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Mooring of Off-Shore Drilling Vessels

by

J.A.W. WHITE

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SUMMARY:

This Record describes the techniques and methods employed to moor various types of drilling vessels and discusses the equipment currently in use. Preliminary investigation of the sea bed and of prevailing meteorological conditions in the area can effect considerable savings in time and money during the actual mooring operations.

INTRODUCTION:

In order to drill a hole at a fixed point on the sea or ocean bed, it is necessary to position a drilling vessel positively with respect to a particular point on the sea bed.

Four methods are available at the present time to achieve this object, vessels being designed at the outset to use one or more of these methods:

1. By partly submerging the drilling vessel so that it sits on the bottom with a proportion of the weight of the vessel being placed on the sea-bed. Friction between the vessel and the sea-bed enables the vessel to withstand forces produced by wind and tide. This method is suitable in water depths from around 30 feet to 150 feet.

2. By jacking up the vessel on legs or stilts. The entire weight is taken on these legs with the "hull" of the vessel lifted clear of the water. Water depths up to 300 feet can be catered for in this fashion but the economic limit is generally around 150 feet.

3. By dynamic positioning. Propellers or water jets may be used to provide thrust to oppose forces produced by wind and tide. Positioning is generally programmed by a computor carried on board the drilling vessel. There is virtually no limit to the water depth.

4. By mooring to anchors or piles.

It is this last method which will be examined in detail.

The mooring of a drilling vessel at a particular location is inevitably only of a temporary nature, lasting for periods between several days and several months. The design of any mooring system is based on three factors only, security, economics and accuracy. By accuracy is meant the ability to maintain position within precise limits notwithstanding adverse forces acting on the vessel. The first choice for mooring always lies with anchors, and it is only when exceptional conditions prevent the use of anchors that the more expensive piles are used.

Compared with a conventional ship, a drilling vessel is at a disadvantage where anchoring is concerned:

1. A ship generally has some choice as to where to anchor and areas of poor holding ground can be avoided.

2. A ship can be allowed to come head to wind and current, presenting the minimum resistance to forces acting on her.

In contrast to this a drilling vessel has certain restrictions:

1. The position of the vessel is chosen by reason of the geology and structure and little or no choice of holding ground can be made.

2. The vessel must be restrained to stay precisely over one point and only limited movement about a vertical axis is possible in order to present a minumum resistance.

POSITIONING:

The geographical location of the well-site is determined on the basis of the geology with little consideration for the nature of the sea-bed or of water conditions.

In all cases it is more convenient for a small survey ship to determine the precise location and mark the position with a system of marker buoys.

For location near to the shore (less than ten miles) visual methods can be used. Marker beacons (minimum 3) on prominent coastal features provide bearing angles to the survey vessel. A pelorus is the only instrument required.

This method has its obvious limitations, being subject to weather conditions, especially visibility, and it is also limited to line of sight.

A more reliable and also more accurate method employes a system of high frequency radio transmitters and receivers. Many commercial systems, such as Electro-tape, HiFix, Raydist, Shoran and Toran, are available and each has its merits and limitations. Range depends on the wavelength (and other parameters) but equipment is available for ranges varying from a few hundred yards (or less) to many hundreds of miles.

The possibility of using laser beams is currently being investigated. This method shows considerable promise over "line of sight" distances but more experience is needed to determine its usefulness.

For the future, it appears that navigation using artificial satellites shows great promise. No shore stations would be required and uniform accuracy anywhere on the earth's surface would be possible. It would also overcome the problem of "sky-wave" which at times makes radio-location methods difficult or impossible to use. Two commercial organisations are already marketing equipment and it must be only a question of time before this method becomes widely available.

SEA-BED INVESTIGATION:

The holding power of an anchor depends upon the size and type of anchor and upon the nature of the sea-bed.

For any particular type of anchor there is an optimum shear-strength of the material forming the sea bed to give maximum holding power. For shear strength less than the optimum, the anchor flukes will be dragged through the sea bed after achieving penetration. Very low shear strength material, such as mud or ooze, will act as a viscous fluid giving negligible holding power. At the other extreme, a very high shear strength sea bed will not allow penetration of the flukes.

