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VERIFICATION OF SPREAD MOORING SYSTEMS FOR FLOATING DRILLING PLATFORMS

VOLUME I:
METHODS FOR MOORING REVIEW

by

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PREFACE

As offshore oil exploration moves into ever deeper waters, greater demands are placed on mooring systems. Safety of the crew, preservation of the environment, and protection of the rig itself demand that mooring systems perform reliably during operations and storms alike. It is the responsibility of the Minerals Management Service (MMS) of the U.S. Department of the Interior to insure the satisfactory performance of mooring equipment aboard exploratory oil rigs in service in United States offshore oil fields. This work was commissioned to provide MMS personnel with a manual for the analytical and physical evaluation of rig mooring systems. The manual developed from a study of a rig mooring failure several years ago on Georges Bank. While that failure was a simple case of wearing size 9 shoes on size 10 feet - the gear was slightly undersized - combined with failure properly to relieve storm loads, what impressed the reviewer was the lack of specific information about the mooring in the submittal to MMS. It seemed that a mooring reviewer's manual could help ensure that mooring components were evaluated as thoroughly as other systems on floating rigs.

The purpose of this manual is to provide a procedural structure in support of this responsibility. It does not purport to be a textbook of mooring analysis or design, nor a compendium of mooring design data. That ground has been well plowed by others. Rather, a procedure for evaluating the mooring gear for a drilling rig is described. The manual provides a basic list of references essential to the evaluation process. The references include tutorial material, compendiums and computer program resources to support the evaluation procedure. Having less than ten references, this library is a valuable complement to the direction provided in this manual.

The procedures outlined in this manual are supported by two programs for a personal computer. A spreadsheet "template" simplifies tabulating projected area for wind and current force estimates. The second program, named RIGMOOR, performs the complex calculations associated with multiple catenary moorings. It is designed for minimal operator input. User's can request further explanation for each input request before entering their response. The spreadsheet program includes graphics commands for plotting RIGMOOR results on a standard PC printer.

Moorload

A sample mooring evaluation problem is introduced in Section 2 and illustrates the discussion in succeeding sections. The rig and assumed mooring design are purely hypothetical, but illustrate methods and demonstrate tools available to a mooring design reviewer.

What is the use of a manual like this? Is it not enough to perform pull tests on the mooring when it is installed? These questions were raised while this manual was being prepared. Verifying by pull tests that anchors are fully set and that the bottom is capable of holding them are prudent actions for any operator, but they are not a panacea for all the ills that can befall a mooring. A pull test has nothing to say about what loads the environment can be expected to impose on the mooring. The mooring design needs to be reviewed in order to compare its design environment with the environment expected at the site.

Pull tests can only give information about the mooring capability for the installed anchor circle. The relation of mooring performance to anchor circle radius is rarely discussed in introductory mooring design manuals, yet this is an important design factor when drag embedment (fluked) anchors are used. It is commonly understood that if the anchor circle is too small, storm loads lift the anchor shank and pry the flukes loose. Less commonly noted is the fact that if the circle is too large the leg parts before the anchor drags. It seems apparent that a well designed mooring holds its design load, but at some level of overload drags its anchors. Once a leg parts, its holding power is lost for the duration, but if an anchor slips, * its bite may shortly be regained. RIGMOOR routinely computes the tradeoff of anchor radius and holding power.

Finally, the mooring responds to environmental loads by displacing within the anchor circle, but a simple pull test performed by hauling in on all the legs to increase the preload does not measure the displacement that the same environmental load would produce nor emulate the effects of the displacement upon the upwind and downwind legs. Workboats and tugs could provide displacement loading, but they do not have sufficient bollard pull to emulate a large storm. Displaced loading can be emulated by using the anchor winches differentially, but the design and conduct of such a pull test is complex and time consuming. Furthermore, the anchor circle must be expanded to allow the lee leg to develop the design load with an eccentric pull test. All told, the mooring design review and the installation pull test provide complementary information. Both have merits and neither can claim to supersede the utility of the other.

This manual is the first in a four-volume set:

Volume I Methods for Spread Mooring Review
Volume II Methods for Spread Mooring Inspection
Volume III Dynamic Modeling in Spread Mooring Review
Volume IV A Static Model for Spread Mooring Review

Volume I decsibes procedures for the analytical evaluation of spread moorings. Volume II is a review of mooring evaluation from the standpoint of the hardware itself - the components, their inspection and testing. Volume III illustrates dynamic modeling of a spread-moored drilling platform and Volume IV contains documentation for the static model, RIGMOOR.

* A mooring

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INTRODUCTION

Figure 1 shows the context in which a mooring evaluation takes place. The circle encloses, figuratively, all the procedures necessary to evaluate a mooring. Information needed to perform the evaluation enters the circle, and the results of the evaluation come out of the circle.

The primary information flow into the mooring design evaluation process is the **mooring design submission** It consists of all the data needed to describe the rig, its mooring gear and its environment: site, weather, seabottom composition and the like. Also entering the process are **requirements** drawn from laws, standard practices and experience, and **resources** drawn from manuals, handbooks, and models. The normal result of an evaluation is to accept the mooring design. Otherwise, information not provided in the submission is requested or recommended improvements are returned.

Figure 2 is an expansion of the interior of Figure 1. It shows five procedures that make up a mooring design evaluation. Each procedure is developed in a corresponding section of this manual. A sample problem is introduced in Section 1 and used throughout the ensuing sections to illustrate their procedures.

1.0 Checking for Completeness

The first step in evaluating a mooring is to determine whether pertinent information has been omitted. This decision is based on the information required for subsequent stages of the review. Thus a data requirement list must be prepared for each of the following tasks. The normal conclusion of the completeness check is to forward the pertinent data requirements to each subsequent stage. Otherwise, request the missing data.

2.0 Reviewing Design Methods

The primary objective of a mooring design is to match the holding capacity of the mooring to the loads imposed by the environment. Thus, the design must show separate determinations of holding capacity and external loading. The purpose of this procedure is to evaluate the methods used for each of the two parts. This review will provide important clues to the care that has been taken with the design and aid selecting appropriate evaluation methods.

3.0 Evaluate Environmental Loads

In these procedures, the specifications as submitted are used to compute holding power and environmental load. This corroborates the design values but also confirms that the design submittal is complete. It is not necessary to repeat all the decisions made during the design process; only the final design is evaluated. Reference 8 includes a survey of 30 computer models of semi-submersible and tension-leg platforms.

Environmental loads (Procedure 3.0) have three primary sources - wind, waves and current. Sea ice approaches the status of an irresistible force, and spread moored rigs have no choice but to move out of its way. Its prevalence at drillsites in polar climates must be evaluated as well as pro-

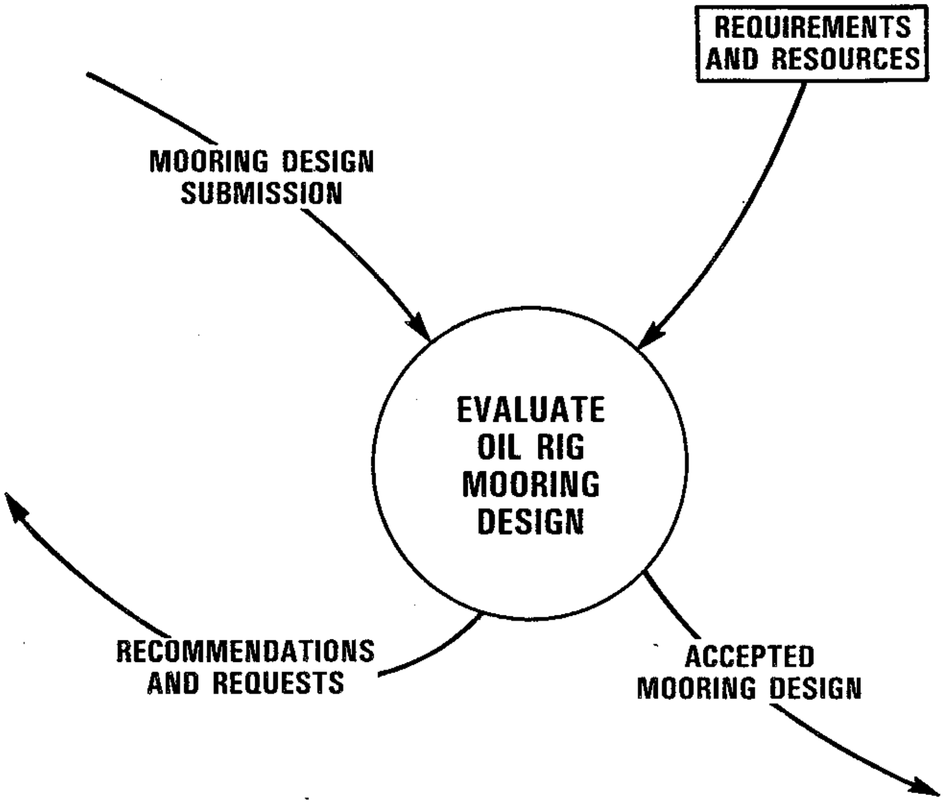

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Figure 1. Mooring Evaluation in Context

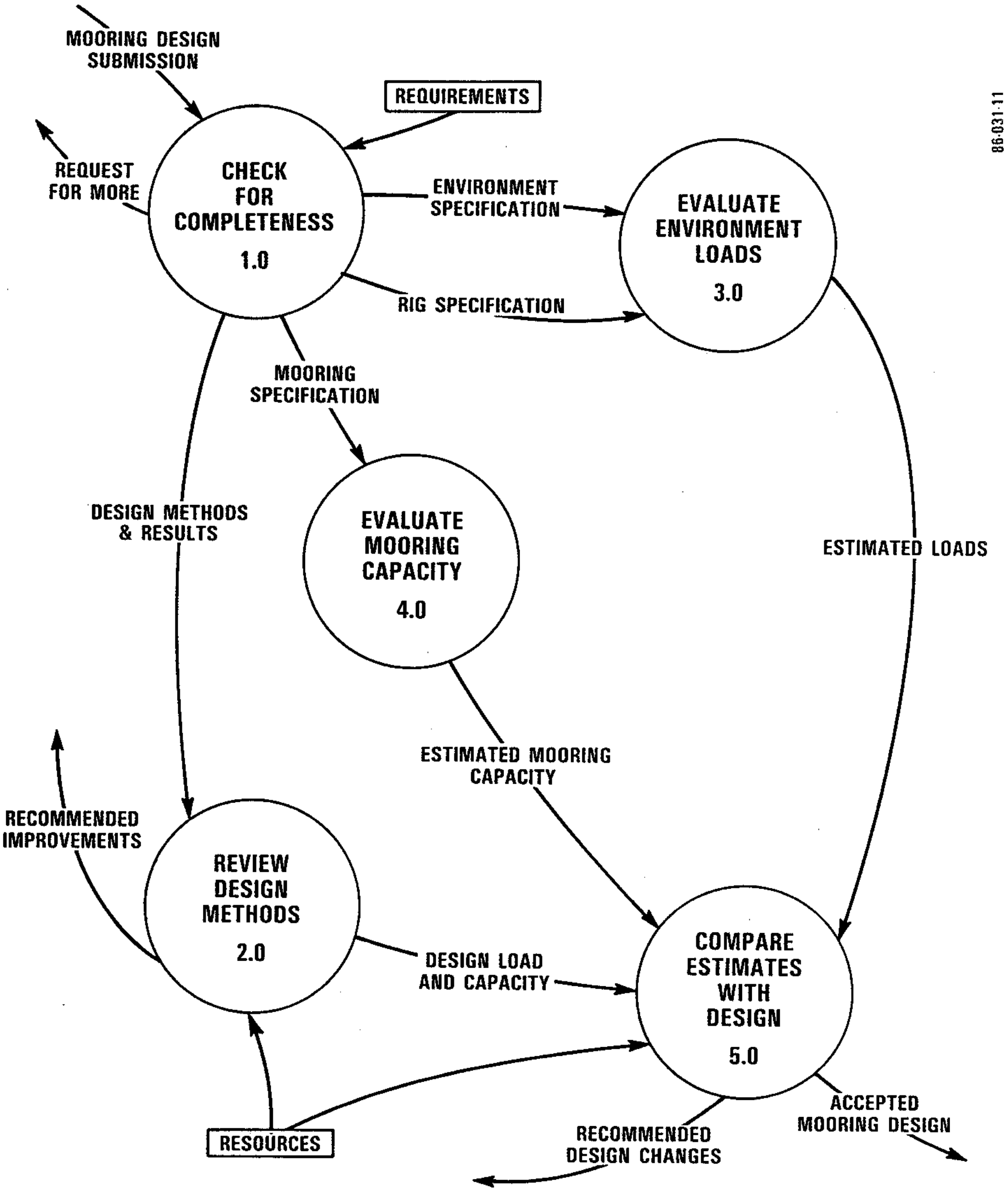

Figure 2. Mooring Evaluation Functions

visions for early warning, so that the rig may conduct an orderly retreat. The composition of the seafloor is an important part of the drilling environment because it strongly affects the type and size of the anchors.

4.0 Evaluate Mooring Capacity

Evaluation of mooring capacity (Procedure 4.0) breaks into several parts. The most difficult computations deal with the composite holding capacity of the spread mooring catenaries. The anchors must be sized to restrain the leg loads and matched to the soil composition at the drillsite. Finally, the winches, fairleads and other handling gear must be matched to the mooring components.

The issue of rig dynamics relates more to its seaworthiness and ability to operate on station than to mooring safety. However, the mooring constrains the rig's response, so that seakeeping models routinely include mooring computations. A dynamic analysis of the sample problem is presented in Volume III. The static results from that study verify RIGMOOR's results.

5.0 Compare Estimates with Design

The final review (Procedure 5.0) compares the environmental load with the holding capacity and the estimates prepared by the reviewer with the design. The normal result is that the design matches load with strength and is accepted. Otherwise the reviewer may suggest design changes to obtain the needed strength.

SECTION 1
CHECK FOR COMPLETENESS

An exhaustive design submission would include all information needed to reconstruct the design. In most cases the reviewer will not want or need to belabor the issue in such detail, especially in regard to advanced wave-force theories. However, the submission should sustain the simpler procedures recommended by ABS (Ref. 2) or API (Ref. 5). The following checklist outlines categories of items to look for.

Rig Geometry.

Scale sketches or drawings of the rig in front, side and top views are used to compute areas exposed to wind, current and waves. The drawings should also indicate the location of the fairlead for each anchor leg. Figure 1-1 is a rough sketch of the hypothetical semi-submersible for the sample calculations throughout this manual. The rough sketch is supported by particular dimensions listed in Table 1-1. A more detailed drawing might not be supported by a table of dimensions.

Anchor Pattern.

The top view of the rig should also show the direction and radius to the anchor from each fairlead. For simplicity of analysis, ease of operation and symmetry of response to environmental forces, the anchor radii are arranged with at least one axis of symmetry, usually port and starboard. If the number of legs is even, then fore and aft symmetry can be imposed as well. Figure 1-2 shows the sample rig and its mooring pattern in plan view, sketched to the same scale as Figure 1-1.

The plan in Figure 1-2 depicts a spread mooring of ten legs in a 0-45-90 degree pattern. The mooring pattern shown might be chosen for a drilling site where the weather or current follows a dominant track. Notice that four legs are active at each end against bow/stern forces, while only three legs are active on each side against beam forces. The directional quality is emphasized by the difference in underwater areas - the beam legs must contend with forces accumulated along the sides of the footers, while the bow/stern areas underwater are much smaller.

Anchor Selection.

The size and kind of anchor are important as well. Most oil rigs use fluked anchors designed to pry themselves free when the shank is lifted from the seafloor. Thus the holding power of these anchors depends on combining the length of the leg, the radius to the anchor and the load on the leg so that the leg does not lift the shank.

Deadweight clumps can be shackled into the leg near the anchor to allow greater loads with shorter legs, but this is rarely done in rig moorings because deploying and recovering the clumps is more troublesome than using longer legs.

The holding power of an anchor depends on its size (weight), shape and the composition of the seafloor. References 1, 6 and 7 provide tutorial and specific technical descriptions of anchor properties.

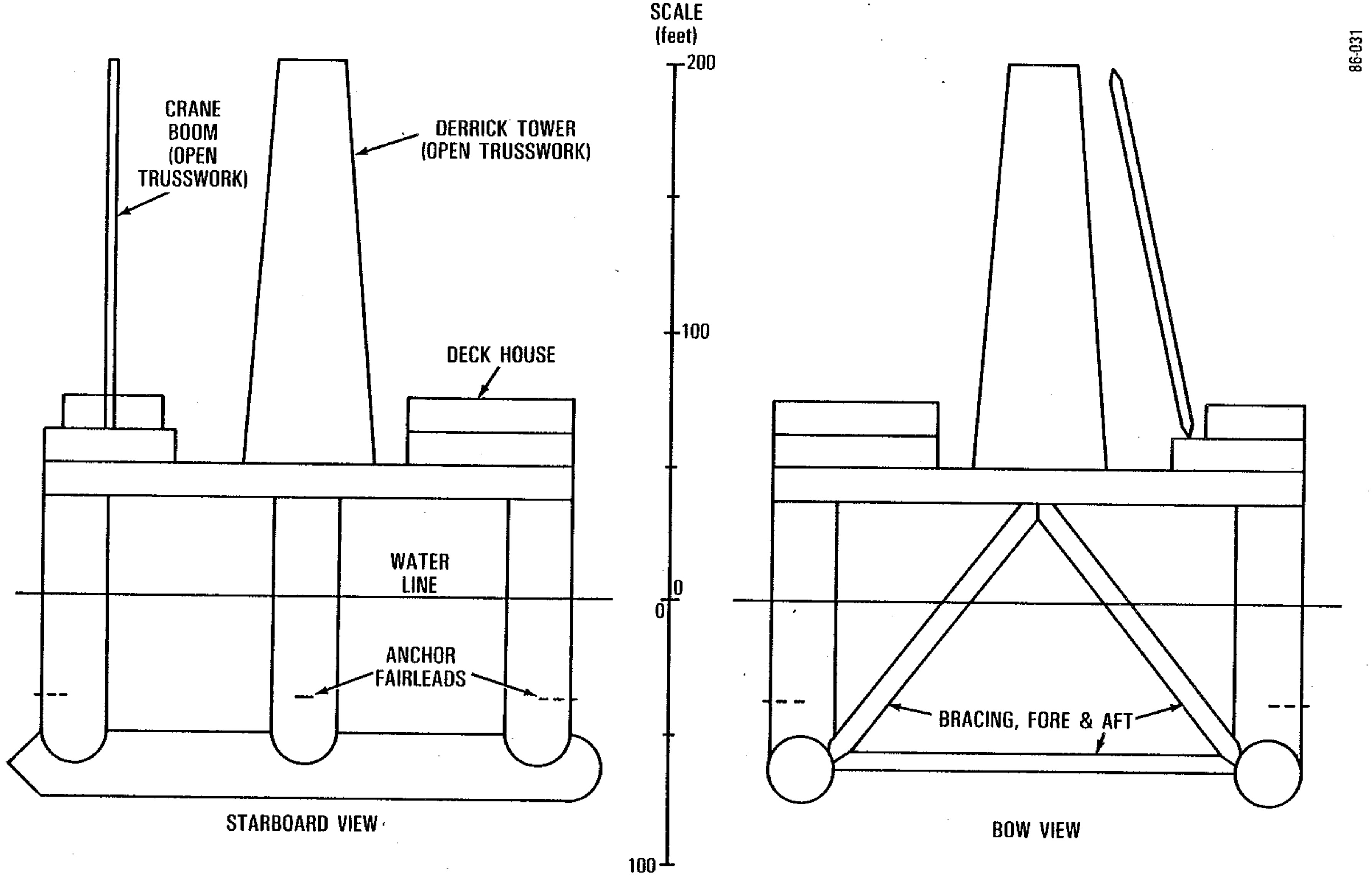

Figure 1-1. Scale Sketch of Semisubmersible Drilling Platform for Sample Problem

Table 1-1. Sample Rig Bill of Particulars

Figure 1-1 is a sketch of a hypothetical semi-submersible rig used to demonstrate the procedures for estimating environmental forces and evaluating mooring capacity. While most dimensions are realistic, they are not intended to be representative in detail. They provide a basis for demonstrating computations and approximate the scale of current drilling rigs.

Main Deck

Length	200 ft
Width	200 ft
Height	12 ft

Crane Base

Length	50 ft
Width	50 ft
Height	12 ft

Derrick Tower (Trusswork)

Base	50 ft sq.
Top	25 ft sq.
Height	150 ft

Caissons (6, cylindrical)

Length	100 ft
Diameter	25 ft

Diagonal Braces (4, cylindrical)

Length	115 ft
Diameter	10 ft

Drilling Trim

Draft	75 ft
Displacement	10300 LT
Flooded	4900 LT

Crew Space (2 stories)

Length	62 ft
Width	62 ft
Height	24 ft

Crane House

Length	38 ft
Width	38 ft
Height	12 ft

Crane Boom (Trusswork)

Base	8 ft sq.
Top	8 ft sq.
Length	138 ft

Footers (2, cylindrical)

Length	200 ft
Diameter	25 ft

Lateral Braces (2, cylindrical)

Length	150 ft
Diameter	10 ft

Towing Trim

Draft	21 ft
Displacement	5400 LT
Flooded	None

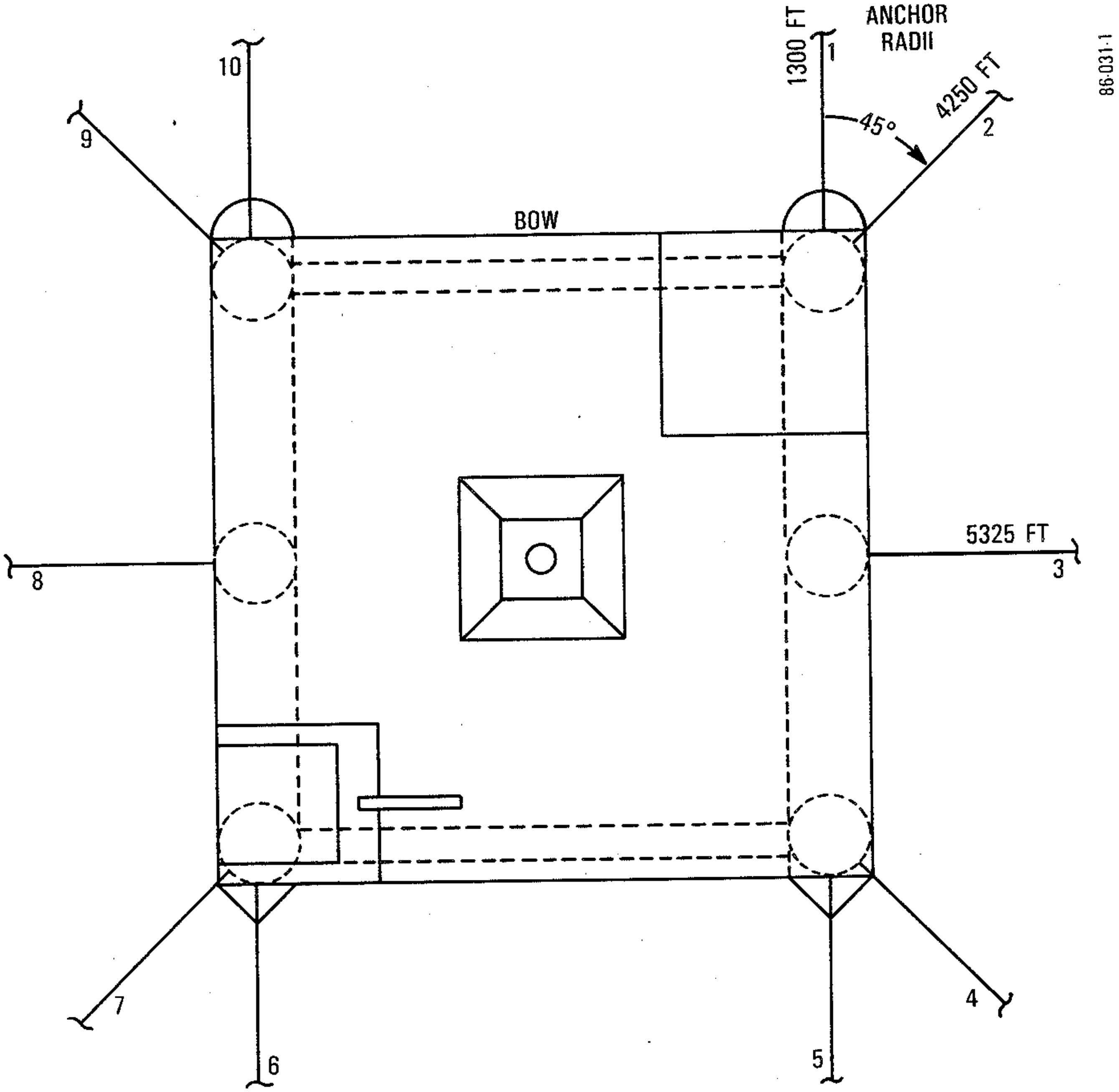

Figure 1-2. Sample Rig Mooring Plan

Drilled-in and explosive embedment anchors restrain both vertical and horizontal loads but they are rarely, if ever, used with current drilling rigs. Deep water drilling with the coming generation of taut-legged moorings and lightweight fiber materials will require these anchors.

Mooring Component List.

A table or assembly schematic detailing the size, weight (in air and in seawater), length and strength of all the components in each leg is essential for computing mooring holding power. Oil rig moorings generally use one of three leg configurations: all wire rope legs; all chain legs; or wire rope coupled to a length of chain at the anchor end. For simplicity and economy, all the legs of a spread mooring are usually alike. Reference 7 includes tables of mooring component characteristics by class and size.

The sample mooring plan shows that three different leg constructions are used. The purpose for this unconventional layout is to demonstrate the ability of the RIGMOOR model to handle a variety of spread moorings. Table 1-2 lists the particulars of this unconventional spread mooring.

The strength and stiffness of a spread mooring depend significantly on the length of the legs in relation to the anchor radius, or preload. So the total length of wire on the winch or chain in the locker is not as important as the amount paid out. This can be varied at a touch on the winch controller, so holding power is usually expressed at a rated preload.

Preload and Pretension.

Preload is the horizontal force with which opposing legs pull against each other. If the preload is zero (a theoretical concept that is not useful in practice), the legs drop vertically to the bottom, then lie on the bottom along a radius to the anchor. Ignoring strength limits, at very large preloads the leg lies along a slant radius from the rig fairlead to the anchor. Two other values stand out: the preload which lifts the anchor shank and the preload which parts the leg.

Once the anchors are set, preload is inversely related to the length of the legs, a fact readily confirmed by intuition: preload goes up as the legs are shortened. Almost as obvious is the relation that stiffness increases with preload. Elasticity of the leg material and anchor capacity limit the leg stiffness.

Pretension is closely related to preload, being the tension produced at the top end of the leg by the preload; pretension is the vector sum of preload and the weight of the suspended length of the leg. Pretension is more readily monitored than preload or leg length. It has the further advantage, as a leg tension, of being directly comparable with breaking strength. Saying the pretension is 20 percent of the breaking strength is more informative than saying the preload is 15 percent of the breaking strength - in the former case one knows immediately that one fifth of the leg strength is being used to provide mooring stiffness.

Table 1-2. Sample Mooring Bill of Particulars

Leg No.	Leg Type	Anchor Direction
1	1	0.
2	2	45.
3	3	90.
4	2	135.
5	1	180.
6	1	180.
7	2	225.
8	3	270.
9	2	315.
10	1	0.

Leg Construction

Leg Type	Segment No.	Material	Size (in)	Quantity (ft)	Deployed[1] (ft)
1	1	Stud-Link Chain	3.	2250[2]	1350
2	1	IWRC Wire Rope (6x37)	3.	6000	4270
3	1[3]	IWRC Wire Rope (6x37)	3.	6000	4800
	2	Stud-Link Chain	3.	540[4]	540

Note
1 Outboard of fairlead.
2 25 shots at 90 feet per shot.
3 Segments count from fairlead toward anchor.
4 6 shots at 90 feet per shot.

Anchor Selection

		Holding Capacity	
Style	Size	Sand	Mud
Stato	15,000 lb	450,000 lb	350,000 lb

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Holding Power.

Holding power is the restoring force produced by a mooring when it is deflected until some design limit is reached - a leg reaches its working load limit, the deflection equals the working limit of the riser pipe, etc. That is, the mooring can restrain an external force of equal magnitude and opposite direction to the holding power. The restoring force of the mooring is the vector sum of the individual leg restoring forces. If the anchor pattern is symmetric and the top ends of the legs are brought to a single fairlead, then the restoring force always lies along the deflection radius. When the leg fairleads are distributed around the rig, the restoring force is only approximately in the same direction as the deflection.
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The holding power varies with the direction of the deflection. As a rule of thumb, the holding power is a minimum when the external force is aligned with one leg, and a maximum when it is aligned midway between two adjacent legs. A polar plot of holding power, sometimes called the holding power "rose", appears as sketched on Figure 1-3, with lobes coinciding with axes of symmetry. The mooring design specification should identify the inner and outer limits of the holding power rose, whether the entire rose is plotted or not.

Holding power is usually established for two conditions, using names like "operational" and "survival." The first condition describes the strength of the mooring without making any adjustment to the mooring nor curtailing drilling operations. The latter condition is the strength of the mooring when drilling operations are curtailed so that the preload can be adjusted for maximum mooring performance. The rig operator, however, should not count on being able to deploy extra legs or piggy-back anchors in the transition between operational and survival status.

Environmental Forces.

There is a corresponding pair of weather conditions that impose the operational and survival loads on the mooring. As foul weather approaches the operational limit, the prudent operator prepares to curtail drilling. Then as the weather worsens, he adjusts the mooring to survival status and prepares, if the forecast warrants, to move the rig away from the storm.

Environmental forces on a drilling rig are produced by wind, waves and currents. The design specification should identify each of these for each of the two mooring conditions. ABS Rules specify a sustained wind speed of 70 knots for the operational condition and 100 knots for survival. The API standard is based on wind probability. Waves should be specified by significant height and period, spectrum, or sea state commensurate with the wind standards. The current must include not only wind driven flow, but also tides, the Gulf Stream or other flows independent of wind.

Environmental standards like the ABS rules (Ref. 2) serve as minimum values. Where the weather is unusually harsh, the weather specification should be based on the local weather profile using historical weather data or on-site survey results.

The reviewer should be familiar with the ABS and API (Ref. 5) methods for estimating wave forces, since many applicants rely on the recommendations of these influential organizations. The ABS method uses height and period to predict wave force. The API predictions use significant wave height and significant wave period based on statistical methods. Reference 8 discusses other wave theories, their characteristic parameters and their utilization in wave force models.

Current forces are predicted from a "current profile" which is a table or graph of current speed as a function of depth.

Ice is characterized, not so much by the force exerted on moored rigs as by the frequency of occurrence, and methods for obtaining advance warning so that the drilling equipment can be removed.

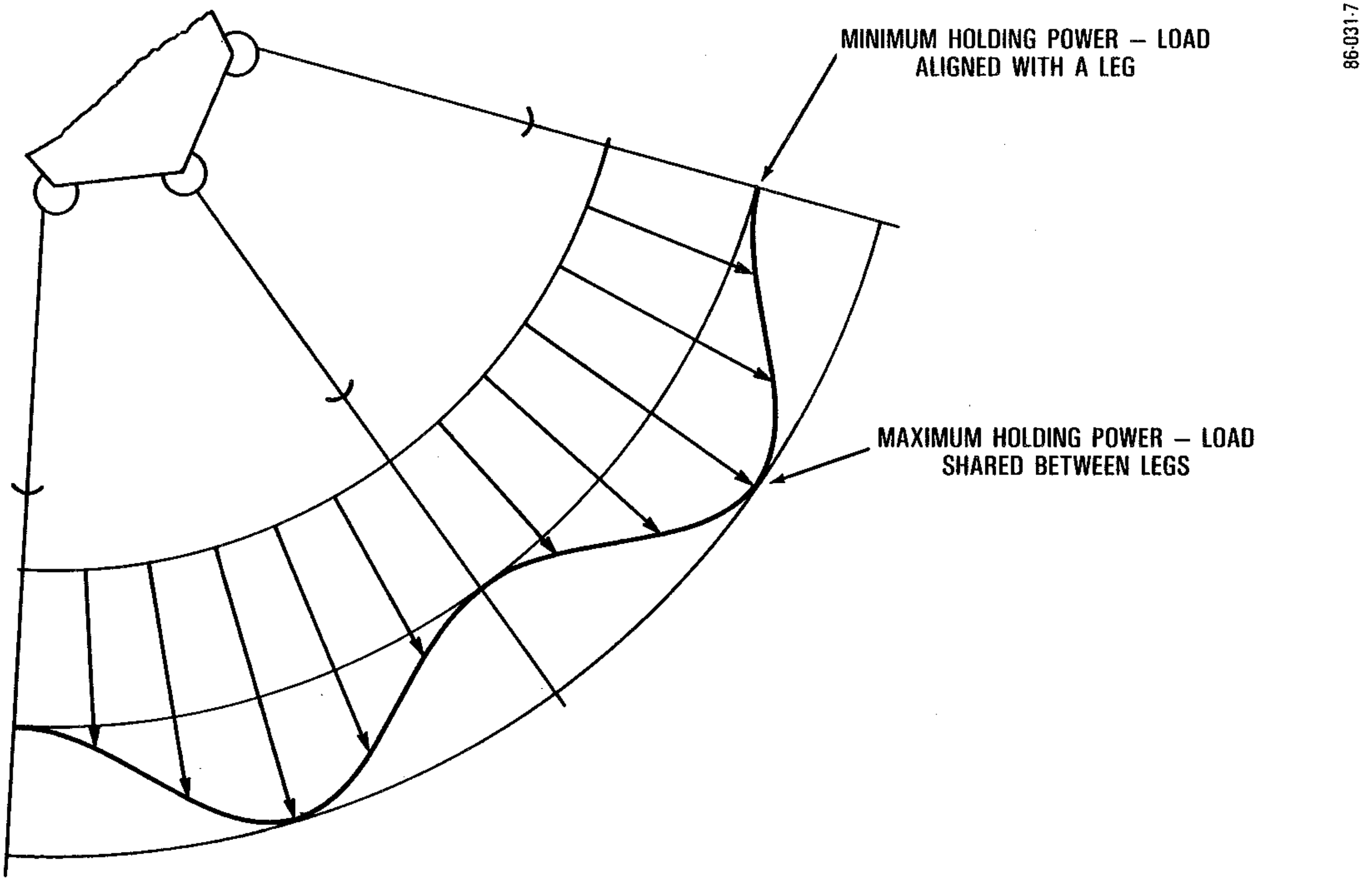

Figure 1-3. Two Lobes of a Holding Power Rose

SECTION 2
REVIEW DESIGN METHODS

Estimating environmental forces, mooring capacity and dynamic response are all highly mathematical and require computer support. A variety of computer programs are used. The mathematical basis of these programs varies, and part of the review of design methods is to evaluate whether the estimates of holding power and weather loading have been derived by reliable models.

A review of design methods also reveals other clues to the care invested in the mooring design. For example, is the environmental specification supported by a field survey at the drill site, by historical data for some area near the drill site, from large scale atlases, or from standard "rules of thumb". This is not to advocate an unthinking devotion to expensive field data. Moorings in established blocks where there is a firm basis of experience do not need to re-study the weather, but when a rig is heading for remote waters it is common prudence to get reliable weather data.

Usually rig moorings are designed to satisfy two states of operation. While names vary, one of the states represents the most severe weather condition in which the rig can operate on a "business as usual" basis. This "Operational" state is characterized by maintaining a tensile safety factor in the mooring legs, typically 3; keeping the moon pool centered over the drill hole within some percentage, usually 5 to 7, of the water depth. Other requirements may also be imposed as appropriate. The second, "Survival," state is marked as the worst weather that the moored rig can ride out safely without leaving the drillsite. This may require uncoupling the riser pipe and relaxing the displacement restriction so that the mooring lines can be adjusted for maximum holding capacity.

