Elongation to break % - wet	9 - 11

Chemical resistance - Dacron dissolves in both strong acids and alkalis. It has good resistance to weak acids and alkalis.

Thermal stability of no concern in the range of temperatures expected for mooring applications. Dacron, just like Nylon, is weakened by prolonged exposure to sunlight.

Dacron, unlike Nylon which is self-extinguishing, will burn slowly when exposed to flame.

4. POLYPROPYLENE & POLYETHYLENE (Type III)

	P/Propylene	P/Ethylene
Tenacity (grams/denier) dry	5.5 - 7.0	5.0 - 7.3
Tenacity (grams/denier) wet	5.5 - 7.0	5.0 - 7.3
Breaking Strength (psi)	NA	50,000 - 90,000
Density (grams/cc)	.90	.95
Elongation to break % - dry	12 - 25	10 - 40
Elongation to break % - wet	NA	10 - 40

Both polyprophlene and polyethylene belong to the general family of Polyolefins. Both have excellent chemical resistance to acids and alkalis. Some swelling and weakening occurs in solvents such as benzene and toluene.

Thermal stability is of no concern in the range of temperatures expected for mooring applications.

If pigmented, both materials are unaffected by prolonged exposure to sunlight.

Both will burn slowly when exposed to open flame.

APPENDIX # B.3

	Natural Rubber	Neoprene
1. Physical Properties		
Specific Gravity	.93	1.25
Coeff. of Thermal Expansion		
(cubical) 10^{-5} per ^{o}F	57	24
Flame Resistance	Poor	Good
2. Mechanical Properties		
Tensile Strength (psi)		
Pure Gum	2,500	3,000-4,000
Black	3,500-4,500	3,000-4,000
Elongation %		
Pure Gum	750-850	800-900
Black	550-650	500-600
Rebound		
Cold	Excellent	Very Good
Hot	Excellent	Very Good
Tear Resistance	Excellent	Fair to Good
3. Chemical Resistance		
Sunlight Aging	Poor	Very Good
Oxidation	Good	Excellent
Heat Aging	Good	Excellent
Acids	Fair to Good	Good to Excellent
Water Swell Resistance	Fair	Fair to Excellent

APPENDIX G

SOIL CONDITIONS

McClelland engineers, inc. / geotechnical consultants

6100 HILLCROFT HOUSTON, TEXAS 77081
TEL. 713 772-3701 TELEX 762-447

Report No. 0178-326-1
January 18, 1979

M. Rosenblatt & Son, Inc.
350 Broadway
New York, New York 10013

Attention: Mr. N. S. Basar
Project Manager

Consultation on Soil Conditions
Station Keeping Subsystem
Modular Experiment OTEC Plant

Gentlemen:

This report presents results of our review of soil conditions for Station Keeping Subsystem for Modular Experiment Offshore Thermal Energy Conversion (OTEC) plant, offshore Puerto Rico. The study was verbally authorized by Mr. Basar on January 2, 1979.

M. Rosenblatt & Son, Inc. is conceptually planning the development of an OTEC plant in the continental margin, offshore Punta Tuna, Puerto Rico for the U.S. Department of Energy. We understand that the plant will be located in 4000 to 4500 ft of water in the Caribbean Sea. Our study was made to estimate soil conditions based on evaluation of available information, to discuss holding power of several type of anchors, and to provide conclusions and recommendations based on the study. These items are discussed briefly below and are followed by a list of references.

Estimated Soil Conditions

A study of available information indicates that the sediments in the general area of the site possibly could be predominantly calcareous oozes to an approximate penetration of about 650 ft below the seafloor[1-3]. Calcareous oozes are composed essentially of the calcium carbonate remains of open sea organisms and vary in texture from sandy silt to clayey silt[1, 4, 6]. The average water content and unit dry weight values reported for calcareous oozes in the area[5] are consistent with those found on a world-wide basis[1]. Based on our experience with calcareous ooze samples from deep continental margins, we recommend that structures in the calcareous oozes be designed for an angle of internal friction of 20°.

Holding Power of Anchors

The holding power of an anchor is frequently expressed as a ratio of the maximum horizontal pull to the anchor weight in air. The holding power is a function of the type of anchor, surface area of anchor resisting load, anchor embedment, and physical properties of soils in which the anchor is embedded. The types of anchors discussed in the following paragraphs include (1) drag anchors, (2) direct embedment anchors, (3) pile anchors, and (4) gravity anchors.