From this it can be seen that the higher the shear strength the better, provided on the other hand that the flukes are able to make adequate penetration of the surface.

Unfortunately much of the data available on anchor penetrating ability has been obtained in materials having shear strengths of 200 lbs/ sq. ft. or less. This is a typical value for sand, mud or silt which is the normal type of "good holding ground" used by conventional merchant ships. Sea bottoms however are often of the order of 10,000 lbs/sq. ft. shear strength and more experimental work is required to determine the holding power of various type of anchors in terrain of this nature.

Samples of the sea bed may be obtained by divers or by some mechanical means. Mechanical samplers are generally of the cylindrical type, taking a cylindrical, vertical core of the sea-bed, or alternatively may be a scoop type, towed behind a vessel.

Cylindrical cores can be cut in soft sediments using a gravity operated device. A heavy lead weight is tripped as the core barrel approaches the sea bed, forcing the barrel until the bottom. It is retrieved by a wire line to the surface vessel.

For harder sediments a conventional type rotary drill can be utilised although as it is generally impossible to re-enter the hole, a wire-line core barrel must be used to recover the cores, and once the bit is worn out, the hole must be abandoned.

Samples of 20 feet, sometimes considerably more, can be obtained in this manner.

By use of a mechanical scoop samples can be picked up while the survey vessel is underway. This method can give a quick overall picture of the surface geology of the sea bed but gives little or no information on how geology varies with depth.

METEOROLOGICAL AND OCEANOGRAPHIC INVESTIGATIONS:

The design of the mooring system depends very greatly on the prevailing conditions at the site in question. On the one hand water may be sheltered and weather conditions predictable and placid. In contrast, some areas of the world are subject to frequent and unpredictable storms with wide tidal variations and strong currents. Cook Inlet in Alaska is an example of the latter, while nearer home, off the North West coast of Australia, tidal variation exceeds 30 feet.

Frequently meteorological information is not available in many of the offshore drilling areas and even where such meteorological information is available it is very sparse. All available information should be collated and investigations of weather records should go back as far as possible to estimate the most severe condition likely to be experienced while the vessel is on location. Generally speaking it is not the prevailing winds which are taken into account when designing the mooring but the strength and direction of storms of maximum severity.

Normally, tidal variations are fairly easy to predict and observation over a very limited period of time enables an accurate assessment of the reliability of this prediction. Sea level variation from other sources such as storm surge is rather more difficult to predict but local experience may give information on this subject.

Currents are variable not only with time but also with depth. Normally, maximum current velocities are observed near the surface of the water although there are many exceptions especially when wind and current are in opposition.

Water currents are produced by tidal variation, by wind, by the flow of water from bays and estuaries and also by density variations between two different types of water. Such density currents are common near the estuaries of large river systems and can, on occasions, be very strong. These latter are not easy to predict and only local experience can be used.

Several organisations undertake meteorological and oceanographic research and their use is extremely worthwhile. The daily cost of a drilling vessel may ammount to as much as 20 thousand dollars per day and even a small delay in mooring the vessel may pay for the cost of such investigations many times over.

MOORING LOADS:

Forces acting on a moored ship are:-

1. Wind loads acting on the above-water surfaces.

2. Current loads acting on the underwater hull and on the marine riser.

3. Shock loads caused by the motion of the ship by wave action.

The magnitude of the forces produced by wind and current can best be determined through model tests in wind-tunnel or water tank.

If it is not possible to undertake model tests such as these, a formula is available to calculate the forces involved:-

$$F = KAS^2$$

Where: F = force in pounds

K = constant, approx. 3.5 for water (current) and 0.004 for air (wind)

A = projected area in sq. ft.

S = fluid velocity (air or water) in knots.

It should be emphasised that this formula should only be used where model tests are not available.

Shock loads are more difficult to predict, but on the other hand, the factors influencing shock loading are well known. Every vessel has a certain period or frequency of roll and of pitch and if this frequency happens to coincide with wave frequency, then roll or pitch can continue to build up until frictional forces produced by the movement of the vessel become large enough to compensate.