A mooring evaluator draws on other resources besides the design submission. They can be divided into four classes. Laws and standards are criteria against which the evaluator measures the design, such as regulations of the U. S. Coast Guard (USCG), and recommended practices of the American Petroleum Institute (API) and rules of the American Bureau of Shipping (ABS). Models and theory are representations of the mooring and its environment by means of experiments, computer program models or theoretical formulas. Engineering and environmental data may be drawn from texts and references.

Not least, the mooring evaluator must draw upon past experience and good judgement in forming his decision. We are not talking, after all, about sending a man to the stars, but rather of providing oversight to an established technology. Hundreds of rigs, large and small, have been successfully moored in good weather and foul at sites all over the globe. Given the bona fide intent to operate with safe equipment, the ability to design a safe mooring exceeds our ability to predict exactly when a mooring will fail. During the life cycle of a rig the emphasis shifts toward inspection and away from mooring design review.

The review of design methods must pick out the characteristics for each mooring state and their limiting values. The corresponding weather parameters, such as sustained wind speed, current profile, tide range, sea state, etc. should also be stated in the design for each operating state.

ABS rules and API practices provide threshold values for design limits. However, the economics of exploratory drilling may force more stringent specifications in order safely to remain operational in an area characterized by severe weather.

SECTION 3
EVALUATE ENVIRONMENTAL LOADS

A good mooring design is one in which the holding capacity of the mooring is well matched to the loads imposed by the environment. Figure 3-1 shows wind, waves, currents and ice as the significant environmental loads. Each of these factors requires information from the environmental sciences. The loads imposed by drifting sea ice are irresistible in the context of conventional spread moorings, and are evaluated in terms of the risk that drifting ice will approach the rig. The remaining loads can be modeled, but require knowledge of the size, shape and texture of the moored vessel.

Predict Wind Forces

The wind force on a complex object such as a semisubmersible drilling rig is the sum of the wind forces on all of its parts. The analysis of wind force in detail quickly becomes like a bog of quicksand as complicated interactions of airflow and part geometry are addressed: parts lie in the wake of other parts; the windspeed increases with height above the sea surface and so on.

The procedure recommended by the American Bureau of Shipping (ABS, Ref. 2) is built around the concept of the pressure produced by the wind measured at a standard height (10 meters above sealevel). A "height coefficient" takes the variation of windspeed with altitude into account and a "shape coefficient" accounts for the shape and texture of the object in the windstream. The wind force on the object is the product of the wind pressure times the area of the object projected onto a plane perpendicular to the wind ("projected frontal area").

The Example Analysis in Reference 5 shows how the complex shape of a drillship is subdivided into smaller parts classed by height above the water line. Their area when projected on a plane perpendicular to the wind direction is calculated. Then height and shape coefficients are assigned, and the resulting wind force summed. Table 3-1 illustrates the decomposition of the sample problem geometry into sub-areas.

An engineering spreadsheet is a convenient way to tabulate the remaining computations. Several well-known programs for personal computers simplify spreadsheet computations. Appendix A describes MOORLOAD, a spreadsheet "template" set up to perform wind and current load calculations. Table 3-2 shows the spreadsheet of wind and current loading for the sample problem.

The ABS wind formulas do not take into account aerodynamic details like turbulence, wake effects and interference. These make precise estimates of the wind force an uncertain art. While it would be disastrous to ignore them in the design of a jet fighter, the uncertainty is acceptable for moorings. Indeed, if we wanted semi-submersibles to fly, we would put wings on them.

Evaluate Current Forces

Current forces are estimated by much the same procedures used to estimate wind forces. The hydrodynamic pressure, that depends on the current speed and water density, is scaled to force units by an area that represents the size of the obstacle and a drag coefficient that represents its shape.

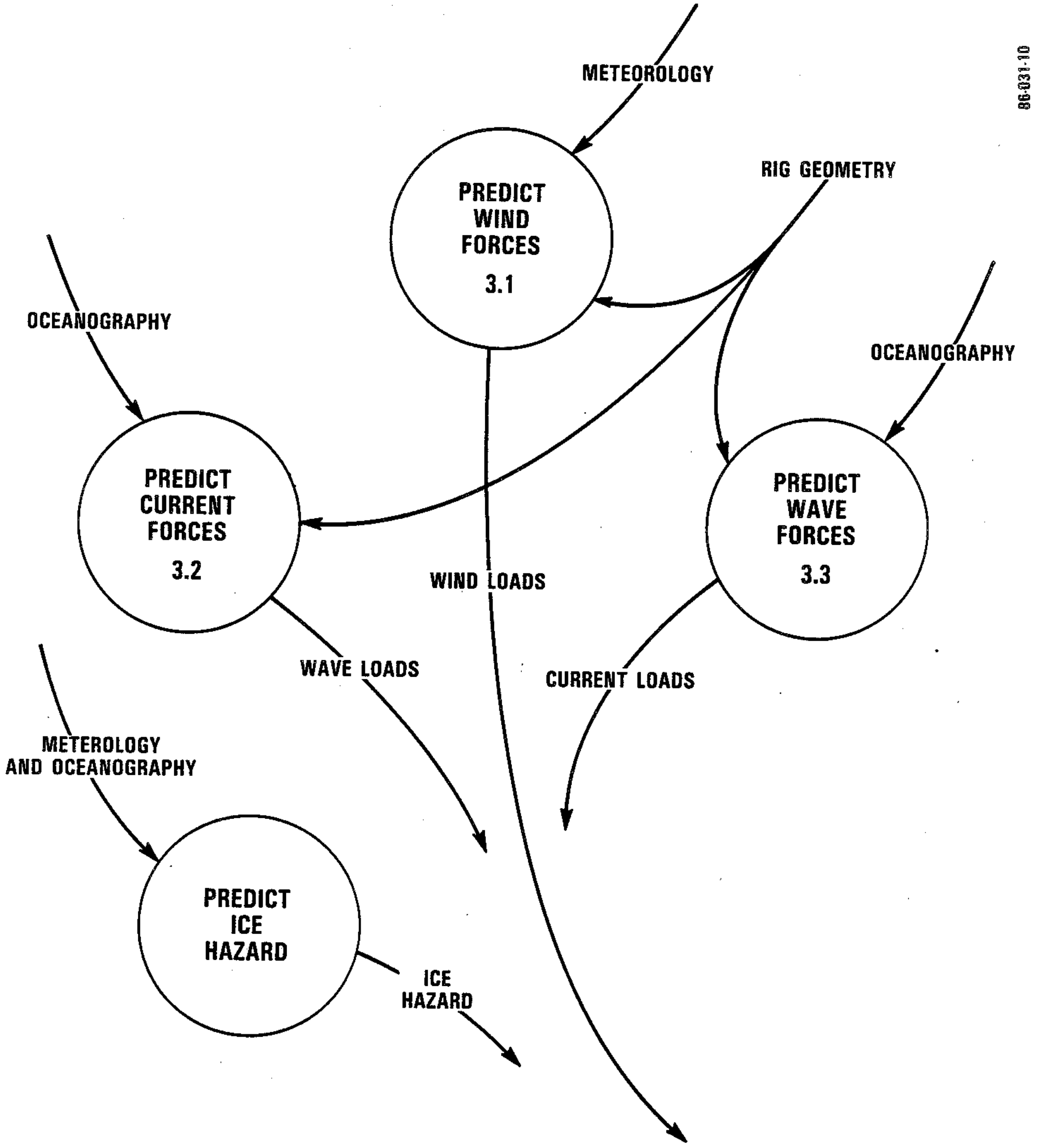

Figure 3-1. Evaluate Environmental Loads

Table 3-1
Areas Exposed to Wind

Areas exposed to wind are grouped in classes by shape factor and height above sealevel.

(1) Cylinders

There are six caissons and four braces extending from the waterline to the underdeck. The projected area is diameter times height:

Caissons 6(25)(38) = 5700 ft^2
Braces 4(10)(38) = $\underline{1520}$
7220 ft^2 0-50 ft height

(2) Deckhouses

The sides of the main deck are below 50 ft. Two deckhouses are shown, one for crewspace, the other for supporting the crane. Each deckhouse has two stories of 12 ft. The crewspace and cranehouse are in the next height class.

Main deck 200(12) = 2400 ft^2 0-50 ft height

Crewspace 2(62)(12) = 1488 ft^2
Cranehouse (50+38)(12) = $\underline{1056}$
2544 ft^2 50-100 ft height

(3) Abovedeck Trusswork

The crane boom is 8 ft square and 138 ft tall, so it is considered in three height classes.

(a) 8(38) = 304 ft^2 50-100 ft height
(b) 8(50) = 400 ft^2 100-150 ft height
(c) 8(50) = 400 ft^2 150-200 ft height

(4) Underdeck Smooth

The smooth area of the underdeck, assuming a 3 degree heel is the flat surface of the tilted deck, projected on a vertical surface.

Underdeck $(200)^2\sin(3)$ = 2093 ft^2 0-50 ft height

(5) Underdeck Trusswork

The projected area of underdeck trusswork can be determined from design drawings. For this example, assume that trusswork occupies 25 percent of the underdeck smooth area.

Trusswork .25(2093) = 523 ft^2 0-50 ft height

(6) Rig Derrick

The rig derrick is usually open trusswork, but may be enclosed to keep out the weather. If it is enclosed, it should be treated as a deckhouse, but in separate height classes.

(a) 50(50.00+41.67)/2 = 2292 ft^2 50-100 ft height
50(41.67+33.33)/2 = 1875 ft^2 100-150 ft height
50(33.33+25.00)/2 = 1458 ft^2 150-200 ft height

Table 3-2. Wind and Current Force Tabulation for Sample Problem

Note: User entries are shown **boldface**.

Wind Force Estimation for Moored Exploratory Oil Drilling Rigs
using ABS formulas and coefficients
David B. Dillon EG&G 1985

		Operating	Survival
Wind Speed	(Knots)	70	100
Current Speed	(Knots)	1	2
Current Depth	(Feet)	300	300
Wind Q	(Lb/SqFt)	16.54099	33.75713
Current Q	(Lb/SqFt)	2.834886	11.33955

Ft/Sec per Knot	1.68781
Truss Factor	.60
Temperature	60 F
Density	(Sl/CuFt)
Air	.00237
Seawater	1.9903

		Height (Feet) Above Waterline								
		0-50	50-100	100-150	150-200	200+				
Height	Shape Coef.	1.00	1.10	1.20	1.30	1.37	Weighted Area	Wind Force, (Lb)		
		- - - Bow-On Projected Area (Sq. Ft.) - - -					(Sq.Ft.)	Operating	Survival	
Cylinders	.50	**7220**	0	0	0	0	3610	59712.980	121863.22	
Hull	1.00	0	0	0	0	0	0	0	0	
Deck Houses	1.00	**2400**	**2544**	0	0	0	5198.4	85986.691	175483.04	
Abovedeck Trusswork	1.50	0	**304**	**400**	**400**	0	1200.96	19865.069	40540.958	*
Underdeck, Smooth	1.00	**2093**	0	0	0	0	2093	34620.295	70653.664	
Underdeck Structures	1.30	**523**	0	0	0	0	407.94	6747.7321	13770.882	*
Rig Derrick	1.25	0	**2292**	**1875**	**1458**	0	4999.95	82704.131	168783.94	*

* Truss Factor applied

Bow-on Wind Force: 289636.90 591095.71 √

↑ OK

Current Force Estimate

	Drag Coefficient		Units	Entry	Weighted Area (Sq.Ft.)	Operation Force (Pounds)	Survival Force (Pounds)
Cylinders	.85	Bow-on Area	(Sq.Ft.)	**13982**	11884.7	33691.774	134767.10
Other Shapes	2.00	Bow-on Area	(Sq.Ft.)	0	0	0	0
Hull	.0056	Wetted Area	(Sq.Ft.)	0	0	0	0
Riser Pipe	.0035	Diameter	(In.)	**20**	5.4977871	15.585602	62.342408
Mooring		No. Legs		**10**			
Chain	1.50	Diameter	(In.)	**1.2**	450	1275.6989	5102.7955
Wire Rope	.50	Diameter	(In.)	**1.8**	225	637.84944	2551.3977

Current Force: 35620.908 142483.63
Total Bow-on Force: 325257.81 733579.34

? 563

(Conti   )

Table 3-2 (Concluded). Beam Wind Force Tabulation for Sample Problem

Note: User entries are shown **boldface.**

		Height (Feet) Above Waterline							
		0-50	50-100	100-150	150-200	200+			
Height	Shape Coef.		1	1.1	1.2	1.3	1.37 Weighted Area	Wind Force, (Lb)	
		- - -	Beam Projected Area (Sq. Ft.)			- - -	(Sq.Ft.)	Operating	Survival
Cylinders	.50	**7220**	0	0	0	0	3610	59712.980	121863.22
Hull	1.00	0	0	0	0	0	0	0	0
Deck Houses	1.00	**2400**	**2544**	0	0	0	5198.4	85986.691	175483.04
Abovedeck Trusswork	1.50	0	**304**	**400**	**400**	0	1200.96	19865.069	40540.958 *
Underdeck, Smooth	1.00	**2093**	0	0	0	0	2093	34620.295	70653.664
Underdeck Structures	1.30	**523**	0	0	0	0	407.94	6747.7321	13770.882 *
Rig Derrick	1.25	0	**2292**	**1875**	**1458**	0	4999.95	82704.131	168783.94 *

* Truss Factor applied

Beam Wind Force: 289636.90 591095.71

OK

Current Force Estimation for Moored Exploratory Oil Drilling Rigs
using ABS formulas and coefficients David B. Dillon EG&G 1985

	Drag Coefficient		Units	Entry	Weighted Area (Sq.Ft.)	Operation Force (Pounds)	Survival Force (Pounds)
Cylinders	.85	Beam Area	(Sq.Ft.)	**19500**	16575	46988.242	187952.97
Other Shapes	2.00	Beam Area	(Sq.Ft.)	0	0	0	0
Hull	.1058	Wetted Area	(Sq.Ft.)	0	0	0	0
Riser Pipe	.0035	Diameter	(In.)	**20**	5.4977871	15.585602	62.342408
Mooring		No. Legs		**10**			
Chain	1.50	Diameter	(In.)	**1.2**	450	1275.6989	5102.7955
Wire Rope	.50	Diameter	(In.)	**1.8**	225	637.84944	2551.3977
					Beam Current Force:	48917.376	195669.50
					Total Beam Force:	338554.27	786765.21

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Current force = (Drag coefficient)(Area)(Dynamic pressure)
Dynamic pressure = (1/2)(Density)(Velocity^2)

In air: Dynamic pressure (Lb/SqFt) = .00338 (Knots^2)
In seawater: Dynamic pressure (Lb/SqFt) = 2.835 (Knots^2)

In the case of wind force, a second coefficient accounts for the normal variation of wind speed relative to the wind at a standard measurement height. This coefficient is unnecessary in the current force formula because the draft of drillships and semi's is typically less than half the height of the derrick. Furthermore, many factors combine to average the water velocity in a "mixed" layer whose depth normally exceeds the draft of semi's. Table 3-3 indicates drag coefficients and reference areas for underwater members.

Table 3-3. Parameters for Estimating Current Forces

Shape	Drag Coefficient	Reference Area
Cylinder	0.85	Projected
Hull (beam)	0.11	Wetted surface
Hull (bow-on)	0.0056	Wetted surface
Other	2.00	Projected

Only in shallow water can a uniform current can be assumed at all depths. In deep water, currents vary in speed and direction with depth, but not in a regular manner that permits a schedule of height coefficients. This complicates precise estimates of the drag on the riser pipe and mooring lines, which extend through the entire water column. However, the drag of the riser pipe and mooring lines is usually only a few percent of the drag on the drillship or semi, so elaborate calculations are unnecessary.

Divide the water column into layers in which the current speed and direction are constant, and compute the riser pipe and mooring line drag separately for each layer. Usually a moving layer over a still layer is sufficient; occasionally a submerged counterflow requires a third layer. This procedure is nearly exact for the riser pipe, which is essentially vertical. The reference area for a riser is the product of its diameter times the thickness of the current layer. The procedure is inexact for mooring lines because they present a continuously varying aspect to the current.

The varying aspect presented by catenary arcs makes an accurate summation of the current drag difficult, although well within the capacity of modern computers. A sophisticated model is not used for large moorings because:

- describing the hydrodynamic properties of the mooring elements and the current structure places an additional burden on the mooring designer/analyst;

- the cost of computer resources is substantially greater; and

- the total drag of the mooring lines rarely exceeds five percent of the drag of a moored semi-submersible.

The working procedure described above - to assume that mooring lines are vertical in any moving layer - is inexact geometrically, but adequate and simple for estimating drag. The reference area for wire rope is the product of the rope diameter times the current layer thickness. Chain diameter is the nominal size of the "wire" from which the links are formed. The shape of the links is accounted for in the drag coefficient, Table 3-4.

Table 3-4. Riser and Mooring Parameters

Shape	Drag Coefficient	Reference Area
Riser	1.00	Projected
Wire rope	1.40	Projected
Chain	2.50	Projected

Reference 1 cites empirical formulas for riser pipe and mooring line drag that imply a one-layer current. The drag coefficients implicit in the empirical multipliers are less than those listed in Table 3-4 in order to account for two-layer current profiles commonly encountered.

Sample Estimate of Current Forces

A two-layer current profile is assumed for the sample problem begun in Section 1. The moving layer extends from the surface to a depth of 300 ft. Below 300 ft, the water is still. Areas exposed to current are classed by shape according to Tables 3-3 and 3-4. The area presented to beam currents is substantially different from the area exposed to bow-on currents, so separate tabulations must be made.

(1) Cylinders
There are six caissons, two footers, four transverse braces and two transverse spacers. The braces are inclined 37 degrees from vertical. Their underwater length is 50/Cos(37) = 62.5 ft.

	Beam Areas		Bow-on Areas	
Caissons	6(25)(50) =	7500 ft^2	6(25)(50) =	7500 ft^2
Footers	2(25)(200) =	10000	$2(pi)(25)^2/4$ =	982
Braces	4(10)(50) =	2000	4(10)(62.5) =	2500
Spacers			2(10)(150) =	3000
Cylinders:		19500 ft^2		13982 ft^2

(2) Riser
20" = 1.67' depth of current
The riser is 20 inches in diameter: (1.67)(300) = 500 ft^2

(3) Mooring lines

There are ten three inch mooring lines. The sample mooring has the unusual feature of three distinct leg styles - four are all chain, three are all wire, and two are wire plus chain. The chain and wire rope have the same nominal size, so the total reference area is the same as if all the legs had been alike. But the drag coefficients for wire rope and chain are very different, so separate projected areas must be estimated for each type. The approximation is made that the legs hang vertically through the current layer:

4 Chain legs:	4(3/12)(300)	= 300 ft^2
6 Wire legs:	6(3/12)(300)	= 450 ft^2

Table 3-2 includes MOORLOAD's current force summary for the sample problem.

Estimate Wave Force

Wave forces, even the force of waves on a rigid structure, are not easily estimated. When waves impact a floating, complex, compliant structure such as a moored semi-submersible, the problem becomes much more difficult to describe mathematically, so that simple tools like MOORLOAD are not useful. The Morison Equation attempts to describe wave forces on a cylindrical piling driven into the seafloor. It has given good results when its coefficients are judiciously selected by an experienced analyst (Ref. 8, v. I, p. 164), and has been the subject of extensive study in the 35 years since its introduction.

The Morison Equation assumes that the piling has negligible effect on the wave. Diffraction theory is used for objects large enough to alter the waveform (Ibid, p. 160). Both theories are differential equations that are solved by numerical methods using large computers. Many theories and variant formulations are being studied.

The American Bureau of Shipping (Ref. 2, App. A) relies on linear wave theory in shallow and deep water expressions. The deepwater equations can be integrated in closed form for simple shapes like the vertical caissons and horizontal footers in a semi-submersible rig:

$$|F_i|_c = C_{mc} D_w (1 - e^{-kL})$$

where $|F_i|_c$ is the amplitude of a sinusoidally varying inertial force on a vertical cylindrical caisson;

C_{mc} is the apparent mass coefficient of the caisson;

D_w is the displacement of the cylinder between the still-water line and the wave crest;

k is the wave number; and

L is the length of the caisson below the still-water line.

The corresponding equation for a horizontal cylindrical footer is:

$$|F_i|_f = (2\ \mathrm{pi})\ C_{mf}\ D_f\ (H_w/L_w)$$

where $|F_i|_f$ is the inertial force amplitude on a footer in a beam sea;

C_{mf} is the apparent mass coefficient of the footer;

D_f is the displacement of the footer;

H_w is the wave height; and

L_w is the wave length.

The semi-submersible shown in Figure 1-1 provides a numerical example. Assume that H_w is 35 ft, crest to trough, and that the wave period, T_w is 12 seconds. The caisson is 25 ft in diameter, and extends 50 ft below the still water level. The footer is the same diameter, but 200 ft long.

Reference 2 recommends a two-dimensional apparent mass coefficient of 1.5 for cylinders more than 8 ft in diameter. A second correction is used to determine the three-dimensional apparent mass coefficient:

$$K = \frac{(l/d)^2}{[1 + (l/d)^2]} ,$$

where l is the cylinder length and d is its diameter. Thus,

$$K_c = \frac{(50/25)^2}{[1 + (50/25)^2]} = 4/5 = 0.80 \text{ for the caissons, and}$$

$$K_f = \frac{(200/25)^2}{[1 + (200/25)^2]} = 64/65 = 0.98 \text{ for the footers.}$$

$$C_{mc} = (1.5)(0.80) = 1.20$$

$$C_{mf} = (1.5)(0.98) = 1.47$$

$$D_w = (\mathrm{pi})(25^2/4)(35/2)(64) = 550{,}000 \text{ lb per caisson}$$

$$D_f = (\mathrm{pi})(25^2/4)(200)(64) = 6{,}300{,}000 \text{ lb per footer}$$

$$L_w = (g)(T^2)/(2\ \mathrm{pi}) = (32.2)(12^2)/(6.28) = 738 \text{ ft}$$

$$k = (2\ \mathrm{pi}) / L_w = 6.28/738 = 0.00851 \text{ ft}^{-1}$$

$$|F_i|_c = (1.20)(550{,}000)(1- e^{(.00851)(50)}) = 229{,}000 \text{ lb/caisson}$$

$$|F_i|_f = (1.47)(6{,}300{,}000)(6.28)(35/738) = 2{,}760{,}000 \text{ lb/footer}$$

Unlike the wind and current forces estimated in previous sections which act over times much longer than the characteristic response periods of a moored vessel, these force estimates represent the amplitude of a periodic force. They are enormous, but their actual effect on the mooring depends on the ratio of wave period to the natural period of the moored rig. The ABS formulations do not provide rig periodicities. Furthermore, the periodicity of these inertial terms means that their time average is zero.

The Recommended Practice of the American Petroleum Institute (RP-2P, Reference 5) acknowledges the difficulty of computing low frequency vessel motions and concentrates instead upon other terms in the wave forcing function, the mean drift force and the wave displacement force. Numerically complex functions are presented graphically, and the remaining computations are simple enough to be done with an engineering calculator or slide rule. Numeric examples are given in RP-2P for both ship shape and semi-submersible rigs.

Large Computer Models

The methods described above provide the simplest means for estimating environmental forces on moored rigs. They are sufficient for evaluating a rig. The rig and mooring designer need more specific results than these formulas provide and may use one of the large computer models to get them. Reference 8 is a detailed review of most of the large models currently in use. They use various mathematical techniques, all numerically intensive, to predict wind, current and wave loadings on moored and unmoored floating objects and their responses.

Large computer models are typically programmed as an assembly of modular "building blocks". The user selects the parts of the model that are appropriate: the module for semi-submersibles instead of the ship shape hull or axisymmetric buoy module; a wave spectrum module from a list of spectra, moored versus unmoored; time domain or frequency domain and so on. In some models the selection includes deciding upon the mathematical method to be employed.

While these features represent successful programming and spell Versatility to the expert user, the novice often reads Bewilderment. Furthermore, the mooring designer is able to concentrate on a single model of his choice and gain familiarity with it. A reviewer is confronted with the full range of models used by designers, and he cannot be expert in all of them, although commercial models are often supported by technical advisors who assist users who call on a telephone "hotline". Volume III shows how the sample problem was set up on a large model, describes the technical adjustments that were made in order to arrive at a solution, and gives a partial listing of the results.

SECTION 4
EVALUATE MOORING CAPACITY

A mooring design is evaluated by making an independent estimate of its holding capacity using the mooring components specified for the design. Figure 4-1 illustrates the function as consisting of four processes. The last two are simple verifications, but the first two are mathematically intense and require computer support. Volume IV describes RIGMOOR, a computer program in the public domain that simplifies these computations.

Reconcile Preload, Leg Length and Anchor Radius

Designing a spread mooring involves selecting six parameters to meet five conditions - mathematically, five equations in six unknowns, which means that mooring solutions are not unique. The designer has one parameter which he may adjust to meet some external optimum condition, such as minimum weight. Appendix B describes one method for optimizing the mooring preload. Preload is the horizontal force with which the legs pull against each other in the absence of external load.

Constraints	Parameters
Environmental load	No. of legs
Load direction	Anchor pattern
Water depth	Material size
Permissible deflection	Leg length
Anchor capacity	Leg preload
	Anchor radius

A common procedure is to select the number of legs, anchor pattern and a trial element size, then compute a table of length, preload and anchor radius subject to the listed constraints. Then a preload is selected from the table, from which the holding power of the mooring is developed.

Compute Holding Power Roses

When the preload, leg length and anchor radius have been reconciled, the load vs deflection curve for each leg can be computed. The static holding power of the rig mooring is then readily computed as the sum of the restoring forces produced by the legs for any deflection. Figure 4-2 shows a symmetric fivelegged spread mooring. The anchors are equi-spaced around an "anchor circle". When no force disturbs the mooring equilibrium, the rig is centered over the drill hole and the legs are drawn to the preload.

The deflection limit on the riser pipe defines a "watch circle" centered on the drill hole. We may, figuratively, move the rig around the watch circle. At each point, the distance to each anchor can be computed, and by means of the X *vs* H relation for the leg, the restoring force for each leg computed. The sum of these forces represents the total restoring force of the mooring. Its vector negative is the environmental force required to deflect the rig to that position on the watch circle. The largest deflection of a leg occurs when the deflection is diametrically opposite the

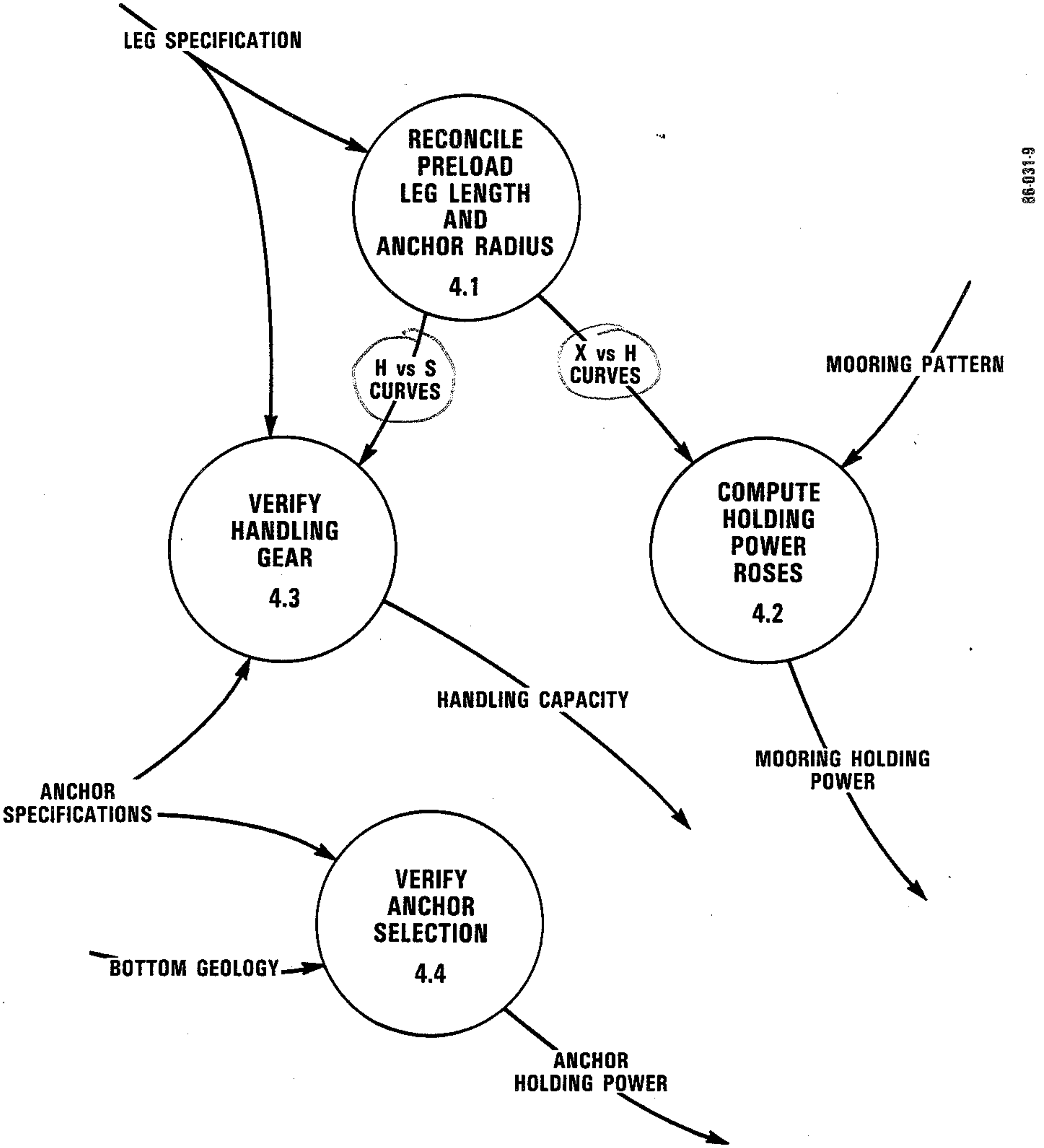


Figure 4-1. Evaluate Mooring Capacity

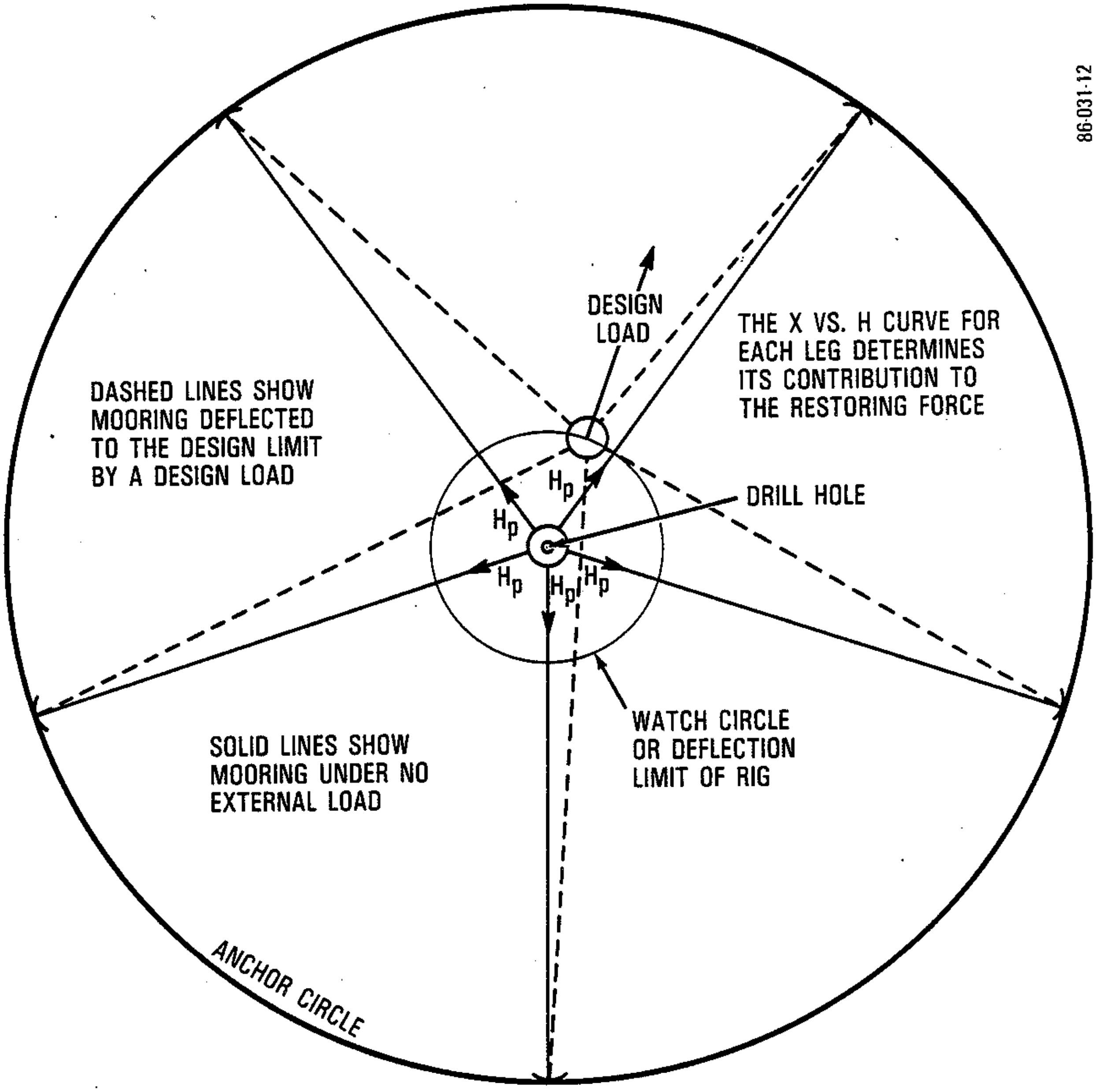


Figure 4-2. Static Mooring Deflection

leg's anchor. That defines the worst loading condition for the leg. For all other points on the watch circle, the leg will be loaded more lightly.

It is apparent from the symmetry of the mooring in Figure 4-2 that the holding power is symmetrical about each leg. We need only consider points on the watch circle in the arc between an anchor radius and the bisector of two anchor radii. When the deflection is diametrically opposed to an anchor, the load concentrates in that leg, giving maximum stiffness and least holding power. When the deflection is evenly divided between legs, the stiffness is least and holding power maximized because the load is shared by two legs. A polar plot of the holding power forms a "rose" with as many "petals" as there are legs. Figure 4-3 shows one half-petal of the holding power rose for the sample problem.

The sample problem was evaluated as described in Appendix C using the RIGMOOR model. Table 4-1 shows the holding power "rose" computed by RIGMOOR. The rose was evaluated over 90 degrees, reflecting the symmetry of the mooring plan sketched on Figure 1-2. Figure 4-3 was plotted from Table 4-1.