Drag Anchors. The holding power of drag anchors installed in a calcareous ooze depends on several variables including weight and configuration of anchor components (i.e., fluke area, fluke-shank angle) and depth of embedment. No published data is available for the holding power of anchors in a calcareous ooze; we can estimate the holding power to range between that for clay and sand conditions. The holding power ratio of a 15 kips Danforth anchor ranges from 2 to 12[8], the former value is lower limiting value for clays and the latter value is upper limiting value for sands. Assuming a holding power ratio of 5 for the largest commercially advertised anchor of 100 kips[8], the anchor will have a holding power of 500 kips. We anticipate the following problems during the installation of drag anchors at the site:

(1) The anchors must be dragged 10 to 50 ft or more in order to embed about 2 to 10 ft below seafloor and develop the rated holding power. The anchors require a near horizontal mooring line at the seafloor. Large scopes of line and other connective gear are required, with the associated surface operational problems in handling the immense amounts of line and in maintaining correct position and course of work barges during placement of anchors.

(2) The near horizontal mooring line at the seafloor can be achieved only by supplying sufficient deadweight ahead of the anchors to balance the vertical load component in the mooring line to the platform. This dead weight has to be provided in the form of heavy chains or clamp weights.

(3) The anchors are able to resist maximum loads only from the direction in which they are dragged during installation. Forces from other directions may greatly reduce their holding power.

Direct Embedment Anchors. Direct embedment anchors are installed by imparting energy directly to anchors at seafloor by several means including a gun or a vibratory hammer. The anchor may be (1) a conventional drag anchor, (2) a solid steel shaft shaped as a projectile with outward opening flukes, or (3) a steel plate with keying flaps. During installation, the conventional drag anchor or steel shaft is driven with the flukes and shaft aligned parallel to each other until adequate embedment is achieved, then the flukes are keyed or rotated by mechanical linkages to a position in which the anchor will provide a maximum area to resist load. A steel plate is driven edgewise and then keyed to the desired position. The holding power of direct embedment anchors installed in a calcareous ooze may vary over a wide range, depending on the surface area available for resisting load, and depth of embedment, e.g., steel plates 5 ft x 5 ft and 10 ft x 10 ft installed 10 ft below seafloor in the calcareous ooze will have uplift holding capacity of 30 and 80 kips, respectively. We foresee the following problems in the use of direct embedment anchors at the site:

(1) Operational problems were frequently encountered in the driving of small anchors with low energy hammers for water depths up to 6000 ft[(7)]. Efficient high energy hammers are needed to drive the large plates, such as 10 ft x 10 ft plates.

(2) The keying operation of the flukes reduces their embedment depth. Further, the rotation of flukes forces the overlying soil to move with it, thus leaving a void beneath the flukes that may be partially filled with the caved-in material from the surrounding soil. This effect is more pronounced for a steel plate compared to the other types.

Pile Anchors. Piles to resist mooring line loads may be installed in a sea bed by either driving or grouting piles in predrilled holes. Presently, piles have been driven in a maximum water depth of about 1000 ft. To drive piles in 4000 to 4500 ft of water, high pressure technology is needed that to our knowledge is not yet developed. The only other means of installing piles at the site is by grouting piles in holes predrilled by the deep sea drilling project drill ship "Glomar Challenger." The diameter of predrilled holes is generally 6 in. larger than that of the pile and the annular space is filled with a cement grout delivered under pressure. Drilling mud may be required during drilling to provide a stable hole and to prevent caving-in of the loose near-seafloor material.

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$$q_u = \gamma D(N_q - 1) + 0.3\gamma B N_\gamma$$

where γ is buoyant unit weight of soil, D is depth of embedment, N_q is 6.4 and N_γ is 5.39 for an angle of internal friction of the calcareous ooze of 20^o, and B is diameter of the anchor. For example, a solid concrete block with B = 50 ft, height = 10 ft, D = 0 ft, γ = 40 pcf will have an ultimate bearing capacity of 3234 psf as computed from the above equation. The bearing pressure at the base of the block is (150 - 64) x 10 = 860 psf. The anchor block won't penetrate the seafloor.

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Conclusions and Recommendations

Selection of a specific type of anchor will depend on the required holding power of an anchor or system of anchors and the feasibility of its successful installation. The quantitative data presented in this report was generated for estimated soil conditions based on our evaluation of available information. We recommend that the soil conditions at the site be determined by drilling a soil boring and by obtaining appropriate soil samples from the soil boring for field and laboratory testing. The required depth of the boring below the seafloor will depend to some extent on the type of anchor to be used. We also recommend that a geotechnical engineer log the boring in the field. This will help us better evaluate the soil parameters needed for anchor design.

If you have any questions concerning this report please call.

Very truly yours,

McCLELLAND ENGINEERS, INC.

Carl W. Fenske, P.E.
Manager of Engineering

RNB/CWF/ps

Attachment: List of References
Copies Submitted (6)

LIST OF REFERENCES

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