Shock loading occurs when the cyclic movement of the vessel becomes large enough to take up all the "slack" in the mooring system and any elongation of the mooring cable is then just due to stretch.

The problem becomes more acute where the cable catenary is less (shallow water) and therefore less "slack" in the system occurs.

An equation governing the various parameters of a catenary is:

$$H = \frac{To}{\mu} \left(\cosh \frac{\mu m}{To} - 1\right)$$

Where H = Sag i.e. the vertical distance between winch and sea-bed.

To = Tension of cable at the winch

μ = Weight per unit length of cable

m = Horizontal distance from winch to point where chain first touches the sea-bed.

Figure 8 illustrates the application of the above formula.

The forces acting on a mooring system can be analysed by means of a simple parallelogram of forces. Figure 9 illustrates this and should be referred to for an explanation of the symbols used.

Fore and aft forces are balanced (or the vessel would move) and therefore:

$$T1 \cos a + T4 \cos d = T2 \cos b + T3 \cos c + c$$

and similarly side forces are balanced:

$$T1 \sin a + T2 \sin b = T3 \sin c + T4 \sin d + F$$

Frequently angles a, b, c and d will be very nearly equal, simplifying the calculation.

Although the above concerns a four cable mooring, similar calculations can be made for other number of mooring cables and for various angles of the forces produced by wind and current.

As far as possible all cables should have similar loads and once the forces on each cable have been calculated as above, it may be advantageous to move the proposed position of one or more anchors in order to balance the load better.

MOORING PATTERNS:

The design of a mooring pattern depends on many factors and generally it is necessary to consider each location on its own merits and design the mooring pattern accordingly.

Nevertheless, patterns do fall into two main categories:

1. Duplicated mooring - figure 2

2. Balanced mooring - figures 3, 4 and 5

With a duplicated mooring system, the basic pattern is achieved using half of the available anchors, the other anchors following the same pattern and being placed alongside the anchors laid earlier. Anchors are therefore paired off. This system has the advantage of simplicity and of flexibility but on the other hand if one anchor of a pair fails due to overloading, then the full load is transferred to the remaining anchor, and this is likely to fail also.

A balanced mooring system is generally preferred, with all anchors being disposed at more or less regular intervals around the vessel. The actual pattern used depends on the oceanographic and meteorological conditions to be expected at this site, the design basis being to provide the maximum safety to the drilling vessel and minimum time lost either "waiting on weather" or through operations being slowed down by vessel movement.

Six freedom movement of the vessel is possible, three of them, namely roll, pitch and yaw being rotation about the metacentric centre and the other three being linear movement of the centre, namely, heave, surge and sway.

Pitch and yaw are not usually a problem, whereas roll is probably the major cause of lost time waiting on weather offshore. To minimise the effect of roll, the vessel should be moored facing the direction of the prevailing swell.

Heave, that is, the vertical movement of the ship, is not by itself generally a problem while drilling. It can however slow down or prevent such operations as running the B.O.P. stack, which require precise location with respect to the landing base. Heave is compensated by various devices:

a) Drilling string - one or more bumper subs are generally placed between the drill pipe and the drill collars

b) Marine riser - a slip joint is incorporated in the design.

c) Guy lines - compensating devices, either hydraulically or gravity operated.

d) Logging cable - either a mechanical or hydraulically operated compensator.

Surge and sway which are fore and aft and athwartship displacements of the vessel may prove troublesome. In shallow water especially, these may be the limiting factors in determining whether operations may continue in bad weather.

The angular displacement allowable for the marine riser varies, according to design and construction, between approximately 6° and 15°. The maximum displacement allowable at the surface is then given by $a = l \sin \theta$ where a is the surface displacement, l the length of marine riser and θ the angle of the riser to the vertical.

A recent development in mooring techniques is turret mooring. All mooring lines are led to a rotating turrent located amidships. The vessel can be rotated with respect to this turret, ensuring that the vessel is at all times on the optimum heading to minimise interference to drilling operations.