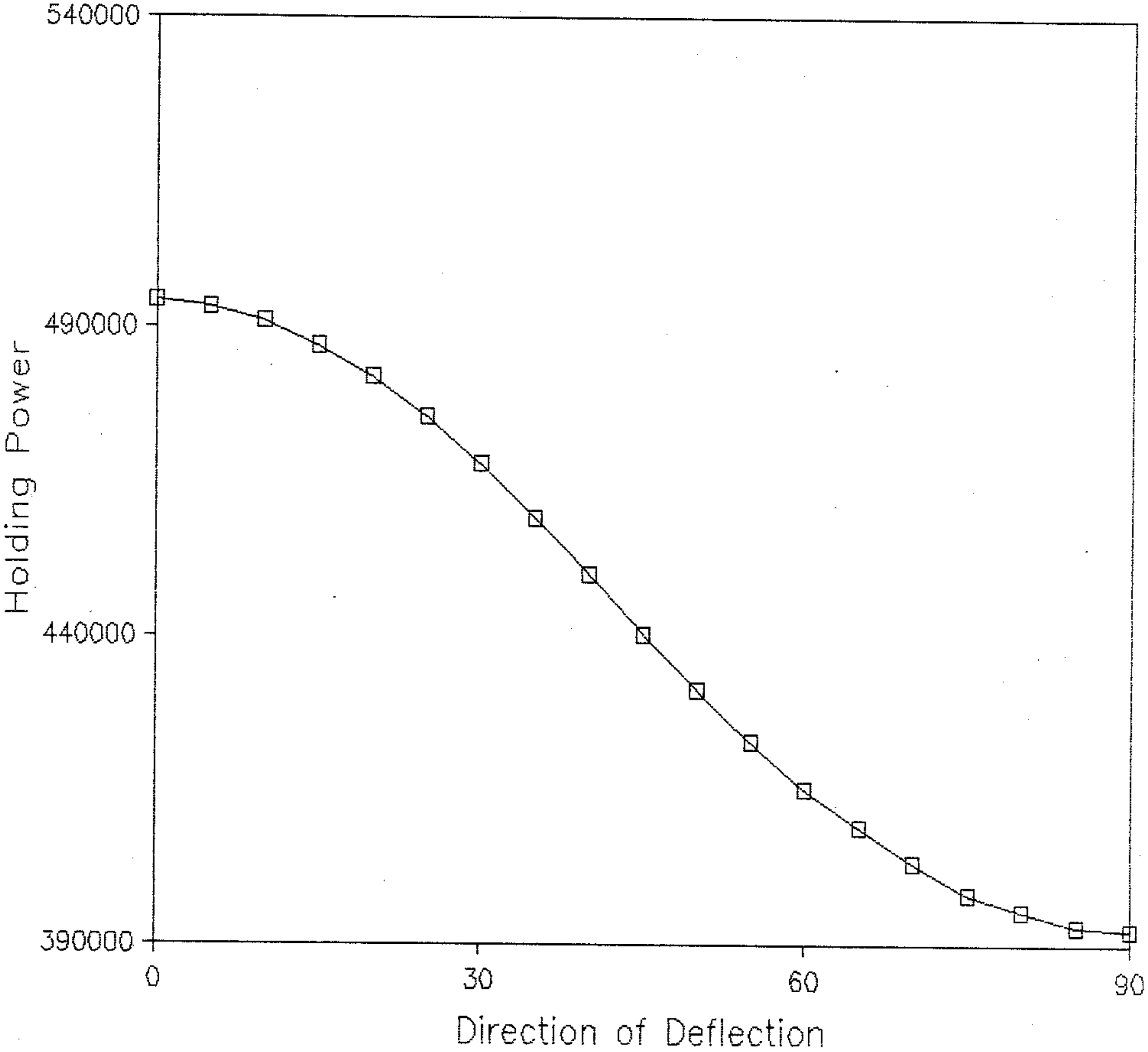
The legs of a spread mooring are deployed from fairleads spaced around the extremities of the rig, and the anchor radii often do not pass thru the center of the moon pool. The leg loads therefore produce yawing moments. The rig rotates in the mooring to the angle which produces no net moment. When

Table 4-1. Sample Problem Holding Power Rose

OPERATIONAL AND SURVIVAL HOLDING POWER ANALYSIS FOR 0. FEET HEAVE

Direction of Rig Deflection	Operational (All legs active)				Survival (Lee legs slacked)			
	Holding Power	Weather Direction	Safety Factor	Rig Yaw	Holding Power	Weather Direction	Safety Factor	Rig Yaw
.00	494178.	.00	3.00	.00	634780.	.00	3.00	.00
5.00	493301.	4.03	3.01	.01	633787.	2.78	3.01	.01
10.00	491053.	8.04	3.03	.01	631181.	5.54	3.03	.03
15.00	486944.	12.28	3.07	.02	626982.	8.36	3.07	.04
20.00	481860.	16.45	3.12	.03	635695.	16.32	3.12	.05
25.00	475494.	20.77	3.15	.03	629824.	18.61	3.15	.06
30.00	467834.	25.17	3.08	.04	622212.	20.88	3.08	.07
35.00	458955.	29.94	3.04	.04	591041.	29.58	3.04	.07
40.00	449943.	34.61	3.01	.04	582831.	32.69	3.01	.08
45.00	440232.	39.53	3.00	.04	573396.	35.93	3.00	.08
50.00	431319.	44.61	3.01	.04	564082.	39.22	3.01	.09
55.00	423004.	49.79	3.04	.04	554633.	42.50	3.04	.10
60.00	415245.	55.34	3.08	.04	544581.	45.99	3.08	.10
65.00	409112.	60.63	3.15	.03	535557.	49.23	3.15	.11
70.00	403312.	66.34	3.13	.03	535412.	58.25	3.13	.10
75.00	398158.	72.40	3.08	.02	527149.	61.16	3.08	.11
80.00	395433.	78.23	3.04	.01	475125.	81.15	3.04	.01
85.00	393146.	84.04	3.01	.01	473852.	85.52	3.01	.01
90.00	392432.	90.00	3.00	.00	473494.	90.00	3.00	.00

↑
Safety factor is 3 when a leg is aligned with the deflection. It is greater than 3 at all other [illegible] [illegible] 2 legs share the load.



plotted by [illegible]

Figure 4-3. Sample Operational Holding Power Rose (One-Half Petal) the rig is deflected, the directions of the anchor radii change slightly (see Figure 4-2 again). If these are unsymmetric the rig rotates slightly to cancel the new leg moments. The rig yaw (in degrees) is shown on Table 4-1 for each loading condition.

The asymmetry of the deflected mooring also means that the restoring force does not exactly parallel the deflection. Figure 4-4 compares the "weather direction" (direction of the external force) to the direction of the resulting deflection, again based on Table 4-1.

Several adjustments can be made to increase the holding power during storms. The easiest is also the most conservative: pay out the leeward legs to reduce their back tension on the upwind legs. If the legs have been optimized according the procedure described above and in Appendix B, the working tension limit is attained when the mooring is deflected to the watch circle aligned opposite an anchor. The safe survival deflection using this procedure is still the operating watch circle, whether the lee legs are slacked or not. Figure 4-5 shows the survival holding power for the sample problem by this method as computed by the RIGMOOR program. The corresponding survival conditions are tabulated in the right half of Table 4-1. The safety factor is exactly three when a leg is aligned with the deflection, under both operational and survival conditions. For other alignments, the safety factor is greater because other legs share more of the load.

Table 4-2 and Table 4-3 show results similar to Table 4-1, except that the rig is assumed to be heaved upward by 10 feet in Table 4-2 and downward in Table 4-3. It is assumed that no dynamic adjustments are made in the legs to compensate for the heave motion. The safety factor is reduced by upward heave - the legs are more taut because the anchors are farther away - and increased by downward displacement. Holding power - actually, the force required to displace the rig - varies inversely. Upward heave increases the holding power, but this no free lunch. It is the consequence of nibbling at the safety factor. In this context, safety factor is the ratio of breaking strength to tension. The tabulated value is the least safety factor in any leg.

The legs aligned with storm forces normally bear the brunt of the load. Additional holding power for survival conditions can be achieved by drawing in on the other upwind legs to increase their share of the load. This is practical only if the rig operator has accurate tension monitors on each leg and an on-line mooring model to ensure that neither the working tension nor the transition load (that lifts anchor shank) is exceeded. This procedure also keeps the deflection within the original watch circle.

Instead of paying out the leeward legs and drawing in the upwind legs, the holding power can be increased by paying out the upwind legs. This has the effect of slacking the leeward legs (by moving the rig closer to the leeward anchors). Furthermore, a sketch like Figure 4-6 shows that the cross-wind legs get a "better angle" on the storm. This procedure also requires careful monitoring of accurate tension meters in conjunction with an on-line mooring model to be done safely. The risk that the lateral force on fluked anchors will "tumble" them and pull them out must be weighed in the decision to use this method.

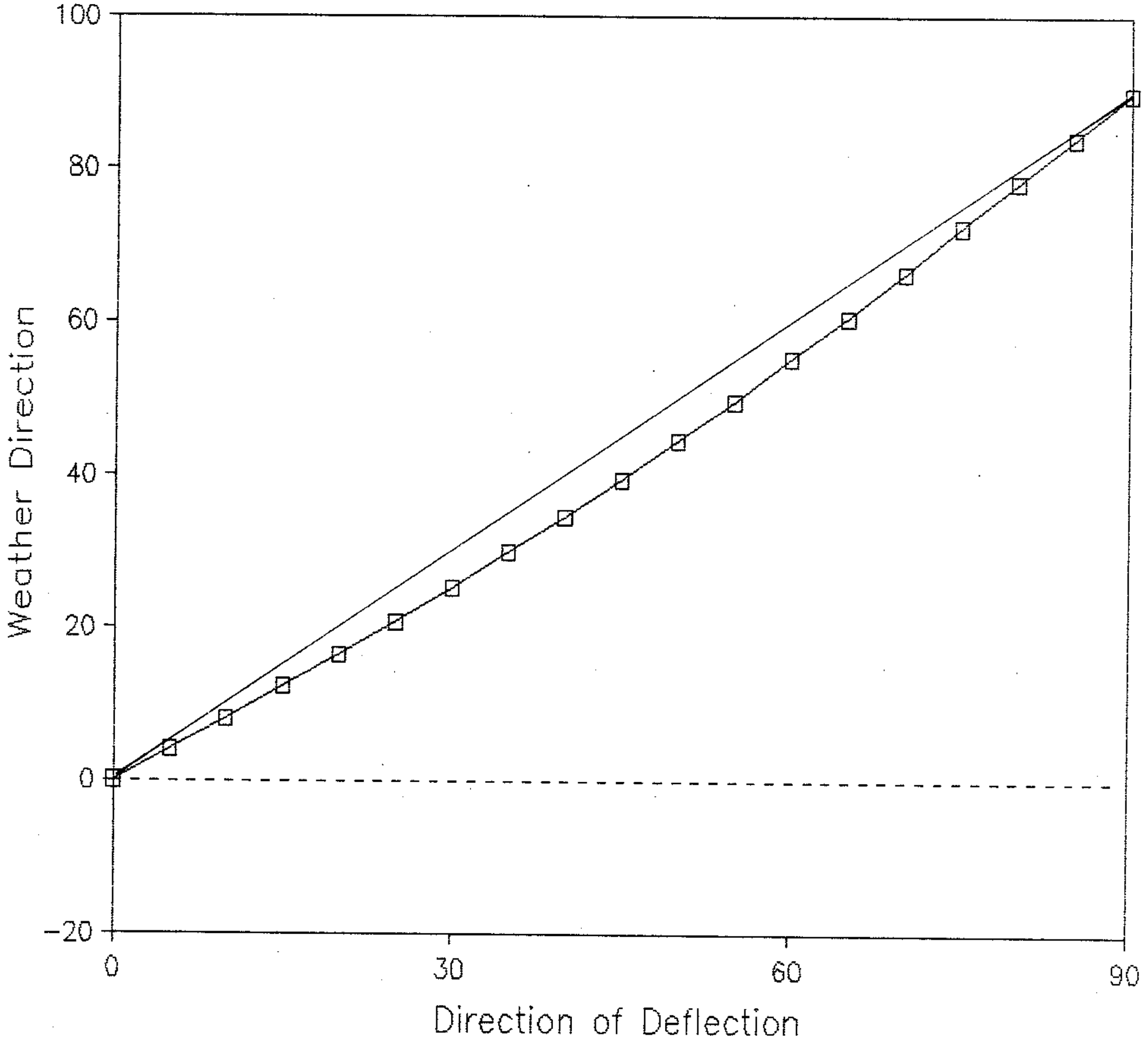


Figure 4-4. Comparison of Load and Deflection Direction

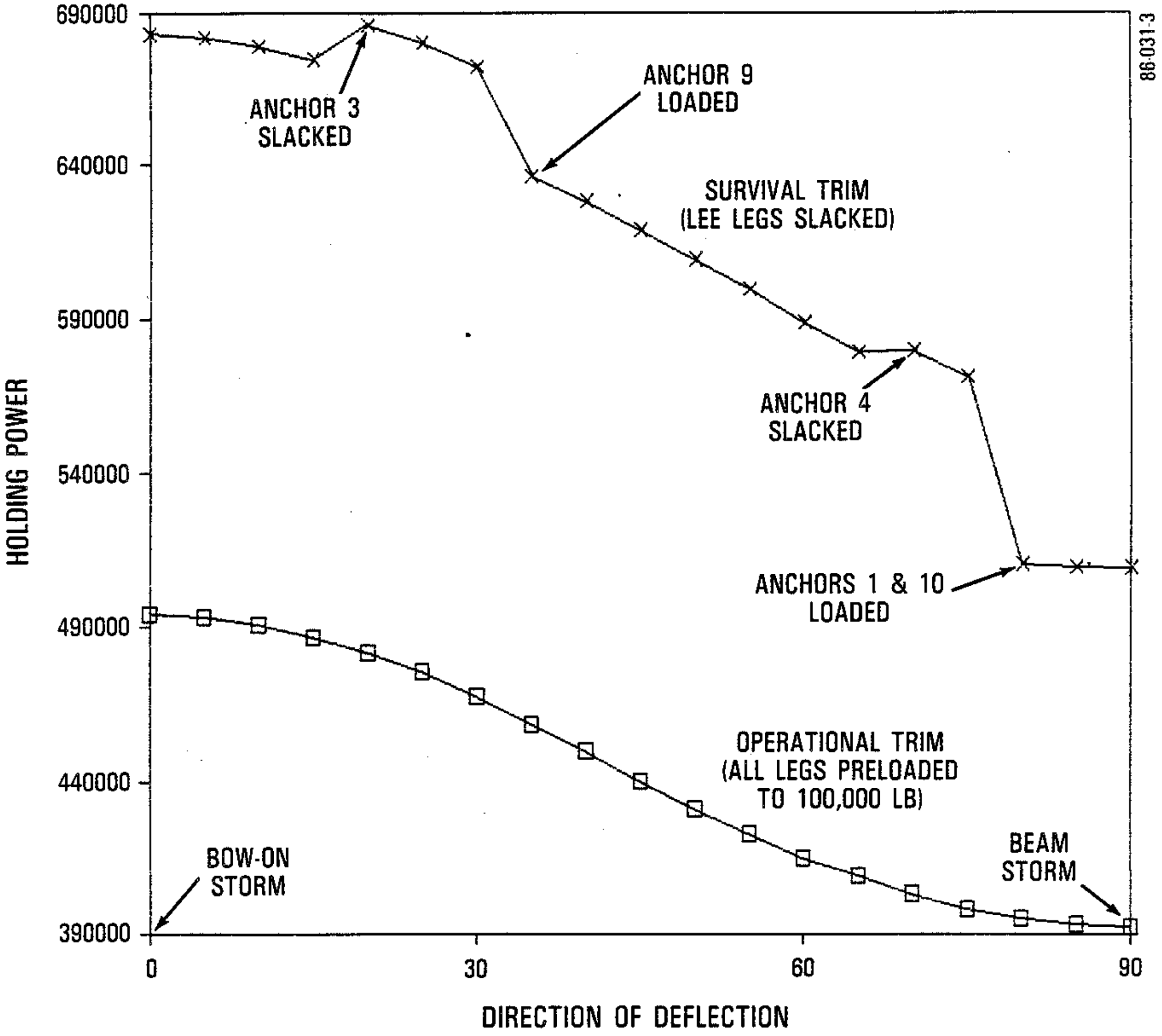


Figure 4-5. Survival Holding Power Rose (One-Half Petal)

Table 4-2. Operational and Survival Holding Power Analysis for 10. Feet Heave

Direction of Rig Deflection	Operational (All legs active)				Survival (Lee legs slacked)			
	Holding Power	Weather Direction	Safety Factor	Rig Yaw	Holding Power	Weather Direction	Safety Factor	Rig Yaw
.00	547551.	.00	2.70	.00	701156.	.00	2.70	.00
5.00	546342.	3.84	2.71	.01	699943.	2.68	2.71	.01
10.00	542064.	7.73	2.73	.01	696220.	5.31	2.73	.03
15.00	535293.	11.79	2.77	.02	690213.	7.99	2.77	.04
20.00	527542.	15.94	2.82	.03	697314.	15.82	2.82	.05
25.00	519008.	20.06	2.89	.03	690281.	18.00	2.89	.06
30.00	508510.	24.45	2.91	.04	680783.	20.24	2.91	.08
35.00	497588.	29.05	2.87	.04	670008.	22.48	2.87	.09
40.00	487109.	33.75	2.84	.05	634667.	31.83	2.84	.08
45.00	475260.	38.64	2.83	.05	622985.	35.06	2.83	.09
50.00	464697.	43.64	2.84	.05	611897.	38.30	2.84	.10
55.00	454504.	48.83	2.87	.04	600325.	41.60	2.87	.10
60.00	444834.	54.27	2.91	.04	588791.	44.95	2.91	.11
65.00	436020.	60.02	2.97	.04	577628.	48.32	2.97	.11
70.00	428080.	65.89	2.97	.03	575075.	57.37	2.97	.11
75.00	422932.	71.73	2.92	.02	566520.	60.19	2.92	.11
80.00	419071.	77.73	2.88	.02	506026.	80.80	2.88	.01
85.00	416614.	83.98	2.85	.01	504316.	85.46	2.85	.01
90.00	415730.	90.00	2.84	.00	503828.	90.00	2.84	.00

Table 4-3. Operational and Survival Holding Power Analysis for -10. Feet Heave

Direction of Rig Deflection	Operational (All legs active)				Survival (Lee legs slacked)			
	Holding Power	Weather Direction	Safety Factor	Rig Yaw	Holding Power	Weather Direction	Safety Factor	Rig Yaw
.00	446249.	.00	3.33	.00	574163.	.00	3.33	.00
5.00	445808.	4.19	3.34	.01	573598.	2.87	3.34	.01
10.00	443871.	8.53	3.36	.01	571270.	5.83	3.36	.02
15.00	441613.	12.68	3.40	.02	568396.	8.63	3.40	.04
20.00	437639.	17.10	3.43	.02	577380.	16.88	3.43	.04
25.00	432755.	21.57	3.34	.03	572890.	19.18	3.34	.06
30.00	426785.	26.22	3.27	.03	566755.	21.58	3.27	.07
35.00	420084.	30.69	3.23	.04	539828.	30.34	3.23	.06
40.00	413715.	35.45	3.20	.04	533263.	33.59	3.20	.07
45.00	406896.	40.31	3.19	.04	526012.	36.84	3.19	.08
50.00	398946.	45.48	3.20	.04	517827.	40.17	3.20	.08
55.00	393088.	50.81	3.23	.04	510701.	43.58	3.23	.09
60.00	387259.	56.06	3.27	.03	502856.	46.84	3.27	.09
65.00	382072.	61.67	3.34	.03	501887.	56.43	3.34	.09
70.00	378441.	67.10	3.32	.03	496449.	59.15	3.32	.10
75.00	375402.	72.69	3.26	.02	490144.	62.00	3.26	.10
80.00	371976.	78.46	3.21	.01	444427.	81.35	3.21	.01
85.00	370105.	84.29	3.19	.01	443685.	85.73	3.19	.01
90.00	369282.	90.00	3.18	.00	443229.	90.00	3.18	.00

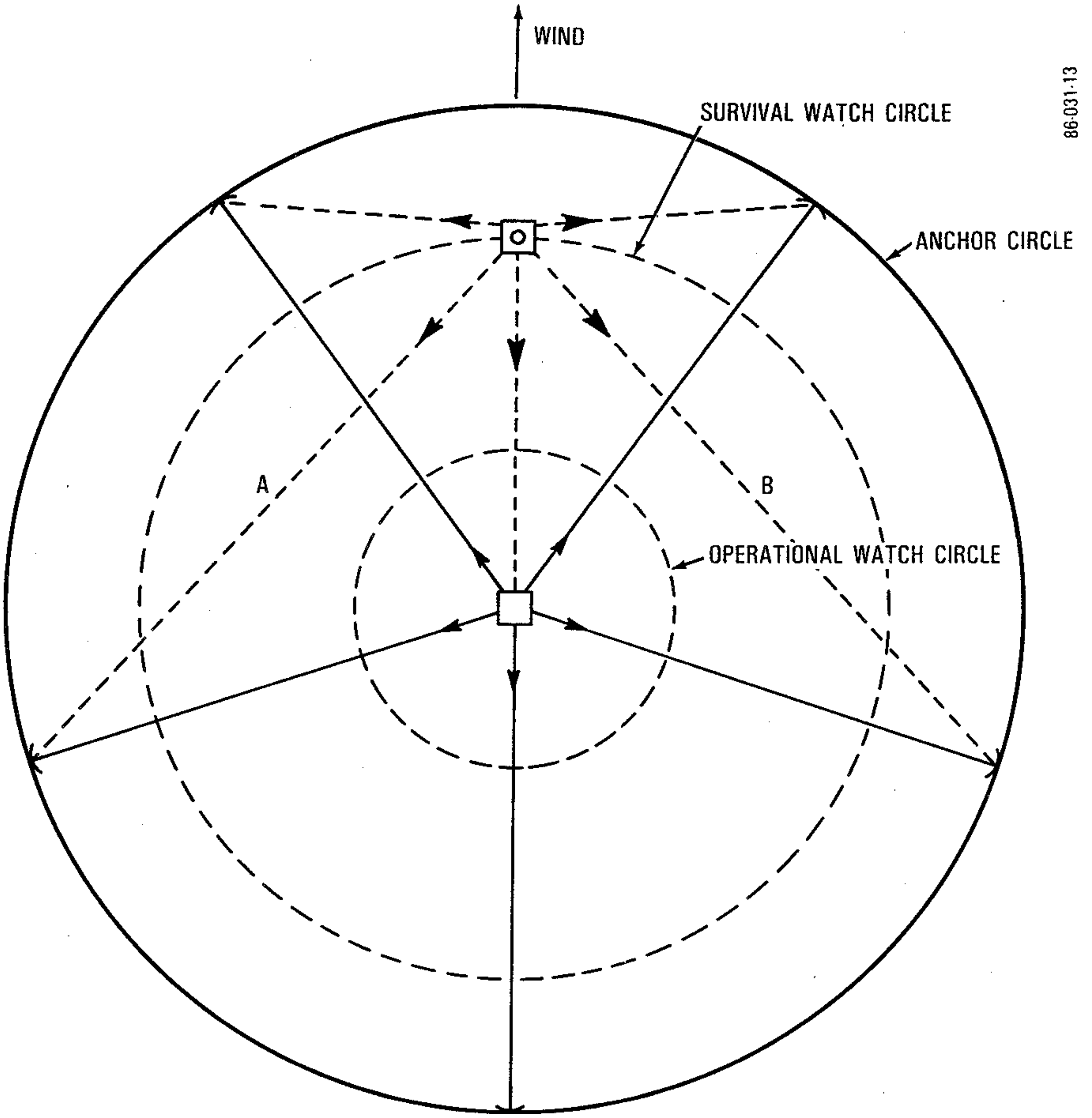


Figure 4-6. Survival Holding Power by Slacking Upwind Legs

When the upwind legs are slacked, the survival watch circle is larger than the operational circle. Upwind legs (A and B) gain a better angle for resisting the storm, but the increased angle may tumble the anchor.

On balance, it is best to design for conservative operation during storms by simply slacking the downwind legs as described above. The other methods can be held in reserve for emergencies.

Verify Handling Gear

This part of the mooring evaluation is not less important because it is not difficult. It is a straightforward check that the mooring winches, wildcats, fairleads and chain lockers are matched to the leg components. The winches must have sufficient line pull to perform anchor setting tests and adjust the line tension under storm loads. A mechanical stop by means of a dog or pawl with a manual emergency release is necessary in addition to friction brakes.

Wire rope is easily damaged by drawing it around sheaves that are too narrow or too small. The ratio of sheave diameter to cable diameter must exceed 20. Level winds or grooved drums help wire rope to wrap neatly on the drum in closely spaced turns. Wildcats and fairleads must be properly sized for chain links to avoid damage. References 1, 6, and 7 each discuss wire rope, chain, winches and windlasses, tensiometers and other deck fittings. Volume II is a survey of mooring hardware, with emphasis on failure modes, inspection methods and testing facilities.

Verify Anchor Selection

Anchors are selected by weight and style. The composition of the seafloor strongly affects the holding power of anchors. References 1, 6 and especially 7 include illustrations of the numerous styles of anchors in common usage as well as technical discussions of holding qualities. Seamen have been devising anchors for as long as they have been "going down to the sea in ships", and analyzing anchor holding power has much the same precision as analysis of the tonal qualities of a Stradivarius.

SECTION 5
COMPARE ESTIMATES WITH DESIGN

The final review (Precedure 5.0) compares the environmental load with the holding capacity and the estimates prepared by the reviewer with the design. The normal result is that the design matches load with strength and is accepted. Otherwise the reviewer may suggest design changes to obtain the needed strength.

Table 5-1 is a comparison of the environmental loads and holding power for the sample problem. The environmental loads are taken from Table 3-2 which shows the wind and current spreadsheet calculations for the sample problem. The holding power results are copied from Tables 4-1, 4-2 and 4-3 based on the RIGMOOR static model. The columns headed "Reserve" contain the difference (Holding Power) - (Loading Force). Positive values indicate extra holding capacity for the environmental condition. Thus, in a 70 kt storm on the bow, the reserve holding power is 494 - 325 = 169 Kips. Negative reserve values mean that the mooring will be overloaded.

Table 5-1. Comparison of Proposed Mooring Holding Power with Estimated Wind and Current Load

		Condition			
		Operational		Survival	
Windspeed (Kt)		70.		100.	
Bow-On	Heave (Feet)	Load (Kips)	Reserve (Kips)	Load (Kips)	Reserve (Kips)
Wind and Current Loading Force		325.		734. ?	
Estimated Mooring Holding Power	0.	494. ✓	169.	C34 ~~683.~~	-51.
	10.	548.	223.	750.	16.
	-10.	446.	121.	623.	-111.
Beam	Heave (Feet)	Load (Kips)	Reserve (Kips)	Load (Kips)	Reserve (Kips)
Wind and Current Loading Force		339.		787. ?	
Estimated Mooring Holding Power	0.	392.	53.	510.	-277.
	10.	416.	77.	540.	-247.
	-10.	369.	30.	479.	-308.

See page C-24

494
169
663

See page C-25

Two facts are apparent in Table 5-1. First, the proposed mooring fails to hold the expected load in a survival wind (100 kt) but is satisfactory in an ordinary storm (70 kt). The second fact is not so easily seen, but notice that the beam wind and current produce larger loads than a bow-on storm. The mooring, on the other hand, is stronger against bow-on than beam storms.

If these facts had occurred singly, the reviewer might take a charitable view and inquire whether there is justification for the discrepancy. Perhaps, for example, the drillsite is unusually sheltered from severe storms. To have the lobes of the holding power rose out of phase with the lobes of the storm loading rose is a clear design error.

In the narrow sense, this concludes the task of mooring review: the proposed mooring is inadequate. But in the real world, a negative review should suggest remedial actions likely to correct the problem. The goal is **not** to redesign the mooring but to suggest profitable directions the redesign might follow. The reviewer should go back over the proposed design in order to pinpoint the weakness.

There is no royal road to effective problem diagnosis, no more in mooring review than in medicine or auto mechanics. In moorings, there are always the simplistic solutions - more legs, more anchors, larger gear - but these can be very costly to implement on an operational rig. There are other avenues that have little or no cost:

- If the weather has a strongly predominant direction, does the rig have a low-drag profile that can be aligned to that direction?
- Can the mooring be installed with the strong lobe of its holding power rose aligned with the predominant storm direction?
- The holding power rose is sensitive to the mooring pattern. Simply changing the direction of the anchors relative to their fairleads can alter the ratio of bow to beam holding power.

Useful recommendations can usually be derived from these approaches without resorting to costly tactics like replacing or relocating mooring gear, especially when a rig has an established operating history.

Applying this to the sample problem, ignore for the moment the different construction of the legs. If the legs have a common construction, then it can be shown from the geometry of the sample mooring pattern (Figure 1-2) that increasing the angle of the corner legs from 45 degrees to 70 degrees off the bow/stern will bring the ratio of bow/beam holding power into better agreement with the ratio of bow/beam storm load:

Ratio	Holding Power	Storm	Value
$\frac{\text{Bow}}{\text{Beam}}$	$= \frac{2 + 2\text{Cos}(70)}{1 + 2\text{Sin}(70)}$	$= \frac{787}{734}$	$= 1.073$

The figures and tables in Section 1 remind us that the sample mooring is an unusual design, with all-chain legs on the bow and stern, wire rope legs at the corners, and two-part legs on the beam. Table C-4 in Appendix C shows the sample runstream for RIGMOOR's analysis of the sample problem. The holding power tables for each leg (pp. C-11 through C-13) can be compared, with interesting results. The preload theory presented in Appendix B says the optimum design for a mooring leg with a drag-embedment (fluked) anchor is adjusted so that the leg will lift the anchor shank if the design load is exceeded.

Table 5-2 compares the optimum design conditions for the three leg types. It was prepared from the H vs S table in appendix C for each leg type. Entries were selected for the least length on the bottom under the design load. (Note: length on bottom is shown as negative in the tables; positive entries denote the upward force of the leg on the anchor, with none on the bottom. This unusual convention is useful because legs lay along the bottom or pull upward on the anchor, but never both). The table shows that combining chain legs with wire rope legs may be useful as an illustration, but not as a mooring. The chain leg has forced a larger preload than is desirable for the other legs. "Forced" because the chain legs would raise their anchor shank at the design load if the preload were lowered to optimize the wire rope legs. The mooring would be substantially improved by using only leg type 2 or leg type 3 for all ten legs.

Table 5-2. Comparison of Optimum Holding Power for Sample Problem Leg Types

Leg Type		Size (In)	Bottomed Length (Feet)	Deployed Length (Feet)	Pre-Load (Kips)	Design Load (Kips)	Holding Power (Kips)
1	Chain	3	38.	1350.	100.4	203.7	103.3
2	Wire	3	39.	3300.	89.5	245.6	156.1
3	Mixed	3	30.*	1250.	41.7	224.4	182.8

* Interpolated

Table 5-3 gives the revised holding power when the mooring pattern is changed to 0-70-90 degrees and all the legs are entirely 3-inch wire rope. The new mooring pattern corrects the bow/beam holding power ratio and increases the holding power, but not enough to restrain the 100 knot storm.

The survival condition for the sample problem simply requires heavier gear. Since the strength of wire rope and chain varies as the square of the diameter, one can estimate the holding power of 3.5-inch legs by scaling the holding power from Table 5-3 (541.8 Kips):

$$(3.5/3.0)^2 = 1.361 \qquad 1.361 * 541.8 = 737.4 \text{ Kips.}$$

The holding power estimated for 3.5-inch wire rope legs matches the required 734 Kips imposed by the 100 knot storm. Table 5-4 verifies that the second revision meets the environmental requirement for the 100 knot storm.

In this section, the sample problem illustrates methods to improve mooring performance. The weak bow/beam holding power ratio was remedied by adjusting the mooring pattern, and heavier legs increased the total strength. The result is a mooring which can be used with safety and confidence in fair weather and foul.

Table 5-3. RIGMOOR Sample Problem Revision One

Water Depth	Design Offset	Safety Factor	No. Anchors	No.Leg Types
312.00	7.00	3.00	10	1

Anchor No.	Type	Fairlead Position X	Fairlead Position Y	Anchor Position X	Anchor Position Y	Anchor Direction	Anchor Radius	Anchor Preload	Top Scope
1	1	88.00	100.00	88.0	3369.9	.00	3270.	89469.	3297.
2	1	96.00	96.00	3168.7	1214.4	70.00	3270.	89469.	3297.
3	1	100.00	.00	3369.9	.0	90.00	3270.	89469.	3297.
4	1	96.00	-96.00	3168.7	-1214.4	110.00	3270.	89469.	3297.
5	1	88.00	-100.00	88.0	-3369.9	180.00	3270.	89469.	3297.
6	1	-88.00	-100.00	-88.0	-3369.9	-180.00	3270.	89469.	3297.
7	1	-96.00	-96.00	-3168.7	-1214.4	-110.00	3270.	89469.	3297.
8	1	-100.00	.00	-3369.9	.0	-90.00	3270.	89469.	3297.
9	1	-96.00	96.00	-3168.7	1214.4	-70.00	3270.	89469.	3297.
10	1	-88.00	100.00	-88.0	3369.9	.00	3270.	89469.	3297.

Leg Type 1

Seg.	Material	Size	Length	Weight	Strength	Elasticity	Buoyancy
1	IWRC Wire Rope	3.000	6000.00	14.4805	750264.	5.7960E+07	0.

OPERATIONAL AND SURVIVAL HOLDING POWER ANALYSIS FOR 0. FEET HEAVE

Direction of Rig Deflection	Operational (All legs active) Holding Power	Weather Direction	Safety Factor	Rig Yaw	Survival (Lee legs slacked) Holding Power	Weather Direction	Safety Factor	Rig Yaw
.00	465021.	.00	3.00	.00	541879.	.00	3.00	.00
5.00	465198.	5.71	2.99	.10	530235.	9.93	2.99	-.34
10.00	466001.	11.23	3.00	.21	532294.	14.37	3.00	-.18
15.00	467259.	16.84	3.03	.31	554145.	24.26	3.03	-.05
20.00	470317.	22.61	3.09	.40	558642.	28.20	3.09	.08
25.00	474444.	28.31	3.17	.47	562829.	32.21	3.17	.20
30.00	479906.	34.10	3.28	.52	568221.	36.41	3.28	.28
35.00	486023.	39.70	3.42	.54	592970.	45.66	3.42	.97
40.00	493392.	45.42	3.48	.57	601661.	49.20	3.48	.96
45.00	502013.	51.00	3.35	.59	610385.	52.72	3.35	.94
50.00	512116.	56.27	3.25	.59	619483.	56.16	3.25	.90
55.00	523504.	61.29	3.17	.56	629051.	59.49	3.17	.84
60.00	535028.	65.99	3.11	.52	637679.	62.66	3.11	.78
65.00	546218.	70.40	3.07	.46	646232.	65.59	3.07	.69
70.00	556106.	74.70	3.05	.38	624208.	76.74	3.05	.47
75.00	564688.	78.87	3.05	.31	631537.	80.28	3.05	.37
80.00	571642.	82.65	3.04	.22	637226.	83.53	3.04	.25
85.00	575587.	86.36	3.01	.11	640977.	86.79	3.01	.13
90.00	576954.	90.00	3.00	.00	642272.	90.00	3.00	.00

Table 5-4. RIGMOOR Sample Problem Revision Two

Water Depth	Design Offset	Safety Factor	No. Anchors	No.Leg Types
312.00	7.00	3.00	10	1

Anchor No.	Type	Fairlead Position X	Fairlead Position Y	Anchor Position X	Anchor Position Y	Anchor Direction	Anchor Radius	Anchor Preload	Top Scope
1	1	88.00	100.00	88.0	3368.7	.00	3269.	120748.	3297.
2	1	96.00	96.00	3167.6	1214.0	70.00	3269.	120748.	3297.
3	1	100.00	.00	3368.7	.0	90.00	3269.	120748.	3297.
4	1	96.00	-96.00	3167.6	-1214.0	110.00	3269.	120748.	3297.
5	1	88.00	-100.00	88.0	-3368.7	180.00	3269.	120748.	3297.
6	1	-88.00	-100.00	-88.0	-3368.7	-180.00	3269.	120748.	3297.
7	1	-96.00	-96.00	-3167.6	-1214.0	-110.00	3269.	120748.	3297.
8	1	-100.00	.00	-3368.7	.0	-90.00	3269.	120748.	3297.
9	1	-96.00	96.00	-3167.6	1214.0	-70.00	3269.	120748.	3297.
10	1	-88.00	100.00	-88.0	3368.7	.00	3269.	120748.	3297.

Leg Type 1

Seg.	Material	Size	Length	Weight	Strength	Elasticity	Buoyancy
1	IWRC Wire Rope	3.500	6000.00	19.7109	1013814.	7.8890E+07	0.

OPERATIONAL AND SURVIVAL HOLDING POWER ANALYSIS FOR 0. FEET HEAVE

Direction of Rig Deflection	Operational (All legs active) Holding Power	Weather Direction	Safety Factor	Rig Yaw	Survival (Lee legs slacked) Holding Power	Weather Direction	Safety Factor	Rig Yaw
.00	629900.	.00	3.00	.00	731616.	.00	3.00	.00
5.00	630702.	5.60	2.99	.10	716250.	9.90	2.99	-.34
10.00	632128.	11.26	3.00	.21	718929.	14.32	3.00	-.18
15.00	633970.	16.84	3.03	.31	748529.	24.27	3.03	-.05
20.00	636305.	22.47	3.09	.39	754069.	28.16	3.09	.09
25.00	640930.	28.28	3.18	.45	759950.	32.22	3.18	.19
30.00	646965.	34.11	3.28	.52	766920.	36.38	3.28	.29
35.00	654809.	39.85	3.42	.55	800674.	45.66	3.42	.97
40.00	664940.	45.46	3.48	.58	811951.	49.19	3.48	.96
45.00	677836.	50.97	3.35	.59	823810.	52.70	3.35	.94
50.00	692694.	56.32	3.25	.58	836250.	56.18	3.25	.90
55.00	707893.	61.23	3.17	.57	848942.	59.49	3.17	.84
60.00	723797.	65.92	3.11	.51	861284.	62.65	3.11	.77
65.00	738661.	70.45	3.07	.44	872306.	65.63	3.07	.69
70.00	752616.	74.78	3.05	.38	842783.	76.81	3.05	.48
75.00	764584.	78.77	3.05	.29	853090.	80.22	3.05	.37
80.00	773734.	82.56	3.04	.20	860836.	83.49	3.04	.25
85.00	779873.	86.36	3.01	.10	865737.	86.81	3.01	.13
90.00	782461.	90.00	3.00	.00	867498.	90.00	3.00	.00

REFERENCES

1. Harris, L.M. Design for Reliability in Deepwater Floating Drilling Operations, The Petroleum Publishing Company, Tulsa, OK, 1979.

    An excellent overview of practical drilling technology. Chapter 5 addresses mooring systems and environmental forces. The latter draws upon formulas recommended by the American Bureau of Shipping (Reference 2).

2. Rules for Building and Classing Mobile Offshore Drilling Units, American Bureau of Shipping, New York, NY, 1985.

    Section 3 shows formulas for estimating wind and current forces. Mooring equipment for drilling rigs is specified by reference to the Rules for steel vessels and barges (Refs. 3 and 4, below). Appendix A outlines a theory of wave forces on ship-shaped hulls and circular caissons and footings in deep water. The theory of wave forces in shallow water does not yield convenient formulas. A set of 9 charts is provided to simplify these computations.

3. Rules for Building and Classing Steel Vessels, American Bureau of Shipping, New York, NY, 1985.

4. Rules for Building and Classing Steel Barges for Offshore Service, American Bureau of Shipping, New York, NY, 1985.

5. The Analysis of Spread Mooring Systems for Floating Drilling Units, Recommended Practice RP 2P, American Petroleum Institute, Dallas, TX, 1982.

    A comprehensive procedure for analyzing spread moorings is presented, with emphasis on practical computation. A simple method for estimating design wind speed and wave height from wind and wave records is shown. The ABS formulas for wind and current forces are accepted, with slightly different values for current drag coefficients. Waves are treated by Mean Drift Force and Response Amplitude Operators in surge and sway. Curves of anchor and line holding power are shown and the summation of catenary forces around the mooring plan geometry illustrated. Section 6 is an example analysis with complete numerical details.

6. Lessons in Rotary Drilling Unit V: Offshore Technology, Petroleum Extenson Service, University of Texas, Austin, TX, 1976.

   This is the fifth Unit in a series of correspondence lessons prepared in cooperation with the International Association of Drilling Contractors. Lesson 1, Wind, Waves, and Weather, and Lesson 2, Spread Mooring Systems provide a tutorial introduction to the subject, with a strong practical emphasis.

7. Shields, D.R., R.L. Wendt and B.A. Johnson, OTEC Mooring Technology, Naval Civil Engineering Laboratory Technical Memorandum No. 44-83-05, Port Hueneme, CA, 1982.

   Existing technology for mooring components prepared for the Ocean Thermal Energy Conversion project, which explored the feasibility of mooring large powerplants in the ocean is summarized in this report. Common mooring components are evaluated, with tables of size and strength, discussion of common failure modes, lists of manufacturers and testing facilities.

8. Rajabi, F., S. Ghosh and C. Oran, Review of Semisubmersible and Tension Leg Platform Analysis Techniques, Naval Civil Engineering Laboratory Technical Memorandum No. 44-85-02CR, 1985 (3 volumes).

   This heavily theoretical study combines a literature review of current methods for estimating environmental forces on floating and moored objects with a review of computer software for designing such ocean structures. The large size of the report itself suggests the principal result - that environmental forces are very difficult to estimate accurately in detail. The report provides a background for evaluating moorings designed using the software tools described in the report.

APPENDIX A

MOORLOAD

MOORLOAD is a template for estimating the wind and wave force on a moored semi-submersible drilling rig using an electronic spreadsheet for a personal computer. "Template" is what a program for a spreadsheet is called. Spreadsheet programs derive their name from the large paper ruled in many columns used for financial calculations. Greybearded engineers may recall the days when engineering calculations were laid out in similar fashion to simplify work with a sliderule. FORTRAN weaned engineers from their slide-rules, but the emergence of electronic spreadsheets has put new life into an old concept. The personal computer screen is used like a camera that can be aimed at any part of a spreadsheet having hundreds of columns and rows.

On a spreadsheet, the intersection of a column and row forms a box or cell. With a paper spreadsheet, one writes a number or a label in a cell. Electronic spreadsheets add a third choice, which is the basis for their popularity: one may write a formula into a cell. The formula describes how to calculate the number to be displayed in the cell. Listing A-1 gives the formulas for the MOORLOAD template. It remains only for the user to fill in the title cell and enter the numbers particular to a mooring problem. The spreadsheet performs all the associated arithmetic.

The template is actually two templates in one. One calculates storm forces aligned with the bow or stern of the rig and the other makes the estimate for beam winds and currents.

MOORLOAD is based on the wind and current force formulas prescribed by the American Bureau of Shipping in Section 3 of Reference 2. Table A-1 shows the empty MOORLOAD template as it exists upon first loading. Table 3-2 is a sample of the template after it has been filled in for the sample problem used throughout this manual. The SuperCalc user's guide tells how to load a template, fill it in, and print the results.

The top line of the MOORLOAD template is reserved for a case title, entered by the user. Below the title are two credit lines. Next are a pair of tables. On the left, the default value for wind speed, current speed and current depth for the operating and survival conditions. Users may alter any of these values. If so, the equivalent pressure of wind/current will be corrected automatically by the spreadsheet monitor. The table on the right consists of reference values for documentation purposes; they would not ordinarily be changed.

The wind load table is a matrix of area subtotals. There is a line in the matrix for each type of structure recognized in the ABS wind force model, and there is a column in the matrix for each height class from sea level to 250 feet. The matrix is initially filled with zeroes; the user simply enters values in appropriate elements of the matrix, ignoring the elements that do not apply to the rig under study. The spreadsheet program sums the weighted areas by row and computes the force produced by the operational wind and the survival wind.

Current forces are computed in a table beneath the wind load matrix. Only a single column of entries is needed - projected areas of cylinders and other shapes, wetted surface of hull shapes, riser pipe diameter, and mooring chain or wire rope size (use whichever material occurs in the current layer defined in the top left table). Current forces are summed and the total is combined with the wind force and displayed. The first page of the template, as described, applies to storms aligned with the bow *or stern* of the rig. The template is repeated on a second page for beam storms.

Table A-1. MOORLOAD Template

Replace element B1 with case title, then /Copy to B70

Wind and Current Force Estimation for Moored Exploratory Oil Drilling Rigs
using ABS formulas and coefficients David B. Dillon EG&G 1985

			Operating	Survival
Change with problem	Wind Speed	(Knots)	70	100
	Current Speed	(Knots)	2	4
	Current Depth	(Feet)	300	300
automatically changed by spreadsheet	Wind Q	(Lb/SqFt)	16.54099	33.75713
	Current Q	(Lb/SqFt)	11.33955	45.35818

Ft/Sec per Knot	1.68781	These values not ordinarily changed
Truss Factor	.60	
Temperature	60 F	
Density	(Sl/CuFt)	
Air	.00237	
Seawater	1.9903	

		Height (Feet) Above Waterline							
		0-50	50-100	100-150	150-200	200+			
	Shape								
Height	Coef.	1.00	1.10	1.20	1.30	1.37	Weighted Area	Wind Force, (Lb)	
		- - - Bow-On	Projected	Area (Sq.	Ft.)	- - -	(Sq.Ft.)	Operating	Survival
Cylinders	.50	0	0	0	0	0	0	0	0
Hull	1.00	0	0	0	0	0	0	0	0
Deck Houses	1.00	0	0	0	0	0	0	0	0
Abovedeck Trusswork	1.50	0	0	0	0	0	0	0	0 *
Underdeck, Smooth	1.00	0	0	0	0	0	0	0	0
Underdeck Structures	1.30	0	0	0	0	0	0	0	0 *
Rig Derrick	1.25	0	0	0	0	0	0	0	0 *
							Bow-on Wind Force: (or stern?)	0	0

* Truss Factor applied

(Continued on next page)

Table A-1 (Continued). MOORLOAD Template

	Drag Coefficient		Units	Entry	Weighted Area (Sq.Ft.)	Operation Force (Pounds)	Survival Force (Pounds)
Cylinders	.85	Bow-on Area	(Sq.Ft.)	0	0	0	0
Other Shapes	2.00	Bow-on Area	(Sq.Ft.)	0	0	0	0
Hull	.0056	Wetted Area	(Sq.Ft.)	0	0	0	0
Riser Pipe	.0035	Diameter	(In.)	0	0	0	0
Mooring		No. Legs		0			
Chain	1.50	Diameter	(In.)	0	0	0	0
Wire Rope	.50	Diameter	(In.)	0	0	0	0
				Current Force:		0	0
				Total Bow-on Force: (or stern) ?		0	0

(Continued on next page)

Table A-1 (Continued). MOORLOAD Template

Use "/Cbl,b70<cr>" to copy case title to page 2

		Height (Feet) Above Waterline							
		0-50	50-100	100-150	150-200	200+			
Height	Shape Coef.	1	1.1	1.2	1.3	1.37	Weighted Area	Wind Force, (Lb)	
	- - -	Beam Projected Area (Sq. Ft.)				- - -	(Sq.Ft.)	Operating	Survival
Cylinders	.50	0	0	0	0	0	0	0	0
Hull	1.00	0	0	0	0	0	0	0	0
Deck Houses	1.00	0	0	0	0	0	0	0	0
Abovedeck Trusswork	1.50	0	0	0	0	0	0	0	0 *
Underdeck, Smooth	1.00	0	0	0	0	0	0	0	0
Underdeck Structures	1.30	0	0	0	0	0	0	0	0 *
Rig Derrick	1.25	0	0	0	0	0	0	0	0 *
					Beam Wind Force:			0	0

* Truss Factor applied

(Concluded on next page)

Table A-1 (Concluded). MOORLOAD Template

	Drag Coefficient		Units	Entry	Weighted Area (Sq.Ft.)	Operation Force (Pounds)	Survival Force (Pounds)
Cylinders	.85	Beam Area	(Sq.Ft.)	0	0	0	0
Other Shapes	2.00	Beam Area	(Sq.Ft.)	0	0	0	0
Hull	.1058	Wetted Area	(Sq.Ft.)	0	0	0	0
Riser Pipe	.0035	Diameter	(In.)	0	0	0	0
Mooring		No. Legs		0			
Chain	1.50	Diameter	(In.)	0	0	0	0
Wire Rope	.50	Diameter	(In.)	0	0	0	0
				Beam Current Force:		0	0
				Total Beam Force:		0	0

Cell address

Format commands
TR = Text right justified
TL = Text left justified
$ = Two decimal places
G = General (number with best fit)

Listing A-1. MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

B1 TL    = "Replace element B1 with case title, then /Copy to B70
B3 TL    = "Wind and Current Force Estimation for Moored
             Exploratory Oil Drilling Rigs
C4 TL    = "using ABS formulas and coefficients
H4 TL    = "David B. Dillon  EG&G  1985
E6 TR    = "Operating
F6 TR    = "Survival
H6 TL    = "Ft/Sec per Knot
J6       = 1.68781
B7 TL    = "Wind Speed
D7       = "(Knots)
E7       = 70
F7       = 100
H7 TL    = "Truss Factor
J7 $     = .6
B8 TL    = "Current Speed
D8       = "(Knots)
E8       = 2
F8       = 4
H8 TL    = "Temperature
J8       = "60 F
B9 TL    = "Current Depth
D9       = "(Feet)
E9       = 300
F9       = 300
H9       = "Density
J9       = "(Sl/CuFt)
B10 TR    = "Wind Q
D10       = "(Lb/SqFt)
E10       = 0.5*J10*J6*J6*E7*E7
F10       = .5*J10*J6*J6*F7*F7
H10       = "Air
J10       = .00237
B11 TL    = "Current Q
D11       = "(Lb/SqFt)
E11       = .5*J11*J6*J6*E8*E8
F11       = .5*J11*J6*J6*F8*F8
H11       = "Seawater
J11       = 1.9903
D13 TL    = "Height (Feet) Above Waterline
C14       = "0-50
D14       = "50-100
E14       = "100-150
F14       = "150-200
G14       = "200+
B15       = "Shape
A16 TR    = "Height
B16 TR    = "Coef.
```

(Continued on next page)

Listing A-1 (Continued). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

C16        = 1
D16        = 1.1
E16        = 1.2
F16        = 1.3
G16        = 1.37
H16 TR     = "Weighted
I16 TL     = "   Wind Force, (Lb)
H17        = "Area
C18 TL     = "- - -  Bow-On Projected Area (Sq. Ft.)  - - -
H18 TR     = "(Sq.Ft.)
I18 TR     = "Operating
J18 TR     = "Survival
A20        = "Cylinders
B20        = 0.5
C20        = 0
D20        = 0
E20        = 0
F20        = 0
G20        = 0
H20        = B20*(C16*C20+D16*D20+E16*E20+F16*F20+G16*G20)
I20        = H20*E10
J20        = H20*F10
A22        = "Hull
B22        = 1
C22        = 0
D22        = 0
E22        = 0
F22        = 0
G22        = 0
H22        = B22*(C16*C22+D16*D22+E16*E22+F16*F22+G16*G22)
I22        = H22*E10
J22        = H22*F10
A24        = "Deck Houses
B24        = 1
C24        = 0
D24        = 0
E24        = 0
F24        = 0
G24        = 0
H24        = B24*(C16*C24+D16*D24+E16*E24+F16*F24+G16*G24)
I24        = H24*E10
J24        = H24*F10
A26        = "Abovedeck Trusswork
B26        = 1.5
C26        = 0
D26        = 0
E26        = 0
F26        = 0
```

(Continued on next page)

Listing A-1 (Continued). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

G26         = 0
H26         = B26*(C16*C26+D16*D26+E16*E26+F16*F26+G16*G26)*J7
I26         = H26*E10
J26         = H26*F10
K26         = " *
A28         = "Underdeck, Smooth
B28         = 1
C28         = 0
D28         = 0
E28         = 0
F28         = 0
G28         = 0
H28         = B28*(C16*C28+D16*D28+E16*E28+F16*F28+G16*G28)
I28         = H28*E10
J28         = H28*F10
A30         = "Underdeck Structures
B30         = 1.3
C30         = 0
D30         = 0
E30         = 0
F30         = 0
G30         = 0
H30         = B30*(C16*C30+D16*D30+E16*E30+F16*F30+G16*G30)*J7
I30         = H30*E10
J30         = H30*F10
K30         = " *
A32         = "Rig Derrick
B32         = 1.25
C32         = 0
D32         = 0
E32         = 0
F32         = 0
G32         = 0
H32         = B32*(C16*C32+D16*D32+E16*E32+F16*F32+G16*G32)*J7
I32         = H32*E10
J32         = H32*F10
K32         = " *
B34 TL      = "* Truss Factor applied
G34         = "Bow-on Wind Force:
I34         = SUM(I20:I32)
J34         = SUM(J20:J32)
H39         = "Weighted
I39         = "Operation
J39         = "Survival
B40         = "Drag
H40         = "Area
I40         = "Force
J40         = "Force
```

(Continued on next page)

Listing A-1 (Continued). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

B41 TL     = "Coefficient
F41        = "Units
G41 TR     = "Entry
H41        = "(Sq.Ft.)
I41        = "(Pounds)
J41        = "(Pounds)
A43        = "Cylinders
B43        = .85
D43 TL     = "Bow-on Area
F43        = "(Sq.Ft.)
G43        = 0
H43        = B43*G43
I43        = H43*E11
J43        = H43*F11
A45        = "Other Shapes
B45        = 2
D45 TL     = "Bow-on Area
F45        = "(Sq.Ft.)
G45        = 0
H45        = B45*G45
I45        = H45*E11
J45        = H45*F11
A47        = "Hull
B47 G      = .0056
D47 TL     = "Wetted Area
F47        = "(Sq.Ft.)
G47        = 0
H47        = B47*G47
I47        = H47*E11
J47        = H47*F11
A49        = "Riser Pipe
B49 G      = .0035
D49 TL     = "Diameter
F49        = "(In.)
G49        = 0
H49        = B49*G49*PI*E9/12
I49        = H49*E11
J49        = H49*F11
A51        = "Mooring
D51 TL     = "No. Legs
G51        = 0
A52        = "Chain
B52        = 1.5
D52 TL     = "Diameter
F52        = "(In.)
G52        = 0
H52        = B52*G52*E9/12*G51
I52        = H52*E11
```

(Continued on next page)

Listing A-1 (Continued). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

J52         = H52*F11
A53         = "Wire Rope
B53         = .5
D53 TL      = "Diameter
F53         = "(In.)
G53         = 0
H53         = B53*G53*E9/12*G51
I53         = H53*E11
J53         = H53*F11
G55         = "Current Force:
I55         = SUM(I43:I53)
J55         = SUM(J43:J53)
G57         = "Total Bow-on Force:
I57         = I34+I55
J57         = J34+J55
B70 TL      = "Use "/Cb1,b70<cr>" to copy case title to page 2
D73 TL      = "Height (Feet) Above Waterline
C74         = "0-50
D74         = "50-100
E74         = "100-150
F74         = "150-200
G74         = "200+
B75         = "Shape
A76 TR      = "Height
B76 TR      = "Coef.
C76         = 1
D76         = 1.1
E76         = 1.2
F76         = 1.3
G76         = 1.37
H76 TR      = "Weighted
I76 TL      = "    Wind Force, (Lb)
H77         = "Area
C78 TL      = "- - -   Beam Projected Area (Sq. Ft.)   - - -
H78 TR      = "(Sq.Ft.)
I78 TR      = "Operating
J78 TR      = "Survival
A80         = "Cylinders
B80         = 0.5
C80         = 0
D80         = 0
E80         = 0
F80         = 0
G80         = 0
H80         = B80*(C76*C80+D76*D80+E76*E80+F76*F80+G76*G80)
I80         = H80*E10
J80         = H80*F10
A82         = "Hull
```

(Continued on next page)

Listing A-1 (Continued). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

B82        = 1
C82        = 0
D82        = 0
E82        = 0
F82        = 0
G82        = 0
H82        = B82*(C76*C82+D76*D82+E76*E82+F76*F82+G76*G82)
I82        = H82*E10
J82        = H82*F10
A84        = "Deck Houses
B84        = 1
C84        = 0
D84        = 0
E84        = 0
F84        = 0
G84        = 0
H84        = B84*(C76*C84+D76*D84+E76*E84+F76*F84+G76*G84)
I84        = H84*E10
J84        = H84*F10
A86        = "Abovedeck Trusswork
B86        = 1.5
C86        = 0
D86        = 0
E86        = 0
F86        = 0
G86        = 0
H86        = B86*(C76*C86+D76*D86+E76*E86+F76*F86+G76*G86)*J7
I86        = H86*E10
J86        = H86*F10
K86        = " *
A88        = "Underdeck, Smooth
B88        = 1
C88        = 0
D88        = 0
E88        = 0
F88        = 0
G88        = 0
H88        = B88*(C76*C88+D76*D88+E76*E88+F76*F88+G76*G88)
I88        = H88*E10
J88        = H88*F10
A90        = "Underdeck Structures
B90        = 1.3
C90        = 0
D90        = 0
E90        = 0
F90        = 0
G90        = 0
H90        = B90*(C76*C90+D76*D90+E76*E90+F76*F90+G76*G90)*J7
```

(Continued on next page)

Listing A-1 (Continued). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

I90        = H90*E10
J90        = H90*F10
K90        = " *
A92        = "Rig Derrick
B92        = 1.25
C92        = 0
D92        = 0
E92        = 0
F92        = 0
G92        = 0
H92        = B92*(C76*C92+D76*D92+E76*E92+F76*F92+G76*G92)*J7
I92        = H92*E10
J92        = H92*F10
K92        = " *
B94 TL     = "* Truss Factor applied
G94        = "Beam Wind Force:
I94        = SUM(I80:I92)
J94        = SUM(J80:J92)
H99        = "Weighted
I99        = "Operation
J99        = "Survival
B100        = "Drag
H100        = "Area
I100        = "Force
J100        = "Force
B101 TL     = "Coefficient
F101        = "Units
G101 TR     = "Entry
H101        = "(Sq.Ft.)
I101        = "(Pounds)
J101        = "(Pounds)
A103        = "Cylinders
B103        = .85
D103 TL     = "Beam Area
F103        = "(Sq.Ft.)
G103        = 0
H103        = B103*G103
I103        = H103*E11
J103        = H103*F11
A105        = "Other Shapes
B105        = 2
D105 TL     = "Beam Area
F105        = "(Sq.Ft.)
G105        = 0
H105        = B105*G105
I105        = H105*E11
J105        = H105*F11
A107        = "Hull
```

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Listing A-1 (Concluded). MOORLOAD Template Formulas

```
SuperCalc ver.  1.12

B107 G     = .1058
D107 TL    = "Wetted Area
F107       = "(Sq.Ft.)
G107       = 0
H107       = B107*G107
I107       = H107*E11
J107       = H107*F11
A109       = "Riser Pipe
B109 G     = .0035
D109 TL    = "Diameter
F109       = "(In.)
G109       = 0
H109       = B109*G109*PI*E9/12
I109       = H109*E11
J109       = H109*F11
A111       = "Mooring
D111 TL    = "No. Legs
G111       = 0
A112       = "Chain
B112       = 1.5
D112 TL    = "Diameter
F112       = "(In.)
G112       = 0
H112       = B112*G112*E9/12*G111
I112       = H112*E11
J112       = H112*F11
A113       = "Wire Rope
B113       = .5
D113 TL    = "Diameter
F113       = "(In.)
G113       = 0
H113       = B113*G113*E9/12*G111
I113       = H113*E11
J113       = H113*F11
G115       = "Beam Current Force:
I115       = SUM(I103:I113)
J115       = SUM(J103:J113)
G117       = "Total Beam Force:
I117       = I94+I115
J117       = J94+J115
```

APPENDIX B

CATENARY PRELOAD THEORY

The catenary is a mathematical function that describes the shape a heavy, flexible, inextensible line suspended between two supports. Table B-1 lists the catenary equations. Lightweight mooring designs take into account the hydrodynamic force distribution along the line. The equations are then expressed in differential form and solved numerically. Hydrodynamic forces on heavy rig mooring lines are much smaller than environmental forces on the rig, so they are usually ignored or lumped with rig forces.

~~~~~~

Table B-1

The Catenary Equations

Tension: $T = H * \mathrm{Sec}(\mathrm{Phi})$

Vertical Load: $V = H * \mathrm{Tan}(\mathrm{Phi})$

Arc Length: $S_2 - S_1 = \frac{H}{w} * (T_2 - T_1)$

Vertical Span: $Y_2 - Y_1 = \frac{H}{w} * (V_2 - V_1)$

Horizontal Span: $X_2 - X_1 = \frac{H}{w} * \mathrm{Ln} \frac{(V_2 + T_2)}{(V_1 + T_1)}$