ANCHORING PROCEDURES:

On arrival at the desired location, an anchor is frequently used to hold the vessel temporarily while the remaining anchors are run out to their permanent positions. An anchor handling vessel is essential for anchoring and in practice all handling of the anchors is made using one or more of these support vessels.

A wire pendant, at least as long as the maximum water depth at the location, is shackled to the crown of the anchor and by means of this the anchor is suspended from the stern of the anchor handling vessel. She then proceeds to the assigned position for this anchor, the anchor cable being systematically slackened off as required. When in position the pendant wire is slackened off to place the anchor on the sea-bed and a buoy attached to the pendant for use when weighing anchor. Anchors are run out following a pattern and when all anchors are in position, mooring cables are one at a time tensioned up to their maximum required load before slackening off to their normal working load. Frequently better holding results are obtained if anchors are allowed to "soak" for periods of one or more days at tensions less than the maximum before subjecting them to maximum pull.

The anchor handling vessels should be properly designed for the job to ensure safe efficient mooring operations.

Qualities to be looked for are:

a) Large diameter stern roller able to withstand maximum pull of the winch

b) Sturdy A-frame wide enough to handle largest anchor in use

c) Powerful engines - 3,000 hp or more preferably

d) Variable pitch propellers - for maximum thrust and east of manoeuvering.

e) Pilot house with all controls to hand and full all-round visibility

f) Radar and radio communication

g) Bow thruster of adequate power

h) Preferably four anchors of her own - these comprise two bow, one on the stern and one amidships

i) Clear working space aft. This latter can only be obtained by arranging bulk storage of cement, barytes, diesel oil and drill water below decks

j) A "Moon pool" or well in the middle of the vessel to allow a drilling unit to be installed if required for sea-bed sampling or for pile drilling.

k) A fully competent crew.

The last item is the most important and is also the most difficult to assess. Standards of seamanship are often poor and it is unfortunate that no means of developing skills is available to the industry.

A modern anchor-handling/support vessel is as sophisticated a vehicle (and as expensive) as a medium-sized air liner but in contrast to airline practice, skill at handling the vessel does not have to be demonstrated to obtain a Master's certificate.

ANCHORS:

In considering anchoring, it is probably best if we start with the anchors themselves. Many types of anchors are available.

1. Fisherman anchor. This is the conventional type of anchor found in small boats but is not suitable for the use in question because of its bulk and very low holding efficiency.

2. Admiralty type anchor. Similar to above but with collapsible stock. Same remarks as above.

3. Stockless. This is the standard anchor for merchant ships but gives poor holding power. Its chief virtue is that it can be housed in the hawse pipe when under way.

4. Mushroom. As its name suggests, it is in the form of a mushroom and is only applicable for soft, homogeneous bottoms such as mud and silt.

5. Admiralty mooring anchor AM12. This is a single fluke design with a high holding efficiency of around 14. Holding efficiency is defined as the ratio of maximum holding pull divided by anchor weight.

6. CQR. This is of the double plough type and provides a high holding efficiency.

7. Danforth. Currently the most popular type of mooring anchor for all types of vessels. Provides a high holding efficiency of between 13 and 23 and is easy to stow.

8. Stato. Very similar to a Danforth and designed to obtain a holding efficiency of 20 in various type of holding conditions.

9. Baldt LWT. Again similar to the Danforth and capable of a high holding efficiency. Probably the most popular type of anchor used for off-shore drilling vessels.

10. Clump. Relies solely on its weight. Not suitable for a temporary mooring.

Anchors are invariably buoyed, the buoy lines being attached to the tripping point of the anchor, enabling easy retrieval or moving of the anchor by a support vessel.

PILES:

As mentioned earlier, anchors are always chosen wherever possible and it is only when conditions preclude their use that consideration should be given to piles.

These are always very much more expensive both in terms of time and money than conventional anchors and in addition one loses the flexibility of operation which anchors give. With anchors, a change of location can be made without trouble, even while the drilling vessel is underway to the new location, while with piles, considerable preliminary work is necessary if costly delays to the drilling vessel itself are to be avoided.

Two methods are available for installing piles in the sea-bed.

a) Driving - using a pile driver

b) Drilling - holes being drilled using rotary drilling equipment.