If subscript 2 denotes the "higher" end of a mooring, then the differences on the left of the equations are all positive. H is the horizontal load acting on the element, w is the linear weight density of the element, and Phi is the angle from H to T. Phi is positive when T tends upward.

~~~~~~

When the element is elastic, the stretched arc length, s, must be distinguished from the unstretched material point, S, and the elastic parameter, AE, enters the equations. The cable functions can still be expressed in formulas when the line obey´s Hook´e Law. Table B-2 shows the form they take. The equations degenerate to the catenary equations above in the limit as AE increases indefinitely.

Mooring line dynamic analysis takes into account the acceleration of the fluid and the inertia of the line. Dynamic solutions fall into two main classes: solutions in the frequency domain and solutions in the time domain. Frequency domain solutions express steady-state dynamics in terms of the amplitude, frequency and phase of sine functions. The three characteristics listed vary along the length of the line. Moorings in a seaway are amenable to this approach. Time domain solutions require simultaneous integration in two dimensions - in time and along the length of the line. Sophisticated numerical procedures are required to address these solutions.

Table B-2

Elastic Cable Functions

$$T = H * \mathrm{Sec}(\mathrm{Phi})$$

$$V = H * \mathrm{Tan}(\mathrm{Phi})$$

$$s_2 - s_1 = S_2 - S_1 + \frac{H}{2AE} * (X_2 - X_1) + \frac{(V_2T_2 - V_1T_1)}{2wAE}$$

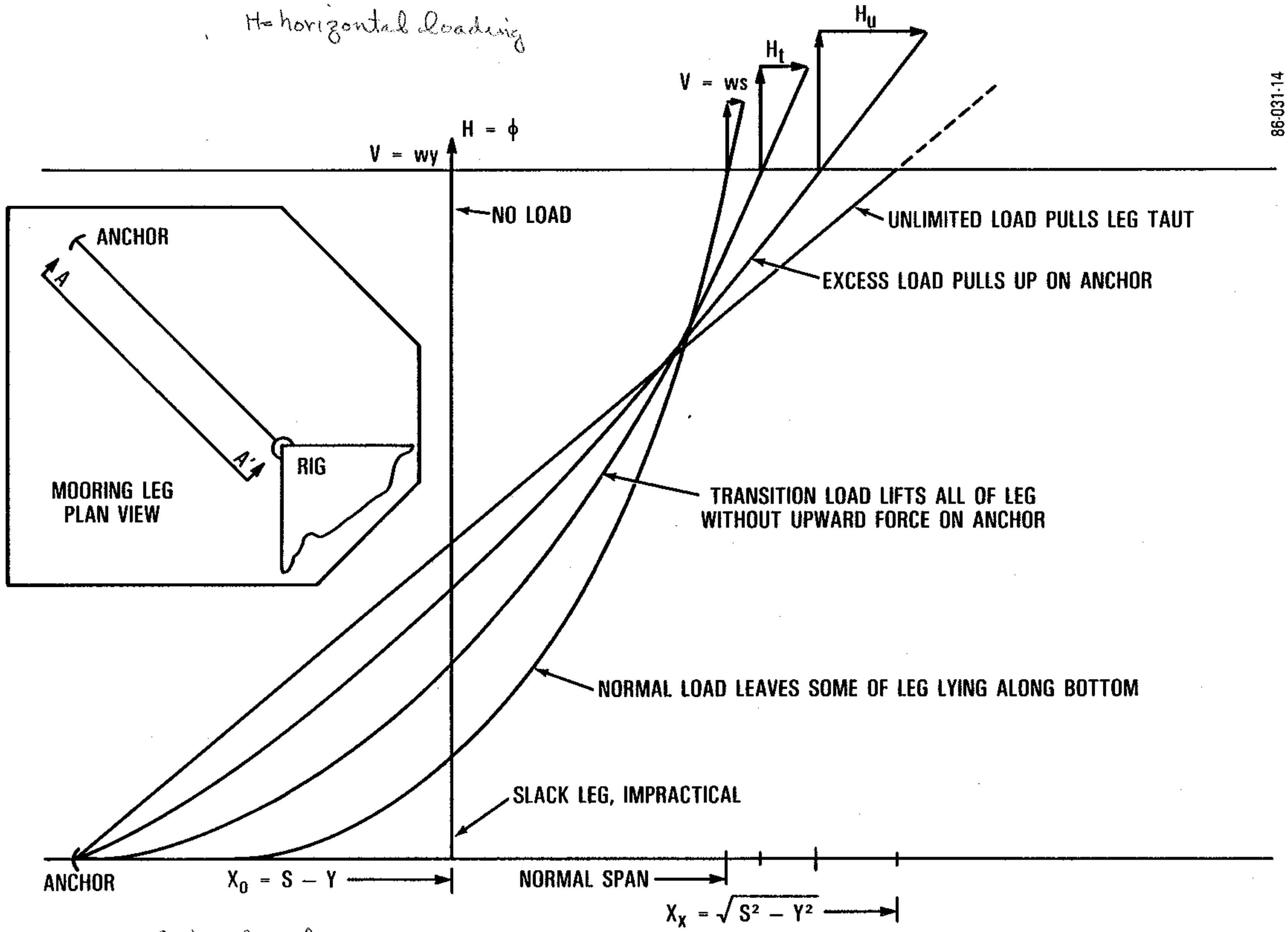
$$y_2 - y_1 = Y_2 - Y_1 + \frac{(V_2 + V_1)}{2AE} * (S_2 - S_1)$$

$$x_2 - x_1 = X_2 - X_1 + \frac{H}{AE} * (S_2 - S_1)$$

Dynamic models of spread moorings for oil rigs rarely include the dynamics of the mooring lines themselves because the mass of the rig far exceeds the mass of the mooring lines. Furthermore, the dynamic excitation comes at or near the surface. The mooring lines provide another restoring force on the rig motions and hold the rig at the mooring site. These models, therefore, cannot predict dynamic mooring line responses, such as standing waves, and their associated failure modes.

The static design of a mooring is built around the displacement vs force function ("X vs H curve") of a single leg. Figure B-1 shows an idealized mooring leg under five horizontal loadings, H. The length of the leg, S, exceeds the depth, Y, so that if H is zero, the line drops vertically to the seabed, then extends along the bottom to the anchor. The vertical load is the weight of the suspended line, wY. If the length of the line is not changed while the horizontal load increases, the intersection of the line with the water surface moves away from the anchor, and the point of tangency with the bottom moves towards the anchor. If H exceeds the value where the point of tangency reaches the anchor, then the angle of the line with the bottom increases, so the line pulls upward on the anchor. When the horizontal load is many times the total weight of the line, wS, the catenary approaches a straight, slant line from the anchor to the surface.

H= horizontal loading



S= length of leg
Y = water depth

Figure B-1. A Mooring Leg at Five Stages of Horizontal Load

static

Figure B-2 is a plot of the displacement vs force function (X vs H curve) for a typical mooring leg. The displacement increases from $X_o = S - Y$ to a maximum X_x that is approached asymptotically with increasing load, H. An X vs H curve implies a fixed water depth, Y, a fixed total length, S, and a fixed line composition, represented by its weight per foot, w. H_t marks the transition load, where the point of tangency with the bottom coincides with the anchor shackle. The asymptote of the X vs H curve for an elastic catenary is sloped and the line elasticity must be included in the specific composition. Thus, no single value exists for X_x when the line is elastic. This is illustrated on Figure B-3 which shows the X vs H curve that corresponds to leg 1 of the sample problem.

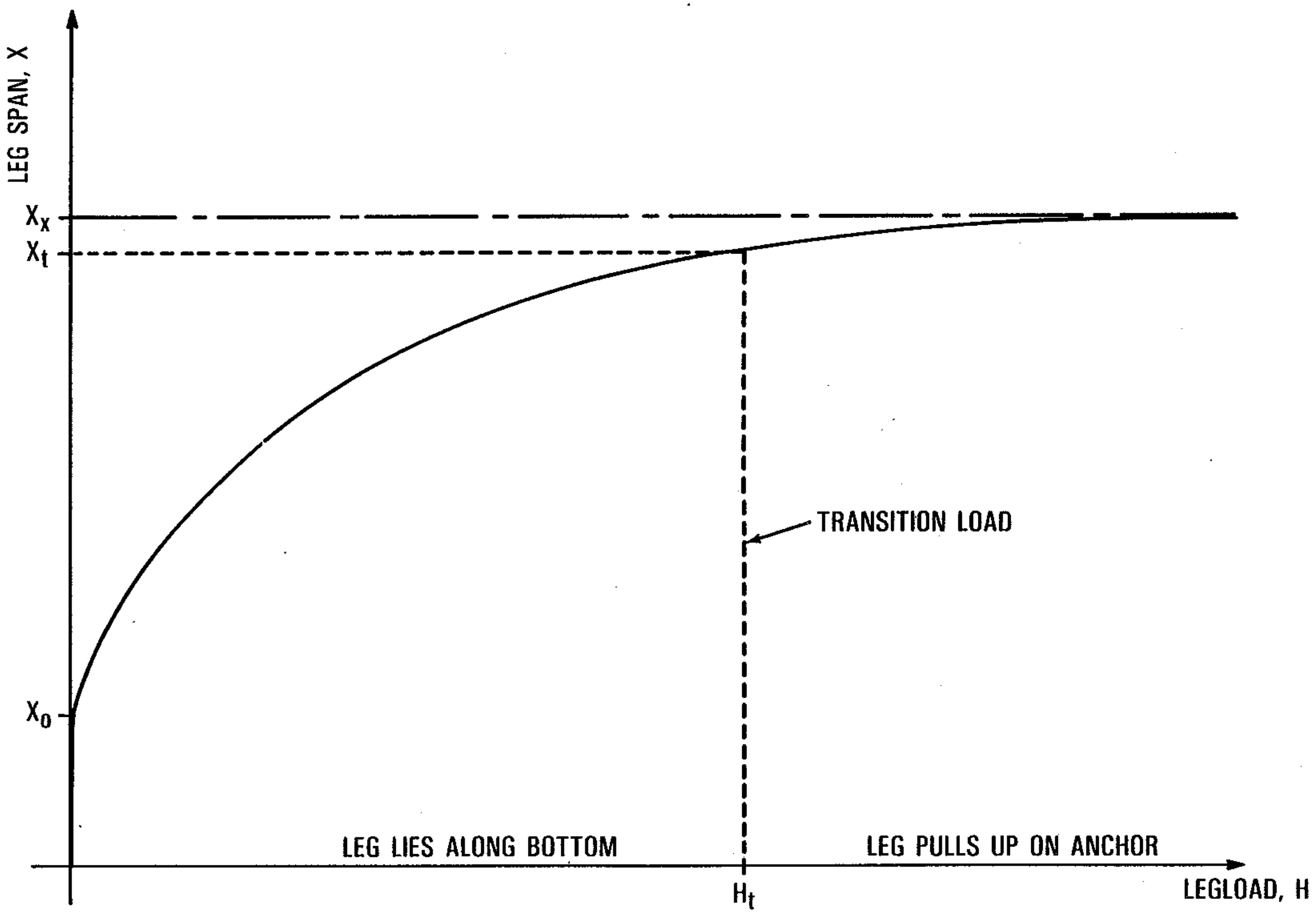
If the line is formed of more than one segment, say chain near the anchor and wire rope near the surface, then the curve is valid only for a specific combination of lengths and sizes of the segments. Using the mooring winches to adjust the tension, for example, does not move along an X vs H curve, but moves to a new X vs H curve for the new leg length.

The asymptote at X_x represents the deflection produced by an infinite load. At some finite value, H_u, the leg will be stressed to its ultimate strength. When a tensile safety factor is applied, there is a corresponding working limit, H_w. As mentioned above, increasing H produces what may be called a "change of state" in the leg. At low values, some of the leg lies along the bottom, but at a transition load, H_t, the leg comes tangent to the bottom at the anchor. When H exceeds H_t, the leg pulls upward on the anchor. Each of these loads has a corresponding displacement: X_u, X_w, and X_t.

Letting a mooring leg go completely slack (H = 0.) is not practical for real moorings. Slack wire rope legs twist about themselves, then self-destruct when pulled taut. The men who have to deal with them have colorful, if impolite, words to describe the resulting snarl. If a spread mooring has no preload - which is what H = 0. implies - then the rig has essentially no restoring moment in yaw and may take one or more full turns winding the legs about each other with disastrous results.

Figure B-4 illustrates another reason why the legs of a spread mooring are always preloaded against each other. The riser pipe limits the deflection of a rig mooring to a few percent of the water depth. The lower shaded area along the X-axis of the figure depicts that deflection, measured up from a small preload. Note the corresponding change in load on the H-axis and reflect that the increase in load represents the holding power of the leg, subject to the deflection constraint. The upper shaded area also represents the deflection constraint, measured down from the working load, X_w. Notice how the change in slope of the X vs H curve yields a much larger holding power for the upper trial. **The shape of the curve says that maximum holding power is obtained when the shaded area is moved as high as can be without violating one of the load limits, H_w or H_t, described above.**

The design deflection is then subtracted to give the deflection at preload, X_p. This is the distance along the bottom from beneath the leg fairlead to the anchor. Reading from the X-axis to the vs H curve and down to the H-axis gives the preload, H_p. The difference between H_w or H_t and H_p is the holding power. Observe yet again: this applies to a fixed total leg length and fixed water depth.



86-031-5

Figure B-2. A Typical X vs H Curve

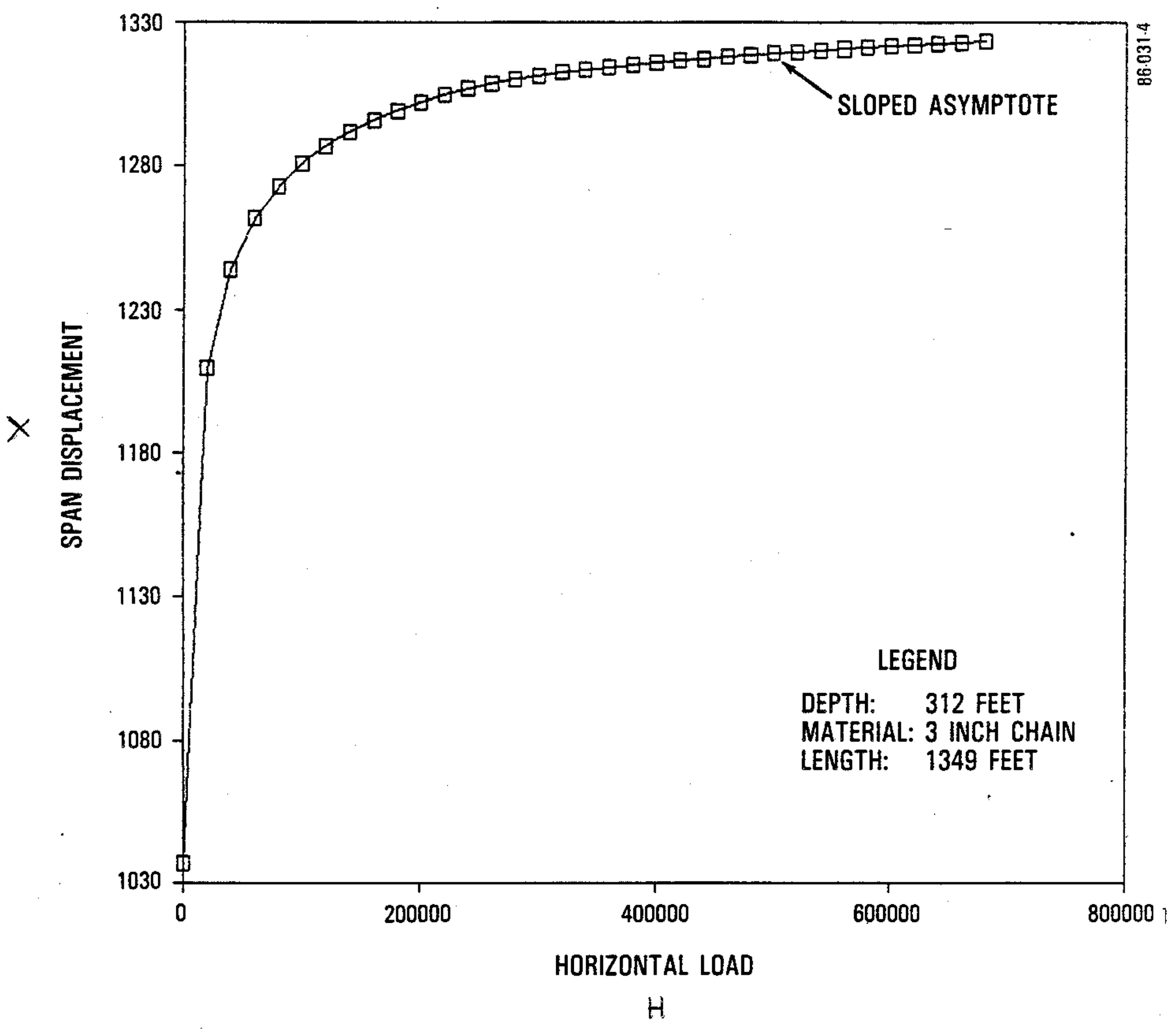


Figure B-3. An X vs H Curve from the Sample Problem

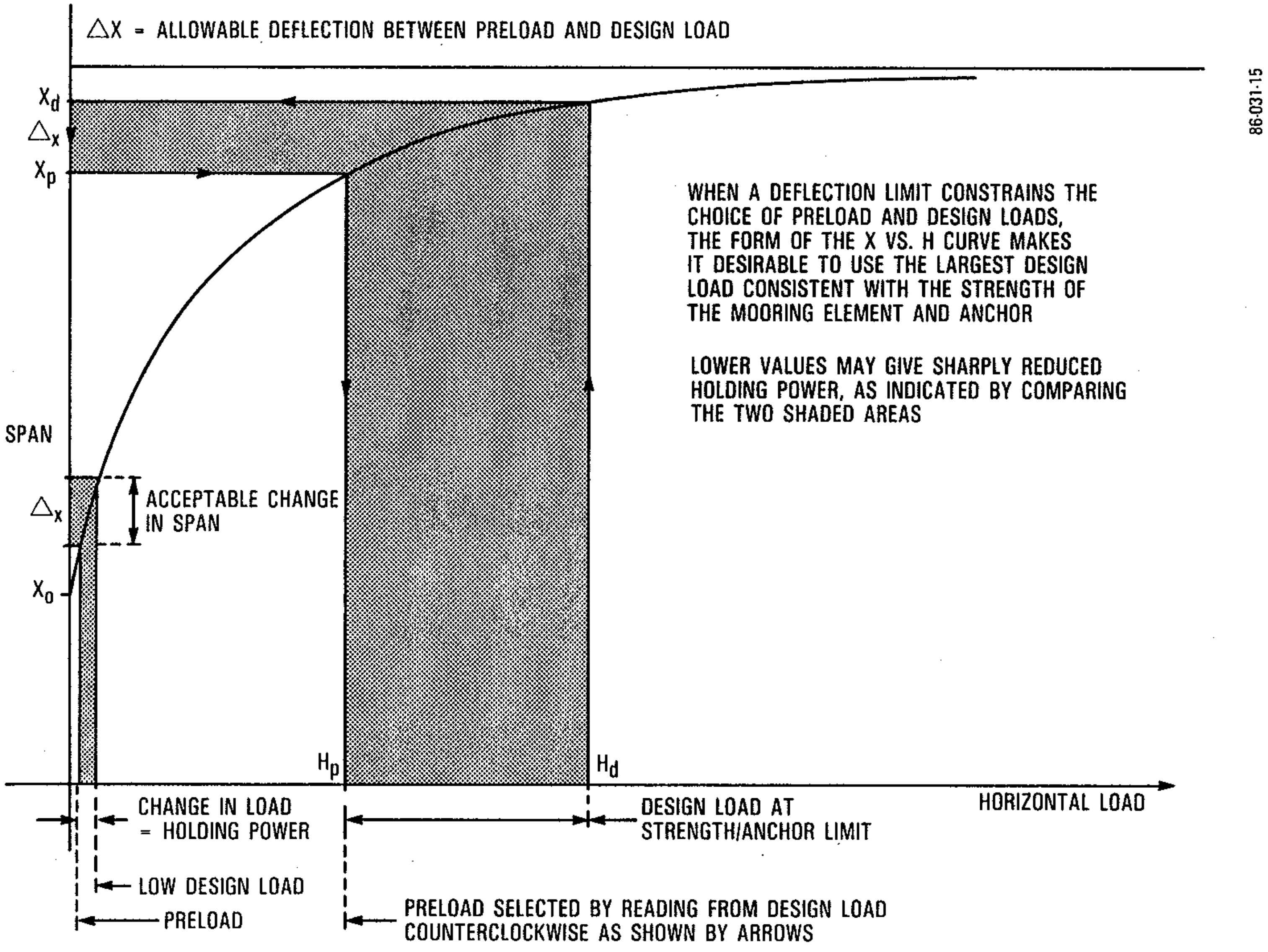


Figure B-4. The Interaction of Preload, Design Load and Deflection Limit with Holding Power

If the leg is slack when the opposite deflection unloads the leg, then tighten the leg. That is, repeat the analysis with a shorter leg.

In fact, one may repeat the analysis using scope (total leg length) as a parameter. The goal is to find the scope for which the transition load, H_t, just exceeds the working load, H_w, for the leg material and size. Longer scopes have no effect on the holding power - the added scope just lies on the bottom - wasting material and forcing the anchor farther from the fairlead. Shorter legs are unsuitable because the design load exceeds H_t, so the anchor shank is lifted. Thus, **finding the scope for which $H_w = H_t$ represents an optimized design.**

The optimization is illustrated on Figure B-5, which shows three curves of horizontal load versus leg length from the sample problem. The upper curve shows the design load, defined as the load which produces the working tension at some point along the leg (the top end of a one-piece leg). The lower curve depicts the corresponding preload for the leg. It is defined by the load whose deflection is less than the design load deflection by a fixed amount, as described on Figure B-4. The peaked curve on Figure B-5 is the holding power for the leg, formed by subtracting the preload from the design load.

The peak of the third curve (S=425 ft) represents the maximum holding power that a leg of that construction can attain in that water depth. The vertical line at S=1350 feet marks the length for which the design load lifts the leg tangent to the bottom at the anchor. Longer legs leave part of the leg along the bottom when the safety factor limit is met. Shorter legs pull up on the anchor at the design load, they are unsuitable for fluked anchors. Thus, maximum holding power for this leg requires an embedment anchor while the most efficient leg for a fluked anchor is longer.

The design load curve is horizontal to the right of the vertical mark because adding more line simply increases the length on the bottom. It permits (or requires, depending on one's viewpoint) the anchor to be placed farther from the rig. The line, embedding itself in the bottom, may contribute to the anchor holding power. The added length cannot contribute to increased design load without violating the working tension limit. The preload curve will also be horizontal for an inelastic leg. For real legs, however, the stretch of the leg lying on the bottom "uses up" part of the allowable deflection, and requires the preload to be closer to the design load. This gives the preload curve a slight upward slope and the holding power curve a slight downward slope.

The catenary equations give a simple test for optimization when mooring leg has uniform properties - all chain or all wire rope. Compute s and t by the following formulas, using any measurement system (metric, English, etc):

$$s = S/Y \qquad t = (2T/wY - 1)^{1/2}$$

where S = Leg length;
Y = Depth;
T = Working tension limit; and
w = Leg weight per unit length.

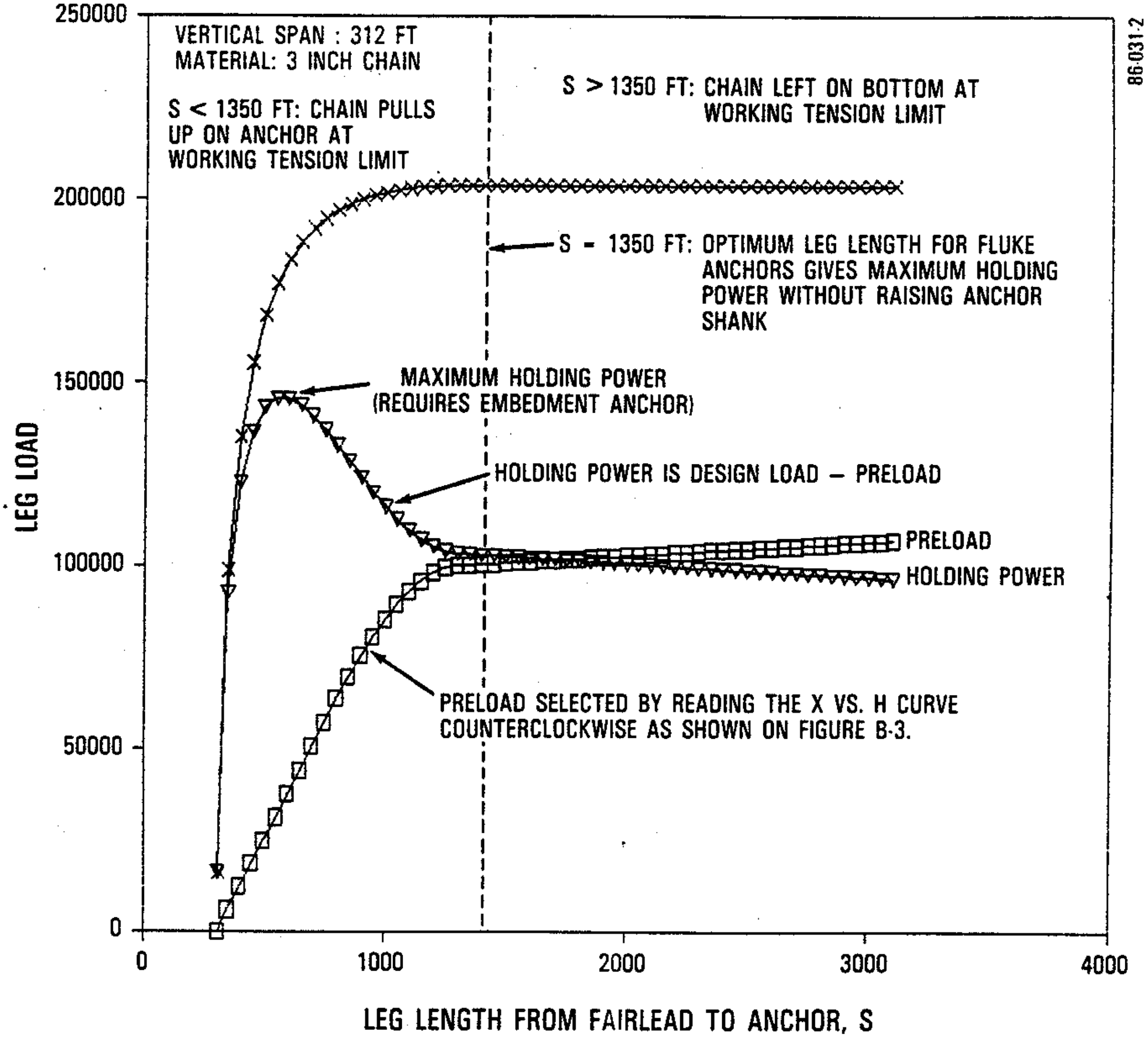


Figure B-5. The H vs S Curve

If $s = t$, then the leg reaches its working tension just when all the leg is lifted free of the bottom. If s is larger than t, the working tension will be exceeded before the anchor shank is lifted. Do the comparison again, using the ultimate strength of the leg to compute t'. If s exceeds t', the design is not only wasteful, the leg will part before lifting the anchor shank. It is better to lift the shank and drag an anchor in a storm than to part the leg.

Consider again the original comparison. If $s < t$, the anchor is too close to the rig: the anchor shank will be lifted before the leg reaches its full working capacity. In a storm, the operator may be mystified by a mooring failure. The load indicated on the tension monitor was within the working strength of the leg and within the capacity of the anchor, which had been well set, yet the anchor slipped. What he can not see is the lifted shank prying the flukes out of the bottom.

The condition that $H_w = H_t$ is an optimum only for mooring legs using fluked anchors. If the leg is secured to an embedment anchor, then the scope can be optimized directly on holding power, and typically at a significantly higher value. But for their cost and inconvenience, moorings optimized to use embedment anchors would be widely used: for the same size leg material at the same working stress and the same deflection, significantly shorter legs at lower preload give greater holding power. Table B-3 gives a numerical comparison of an optimized mooring for a fluked anchor with an optimized leg for an embedment anchor based on Figure B-5.

Table B-3

Comparison of Mooring Legs
Optimized for Fluked and Embedment Anchors

Anchor Type	Fluked	Embedment
Water Depth, ft	312	312
Leg Material	Chain	Chain
Material Size, in	3	3
Deflection (Percent of Depth)	7	7
Tensile Safety factor at Design Load	3	3
Scope, ft	1350	550
Design Load, kps	204	177
Preload, kps	100	31
Holding Power, kps	104	146

The optimized embedment anchor uses 40 percent as much wire rope while giving 40 percent more holding power than the optimized fluked anchor mooring. Whence the "free lunch"? The fluked anchor design requires the long scope in order to keep from lifting the shank at design load. The high preload is then required to contain the design deflection within 7 percent of the water depth. There's not much left on the lunch plate after the preload eats up the holding power.

APPENDIX C

Sample Rig Definition Session for RIGMOOR

Table C-1 is a transcript of a RIGMOOR session in which the sample mooring used in this manual is defined. User entries are <u>underlined</u>. Brackets ([]) enclose remarks explaining the entries. Refer to Figure 1-2 to review the mooring pattern, and to Table 1-2 for the bill of particulars. Table C-2 is an abstract of the user entries dispersed throughout Table C-1, and Table C-3 is a listing of the file produced by the session. From that file, the RIGMOOR computed the analysis presented in Table C-4.

Table C-1. Sample Rig Definition Session

```
                         * * *    New Screen    * * *


                                   RIGMOOR

                     MULTI-LEG SURFACE MOORING DESIGN REVIEW



                                DAVID B. DILLON

                            EG&G OCEAN SYSTEMS GROUP

                               9220 GAITHER ROAD

                            GAITHERSBURG, MD 20877

                                (301) 840-3323




Note: Enter ? in place of any entry to receive on-screen help.

Enter Drive and Rig Name
        A:RIGNAM
?=Help: ? <cr>                            [Novice operator requests help]
```

(Continued on next page)

Table C-1 (Continued). Sample Rig Definition Session

```
                                          [Help message on new screen]

     The RIGMOOR system creates several disk files for each mooring problem.
You may assign the drive, path and root name for the current problem.  These
will be used to form the entire name for files used by RIGMOOR. The root name
must have exactly six (6) letters and/or numerals.

     Use a "root name" that identifies the mooring problem.  Extensions that
identify the purpose and content of each file are added by RIGMOOR.  For
example, the root name for an analysis of rig 113 of the Big Oil Co. might be
BIG113. RIGMOOR would then create files named:

   BIG113DF.RIG   to store the parameters that define the rig and its mooring;
   BIG113XH.L01   to hold the force/displacement table for leg type 1, etc; and
   BIG113HS.L02   for the preload vs scope for leg type 2, etc.

Lowercase letters are changed to UPPERCASE by RIGMOOR.

Enter Drive and Rig Name                  [RIGMOOR resumes after help message]
        A:RIGNAM
?=Help: <cr>                              [Null entry ignored]
?=Help: C:SAMPLE <cr>                     [User selects root name]

New File: C:SAMPLEDF.RIG

                        * * *    New Screen    * * *

                  EXPLORATORY OIL RIG MOORING LEG ANALYSIS

David B. Dillon   EG&G, Inc.              Current Rig Definition Root: SAMPLE
------------------------------------------------------------------------------
   Entry   Operation

     1     Compute operational and survival holding power rose for mooring
     2     Adjust anchor leg lengths for mooring preload
     3     Compute preload vs scope (H vs S) for each leg type
     4     Compute offset  vs load  (X vs H) for each anchor leg

     5     Display and print operational and survival holding power roses
     6     Display and print preload vs scope tables
     7     Display and print offset  vs load  tables
     8     Display and print current rig definition

     9     Select another rig definition file, old or new
     0     Define a new rig

     Q     Quit
------------------------------------------------------------------------------
   Enter 0 through 9 or Q
?=Help: ? <cr>                            [Help requested for main menu]
```

(Continued on next page)

Table C-1 (Continued). Sample Rig Definition Session

```
                                      [Help message on new screen]

     RIGMOOR supports 10 command functions, listed on the menu. Commands are
selected by pressing a numeral (0 - 9) and the RETURN or ENTER key. Commands 1-
4 perform mooring computations; 5-8 provide printed displays; 9 and 0 select a
mooring definition.  All computed tables are stored on disk.
```

perform mooring computations

Function 1 includes functions 2, 3, and 4.

```
Function 1 is the most general command. It finds the operational and survival
           holding power of a mooring as a function of storm direction.
Function 2 adjusts the length of each leg based on the mooring preload.
Function 3 relates preload, holding load and anchor radius to leg length.
Function 4 computes the displacement function for each unique leg.
```

provide printed displays

```
Function 5 prints the leg loadings for the holding power roses.
Functions 6 and 7 print the H vs S and X vs H tables.
Function 8 prints the Rig Definition File currently active.
```

select a mooring definition

```
Function 9 allows you to change the file currently selected.
Function 0 prompts for the parameters of a new Rig Definition File.

     Enter a Q (or q) to end the session.
Pause.
Please press <return> to continue. <cr>

                    * * *    New Screen    * * *

             EXPLORATORY OIL RIG MOORING LEG ANALYSIS

David B. Dillon   EG&G, Inc.          Current Rig Definition Root: SAMPLE


-------------------------------------------------------------------------
   Entry   Operation

     1     Compute operational and survival holding power rose for mooring
     2     Adjust anchor leg lengths for mooring preload
     3     Compute preload vs scope (H vs S) for each leg type
     4     Compute offset  vs load  (X vs H) for each anchor leg

     5     Display and print operational and survival holding power roses
     6     Display and print preload vs scope tables
     7     Display and print offset  vs load  tables
     8     Display and print current rig definition

     9     Select another rig definition file, old or new
     0     Define a new rig

     Q     Quit
-------------------------------------------------------------------------
   Enter 0 through 9 or Q
?=Help: 0 <cr>                        [User enters zero: Define a new Rig]
```

(Continued on next page)

Table C-1 (Continued). Sample Rig Definition Session

```
Job Name (1-72 char.)
?=Help: RIGMOOR Sample Problem <cr>     [Title for this analysis]

Water Depth in feet (>0)
?=Help: 312 <cr>                        [Distance from fairleads to bottom]

Offset at Design Load (percent of depth, 5-7 typical)
?=Help: 7 <cr>                          [Watch circle radius]

Tensile Safety Factor at design load (> 1, 3 typical)
?=Help: 3 <cr>                          [Working tension / Breaking strength]

No. of Anchors (2-12)
?=Help: 10 <cr>                         [10 leg mooring; piggybacks count 1]

No. of different Legs (1 -10)
?=Help: 3 <cr>                          [Unusual mooring has dissimilar legs]

No. of segments (1-5) in leg type  1
?=Help: 1 <cr>                          [Describe 1st leg style]

                    * * *    New Screen    * * *
                                  ⑤
Each segment is specified by five parameters:

①Material Codes:  1=Stud-link Chain   2=IWRC Wire Rope   3=Fiber Core Wire Rope

②Diameter in inches.  Weight and strength will be scaled on diameter for you.
                                          ↙ ?. No of feet in chain locker?
③Length in feet.  The length of the top segment will be adjusted by preload.

④Elasticity, EA, in pounds. Use 0 for inextensible.  RIGMOOR will provide a
    realistic value if you enter -1.

⑤Intersegment Load in pounds, at top of segment.  This is immersed displacement
    minus weight, positive for buoys, negative for weights.  Use 0 if none.
    Neither the rig at the top nor the anchor at the bottom is an intersegment
    load.

You may enter these five values in one line, or one at a time.

Code, Diameter, Length, Elasticity & Node buoyancy in segment 1
?=Help: 1,3,6000,-1,0 <cr>          [   1:    Leg is stud-link chain          ]
                                    [   3:    Nominal inches "wire diameter"]
                                    [6000:    Total feet in chain locker      ]
                                    [  -1:    RIGMOOR to estimate elasticity]
                                    [   0:    No inter-segment load           ]
No. of segments (1-5) in leg type  2
?=Help:  1 <cr>                     [Second leg style is all IWRC]
```

(Continued on next page)

Table C-1 (Continued). Sample Rig Definition Session

```
Each segment is specified by five parameters:

Material Codes:  1=Stud-link Chain   2=IWRC Wire Rope   3=Fiber Core Wire Rope

Diameter in inches.  Weight and strength will be scaled on diameter for you.

Length in feet.  The length of the top segment will be adjusted by preload.

Elasticity, EA, in pounds. Use 0 for inextensible.  RIGMOOR will provide a
   realistic value if you enter -1.

Intersegment Load in pounds, at top of segment.  This is immersed displacement
   minus weight, positive for buoys, negative for weights.  Use 0 if none.
   Neither the rig at the top nor the anchor at the bottom is an intersegment
   load.

You may enter these five values in one line, or one at a time.

Code, Diameter, Length, Elasticity & Node buoyancy in segment 1
?=Help: 2,3,6000,-1,0 <cr>                [2: Segment is IWRC]

No. of segments (1-5) in leg type  3
?=Help: 2 <cr>                            [2 segments in 3rd leg style]

                        * * *    New Screen    * * *

Each segment is specified by five parameters:

Material Codes:  1=Stud-link Chain   2=IWRC Wire Rope   3=Fiber Core Wire Rope

Diameter in inches.  Weight and strength will be scaled on diameter for you.

Length in feet.  The length of the top segment will be adjusted by preload.

Elasticity, EA, in pounds. Use 0 for inextensible.  RIGMOOR will provide a
   realistic value if you enter -1.

Intersegment Load in pounds, at top of segment.  This is immersed displacement
   minus weight, positive for buoys, negative for weights.  Use 0 if none.
   Neither the rig at the top nor the anchor at the bottom is an intersegment
   load.

You may enter these five values in one line, or one at a time.

Code, Diameter, Length, Elasticity & Node buoyancy in segment 1
?=Help: 2,3,5460,-1,0 <cr>                [Top segment is IWRC]

Code, Diameter, Length, Elasticity & Node buoyancy in segment 2
?=Help: 1,3,540,-1,0 <cr>                 [Six shots chain at anchor]
```

(Concluded on next page)

5,50,5

Table C-1 (Concluded). Sample Rig Definition Session

```
Enter the Position (x,y) of each fairlead on the rig,
the Direction (Deg.) to its anchor, and the Leg Type (1 - 3)

Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  1
?=Help: 88,100,0,1 <cr>                 [See Plan View, Fig. 1-2, Chain leg]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  2
?=Help: 96,96,45,2 <cr>                 [Wire rope legs on corners]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  3
?=Help: 100,0,90,3 <cr>                 [Composite leg on starboard beam]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  4
?=Help: 96,-96,135,2 <cr>               [Wire rope on corner leg]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  5
?=Help: 88,-100,180,1 <cr>              [Chain on stern leg]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  6
?=Help: -88,-100,-180,1 <cr>            [Chain on stern leg]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  7
?=Help: -96,-96,-135,2 <cr>             [Wire rope on corner leg]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  8
?=Help: -100,0,-90,3 <cr>               [Composite leg on port beam]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead  9
?=Help: -96,96,-45,2 <cr>               [Wire rope on corner leg]
Position (X,Y in feet), Anchor Direction (Deg.), and Leg Type for fairlead 10
?=Help: -88,100,0,1 <cr>                [Chain on port bow leg]

                     * * *    New Screen    * * *

               EXPLORATORY OIL RIG MOORING LEG ANALYSIS

David B. Dillon   EG&G, Inc.           Current Rig Definition Root: SAMPLE
                             RIGMOOR Sample Problem

-------------------------------------------------------------------------
   Entry   Operation

     1     Compute operational and survival holding power rose for mooring
     2     Adjust anchor leg lengths for mooring preload
     3     Compute preload vs scope (H vs S) for each leg type
     4     Compute offset  vs load  (X vs H) for each anchor leg

     5     Display and print operational and survival holding power roses
     6     Display and print preload vs scope tables (H vs S)
     7     Display and print offset  vs load  tables (X vs H)
     8     Display and print current rig definition

     9     Select another rig definition file, old or new
     0     Define a new rig

     Q     Quit
-------------------------------------------------------------------------
   Enter 0 through 9 or Q
?=Help: q <cr>                          [Definition complete, end session
Stop - Program terminated.               Operatorcould have proceded to run
                                         the case by entering a 1 here.]
```

Table C-2. Abstract of User Entries Required for Rig Definition

C:SAMPLE	[Identify root name for rig definition file]
0	[Elect function 0: Define a rig]
RIGMOOR Sample Problem	[Name for case study]
312	[Water depth (feet) **below fairlead level**]
7	[Watch circle radius, percent of depth]
3	[Leg tensile safety factor]
10	[Number of actual legs]
3	[Number of different leg types]
1	[Segments in first leg type]
1,3,6000,-1,0	[Description[1], segment 1 of leg type 1]
1	[Segments in second leg type]
2,3,6000,-1,0	[Description, segment 1 of leg type 2]
2	[Segments in third leg type]
2,3,5460,-1,0	[Description, segment 1 of leg type 3]
1,3,540,-1,0	[Description, segment 2]
88,100,0,1	[Location[2] of fairlead 1]
96,96,45,2	[Fairlead 2]
100,0,90,3	[Fairlead 3]
96,-96,135,2	[Fairlead 4]
88,-100,180,1 ?	[Fairlead 5]
-88,-100,-180,1	[Fairlead 6]
-96,-96,-135,2	[Fairlead 7]
-100,0,-90,3	[Fairlead 8]
-96,96,-45,2	[Fairlead 9]
-88,100,0,1	[Fairlead 10: Rig definition complete]
q	[Elect to quit, could proceed with Function 1]

Note 1: Five parameters describe segments:
Material code: 1=Chain 2=Wire Rope, etc.
Nominal size: Diameter, In
Segment length, Ft (Segment 1 will be adjusted for preload later)
Elasticity EA, Lb (-1 for estimate)
Intersegment buoyancy, Lb

Note 2: Four parameters describe fairlead/anchor combinations:
X-position, Ft starboard of rotary table
Y-position, Ft forward of rotary table
Direction from fairlead to anchor buoy, Deg. clockwise of forward
Type code of leg between fairlead and anchor

Table C-3. Rig Definition Listing for Sample Problem

```
        10        20        30        40        50        60        70        80
[23456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789  Annotations:    ]
RIGMOOR Sample Problem                                                           [Case study title]
    312.00      7.00      3.00 10  3  1  1  2  0  0  0  0  0  0  0  0  0         [See Note 1 for field list]
     88.00    100.00    0.        0.       .000      0.           0.      0.   1 [Description, Fairlead/anchor 1]
     96.00     96.00    0.        0.     45.000      0.           0.      0.   2 [Fairlead/anchor 2: See Note 2]
    100.00       .00    0.        0.     90.000      0.           0.      0.   3 [Fairlead/anchor 3:  for field]
     96.00    -96.00    0.        0.    135.000      0.           0.      0.   2 [Fairlead/anchor 4:  description]
     88.00   -100.00    0.        0.    180.000      0.           0.      0.   1 [Fairlead/anchor 5]
    -88.00   -100.00    0.        0.   -180.000      0.           0.      0.   1 [Fairlead/anchor 6]
    -96.00    -96.00    0.        0.   -135.000      0.           0.      0.   2 [Fairlead/anchor 7]
   -100.00       .00    0.        0.    -90.000      0.           0.      0.   3 [Fairlead/anchor 8]
    -96.00     96.00    0.        0.    -45.000      0.           0.      0.   2 [Fairlead/anchor 9]
    -88.00    100.00    0.        0.       .000      0.           0.      0.   1 [Fairlead/anchor 10]
    1     3.000   6000.00   77.9986   683847.        0. .7736E+08                [Description, Segment 1 of leg type 1]
    2     3.000   6000.00   14.4805   750264.        0. .5796E+08                [Seg. 1, Type 2: See Note 3]
    2     3.000   5460.00   14.4805   750264.        0. .5796E+08                [Seg. 1, Type 3  for field]
    1     3.000    540.00   77.9986   683847.        0. .7736E+08                [Seg. 2, Type 3  list]
```

~~~~~~

Note 1: Header record fields: (1) 312.00=Water depth, Ft below fairleads, (2) 7.00=Watch circle radius, percent of depth; (3) 3.00=Leg tensile safety factor; (4) 10=Number of legs, (5) 3=Number of leg types; (6) 1 1 2, etc.=Number of segments in each leg type, 0=unused.

Note 2: There is one fairlead/anchor record for each fairlead. The fields, using the first record as a template, are: (1) 88.00=X-position of fairlead, Ft starboard of rotary table; (2) 100.00=Y-position, Ft forward of rotary table; (3) 0.=Unspecified X-position of anchor, Ft starboard of BOP stack; (4) 0.=Unspecified Y-position, Ft forward of BOP stack; (5) .000=Direction from fairlead to anchor, Deg. clockwise from forward; (6) 0.=Unspecified horizontal radius, Ft from fairlead to anchor; (7) 0.=Unspecified leg preload, Lb; (8) 0.=Unspecified length of leg segment 1, Ft deployed outboard of fairlead; (8) 1=leg type. Unspecified quantities are determined according to the preload established for the leg during the analysis.

Note 3: Segments are grouped by leg type and listed in sequence from fairlead to anchor. The fields, using the first record as template are: (1) 1=Material code (1=Chain, 2=Wire Rope), (2) 3.000=Nominal diameter, In, (3) 6000.00=Segment length, Ft; (4) 0.=Buoyant load, Lb at anchor end of segment, (7) .7736E+08=Elasticity, EA, of segment, Lb. The length of segment 1 is nominal. It will be adjusted for preload during the calculations. The length of other segments is fixed.
~~~~~~

following pages

Table C-4 shows the successive screen displays for RIGMOOR's review of the sample problem. The review is based on the optimized preload theory described in Appendix B. The theory may be discerned in the H vs S tables that begin on page C-11. There is a table for each of the three leg types in the sample problem.

Each table shows the effects of increasing the length of the top segment of the leg. There is only one segment for types 1 and 2, so the least length is 312 feet: just enough to span the depth from the fairlead to the bottom. Leg type 3 has two segments, and the bottom segment is more than long enough to span the depth, so the top segment starts undeployed. Note that in each table there comes a point where increasing the length has no effect on the Design Load: the added length at the fairlead just lays more on the bottom.

Note also that throughout the tables, the difference between Prespan (horizontal span at the stated Preload) and Design Span is 22 feet - just 7 percent of the vertical span (312 feet below the fairleads).

The second, third and fourth columns are headed collectively, "Force/ Length on Bottom". **Positive** values in these columns are the upward force (Lb) that the leg exerts on the anchor - none of the leg lies along the bottom in that case. **Negative** values represent the contrasting condition. The upward force is zero, and the number (ignoring the minus sign) represents the length lying on the bottom, in feet. Column 2, labeled "Slack" means there is no horizontal load on the leg. The length on the bottom is also the Slack Span, since the rest of the leg hangs vertically. Columns 3 and 4 describe the leg when the horizontal Preload and Design Load are applied, respectively.

Table C-4. RIGMOOR Analysis of Sample Problem

```
                              RIGMOOR

                 MULTI-LEG SURFACE MOORING DESIGN REVIEW


                          DAVID B. DILLON

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                         9220 GAITHER ROAD

                      GAITHERSBURG, MD 20877

                          (301) 840-3323



Note: Enter ? in place of any entry to receive on-screen help.

Enter Drive and Rig Name
        A:RIGNAM
?=Help: C:SAMPLE <cr>        [Root name for rig definition file]

                         * * *   New Screen   * * *

                EXPLORATORY OIL RIG MOORING LEG ANALYSIS

David B. Dillon   EG&G, Inc.              Current Rig Definition Root: SAMPLE
                             RIGMOOR Sample Problem

-------------------------------------------------------------------------------
   Entry   Operation

     1     Compute operational and survival holding power rose for mooring
     2     Adjust anchor leg lengths for mooring preload
     3     Compute preload vs scope (H vs S) for each leg type
     4     Compute offset  vs load  (X vs H) for each anchor leg

     5     Display and print operational and survival holding power roses
     6     Display and print preload vs scope tables
     7     Display and print offset  vs load  tables
     8     Display and print current rig definition

     9     Select another rig definition file, old or new
     0     Define a new rig

     Q     Quit
-------------------------------------------------------------------------------
   Enter 0 through 9 or Q
?=Help: 1 <cr>               [Function 1 includes functions 2, 3 and 4]
```

This appears on screen but is not printed

These headings explained on page 3-5, Vol IV

```
                          H vs S  for Leg Type  1       [Start Function 3]

                 First Scope   Last Scope   Scope Step   Max. Load
                  3.12000E+02  3.12000E+03  5.00000E+01  2.27949E+05

   Top   - Force/Length on Bottom -      Pre-     Design     Pre-     Design   Holding
  Scope     Slack   Preload    Design     Span      Span      Load      Load     Power
   312.        0.      236.   203036.       2.       24.       27.    16234.    16207.
   350.      -38.     3228.   178183.     139.      161.     5955.    98678.    92723.
   400.      -88.     4090.   152267.     230.      252.    12433.   135282.   122849.
   450.     -138.     4167.   131665.     304.      326.    18714.   155404.   136690.
   500.     -188.     3866.   114794.     370.      392.    25004.   168251.   143247.
   550.     -238.     3327.   100636.     432.      454.    31364.   177083.   145719.
   600.     -288.     2611.    88512.     492.      513.    37800.   183444.   145643.
   650.     -338.     1738.    77958.     549.      571.    44281.   188171.   143890.
   700.     -388.      752.    68625.     605.      627.    50823.   191773.   140949.
   750.     -438.       -5.    60279.     660.      682.    57353.   194557.   137204.
   800.     -488.      -21.    52734.     715.      736.    63707.   196736.   133029.
   850.     -538.      -41.    45847.     768.      790.    69776.   198454.   128678.
   900.     -588.      -63.    39508.     821.      843.    75473.   199813.   124339.
   950.     -638.      -89.    33633.     874.      896.    80707.   200885.   120177.
  1000.     -688.     -117.    28148.     926.      948.    85436.   201727.   116291.
  1050.     -738.     -148.    23000.     978.      999.    89576.   202378.   112802.
  1100.     -788.     -183.    18143.    1029.     1051.    93081.   202871.   109791.
  1150.     -838.     -221.    13543.    1080.     1102.    95899.   203229.   107330.
  1200.     -888.     -262.     9157.    1131.     1153.    98068.   203475.   105407.
  1250.     -938.     -306.     4968.    1182.     1203.    99456.   203621.   104165.
  1300.     -988.     -353.      953.    1232.     1254.   100185.   203679.   103494.
  1350.    -1038.     -402.      -38.    1282.     1304.   100402.   203681.   103280.
  1400.    -1088.     -451.      -88.    1332.     1354.   100594.   203681.   103087.
  1450.    -1138.     -500.     -138.    1382.     1404.   100769.   203681.   102912.
  1500.    -1188.     -549.     -188.    1432.     1454.   100974.   203680.   102706.
  1550.    -1238.     -599.     -238.    1482.     1504.   101163.   203681.   102518.
  1600.    -1288.     -648.     -288.    1533.     1554.   101375.   203681.   102306.
  1650.    -1338.     -697.     -338.    1583.     1605.   101558.   203681.   102124.
  1700.    -1388.     -746.     -388.    1633.     1655.   101753.   203681.   101929.
  1750.    -1438.     -795.     -438.    1683.     1705.   101948.   203681.   101733.
  1800.    -1488.     -845.     -488.    1733.     1755.   102138.   203681.   101543.
  1850.    -1538.     -894.     -538.    1783.     1805.   102334.   203681.   101348.
  1900.    -1588.     -943.     -588.    1833.     1855.   102527.   203681.   101155.
  1950.    -1638.     -992.     -638.    1884.     1905.   102717.   203681.   100964.
  2000.    -1688.    -1041.     -688.    1934.     1956.   102912.   203681.   100769.
  2050.    -1738.    -1090.     -738.    1984.     2006.   103100.   203681.   100581.
  2100.    -1788.    -1140.     -788.    2034.     2056.   103302.   203681.   100379.
  2150.    -1838.    -1189.     -838.    2084.     2106.   103462.   203681.   100219.
  2200.    -1888.    -1238.     -888.    2134.     2156.   103671.   203681.   100010.
  2250.    -1938.    -1287.     -938.    2184.     2206.   103851.   203681.    99831.
  2300.    -1988.    -1337.     -988.    2234.     2256.   104036.   203681.    99645.
  2350.    -2038.    -1386.    -1038.    2285.     2306.   104236.   203681.    99445.
  2400.    -2088.    -1435.    -1088.    2335.     2357.   104433.   203681.    99248.
  2450.    -2138.    -1484.    -1138.    2385.     2407.   104618.   203681.    99063.
  2500.    -2188.    -1534.    -1188.    2435.     2457.   104803.   203681.    98879.
  2550.    -2238.    -1583.    -1238.    2485.     2507.   104996.   203681.    98686.
  2600.    -2288.    -1632.    -1288.    2535.     2557.   105183.   203681.    98498.
  2650.    -2338.    -1681.    -1338.    2585.     2607.   105368.   203681.    98313.
```

difference is 22 (7% of 312 depth)

No increase in design load after here—just laying chain on bottom on screen but not printed

```
                          H vs S for Leg Type  2     [Continue Function 3]

                First Scope   Last Scope   Scope Step   Max. Load
                 3.12000E+02  5.64080E+03  1.00000E+02  2.50088E+05

  Top   - Force/Length on Bottom -     Pre-     Design      Pre-     Design   Holding
 Scope     Slack   Preload   Design    Span      Span       Load      Load     Power
  312.        0.    16579.  243188.       7.       29.       438.    22925.    22487.
  400.      -88.      856.  189583.     231.      253.      2404.   156116.   153712.
  500.     -188.      876.  150373.     372.      393.      4869.   194171.   189301.
  600.     -288.      739.  123983.     494.      515.      7483.   211996.   204513.
  700.     -388.      530.  104926.     608.      630.     10293.   222048.   211755.
  800.     -488.      280.   90453.     718.      740.     13312.   228325.   215013.
  900.     -588.        0.   79040.     826.      848.     16534.   232524.   215990.
 1000.     -688.      -22.   69756.     933.      954.     19934.   235474.   215541.
 1100.     -788.      -48.   62037.    1038.     1060.     23444.   237627.   214183.
 1200.     -888.      -76.   55475.    1142.     1164.     27075.   239242.   212167.
 1300.     -988.     -107.   49816.    1246.     1267.     30782.   240484.   209702.
 1400.    -1088.     -141.   44861.    1349.     1371.     34549.   241457.   206908.
 1500.    -1188.     -178.   40471.    1451.     1473.     38355.   242232.   203876.
 1600.    -1288.     -217.   36539.    1554.     1576.     42192.   242856.   200665.
 1700.    -1388.     -259.   32984.    1656.     1678.     46006.   243364.   197358.
 1800.    -1488.     -303.   29743.    1758.     1780.     49811.   243782.   193970.
 1900.    -1588.     -350.   26768.    1860.     1881.     53551.   244126.   190575.
 2000.    -1688.     -400.   24019.    1961.     1983.     57223.   244412.   187189.
 2100.    -1788.     -453.   21462.    2063.     2084.     60785.   244650.   183865.
 2200.    -1888.     -508.   19072.    2164.     2186.     64225.   244848.   180623.
 2300.    -1988.     -567.   16827.    2265.     2287.     67534.   245012.   177478.
 2400.    -2088.     -628.   14705.    2366.     2388.     70688.   245149.   174460.
 2500.    -2188.     -693.   12698.    2467.     2489.     73646.   245261.   171615.
 2600.    -2288.     -760.   10790.    2568.     2590.     76409.   245352.   168944.
 2700.    -2388.     -831.    8969.    2669.     2691.     78955.   245425.   166471.
 2800.    -2488.     -904.    7226.    2770.     2791.     81309.   245483.   164174.
 2900.    -2588.     -980.    5553.    2870.     2892.     83405.   245527.   162121.
 3000.    -2688.    -1059.    3945.    2971.     2993.     85286.   245558.   160272.
 3100.    -2788.    -1141.    2393.    3071.     3093.     86934.   245578.   158644.
 3200.    -2888.    -1226.     893.    3172.     3194.     88322.   245588.   157266.
 3300.    -2988.    -1313.     -39.    3272.     3294.     89498.   245590.   156091.
 3400.    -3088.    -1401.    -139.    3373.     3395.     90631.   245589.   154959.
 3500.    -3188.    -1489.    -239.    3473.     3495.     91764.   245589.   153825.
 3600.    -3288.    -1577.    -339.    3574.     3595.     92895.   245589.   152694.
 3700.    -3388.    -1665.    -439.    3674.     3696.     94020.   245589.   151569.
 3800.    -3488.    -1753.    -539.    3774.     3796.     95139.   245589.   150450.
 3900.    -3588.    -1841.    -639.    3875.     3897.     96263.   245589.   149326.
 4000.    -3688.    -1930.    -739.    3975.     3997.     97391.   245589.   148198.
 4100.    -3788.    -2018.    -839.    4076.     4098.     98497.   245589.   147093.
 4200.    -3888.    -2107.    -939.    4176.     4198.     99621.   245589.   145969.
 4300.    -3988.    -2195.   -1039.    4277.     4298.    100724.   245589.   144865.
 4400.    -4088.    -2284.   -1139.    4377.     4399.    101835.   245589.   143755.
 4500.    -4188.    -2373.   -1239.    4477.     4499.    102926.   245589.   142663.
 4600.    -4288.    -2462.   -1339.    4578.     4600.    104006.   245589.   141583.
 4700.    -4388.    -2551.   -1439.    4678.     4700.    105107.   245589.   140482.
 4800.    -4488.    -2640.   -1539.    4779.     4801.    106182.   245589.   139407.
 4900.    -4588.    -2730.   -1639.    4879.     4901.    107269.   245589.   138320.
 5000.    -4688.    -2819.   -1739.    4980.     5001.    108324.   245589.   137265.
```

on screen but not printed

```
                        H vs S for Leg Type  3     [Conclude Funtion 3]

            First Scope   Last Scope   Scope Step   Max. Load
            .00000E+00   5.64080E+03  1.00000E+02  2.27949E+05

  Top   - Force/Length on Bottom -    Pre-    Design     Pre-    Design   Holding
 Scope    Slack   Preload   Design    Span     Span      Load     Load     Power
    0.    -228.    3441.  103288.     420.     442.    30074.  175549.  145476.
  100.    -328.    1581.   82361.     538.     560.    41814.  190959.  149145.
  200.    -428.     -16.   66318.     650.     672.    51043.  200505.  149462.
  300.    -528.     -63.   53625.     759.     781.    57154.  206867.  149712.
  400.    -628.    -119.   43314.     866.     888.    60090.  211334.  151244.
  500.    -728.    -182.   34750.     972.     993.    60054.  214597.  154543.
  600.    -828.    -248.   27501.    1076.    1098.    57422.  217057.  159635.
  700.    -928.    -314.   21267.    1180.    1202.    52897.  218959.  166061.
  800.   -1028.    -375.   15828.    1283.    1305.    47591.  220460.  172870.
  900.   -1128.    -426.   11025.    1386.    1408.    43151.  221667.  178517.
 1000.   -1228.    -463.    6742.    1488.    1510.    40658.  222651.  181993.
 1100.   -1328.    -489.    2882.    1590.    1612.    40069.  223463.  183394.
 1200.   -1428.    -508.      -8.    1692.    1714.    40804.  224141.  183337.
 1300.   -1528.    -523.     -50.    1794.    1816.    42514.  224720.  182206.
 1400.   -1628.    -535.     -89.    1895.    1917.    44920.  225220.  180300.
 1500.   -1728.    -573.    -126.    1997.    2019.    47736.  225652.  177916.
 1600.   -1828.    -631.    -161.    2098.    2120.    50624.  226025.  175402.
 1700.   -1928.    -690.    -194.    2200.    2222.    53522.  226348.  172826.
 1800.   -2028.    -751.    -226.    2301.    2323.    56415.  226626.  170211.
 1900.   -2128.    -813.    -255.    2402.    2424.    59264.  226866.  167601.
 2000.   -2228.    -876.    -284.    2503.    2525.    62073.  227071.  164999.
 2100.   -2328.    -941.    -311.    2604.    2626.    64812.  227248.  162436.
 2200.   -2428.   -1008.    -337.    2705.    2727.    67438.  227398.  159959.
 2300.   -2528.   -1077.    -362.    2806.    2828.    69953.  227525.  157572.
 2400.   -2628.   -1148.    -386.    2907.    2929.    72349.  227631.  155282.
 2500.   -2728.   -1221.    -409.    3008.    3030.    74593.  227719.  153125.
 2600.   -2828.   -1297.    -431.    3109.    3131.    76691.  227790.  151099.
 2700.   -2928.   -1375.    -452.    3209.    3231.    78610.  227847.  149236.
 2800.   -3028.   -1455.    -473.    3310.    3332.    80336.  227889.  147553.
 2900.   -3128.   -1537.    -493.    3410.    3432.    81887.  227920.  146033.
 3000.   -3228.   -1622.    -513.    3511.    3533.    83246.  227939.  144693.
 3100.   -3328.   -1709.    -532.    3611.    3633.    84384.  227948.  143564.
 3200.   -3428.   -1798.    -597.    3712.    3734.    85370.  227949.  142579.
 3300.   -3528.   -1888.    -697.    3812.    3834.    86331.  227949.  141618.
 3400.   -3628.   -1977.    -797.    3913.    3934.    87286.  227949.  140663.
 3500.   -3728.   -2067.    -897.    4013.    4035.    88249.  227949.  139700.
 3600.   -3828.   -2156.    -997.    4113.    4135.    89196.  227949.  138753.
 3700.   -3928.   -2246.   -1097.    4214.    4236.    90154.  227949.  137795.
 3800.   -4028.   -2336.   -1197.    4314.    4336.    91106.  227949.  136843.
 3900.   -4128.   -2426.   -1297.    4415.    4436.    92052.  227949.  135897.
 4000.   -4228.   -2516.   -1397.    4515.    4537.    92999.  227949.  134950.
 4100.   -4328.   -2606.   -1497.    4615.    4637.    93926.  227949.  134023.
 4200.   -4428.   -2696.   -1597.    4716.    4738.    94862.  227949.  133087.
 4300.   -4528.   -2786.   -1697.    4816.    4838.    95813.  227949.  132136.
 4400.   -4628.   -2876.   -1797.    4917.    4938.    96747.  227949.  131202.
 4500.   -4728.   -2967.   -1897.    5017.    5039.    97667.  227949.  130282.
 4600.   -4828.   -3057.   -1997.    5117.    5139.    98589.  227949.  129360.
 4700.   -4928.   -3148.   -2097.    5218.    5240.    99498.  227949.  128451.
```

```
                       Mooring Definition for Root Name
                                  C:SAMPLE

                             RIGMOOR Sample Problem     [Preload unspecified]

                         Water    Design    Safety    No.      No.Leg
                         Depth    Offset    Factor   Anchors    Types
                        312.00     7.00      3.00     10         3


 Anchor  Fairlead Position   Anchor Position    Anchor  Anchor   Anchor     Top
No. Type     X        Y        X         Y  Direction Radius  Preload   Scope
  1   1    88.00   100.00     .0        .0      .00     0.        0.        0.
  2   2    96.00    96.00     .0        .0    45.00     0.        0.        0.
  3   3   100.00      .00     .0        .0    90.00     0.        0.        0.
  4   2    96.00   -96.00     .0        .0   135.00     0.        0.        0.
  5   1    88.00  -100.00     .0        .0   180.00     0.        0.        0.
  6   1   -88.00  -100.00     .0        .0  -180.00     0.        0.        0.
  7   2   -96.00   -96.00     .0        .0  -135.00     0.        0.        0.
  8   3  -100.00      .00     .0        .0   -90.00     0.        0.        0.
  9   2   -96.00    96.00     .0        .0   -45.00     0.        0.        0.
 10   1   -88.00   100.00     .0        .0      .00     0.        0.        0.

Leg Type  1
Seg. Material         Size     Length     Weight  Strength Elasticity Buoyancy
  1 Stud-link Chain   3.000   6000.00    77.9986   683847. 7.7360E+07       0.

Leg Type  2
Seg. Material         Size     Length     Weight  Strength Elasticity Buoyancy
  1  IWRC Wire Rope   3.000   6000.00    14.4805   750264. 5.7960E+07       0.

Leg Type  3
Seg. Material         Size     Length     Weight  Strength Elasticity Buoyancy
  1  IWRC Wire Rope   3.000   5460.00    14.4805   750264. 5.7960E+07       0.
  2 Stud-link Chain   3.000    540.00    77.9986   683847. 7.7360E+07       0.

                                                      [Start Function 2]
                              Anchor    Preload Ratio
                                1          1.000000
                                2          1.000000  [Mooring is symmetric]
                                3          1.000000  [about diametrically ]
                                4          1.000000  [opposed legs, so all]
                                5          1.000000  [legs get the same   ]
                                6          1.000000  [preload.            ]
                                7          1.000000
                                8          1.000000
                                9          1.000000
                               10          1.000000

Average Preload (    30073.8 -   107044.8  E=Estimate  U=Use)
?=Help: E <cr>                                   [Let RIGMOOR optimize preload]
```

Help 15   ?

```
                Anchor Properties for Average Preload =   100396.8

Anc-   Top   Force/Length on Bottom   Pre-   Design   Pre-    Design  Holding
hor   Scope   Slack    Hpre    Hdes   Span    Span    Load     Load    Power
  1   1349.  -1037.   -401.    -16.   1281.   1303. 100397. 203681. 103285.
  2   4270.  -3958.  -2169.  -1009.   4247.   4269. 100397. 245589. 145193.
  3   4798.  -5026.  -3237.  -2195.   5316.   5338. 100397. 227949. 127552.
  4   4270.  -3958.  -2169.  -1009.   4247.   4269. 100397. 245589. 145193.
  5   1349.  -1037.   -401.    -16.   1281.   1303. 100397. 203681. 103285.
  6   1349.  -1037.   -401.    -16.   1281.   1303. 100397. 203681. 103285.
  7   4270.  -3958.  -2169.  -1009.   4247.   4269. 100397. 245589. 145193.
  8   4798.  -5026.  -3237.  -2195.   5316.   5338. 100397. 227949. 127552.
  9   4270.  -3958.  -2169.  -1009.   4247.   4269. 100397. 245589. 145193.
 10   1349.  -1037.   -401.    -16.   1281.   1303. 100397. 203681. 103285.

                          Anchor    Preload Ratio
                             1        1.000000
                             2        1.000000
                             3        1.000000
                             4        1.000000
                             5        1.000000
                             6        1.000000
                             7        1.000000
                             8        1.000000
                             9        1.000000
                            10        1.000000

Average Preload (   30073.8 -   107044.8  E=Estimate  U=Use)
?=Help: U <cr>                           [Use preload estimate in Function 4]

Initial, Final, Step Rig Deflection Angles (0=Forward)
?=Help: 0,90,5 <cr>                     [Select limits of holding power rose]
```

Help 21

Bud gets to here - error code - back to beginning.

```
                         Mooring Definition for Root Name
                                  C:SAMPLE           [Leg length adjusted]
                                                     [     for preload     ]
                              RIGMOOR Sample Problem

                     Water    Design    Safety     No.      No.Leg
                     Depth    Offset    Factor   Anchors     Types
                    312.00     7.00      3.00      10          3


 Anchor   Fairlead Position   Anchor Position     Anchor  Anchor   Anchor      Top
No. Type     X        Y         X        Y     Direction Radius  Preload    Scope
  1   1    88.00   100.00     88.0   1380.8        .00  1281.   100397.     1349.
  2   2    96.00    96.00   3098.9   3098.9      45.00  4247.   100397.     4270.
  3   3   100.00      .00   5416.2       .0      90.00  5316.   100397.     4798.
  4   2    96.00   -96.00   3098.9  -3098.9     135.00  4247.   100397.     4270.
  5   1    88.00  -100.00     88.0  -1380.8     180.00  1281.   100397.     1349.
  6   1   -88.00  -100.00    -88.0  -1380.8    -180.00  1281.   100397.     1349.
  7   2   -96.00   -96.00  -3098.9  -3098.9    -135.00  4247.   100397.     4270.
  8   3  -100.00      .00  -5416.2       .0     -90.00  5316.   100397.     4798.
  9   2   -96.00    96.00  -3098.9   3098.9     -45.00  4247.   100397.     4270.
 10   1   -88.00   100.00    -88.0   1380.8        .00  1281.   100397.     1349.

Leg Type  1
Seg. Material          Size     Length     Weight  Strength Elasticity Buoyancy
  1 Stud-link Chain    3.000   6000.00    77.9986   683847. 7.7360E+07        0.

Leg Type  2
Seg. Material          Size     Length     Weight  Strength Elasticity Buoyancy
  1  IWRC Wire Rope    3.000   6000.00    14.4805   750264. 5.7960E+07        0.

Leg Type  3
Seg. Material          Size     Length     Weight  Strength Elasticity Buoyancy
  1  IWRC Wire Rope    3.000   5460.00    14.4805   750264. 5.7960E+07        0.
  2 Stud-link Chain    3.000    540.00    77.9986   683847. 7.7360E+07        0.
```

```
        OPERATIONAL AND SURVIVAL HOLDING POWER ANALYSIS FOR   0. FEET HEAVE

                                       C:SAMPLE
Direction | Operational (All legs active)  |  Survival (Lee legs slacked)
 of Rig   | Holding  Weather  Safety   Rig |  Holding  Weather  Safety   Rig
Deflection|  Power  Direction Factor   Yaw |   Power  Direction Factor   Yaw
   .00     494178.      .00    3.00    .00    634780.      .00    3.00    .00
  5.00     493301.     4.03    3.01    .01    633787.     2.78    3.01    .01
 10.00     491053.     8.04    3.03    .01    631181.     5.54    3.03    .03
 15.00     486944.    12.28    3.07    .02    626982.     8.36    3.07    .04
 20.00     481860.    16.45    3.12    .03    635695.    16.32    3.12    .05
 25.00     475494.    20.77    3.15    .03    629824.    18.61    3.15    .06
 30.00     467834.    25.17    3.08    .04    622212.    20.88    3.08    .07
 35.00     458955.    29.94    3.04    .04    591041.    29.58    3.04    .07
 40.00     449943.    34.61    3.01    .04    582831.    32.69    3.01    .08
 45.00     440232.    39.53    3.00    .04    573396.    35.93    3.00    .08
 50.00     431319.    44.61    3.01    .04    564082.    39.22    3.01    .09
 55.00     423004.    49.79    3.04    .04    554633.    42.50    3.04    .10
 60.00     415245.    55.34    3.08    .04    544581.    45.99    3.08    .10
 65.00     409112.    60.63    3.15    .03    535557.    49.23    3.15    .11
 70.00     403312.    66.34    3.13    .03    535412.    58.25    3.13    .10
 75.00     398158.    72.40    3.08    .02    527149.    61.16    3.08    .11
 80.00     395433.    78.23    3.04    .01    475125.    81.15    3.04    .01
 85.00     393146.    84.04    3.01    .01    473852.    85.52    3.01    .01
 90.00     392432.    90.00    3.00    .00    473494.    90.00    3.00    .00

   Rig Heave
    Downward: -1 thru -99 Feet
      Upward:  1 thru  99 Feet
Command Menu:  0
?=Help: 10 <cr>                                          [Rig on wave crest]
```

Help 25

```
   OPERATIONAL AND SURVIVAL HOLDING POWER ANALYSIS FOR  10. FEET HEAVE

                      C SAMPLE
Direction  | Operational (All legs active)        |  Survival (Lee legs slacked)
 of Rig    | Holding  Weather  Safety    Rig      |  Holding  Weather  Safety    Rig
Deflection |  Power  Direction Factor    Yaw      |   Power  Direction Factor    Yaw
    .00      547551.       .00   2.70      .00       701156.       .00   2.70      .00
   5.00      546342.      3.84   2.71      .01       699943.      2.68   2.71      .01
  10.00      542064.      7.73   2.73      .01       696220.      5.31   2.73      .03
  15.00      535293.     11.79   2.77      .02       690213.      7.99   2.77      .04
  20.00      527542.     15.94   2.82      .03       697314.     15.82   2.82      .05
  25.00      519008.     20.06   2.89      .03       690281.     18.00   2.89      .06
  30.00      508510.     24.45   2.91      .04       680783.     20.24   2.91      .08
  35.00      497588.     29.05   2.87      .04       670008.     22.48   2.87      .09
  40.00      487109.     33.75   2.84      .05       634667.     31.83   2.84      .08
  45.00      475260.     38.64   2.83      .05       622985.     35.06   2.83      .09
  50.00      464697.     43.64   2.84      .05       611897.     38.30   2.84      .10
  55.00      454504.     48.83   2.87      .04       600325.     41.60   2.87      .10
  60.00      444834.     54.27   2.91      .04       588791.     44.95   2.91      .11
  65.00      436020.     60.02   2.97      .04       577628.     48.32   2.97      .11
  70.00      428080.     65.89   2.97      .03       575075.     57.37   2.97      .11
  75.00      422932.     71.73   2.92      .02       566520.     60.19   2.92      .11
  80.00      419071.     77.73   2.88      .02       506026.     80.80   2.88      .01
  85.00      416614.     83.98   2.85      .01       504316.     85.46   2.85      .01
  90.00      415730.     90.00   2.84      .00       503828.     90.00   2.84      .00

   Rig Heave
    Downward: -1 thru -99 Feet
      Upward:  1 thru  99 Feet
Command Menu:  0
?=Help: -10 <cr>                                      [Rig in wave trough]
```

```
             OPERATIONAL AND SURVIVAL HOLDING POWER ANALYSIS FOR -10. FEET HEAVE

                       C:SAMPLE
Direction  | Operational (All legs active)        |  Survival (Lee legs slacked)
 of Rig    | Holding  Weather  Safety    Rig      |  Holding  Weather  Safety    Rig
Deflection |  Power  Direction Factor    Yaw      |   Power  Direction Factor    Yaw
    .00      446249.      .00   3.33     .00         574163.      .00   3.33     .00
   5.00      445808.     4.19   3.34     .01         573598.     2.87   3.34     .01
  10.00      443871.     8.53   3.36     .01         571270.     5.83   3.36     .02
  15.00      441613.    12.68   3.40     .02         568396.     8.63   3.40     .04
  20.00      437639.    17.10   3.43     .02         577380.    16.88   3.43     .04
  25.00      432755.    21.57   3.34     .03         572890.    19.18   3.34     .06
  30.00      426785.    26.22   3.27     .03         566755.    21.58   3.27     .07
  35.00      420084.    30.69   3.23     .04         539828.    30.34   3.23     .06
  40.00      413715.    35.45   3.20     .04         533263.    33.59   3.20     .07
  45.00      406896.    40.31   3.19     .04         526012.    36.84   3.19     .08
  50.00      398946.    45.48   3.20     .04         517827.    40.17   3.20     .08
  55.00      393088.    50.81   3.23     .04         510701.    43.58   3.23     .09
  60.00      387259.    56.06   3.27     .03         502856.    46.84   3.27     .09
  65.00      382072.    61.67   3.34     .03         501887.    56.43   3.34     .09
  70.00      378441.    67.10   3.32     .03         496449.    59.15   3.32     .10
  75.00      375402.    72.69   3.26     .02         490144.    62.00   3.26     .10
  80.00      371976.    78.46   3.21     .01         444427.    81.35   3.21     .01
  85.00      370105.    84.29   3.19     .01         443685.    85.73   3.19     .01
  90.00      369282.    90.00   3.18     .00         443229.    90.00   3.18     .00

   Rig Heave
    Downward: -1 thru -99 Feet
      Upward:  1 thru  99 Feet
  Command Menu:  0
  ?=Help: 0 <cr>                                                  [No more cases]
```

```
                  EXPLORATORY OIL RIG MOORING LEG ANALYSIS

David B. Dillon   EG&G, Inc.           Current Rig Definition Root: SAMPLE
                                  RIGMOOR Sample Problem

------------------------------------------------------------------------------
   Entry   Operation

     1     Compute operational and survival holding power rose for mooring
     2     Adjust anchor leg lengths for mooring preload
     3     Compute preload vs scope (H vs S) for each leg type
     4     Compute offset  vs load  (X vs H) for each anchor leg

     5     Display and print operational and survival holding power roses
     6     Display and print preload vs scope tables
     7     Display and print offset  vs load  tables
     8     Display and print current rig definition

     9     Select another rig definition file, old or new
     0     Define a new rig

     Q     Quit
------------------------------------------------------------------------------
   Enter 0 through 9 or Q
?=Help: 5 <cr>                        [Review Holding Power Roses in detail]
```

```
                    Mooring Definition for Root Name
                               C:SAMPLE

                        RIGMOOR Sample Problem

               Water    Design    Safety     No.       No.Leg
               Depth    Offset    Factor   Anchors      Types
              312.00     7.00      3.00      10           3


 Anchor   Fairlead Position   Anchor Position     Anchor   Anchor    Anchor      Top
No. Type     X         Y         X         Y   Direction  Radius   Preload     Scope
  1   1     88.00   100.00      88.0    1380.8       .00   1281.   100397.     1349.
  2   2     96.00    96.00    3098.9    3098.9     45.00   4247.   100397.     4270.
  3   3    100.00      .00    5416.2        .0     90.00   5316.   100397.     4798.
  4   2     96.00   -96.00    3098.9   -3098.9    135.00   4247.   100397.     4270.
  5   1     88.00  -100.00      88.0   -1380.8    180.00   1281.   100397.     1349.
  6   1    -88.00  -100.00     -88.0   -1380.8   -180.00   1281.   100397.     1349.
  7   2    -96.00   -96.00   -3098.9   -3098.9   -135.00   4247.   100397.     4270.
  8   3   -100.00      .00   -5416.2        .0    -90.00   5316.   100397.     4798.
  9   2    -96.00    96.00   -3098.9    3098.9    -45.00   4247.   100397.     4270.
 10   1    -88.00   100.00     -88.0    1380.8       .00   1281.   100397.     1349.

Leg Type  1
Seg. Material          Size     Length    Weight   Strength Elasticity Buoyancy
  1 Stud-link Chain    3.000   6000.00   77.9986    683847. 7.7360E+07       0.

Leg Type  2
Seg. Material          Size     Length    Weight   Strength Elasticity Buoyancy
  1  IWRC Wire Rope    3.000   6000.00   14.4805    750264. 5.7960E+07       0.

Leg Type  3
Seg. Material          Size     Length    Weight   Strength Elasticity Buoyancy
  1  IWRC Wire Rope    3.000   5460.00   14.4805    750264. 5.7960E+07       0.
  2 Stud-link Chain    3.000    540.00   77.9986    683847. 7.7360E+07       0.
```

These headings explained on pages 3-2 and 55, Vol. II

```
                                                                  Page 1
                                  C:SAMPLE
                           RIGMOOR Sample Problem
               Operational Holding Power Rose for   0. Ft Rig Heave

Deflection  Holding  Weather    Force Components  Safety  CW Moment    Yaw
 Direction   Power  Direction    X         Y      Factor (Normalized) Angle
    .00    494178.     .000      0.   -494178.  3.001     .0000     .0000

 Anchor       Load      Span   X-Load     Y-Load  Safety CW Moment  Active
   1         57119.   1259.0       0.     57119.  8.474   -2.2924     T
   2         53129.   4231.4   37705.     37431. 13.425     .0120     T
   3        100626.   5316.2  100625.      -413.  6.803     .0189     T
   4        193532.   4262.3  136351.   -137342.  3.797     .0434     T
   5        203883.   1302.7       0.   -203883.  3.001    8.1826     T
   6        203883.   1302.7       0.   -203883.  3.001   -8.1826     T
   7        193532.   4262.3 -136351.   -137342.  3.797    -.0434     T
   8        100626.   5316.2 -100625.      -413.  6.803    -.0189     T
   9         53129.   4231.4  -37705.     37431. 13.425    -.0120     T
  10         57119.   1259.0       0.     57119.  8.474    2.2924     T


Deflection  Holding  Weather    Force Components  Safety  CW Moment    Yaw
 Direction   Power  Direction    X         Y      Factor (Normalized) Angle
    5.00   493301.    4.027   -34640.  -492083.  3.008     .0003     .0070

 Anchor       Load      Span   X-Load     Y-Load  Safety CW Moment  Active
   1         57227.   1259.1     -87.     57227.  8.460   -2.3010     T
   2         50592.   4230.1   35893.     35655. 14.087     .0100     T
   3         93481.   5314.3   93481.      -383.  7.396     .0169     T
   4        183003.   4260.9  128894.   -129909.  4.007     .0431     T
   5        203176.   1302.6    -295.   -203176.  3.010    8.1665     T
   6        203341.   1302.6    -295.   -203341.  3.008   -8.1485     T
   7        203376.   4263.6 -143334.   -144282.  3.614    -.0431     T
   8        109129.   5318.1 -109128.      -447.  6.318    -.0210     T
   9         55896.   4232.8  -39681.     39368. 12.702    -.0141     T
  10         57203.   1259.1     -87.     57203.  8.463    2.2915     T


Deflection  Holding  Weather    Force Components  Safety  CW Moment    Yaw
 Direction   Power  Direction    X         Y      Factor (Normalized) Angle
   10.00   491053.    8.043   -68710.  -486222.  3.030    -.0001     .0141

 Anchor       Load      Span   X-Load     Y-Load  Safety CW Moment  Active
   1         57529.   1259.4    -174.     57528.  8.422   -2.3174     T
   2         48307.   4228.9   34259.     34057. 14.684     .0081     T
   3         86495.   5312.4   86495.      -350.  7.993     .0150     T
   4        172302.   4259.4  121324.   -122346.  4.257     .0421     T
   5        201224.   1302.3    -582.   -201223.  3.034    8.1001     T
   6        201556.   1302.4    -583.   -201555.  3.030   -8.0648     T
   7        212622.   4264.7 -149903.   -150789.  3.462    -.0420     T
   8        117567.   5320.0 -117566.      -476.  5.837    -.0230     T
   9         58872.   4234.3  -41805.     41452. 11.924    -.0163     T
  10         57479.   1259.3    -174.     57479.  8.429    2.2982     T
```

```
                              C:SAMPLE
                       RIGMOOR Sample Problem
           Operational Holding Power Rose for   0. Ft Rig Heave


Deflection  Holding  Weather    Force Components    Safety  CW Moment    Yaw
 Direction   Power  Direction    X          Y       Factor (Normalized) Angle
   15.00    486944.   12.282  -103583.  -475799.   3.068       .0001    .0215

  Anchor        Load      Span    X-Load     Y-Load  Safety CW Moment  Active
     1         58020.   1259.8     -262.     58019.  8.360   -2.3415     T
     2         46289.   4227.9    32815.     32647. 15.211     .0063     T
     3         79703.   5310.6    79702.      -316.  8.590     .0131     T
     4        161155.   4257.8   113447.   -114457.  4.532     .0405     T
     5        198274.   1301.9     -855.   -198273.  3.075    7.9931     T
     6        198717.   1302.0     -857.   -198715.  3.068   -7.9395     T
     7        220825.   4265.7  -155745.   -156548.  3.331    -.0403     T
     8        126766.   5321.9  -126765.      -503.  5.423    -.0251     T
     9         63078.   4235.9   -44802.     44403. 11.206    -.0189     T
    10         57945.   1259.7     -262.     57944.  8.370    2.3126     T


Deflection  Holding  Weather    Force Components    Safety  CW Moment    Yaw
 Direction   Power  Direction    X          Y       Factor (Normalized) Angle
   20.00    481860.   16.450  -136453.  -462136.   3.124       .0000    .0276

  Anchor        Load      Span    X-Load     Y-Load  Safety CW Moment  Active
     1         58695.   1260.4     -350.     58694.  8.275   -2.3729     T
     2         44554.   4227.0    31573.     31436. 15.665     .0047     T
     3         74550.   5308.8    74549.      -288.  9.325     .0115     T
     4        150410.   4256.1   105862.   -106848.  4.863     .0387     T
     5        194423.   1301.3    -1109.   -194420.  3.132    7.8491     T
     6        194992.   1301.4    -1112.   -194989.  3.124   -7.7792     T
     7        228224.   4266.6  -161027.   -161730.  3.230    -.0376     T
     8        136105.   5323.7  -136104.      -526.  5.043    -.0270     T
     9         68110.   4237.6   -48386.     47935. 10.514    -.0218     T
    10         58599.   1260.3     -350.     58598.  8.287    2.3345     T


Deflection  Holding  Weather    Force Components    Safety  CW Moment    Yaw
 Direction   Power  Direction    X          Y       Factor (Normalized) Angle
   25.00    475494.   20.772  -168637.  -444585.   3.146       .0003    .0326

  Anchor        Load      Span    X-Load     Y-Load  Safety CW Moment  Active
     1         59549.   1261.1     -439.     59548.  8.168   -2.4114     T
     2         43116.   4226.3    30541.     30434. 16.040     .0032     T
     3         69555.   5307.0    69554.      -259. 10.036     .0100     T
     4        139402.   4254.3    98097.    -99045.  5.217     .0366     T
     5        189548.   1300.6    -1337.   -189543.  3.205    7.6632     T
     6        190220.   1300.7    -1341.   -190215.  3.195   -7.5779     T
     7        234355.   4267.3  -165421.   -166007.  3.146    -.0339     T
     8        145739.   5325.5  -145738.      -543.  4.709    -.0286     T
     9         73347.   4239.4   -52116.     51612.  9.793    -.0247     T
    10         59435.   1261.0     -438.     59434.  8.182    2.3638     T
```

```
                              C:SAMPLE
                        RIGMOOR Sample Problem
              Survival   Holding Power Rose for   0. Ft Rig Heave


Deflection  Holding  Weather     Force Components   Safety  CW Moment     Yaw
 Direction   Power  Direction     X          Y      Factor (Normalized)  Angle
      .00   683277.      .000        0.  -683277.    3.001      .0000    .0000

  Anchor        Load     Span    X-Load     Y-Load   Safety CW Moment  Active
    1             0.   1259.0        0.         0.    .000      .0000    F
    2             0.   4231.4        0.         0.    .000      .0000    F
    3        100626.   5316.2   100625.      -413.   6.803      .0189    T
    4        193532.   4262.3   136351.   -137342.   3.797      .0434    T
    5        203883.   1302.7        0.   -203883.   3.001     8.1826    T
    6        203883.   1302.7        0.   -203883.   3.001    -8.1826    T
    7        193532.   4262.3  -136351.   -137342.   3.797     -.0434    T
    8        100626.   5316.2  -100625.      -413.   6.803     -.0189    T
    9             0.   4231.4        0.         0.    .000      .0000    F
   10             0.   1259.0        0.         0.    .000      .0000    F


Deflection  Holding  Weather     Force Components   Safety  CW Moment     Yaw
 Direction   Power  Direction     X          Y      Factor (Normalized)  Angle
     5.00   682227.     2.577   -30673.  -681537.    3.008     -.0001    .0145

  Anchor        Load     Span    X-Load     Y-Load   Safety CW Moment  Active
    1             0.   1259.1        0.         0.    .000      .0000    F
    2             0.   4230.1        0.         0.    .000      .0000    F
    3         93481.   5314.3    93481.      -382.   7.396      .0164    T
    4        183003.   4260.9   128895.   -129909.   4.007      .0415    T
    5        203088.   1302.6     -293.   -203088.   3.011     8.1617    T
    6        203428.   1302.6     -293.   -203428.   3.006    -8.1533    T
    7        203376.   4263.6  -143333.   -144283.   3.614     -.0447    T
    8        109129.   5318.1  -109128.      -447.   6.318     -.0216    T
    9             0.   4232.8        0.         0.    .000      .0000    F
   10             0.   1259.1        0.         0.    .000      .0000    F


Deflection  Holding  Weather     Force Components   Safety  CW Moment     Yaw
 Direction   Power  Direction     X          Y      Factor (Normalized)  Angle
    10.00   679460.     5.135   -60808.  -676734.    3.030      .0001    .0286

  Anchor        Load     Span    X-Load     Y-Load   Safety CW Moment  Active
    1             0.   1259.4        0.         0.    .000      .0000    F
    2             0.   4228.9        0.         0.    .000      .0000    F
    3         86495.   5312.4    86495.      -349.   7.993      .0140    T
    4        172299.   4259.4   121323.   -122342.   4.257      .0393    T
    5        201053.   1302.3     -578.   -201052.   3.036     8.0908    T
    6        201724.   1302.4     -580.   -201724.   3.028    -8.0741    T
    7        212622.   4264.7  -149902.   -150790.   3.462     -.0455    T
    8        117567.   5320.0  -117566.      -476.   5.837     -.0244    T
    9             0.   4234.3        0.         0.    .000      .0000    F
   10             0.   1259.3        0.         0.    .000      .0000    F
```

```
                            C:SAMPLE
                      RIGMOOR Sample Problem
              Survival   Holding Power Rose for   0. Ft Rig Heave


Deflection  Holding  Weather    Force Components   Safety  CW Moment     Yaw
 Direction   Power  Direction     X          Y     Factor (Normalized)  Angle
   90.00    509642.   90.000  -509642.         0.   3.004      .0000    .0000

 Anchor         Load      Span   X-Load     Y-Load  Safety CW Moment  Active
    1        101060.    1281.0    -1723.   101045.   5.461   -4.1339     T
    2             0.    4231.4        0.        0.    .000     .0000     F
    3             0.    5294.4        0.        0.    .000     .0000     F
    4             0.    4231.4        0.        0.    .000     .0000     F
    5        101060.    1281.0    -1723.  -101045.   5.461    4.1339     T
    6        101060.    1281.0    -1723.  -101045.   5.461   -3.9767     T
    7        193532.    4262.3  -137342.  -136351.   3.797     .0434     T
    8        228065.    5338.0  -228065.        0.   3.004     .0000     T
    9        193532.    4262.3  -137342.   136351.   3.797    -.0434     T
   10        101060.    1281.0    -1723.   101045.   5.461    3.9767     T

  Rig Heave
   Downward: -1 thru -99 Feet
     Upward:  1 thru  99 Feet
Command Menu:  0
?=Help: 0 <cr>                                        [No more rose reviews]
```

```
                    EXPLORATORY OIL RIG MOORING LEG ANALYSIS

David B. Dillon   EG&G, Inc.               Current Rig Definition Root: SAMPLE
                                      RIGMOOR Sample Problem

--------------------------------------------------------------------------------
   Entry   Operation

     1     Compute operational and survival holding power rose for mooring
     2     Adjust anchor leg lengths for mooring preload
     3     Compute preload vs scope (H vs S) for each leg type
     4     Compute offset  vs load  (X vs H) for each anchor leg

     5     Display and print operational and survival holding power roses
     6     Display and print preload vs scope tables
     7     Display and print offset  vs load  tables
     8     Display and print current rig definition

     9     Select another rig definition file, old or new
     0     Define a new rig

     Q     Quit
--------------------------------------------------------------------------------
   Enter 0 through 9 or Q
?=Help: q <cr>                                         [Quit RIGMOOR]

Stop - Program terminated                              [End of session]
```

TECHNICAL REPORT
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VERIFICATION OF SPREAD MOORING SYSTEMS FOR FLOATING DRILLING PLATFORMS

VOLUME II:
METHODS FOR MOORING INSPECTION

by

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WOODS HOLE, MASSACHUSETTS

Prepared for

TECHNOLOGY ASSESSMENT AND RESEARCH BRANCH
MINERALS MANAGEMENT SERVICE
RESTON, VIRGINIA 22091

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EG&G

DISCLAIMER

PREFACE

As offshore oil exploration moves into ever deeper waters, greater demands are placed on mooring systems. Safety of the crew, preservation of the environment, and protection of the rig itself demand that mooring systems perform reliably during operations and storms. It is the responsibility of the Minerals Management Service (MMS) of the U.S. Department of the Interior to inspect the mooring equipment aboard exploratory oil rigs in service in United States offshore oil fields and evaluate the ability of the mooring equipment to perform safely in service.

This volume is part of a four-volume set. The purpose of these manuals is to provide a procedural structure to support the responsibilities mentioned above. It does not purport to be a textbook of mooring analysis or design, nor a compendium of mooring design data. That ground has been well plowed by others. Rather, a procedure for evaluating the mooring gear for a drilling rig is described.

Volume I	Methods for Spread Mooring Review
Volume II	Methods for Spread Mooring Inspection
Volume III	Dynamic Modeling in Spread Mooring Review
Volume IV	A Static Model for Spread Mooring Review

Volume I describes five steps for evaluating a mooring design and illustrates the procedures by evaluating a sample semisubmersible mooring. Volume II - this volume - is a review of mooring evaluation from the standpoint of the hardware itself: the components of a typical mooring, their inspection and testing. Volume III illustrates how to model the dynamic response of a floating drilling platform moored in a seaway using a large commercial computer model. Volume IV documents RIGMOOR, a computer program written to simplify estimating the static holding power of spread moorings.

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INTRODUCTION

Semi-submersible offshore exploratory drilling platforms are anchored where water depth does not exceed 15000 ft. Dynamic positioning is commonly used in greater depths. When anchored, the semi-submersible uses a spread mooring system consisting of eight or more anchors.

Each anchor line consists of chain, or a combination of wire rope and chain (See Figure 1). All chain is generally used in water depths less than 600 ft. A wire rope pennant is attached to the anchor crown for lowering and retrieving the anchor. This line is buoyed off after the anchor is in place.

Each anchor weights 20,000 to 30,000 pounds. Additional piggy-back anchors are used if additional holding power is required. The length of the mooring line is usually five or more times the water depth. The anchor chain leads to a fairlead at the rig which is underwater when the hulls are submerged for drilling. The chain then passes over a wildcat and thence into the chain locker. A separate drum holds the wire rope.

This volume discusses the types of mooring materials used in spread moorings, their mechanical properties and criteria to judge their condition and remaining strength.

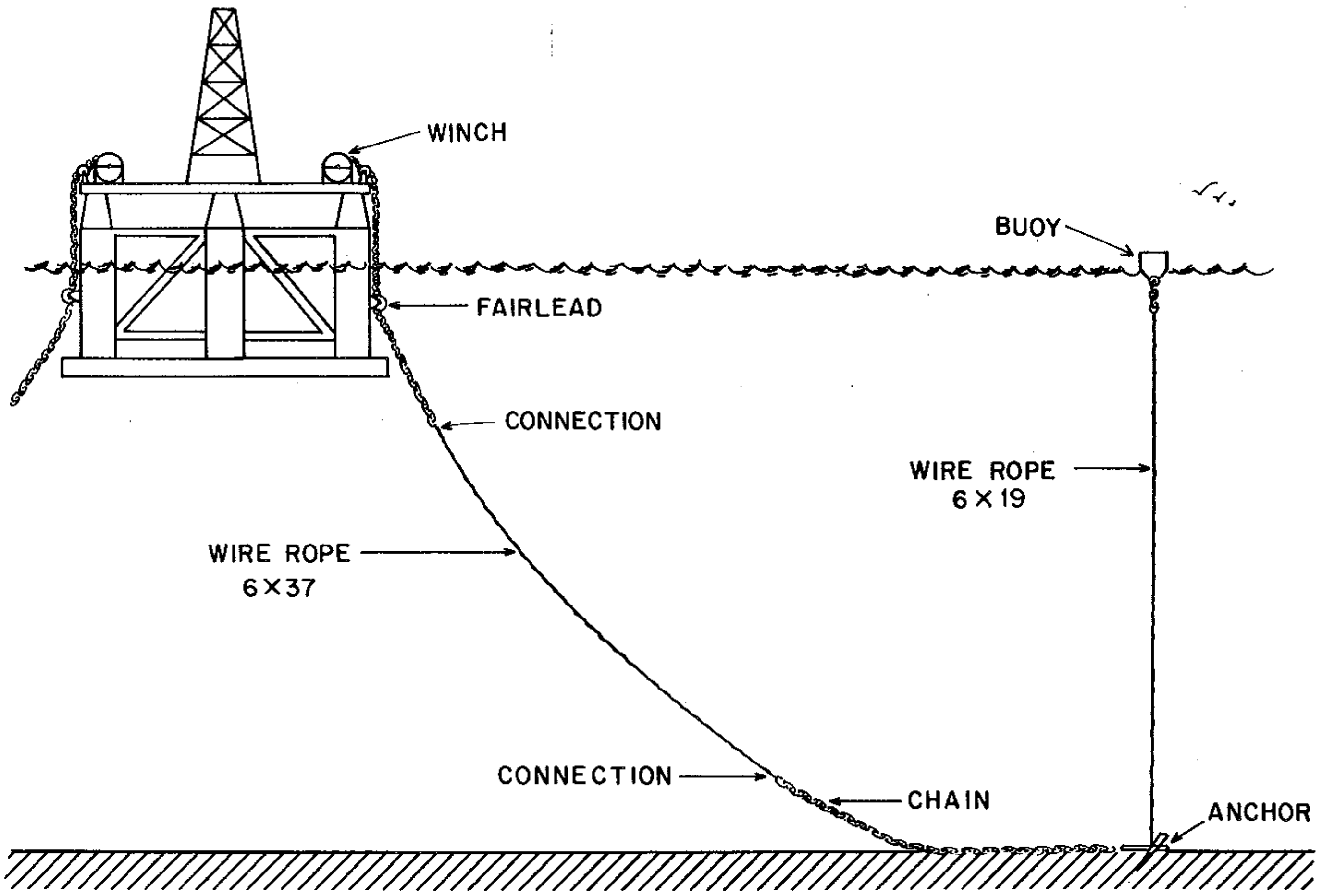


Figure 1. Typical Spread Mooring

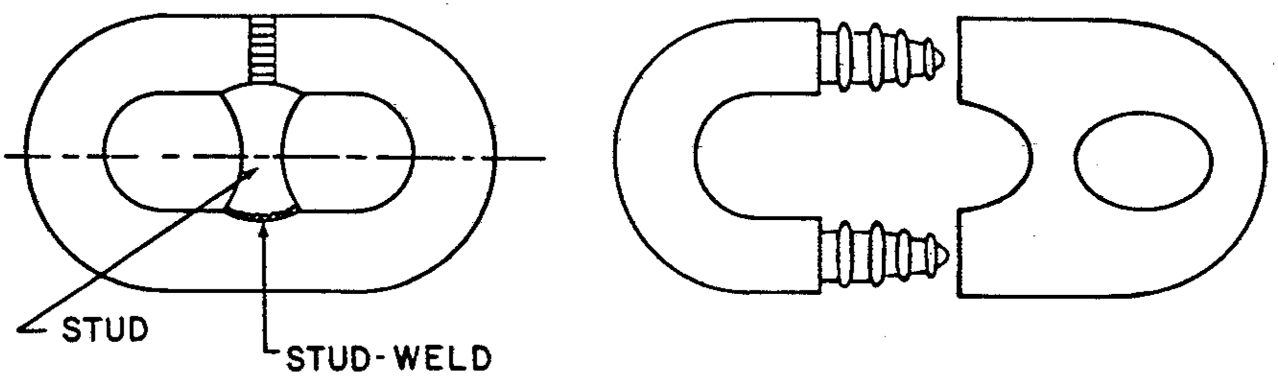
SECTION 1

CHAIN AND CONNECTING HARDWARE

1.1 CHAIN

1.1.1 General. Moored drilling platforms generally use all chain mooring legs in water depths up to 500-600 ft. A combination chain and wire rope mooring is frequently used in greater depths. Two types of chain are used: flash butt welded stud link and Di-Lok stud link in sizes varying from two to four inches and are shown in Figure 1-1. Ship Grade II chain is gradually being replaced by extra high strength (Grade III ABS) having an ultimate tensile strength of 100, psi. A super strength chain is finding increased use in the industry as Grade IV. Table 1-1 shows the ABS proof and breaking loads for chain sizes between two and four inches. A three inch super oil rig quality chain with a breaking strength of 1.3×10^6 pounds in frequently used in the North Sea.

The maximum tension in a mooring chain should not exceed approximately 35% of its breaking strength or 50% of its proof load. 50% of breaking strength may be tolerated on a limited basis under conditions of maximum survival. Continuous operating loads between 15 and 20 percent of the breaking load will result in longer-life performance.



FLASH BUTT WELDED STUD CHAIN

DI-LOK STUD LINK CHAIN

Figure 1-1. Stud-Link Chain Types

Table 1-1
Mooring Chain Proof and Break Tests

CHAIN SIZE	GRADE 2		GRADE 3		SUPER HIGH STRENGTH		DI - LOK	
	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)
2	227	318	318	454	324	489	322	488
2 1/16	241	337	337	482			342	518
2 1/8	255	357	357	510	364	548	362	548
2 3/16	269	377	377	538			382	579
2 1/4	284	396	396	570	405	611	403	610
2 5/16	299	418	418	598			425	642
2 3/8	314	440	440	628	449	676	447	675
2 7/16	330	462	462	660			469.5	709.5
2 1/2	346	484	484	692	494	744	492	744
2 9/16	363	507	507	726			516	778
2 5/8	379	530	530	758	541	815	540	813
2 11/16	396	554	554	792			565	849
2 3/4	413	578	578	862	590	889	590	885
2 13/16	431	603	603	861			615	925
2 7/8	449	628	628	897	640	965	640	965
2 15/16	467	654	654	934			666.5	1005
3	485	679	679	970	693	1044	693	1045
3 1/16	504	705	705	1008			720.5	1086.5
3 1/8	523	732	732	1046	747	1125	748	1128
3 3/16	542	759	759	1084			776.05	1169
3 1/4	562	787	787	1124	802	1209	804.1	1210
3 5/16	582	814	814	1163			833.15	1253
3 3/8	602	843	843	1204	859	1295	862.2	1296
3 7/16	622	871	871	1244			892.1	1339.55
3 1/2	643	900	900	1285	918	1383	922	1383
3 5/8	685	958	958	1369	977	1473	1021	1566
3 3/4	728	1019	1019	1455	1039	1566	1120	1750
3 7/8	772	1080	1080	1543	1101	1660		
4					1165	1756		

1.1.2 Causes of Damage. It has been estimated that chain failures occur as often as one per month on North Sea mobile offshore units (Ref. 1). These failures often lead to disruption of the drilling operating resulting in costly delays.

Failures originate from two principal causes, 1) production defects and irregularities and 2) mechanical damage through use. In one study (Ref. 1) laboratory examinations of both failed and neighbor links (links adjacent to those which failed) resulted in the observation of a number of different causes for the failures, the majority originating from defective chain production. The most commonly observed defects and irregularities were:

- Poor heat treatment
- Weld defects
- Burn marks
- Hydrogen cracks
- Longitudinal cracks
- Surface carburization
- Loose studs
- Poor stud welds
- Weld repairs
- Poor trimming

Another source (Ref. 2) mentions the following causes for some failures in common links as:

- Internal unsoundness
  - Casting blowholes
- Weld unsoundness
  - Lack of fusion
- Heat affected zone (HAZ)
  - Microcracking
- Brittle failure
  - Improper heat treatment
- Manufacturing variables
- Improper operation
  - Overloading
  - Incorrect lead angles
  - Fatigue

1.1.3 Quality Control, Testing and Inspection. Offshore mooring chain must be regarded as complex structures dependent upon proper design, technological know-how and reliable manufacturing processes as well as implemented QA/QC routines.

Manufacturing. The manufacturing process requires a series of controlled operations including inspection and testing of the finished product. American Petroleum Institute specifications (Ref. 3) lists the tests which are performed at each step of the manufacturing process. The publication lists the bar stock chemical composition and mechanical properties required for chain material. A detailed set of requirements and tests are then listed. Included are tensile and impact specifications, dimensional tolerances, identification procedures, heat treating, cleaning, and test inspection. Details of proof and break tests are given with sample lengths.

Design Strength and Recommended Testing. It is recommended that all components of the system have a safety factor of three based on the strength of new components. The chain size and type should be selected on this criterion of three times the tension experiences under the most severe loading anticipated. Shop testing to loads of 150% of the maximum anticipated loads should then be made. The frequency of the shop test depends on the age and service of the chain. In general, new chain should be tested every four to five years initially and as frequently as every two years when it reaches 20 years of age (Ref. 4).

When installing the drilling rig, the initial tensioning of each anchor provides a most important test for the entire system. Initial tensioning with values of tension equal to the calculated highest storm load provide an in site test of the chain and other mooring components.

Inspection. All chain should be periodically inspected and test loaded to insure reliability. Inspection of the condition of rig mooring chain can best be done when the rig is being moved or in drydock. When retrieving the anchor, the chain will be hauled aboard providing an opportunity for visual inspection of the links. The same opportunity exists during anchor deployment. A better opportunity exists during periods of rig overhaul and drydocking. At this time the chain can be removed from the chain locker and be laid out on a dock for a more thorough inspection. Links may also be removed for laboratory tests.

American Bureau of Shipping inspections of chain and chain lockers while the rig is in drydock are recommended every three years.

Visual Inspection. At each opportunity a visual detailed inspection of the common links should be make. Of particular interest are sections of the chain which have resided in the fairlead, have been in the splash zone or have been tangential to the ocean floor.

The surface of the links should be examined for fatigue cracks, gouges and other surface defects. Deep pitting is indicative of heavy corrosion. All welds should be checked. Loose studs can be detected by hitting them with a hammer. Links should be inspected for abrasion and wear. Elongation of a link can be due to overload or wire diameter decrease due to corrosion or abrasion. No criteria are available for chain removal when damage is primarily be fatigue. When fatigue is a problem, usual field practice keeps a chain in service until breakage or general deterioration begin to show (Ref. 5). Any cracks observed should be carefully examined both visually and by other fault testing methods. Di-Lok chain should be checked for separation between the male and female sections and longitudinal cracks in the female section.

Dimension Checks. Measurements of wire size and link length can reveal corrosion and abrasion damage and/or overload history. The grip area should be closely scrutinized for wear. Table 1-2 shows wire diameter reductions justifying replacement. Maximum elongation permitted over five links is 55% of the wire diameter. Table 1-3 shows the length and allowable tolerance over five links for chain sizes between two and four inches. The weight per foot is also shown.

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Table 1-2. Chain Diameter Reduction
(from Reference 4)

Chain Diameter (Inches)	Diameter Reduction (Inches)
1.75 - 2.00	0.25
2.00 - 2.50	0.31
2.50 - 3.00	0.38
3.00 - 3.50	0.44
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Table 1-3 (from ABSS)
Mooring Chain Length Over Five Links and Approximate Weight

NOMINAL DIAMETER (inches)	CHAIN LENGTH OVER 5 LINKS		APPROXIMATE WEIGHT (lbs/ft.)
	Minimum (inches)	Maximum (inches)	
2	44.00	45.10	39.7
2 1/8	46.75	47.95	44.8
2 1/4	49.50	50.75	50.2
2 3/8	52.25	53.55	56.0
2 1/12	55.00	56.40	62.0
2 5/8	57.75	59.20	68.4
2 3/4	60.50	62.00	75.0
2 7/8	63.25	64.85	82.0
3	66.00	67.65	89.3
3 1/8	68.75	70.75	96.9
3 1/4	71.50	73.25	104.8
3 3/8	74.25	76.10	113.0
3 1/2	77.00	78.95	121.5
3 5/8	79.75	81.75	130.4
3 3/4	82.50	84.55	139.5
3 7/8	85.25	87.40	149.0
4	88.00	90.20	158.7

Locating Faults. Links may be further examined by non-destructive methods to locate faults. Fatigue cracks can be more readily observed by first cleaning the link and applying a dye penetrant or by magnetic particle inspection (Magnaflux).

1.2 CONNECTING HARDWARE

1.2.1 General. Connecting elements are used to join the various sections of the mooring together. A typical anchor connecting arrangement is shown in Figure 1-2. Common types of connecting hardware, detachable links, and swivels are shown in Figure 1-3.

Historically, connecting elements represent weak points in a mooring system accounting for most failures. This especially true with fatigue failures, where life expectancies of connecting elements may be only 30% to 50% of the chain itself.

Connecting elements should be inspected often and replaced after ten years of service or when the mooring chain is renewed.

1.2.2 Causes of Damage. Wear, corrosion and fatigue are the principal sources of damage to connecting links. However mechanical damage may occur from improper handling, windlass malfunction or fairlead problems.

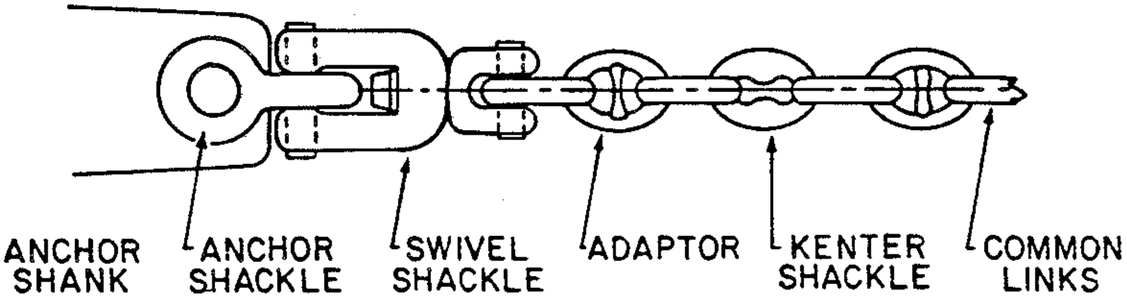
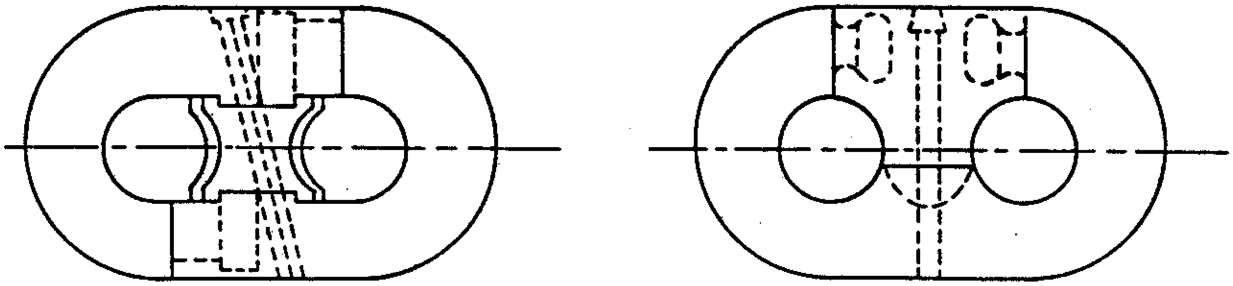
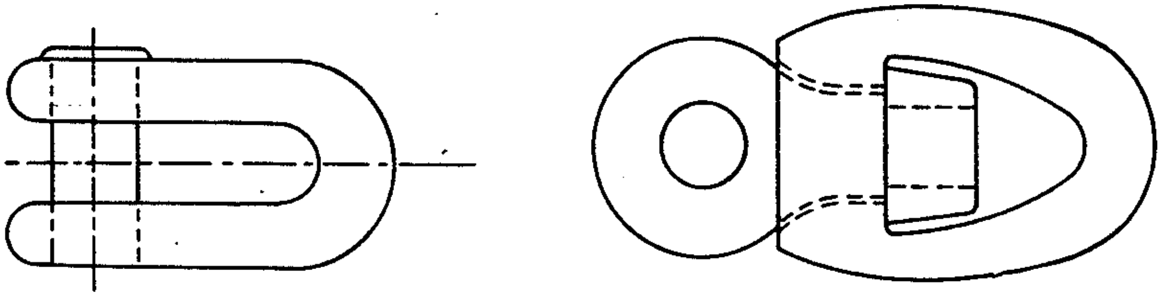


Figure 1-2. Anchor End Construction



KENTER-TYPE CONNECTING LINK

BALDT-TYPE CONNECTING LINK



D-SHACKLE

SWIVEL

Figure 1-3. Common Auxiliary Chain Mooring Elements

1.2.3 Inspection and Testing

D-Anchor Shackles. The D-shackle as used at the anchor and in the chain locker has a fatigue life equal to or greater than common chain links. They should be inspected yearly by thoroughly cleaning and magnetic particle inspection. They should be discarded if cracks or wear reduction of 10% or more of its diameter is noted (Ref. 4).

Swivels. Some mooring arrangements use swivel shackles at the anchor. This element has a short fatigue life and is subject to internal wear. One set of fatigue tests found that swivels failed at about 3% of the life of the chain. For this reason many operators do not use swivels. They should be inspected yearly and discarded if worn more than 10%. They should be cleaned and subjected to magnetic particle inspection.

Kenter Detachable Links. Experience has shown that the failure frequency of detachable links is significantly higher than common stud links. The Kenter link fatigue characteristics are primarily controlled by the distribution of stresses within the link locking mechanism. One test showed that all fatigue failures had been initiated at the sharp corners of the locking chambers of the links.

The test results indicated that the mean fatigue life of the link was approximately 1/5 of the mean fatigue life of the common three inch stud link chain (Ref. 6). It was found in the above fatigue test that crack growth in the Kenter-type was rather slow and that cracks could easily be detected by means of a dye penetrant or a magnetic particle test on the flanges of the locking mechanism.

The links should be replaced if cracks are visible or if they show more than 10% wear reduction in diameter (Ref. 4).

Baldt Detachable Links. Another type of detachable link, the Baldt link is also frequently used. This link is subject to the same inspection steps as the Kenter link with replacement recommended where fatigue cracks occur or abnormal wear is evident.

Fairleads, Wildcats. An examination of the fairleads and wildcats should be an essential part of the overall mooring inspection. If the pockets are worn or gouged, excessive wear or bending of the chain may take place. Fairleads should be regularly lubricated and inspected whenever the rig is up on its hulls, such as in a shipyard or during a move.

1.3 FIELD INSPECTION TOOLS

Calipers should be available for determining wear or loss of metal through corrosion or wear. A steel tape should be available for link length measurements. Hardware elements can be cleaned with a wire brush and solvents prior to inspection. A dye penetrant kit and/or a magnetic particle tester will facilitate the locating of cracks from stress fatigue.

1.4 TESTING FACILITIES

New or used chain can be examined and tested at most chain manufacturers and at some commercial testing laboratories. A full facility for testing used chain is equipped to clean the sample specimen (5-7 links) and to perform mechanical property tests. These tests consist of impact tests of both the barstock and the welded area, a breaking test, and elongation and reduction in area measurements. Magnetic particle and utltrasonic inspection is generally available.

Some testing laboratories/facilities and their capabilities are:

(1) Baldt, Inc.
P.O. Box 350
Chester, PA 19016 215-447-5231

Baldt has full facilities for testing new and used chain in connecting hardware. They typically will clean, visually inspect (dimension and weight), and use magnetic particle and ultrasonic testing. A minimum of five links are required for proof and break tests. The cut link is used for mechanical property tests

(2) Washington Chain (Division of Baldt)
P.O. Box 3645
Seattle, WA 98124 206-623-8500

Capable of proof and break testing up to two million pounds. They clean, visually inspect, dimension and weigh and use dye penetrant for the detection of fatigue cracks.

They have magnafluxing done outside. Need at least three links for proof and break test.

(3) Battelle Petroleum Technology Center
1100 Rankin Road
Houston, TX 77073 713-821-9331

Battelle can proof and break test presently to a maximum capacity of 1.2 million pounds. The facility eventually will be capable of higher loadings. They provide cleaning, visual inspection, dimension and weight observations, dye penetrant and ultrasonic testing. An outside lab is used for magnaflux tests.

Typical non-laboratory services provided to the industry are:

(1) Vicinay International Chain
2226 S Loop West 255
Houston, TX 77054 713-664-6997

Vicinay has factories and complete test facilities in Spain, England and Brazil. While they have no factory in the U.S. they do have a team of inspectors available to assist in chain inspection and tests at other facilities. These inspectors are available for field inspections and can perform tests including ultrasonics.

(2) Hamanaka International, Inc.
1980 Post Oak Blvd., Suite 1000
Houston, TX 77056 713-627-7201

Hamanaka does not have a factory and test facilities in the U.S. but will assist in field inspections and tests at other facilities.

(3) Global Divers and Contractors, Inc.
P.O. 68
Maurice, LA 70555 318-894-6500

Global can supply diving services for the underwater inspection of chain, anchors, connecting hardware and pennant lines.

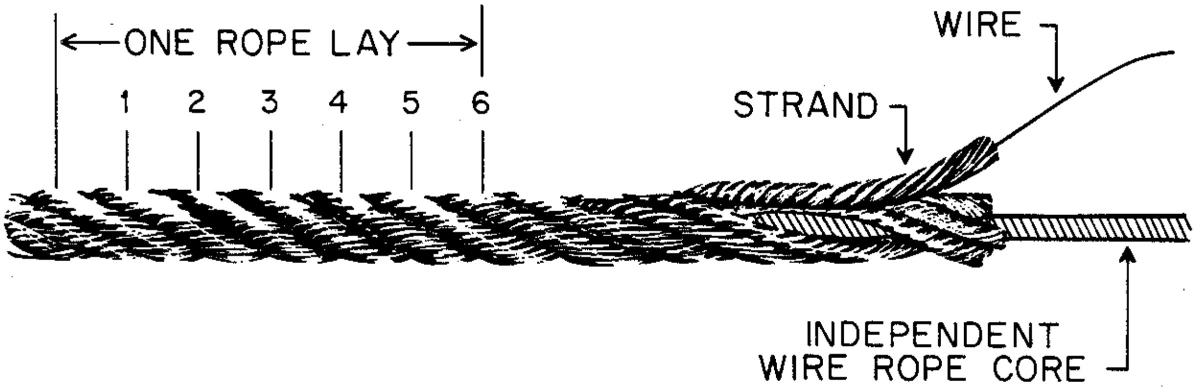
SECTION 2

WIRE ROPE TERMINATIONS

2.1 Wire Rope

2.1.1 General. As water depth increases the weight of the chain required to moor a drilling platform becomes prohibitive. Wire rope of equal strength but lesser weight is then used to connect the ground tackle to the platform. Wire rope pendants are also used to connect the anchor buoys to the anchor crown (see Figure 1).

The elementary unit of any wire rope is the wire. Wires are obtained by drawing through reducing dies to the desired size, rods of the metal selected for the rope. The specified strength and ductility of the wires is obtained by a combination of drawing and annealing operations. Wires are then spooled on bobbins which fit into stranding machines. Wire ropes are manufactured by first winding individual wires into strands and then winding the strands together around a core (Figure 2-1). When the strands are laid in a clockwise direction around the core, the wire rope construction is called a right lay. If the wires in the strand are laid in the opposite direction the resulting wire rope construction is a right lay, regular lay. Almost all wire rope used in offshore mooring systems is of the right lay, regular lay configuration and is of either the 6x19 or the 6x37 class. The number 6 referes to the number of strands twisted around the rope core, and the numbers 19 or 37 refer to the average number of individual wires per strand. The core of these ropes is almost exclusively made of a smaller wire rope, named independent wire rope core (IWRC).



6x9 RIGHT LAY, REGULAR LAY

Figure 2-1. Components of a Typical Wire Rope

6x19 wire ropes have larger wires than 6x37 ropes of equal strength, and therefore have better resistance to corrosion and axial fatigue. However they have become increasingly stiffer as their size increases. When higher strength is required, more flexible 6x37 wire ropes must be used. All cables used in a seawater should be zinc coated or galvanized. There is a definite advantage in using galvanized wires for zinc in anodic to steel, and therefore, the zinc coating will act as a sacrificial anode at the points where the coating may break and the steel becomes exposed to seawater.

A jacket of extruded plastic - such as high density polyethylene - placed over wire ropes constitutes an additional barrier between the wires and the corrosive environment. Years of experience have shown a sustained tendency for plastic jacketed ropes to have a far better endurance and much longer service life than bare wire ropes (Ref. 7).

The grades of carbon steel commonly used to manufacture wire ropes are Improved Plow steel (IPS) and Extra-Improved Plow steel (XIPS).

The nominal strength of galvanized and non-galvanized (bright) wire ropes used as anchor lines in spread mooring systems, as specified by the American Petroleum Institute (Ref. 8) is shown in Table 2-1. As with anchor chain, wire rope diameters should be selected to provide three times the strength required under the most severe loading conditions.

2.1.2 Causes of Damage. During their service life mooring lines are constantly subjected to the combined detrimental effects of corrosion and fatigue. Vessel motion due to wave and wind action impart cyclic loads to the mooring lines. Steel wires when submitted to repeated stress cycles of sufficient amplitude will develop minute cracks that tend to grow and propagate across the metal until the whole wire breaks. Sea water corrosion accelerates the process. Large tension means combined with large deviations from the mean - as the case would be in stormy seas - will result in the greatest fatigue damage.

In addition to corrosion and fatigue wire ropes used in spread moorings can be damaged by abrasion, crushing, and kinking. Abrasion can and will occur if the rope is let free to contact the bottom, as often the case is with the anchor buoy pendants. Crushing happens when the wire rope is hauled through sheaves of incorrect diameter and/or groove for the particular rope size.

Kinks are the mortal enemy of wire ropes They start as a loop of the rope winding on itself and when the loop is pulled tight, wires and strands are permanently bent, ruining the rope at the point of kink. There are two kinds of kinks - tightening kinks and loosening links. The first tightens the lay of the wire rope, while the second tends to open the rope. Loosening kinks are more damaging and easier to form. Most of the kinks originate the torisonal energy stored in the rope followed by slack conditions. Proper handling techniques can minimize the danger of kinks. In particular, in free handing operations such as lowering of mooring anchors, ropes should not be allowed to twist or become slack.

For a more detailed description of wire rope field problems and field care the reader is referred to the API publication RP9B (Ref. 9).

Table 2-1
Strength of 6x19, 6x37 and 6x61 Construction Mooring Wire Rope, Independent Wire Rope Core

NOMINAL DIAMETER (inches)	APPROXIMATE WEIGHT (lbs./ft.)	NOMINAL STRENGTH	
		Galvinized (lbs.)	Bright (lbs.)
1	1.85	93,060	95,800
1 1/8	2.34	117,000	119,000
1/4	2.89	143,800	145,000
1 3/8	3.50	172,800	174,000
1 1/2	4.16	205,200	205,000
1 5/8	4.88	237,600	250,000
1 3/4	5.67	275,400	287,000
1 7/8	6.50	313,200	327,000
2	7.39	356,400	369,000
2 1/8	8.35	397,800	413,000
2 1/4	9.36	444,600	461,000
2 3/8	10.40	493,200	528,000
2 1/2	11.60	543,600	604,000
2 5/8	12.80	593,800	658,000
2 3/4	14.00	649,800	736,000
2 7/8	15.30	705,600	796,000
3	16.60	765,000	856,000
3 1/8	18.00	824,400	920,000
3 1/4	19.50	885,600	984,000
3 3/8	21.00	952,200	1,074,000
3 1/2	22.70	1,015,000	1,144,000
3 3/4	26.00	1,138,000	1,290,000
4	29.60	1,283,000	1,466,000
4 1/4	33.30	1,438,000	1,606,000
4 1/2	37.40	1,598,000	1,774,000
4 3/4	41.70	1,766,000	1,976,000

2.1.3 Inspection and Testing

New Wire Rope. Because most wire ropes are manufactured and tested according to strict manufacturing and testing specifications (see Ref. 8), it is not usually necessary to test new ropes in the field. Manufacturers test certification for the particular reel should be available on request from the vendor. Sometimes it is good practice to pull test representative samples of new wire rope assemblies to ascertain the holding power of wire rope terminations applied in the field (see Section 2.2). Uncertified wire rope should be tested following the procedure outlines in Ref. 8. A list of wire rope testing facilities is given in Section 2.4.

Used Wire Rope. Ropes should be regularly inspected to ascertain their present condition as compared to their new condition. The inspector, either by judgement based on experience or by some prescribed procedure, estimates the remaining strength of the rope and thus determine the degree of operational safety at the time.

The best time to inspect mooring wire ropes is when the drilling rig is shut down and relocated. On every rig move the wire ropes should be carefully inspected for broken wires, wear, corrosion, reduced rope diameter, kinks and crushing. Magnetic and electronic devices may be used to assist inspection procedure. Visual inspection is still the best method for assessing a rope condition and for determining the proper time for its removal.

Significant modes of rope deterioration are hereafter discussed in further detail.

Broken Wires. Broken wires are often difficult to detect. It is important to clean the rope surface so that broken wires become visible. Holding a cotton rag around the rope as it is slowly hoisted will not only clean the rope but will enable small pieces of cotton to be caught by protruding wires, thus pinpointing their location (Ref. 10).

The broken wires should be carefully inspected so as to identify the mode and causes of deterioration. A magnifying glass can be used to advantage for this purpose. If the wires are badly flattened then wear due to abrasion certainly was a factor of failure. If the breaks are square across, the probable cause of failure is fatigue. Corrosion breaks are recognizable by a severly pitted wire surface and a needle point at the break. Cups and cones are typical of tension - overloading-breaks. Typical wire fracture modes are shown in Figure 2-2 (Ref. 11).

Wear. Wear can be exterior or interior. Exterior wear is detected by worn spots on the outer wires. It is caused by abrasion of the rope dragging on the bottom or being pulled through sheaves of the wrong size or in poor condition. Interior wear can be detected by prying the rope open with the help of a screwdriver or marlin spike. It is caused by excessive internal friction, usually due to a lack or a loss of rope lubricant.

Corrosion. A rusty wire rope should be carefully inspected to assess the extent of the corrosion process. Particles or flakes of rust which fall out when the rope is pried open indicate that the protective zinc coating has been lost and that the size of the wires in the rope have been reduced through oxidization.

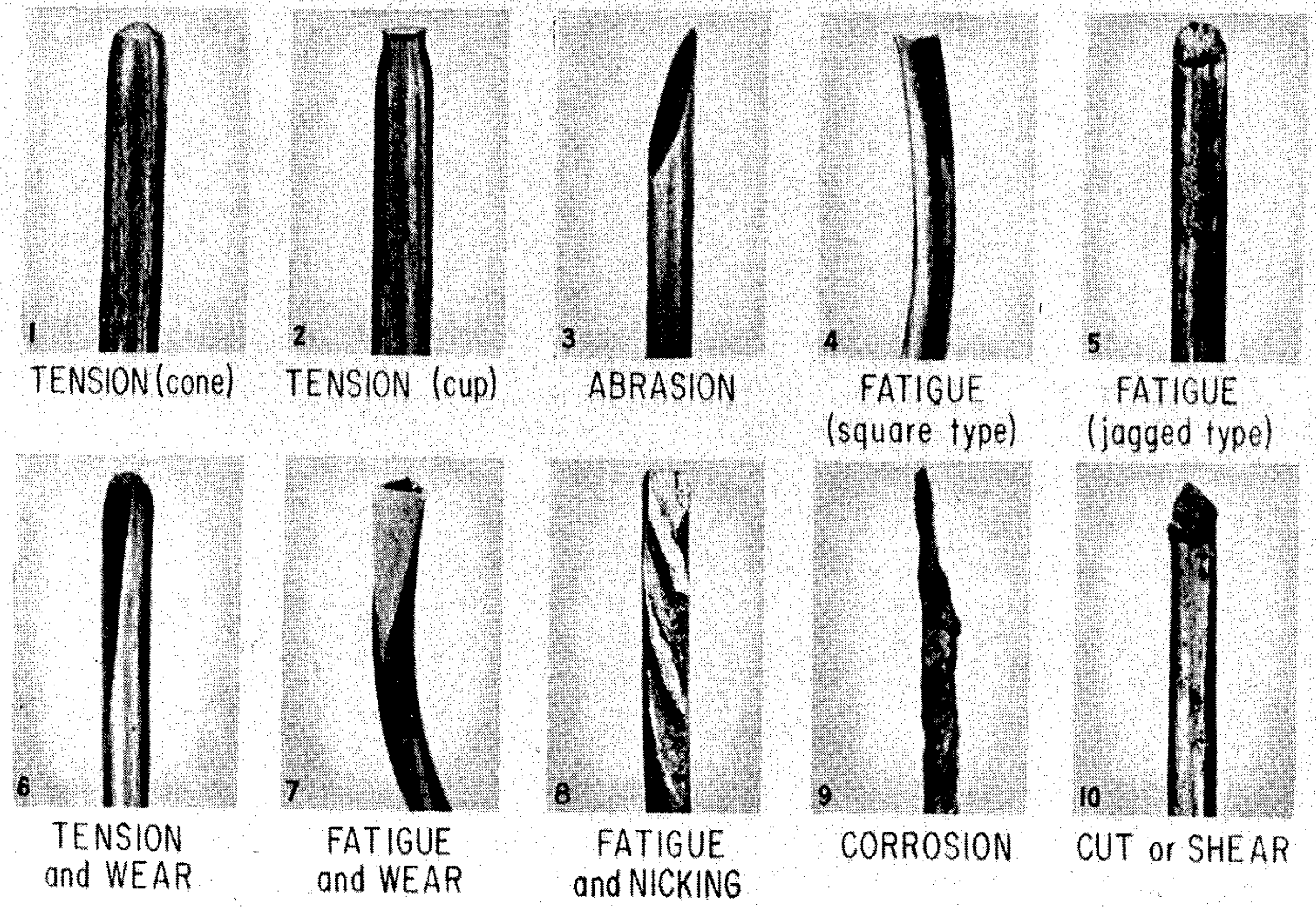


Figure 2-2. Typical Wire Rope Fracture Faces

Corrosion should be controlled not only because of the additional rope service, but because corrosion control makes it easier to judge the rope condition by visual inspection.

Often ropes will corrode at a faster rate in air - when stored on the winch drum, for example - than when immersed in sea water. Thus it is imperative that ropes be fresh water rinsed and properly lubricated every time the rig is moved.

It is extremely difficult to assess the remaining strength of a corroded rope solely by inspection. When in doubt, representative sections, preferably close to the socketed ends, should be cut off and tensile tested. Even then, a good remaining strength is no insurance against accelerated fatigue failure of a dried and internally abrasive rope.

Reduced Rope Diameter. The diameter of a new rope is the diameter of the smallest circle which fully contains the rope. A significant reduction of rope diameter can be the result of loss of metallic area due to corrosion and war of the wires or from excessive stretching due to broken wires. Rope diameters should preferably be measured with a three point micrometer.

Mechanical Damage. Rope structural damage includes: Kinks, dog-legs, birdcages, and crushed strands. These cause permanent rope deformations which are easy to spot.

2.1.4 Wire Rope Retirement Criteria

The decision for the removal and replacement of a used wire rope is a difficult one. Officials must make a decision, keeping in mind that for economic reasons all possible service must be obtained from the rope before its retirement while maintaining the necessary degree of safety.

Retirement criteria found in the literature vary from different wire rope types and applications. Based on common sense and experience, the following guidelines for the retirement of ropes used in spread mooring applications are proposed (see Ref. 4):

- The condition of the worst rope lay is a safe guide for rope removal. In other words, the worst rope lay dictates if a rope (or rope section) should be removed. A rope lay is that length of rope in which one strand makes one complete revolution about the core (Figure 2-1).
- A rope should be replaced whenever the number of outside and inside broken wires per rope lay equal 10% or more of the wires in the rope (excluding those of the core). For example a 6x19 rope, which has 114 wires, should be replaced if the number of broken wires found in a rope lay is 11 or more.
- In general, a rope should be replaced if the diameter is reduced by as much as 6%. For example a two inch rope reduced to 1 7/8 inches (a 1/8 inch diameter loss) has its diameter reduced by 6.25% and should be replaced.

- A badly corroded and dry rope, exhibiting flaking rust and markings of internal wear over a major portion of its length should be retired from service.

- Kinked, crushed, bird-caged ropes should always be replaced, or cut off if the damage is near one end.

2.2 Termination

2.2.1 General. Wire ropes used in spread moorings must be terminated at their points of attachment to each other or to other components of the mooring legs. Standard wire terminations include swaged sockets, zinc or resin poured sockets and eyes. Typical terminations are shown in Figure 2-3.

To resist shock loads and deterioration due to fatigue, corrosion and bottom chafing, good practice recommends to use mooring wire rope fittings of a higher strength and quality than the fittings used in many land applications. In particular, all sockets should be made from forged steel rather than cast steel to provide the extra strength needed in offshore service.

Swaged sockets are attached to the rope by inserting the rope in the shank of the fitting and then pressing or swaging the shank on to the rope with the help of an hydraulic press.

Zinc poured or thermoset resin poured sockets are attached by first inserting the wire rope end into the socket. The end is then splayed or "broomed out", properly cleaned, and pulled back in the socket. The filling material is then poured into the socket.

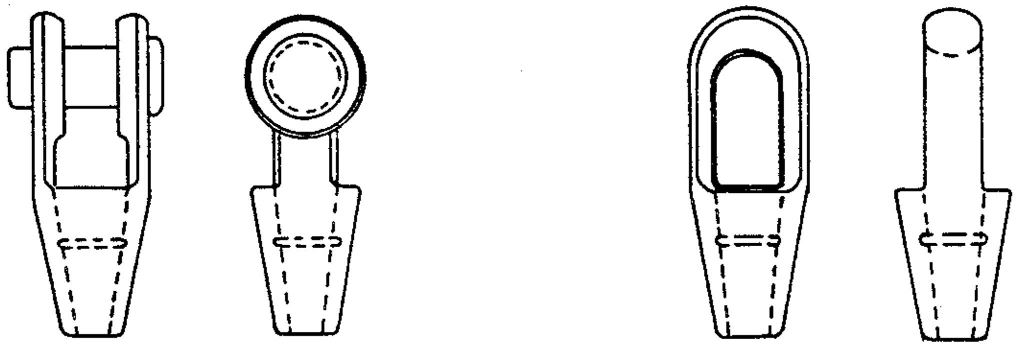
An eye termination is obtained by placing the wire rope in the groove of a drop forged steel thimble, and then attach the short end to the long end with wire clips as required.

Swaged sockets must be applied by wire rope manufacturers or riggers who have the heavy equipment required to swage wire ropes of large diameters. Poured sockets can be applied in the field, but their holding power is much more susceptible to quality control. Eye terminations, using wire rope clips, are the least reliable of the three. Specified materials and procedures to properly terminate wire ropes for offshore applications are fully reviewed in API RP9B "Application, Care and Use of Wire Rope for Oil Field Service" (Ref. 9).

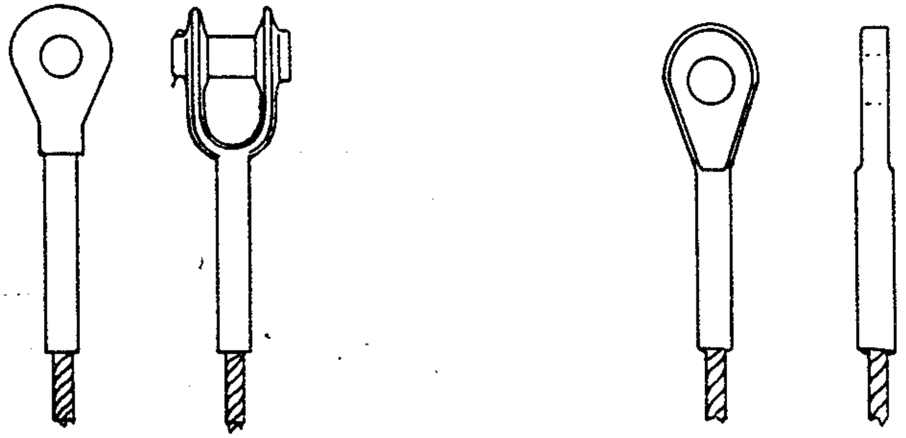
2.2.2 Inspection and Testing. Much like chain and ground tackle fittings previously reviewed wire rope sockets should be carefully inspected for signs of deterioration due to wear, corrosion and fatigue. Often cracks can be seen in the shanks of swaged fittings.

The best way to ascertain the maximum holding power of new wire rope assemblies is to pull test lengths of the same wire rope terminated at both ends with fittings similar in all respects (material and method of application) to those to be used in the field. Correctly applied swaged or poured terminations should develop the full strength of the rope.

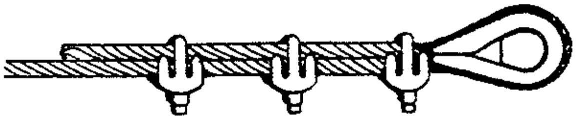
Used wire rope assemblies, like other components of the mooring legs, should be pull tested to 1.5 times the maximum load expected in service.



SPELTER SOCKET
(ZINC OR EPOXY FILLED)



SWAGE SOCKETS



EYE TERMINATION

Figure 2-3. Typical Wire Rope Terminations

2.3 Field Inspection Tools

The following is a list of hand tools normally used to perform field inspections of wire ropes:

- Gloves. Work gloves should be worn to protect the hands from sharp broken wires (fish hooks).
- Cleaning fluids and rags should be in the field testing box. They will help clean the rope of grease and rust at points of inspection, and they may help find outside broken wires as previously explained.
- Marlin spike or large screwdriver, to pry the rope open and help inspecting the rope inside and the core.
- Magnifying glass to look at fracture faces of broken wires.
- Carpenter measuring tape, 10 to 12 ft., flexible, to measure length of rope lay, or strand lay, or rope circumference, or length of rope as required.
- Micrometers. A three point micrometer (see Figure 2-4) is preferred to measure the diameter of wire ropes.
- Calipers. Calipers can also be used to measure wire rope diameters. The proper use of calipers is shown in Figure 2-5.
- Groove Gages. This set of gages is used to check the diameter of sheave grooves, thus assessing that the sheave used has the proper groove for the wire rope passing through (see Figure 2-6).
- Electromagnetic Cable Testers. Inspection of wire ropes can also be performed automatically with the help of electromagnetic nondestructive test equipment. Normally such inspections are carried out by agencies whose trained personnel are expert in interpreting the signals resulting from broken wires or reduced rope diameter. Operators and/or vendors of such equipment are listed on Section 2.4. As excellent introduction to the working principles of electromagnetic wire rope testing is presented in Ref. 10, Chapter 1.

2.4 Wire Rope Testing Facilities

Table 2-2 is a partial list of U.S. based laboratories and facilities who can pull test wire rope assemblies and perform other mechanical and nondestructive tests of new and used wire rope. An extensive list of worldwide testing laboratories can be found in Ref. 8.

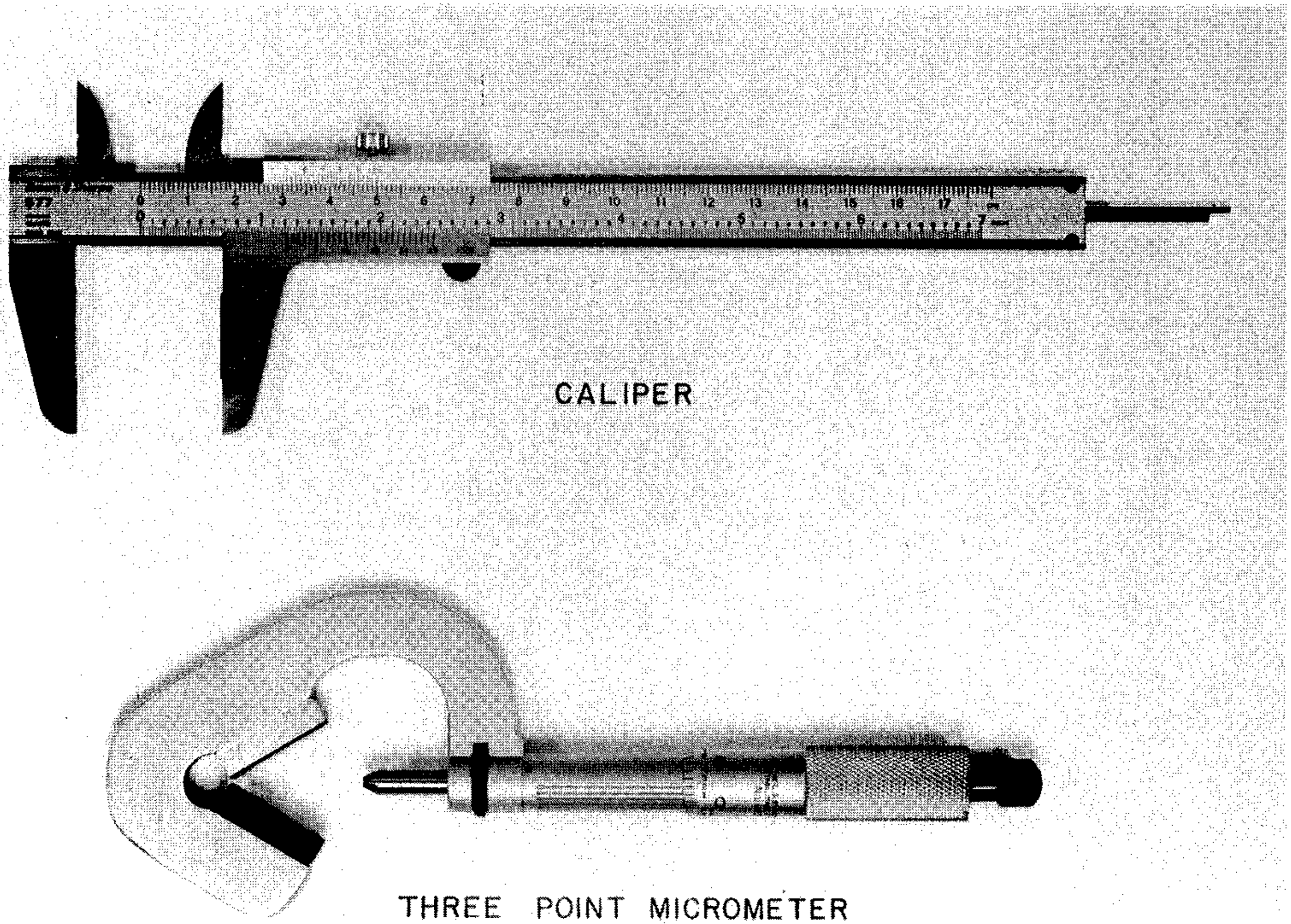


Figure 2-4. Tools for Sizing Wire Rope

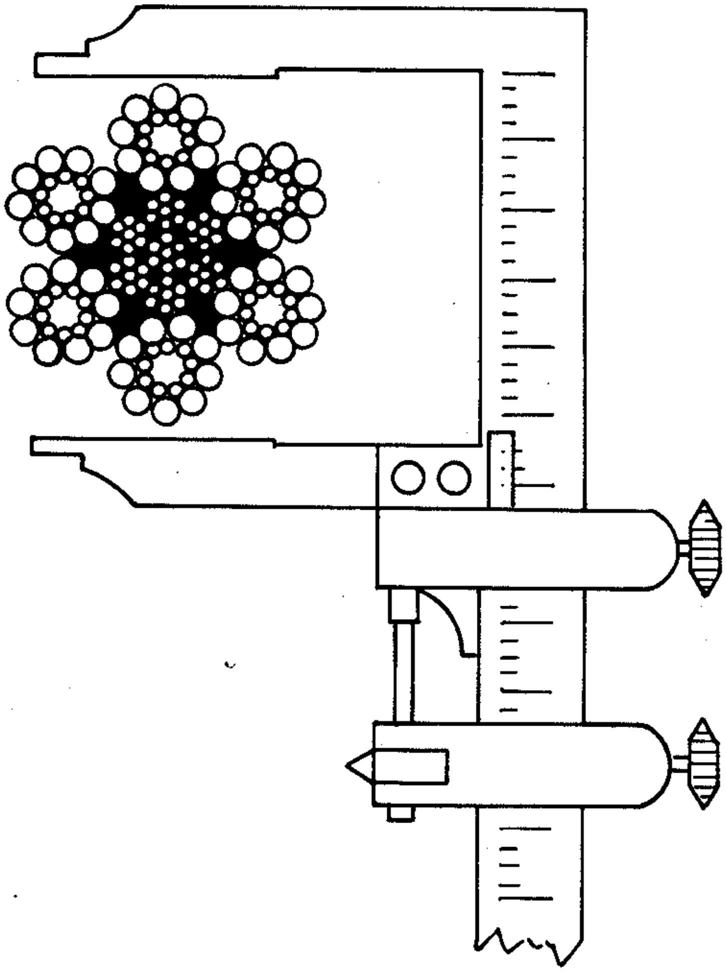
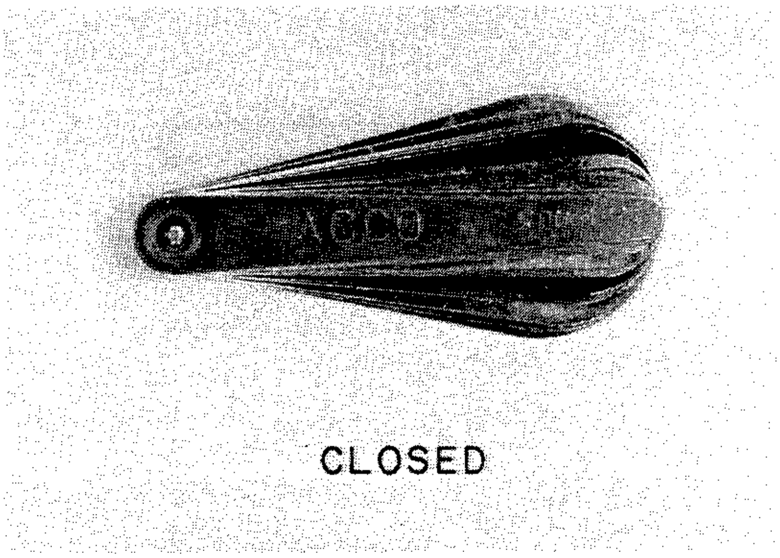


Figure 2-5. Correct Way to Measure the Diameter of Wire Rope



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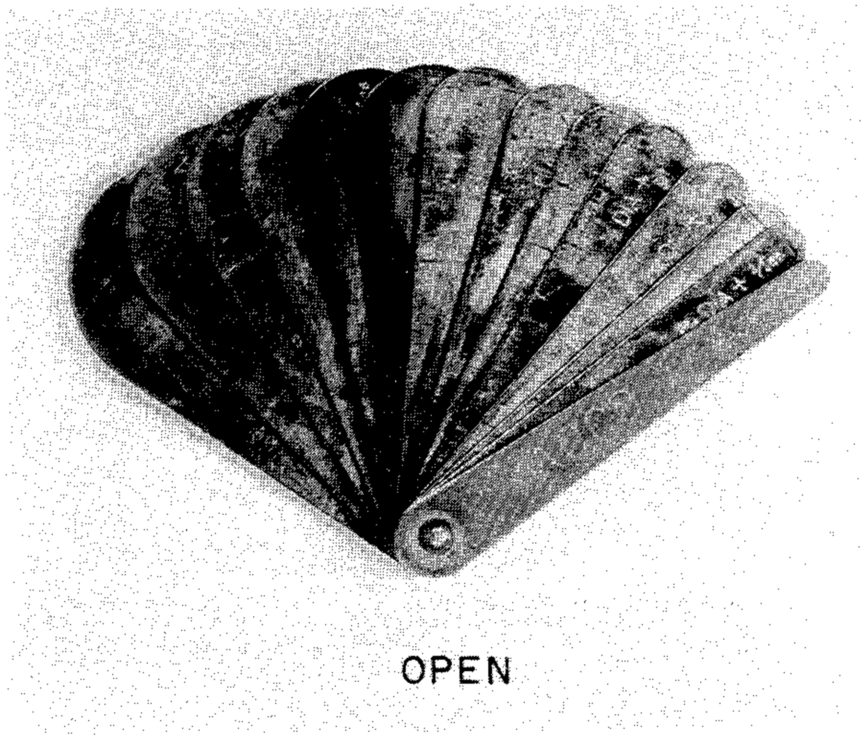


OPEN

Figure 2-6. Groove Gages for Wire Rope Sheaves

Table 2-2. Wire Rope Testing Facilities in the United States

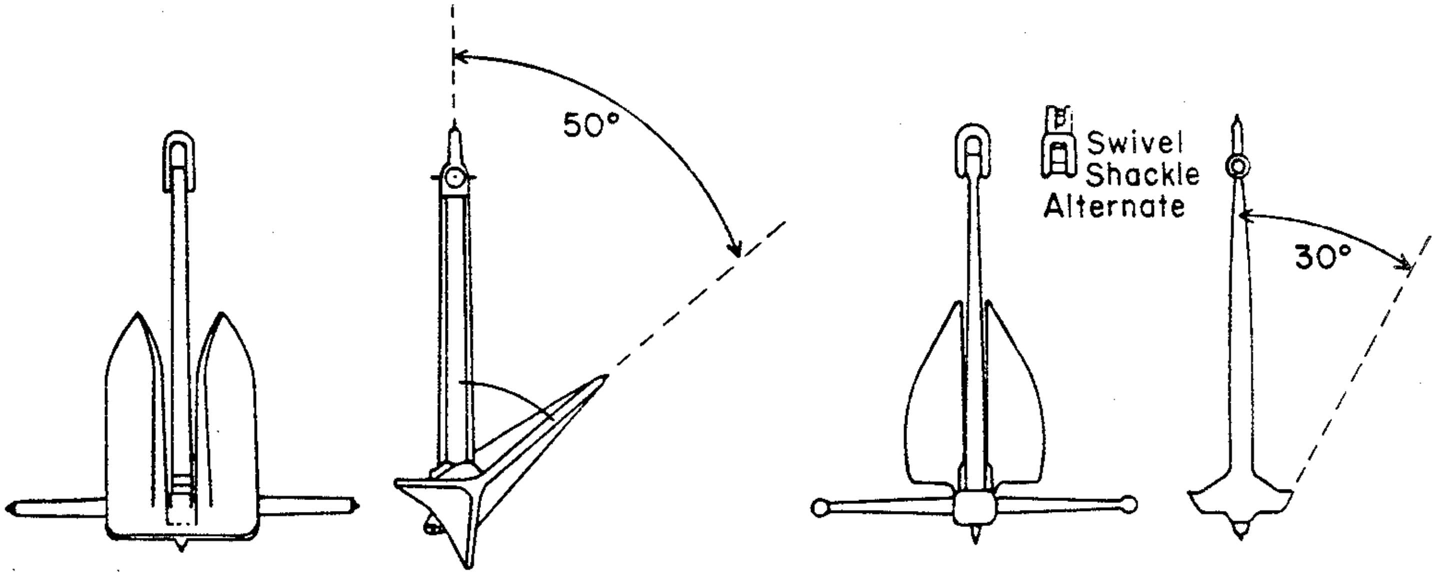
American Standards Testing Bureau, Inc.	New York, NY
Battelle Petroleum Technology Center	Houston, TX
Bethlehem Wire Rope Division, Bethlehem Steel	Williamsport, PA
Bridon-American Corporation	West Pittston, PA
Haller Testing Laboratories, Inc.	New York, NY
Hanks, Abbot A., Inc.	San Francisco, CA
Hurst Metallurgical Research Lab, Inc.	Euless, TX
Leschen Wire Rope Co.	St. Joseph, MO
Preformed Line Products	Cleveland, OH
Rochester Corporation	Culpepper, VA
Shilstone Testing Laboratory	Houston, TX
Southwestern Laboratories	Houston, TX
United States Steel Corporation	Trenton, NJ
Wire Rope Corporation of American	St. Joseph, MO
Magnetic Analysis Corporation*	Mt. Vernon, NY

* Magnetic inspection of wire rope

SECTION 3

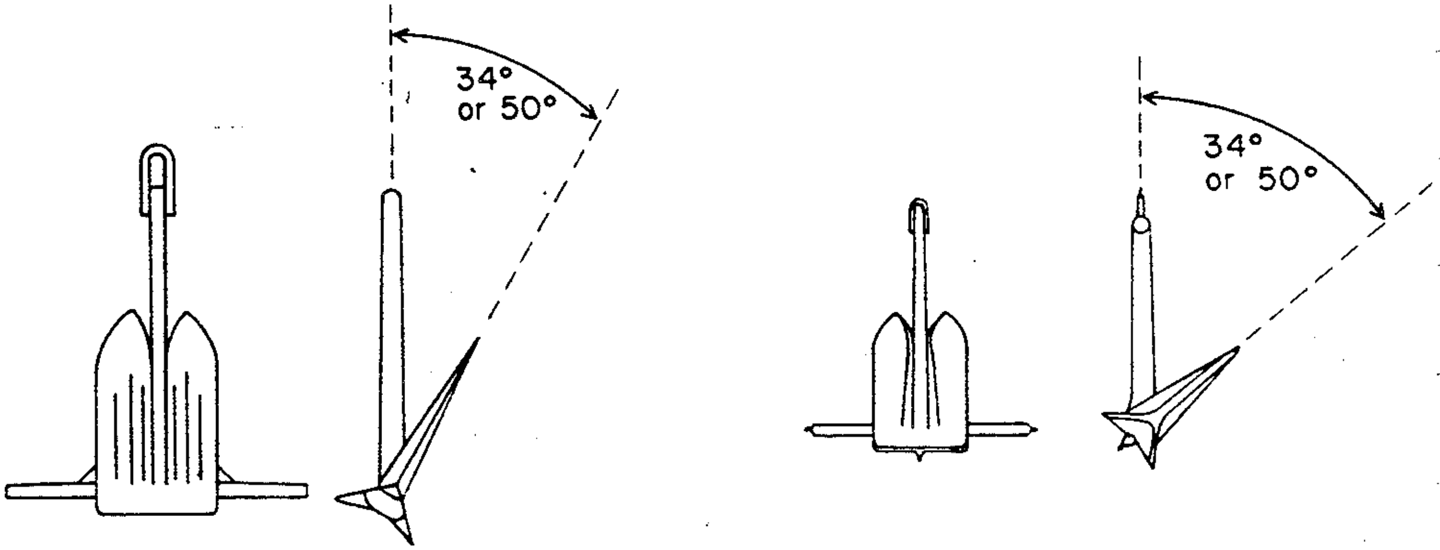
ANCHORS

The type of anchor used on offshore rigs varies with the operator and bottom sediment conditions. Most rigs use anchors weighing between 20,000 and 30,000 lbs. Figure 3-1 shows types frequently used. The Light Weight Navy, Moorfast, Offdrill and Stato anchors are most frequently used in the gulf of Mexico, Stevin anchors in the North Sea and anchors such as the Bruce in the Beaufort Sea. Anchors should be cleaned and visually inspected at each hauling. The use of dye penetrant or magnetic particle inspection techniques will facilitate the discovery of stress fatigue cracks or other imperfections.



OFFDRILL II ANCHOR

U.S. NAVY LIGHT WEIGHT ANCHOR



STATO MOORING ANCHOR

MOORFAST ANCHOR

Figure 3-1. Common Anchor Types for Offshore Rigs

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