When driven piles are chosen, a wide range of sizes and types of piles are available. Steel "H" section piles are probably the most common but other materials and sections can be used according to availability. The pile driver can either be a submersible type, acting directly on top of the pile or it can be mounted on a vessel, the blows of the pile driver being transmitted to the pile through a pile extension.

The submerged pile driver can be electrically or pneumatically driven. The latter type has a depth limitation caused by excessive back pressure on the exhaust unless a high-pressure line is used for both the inlet and the exhaust to enable the tool to operate independently of any external pressure. Some method of gauging progress of pile penetration must be used but this poses no particular problems. Large capacity compressors are required to operate an air driven pile driver.

The submerged pile driver is suspended from a surface vessel, which itself must be anchored to hold its location over the desired position. Once one pile has been driven, this may be used to position the vessel for subsequent piles. A jig holds the pile and the pile driver in position on the sea-bed. This jig can be retrieved for use with subsequent piles.

Pile driving is eminently suitable where shallow, calm water conditions exist: It is perhaps ironic that in these conditions piles are seldom required, as conventional anchoring presents no problems.

For deep, rough water, drilling in of the piles is generally the preferred method.

Several alternatives are available - for example, either a small portable rig (mounted on a supply vessel or tender) or the drilling rig of the vessel to be moored may be used. The former is usually much cheaper, but in really difficult conditions it may not provide a stable enough platform for the operation of the rotary rig.

Two basic methods are available for the placement of drilled in piles.

In the first method, a hole is drilled to the appropriate depth in the sea bed, the bit and drilling string are pulled out and then the pile is lowered into the hole and cemented. Any size or shape of pile can be used providing a large enough bit is used to drill a suitably sized hole. Cementing can be accomplished by lowering a pipe alongside the pile and pumping cement through it.

The second method involves the use of an under-reamer type of bit. This bit has arms, to which are attached cutters, which are normally retracted. Mud pressure operates a piston within the bit which pushes the arms out to the drilling position. The pile used for this method is a cylindrical steel pipe with an internal diameter large enough to accommodate the bit in a closed position. In practice, the bit and pile are lowered simultaneously on the drill string, the bit is placed on the sea bottom, the mud pumps started (which will expand the bit) and hole drilled to the appropriate depth (30-50 ft.); the pile can be lowered as hole is made. When the pile is at total depth, cement can be pumped through the drill string and finally the bit in the retracted position can be retrieved, leaving the pile in situ.

In all cases the pile is fitted at the top with a swivel sleeve to which the mooring cable can be attached. The swivel obviates any torsional loading to the pile. See figure 7 for details of a pile mooring system.

MOORING CABLE:

Either chain or wire rope or a combination of both may be used. If the latter, the chain section is always placed nearest the anchor.

1. Chain is the established bype of cable used by ships for anchoring. It is easy to handle and because of its construction, even the heaviest grade can pass easily round a small radius. The weight of a chain makes it form a well-marked catenary which acts as a shock absorber. One disadvantage of chain is that it is less convenient to instal a tension-gauge on it to record cable pull.

Size of chain is determined by the diameter of the bar-stock used for the links. 2" studded link chain is commonly used for off-shore drilling vessels.

The following formula may be used for approximate values of various properties of a chain.

(Diameter measured in inches).

Breaking strain (tons	= $Diameter^2 \times 27$
Proof strain (tons)	= $Diameter^2 \times 18$
Weight of chain (lbs per fathom)	= $Diameter^2 \times 54$
Stowage required (cu. ft. per 100 fathom)	= $Diameter^2 \times 35$

2. Wire-rope is normally wound on a winch drum and requires some kind of sheave to take care of the change of angle at the gunwhale of the vessel. It is not generally practicable to make wire-rope as heavy as the chain it replaces and consequently the catenary between anchor and vessel is less, reducing the ability of the system to absorb shock loading.

3. A combination system is frequently used with chain next to the anchor and then a wire-rope attached to a winch on the vessel.

WINCHES:

Several types of winches are available:-

1. Diesel (a) direct drive
   (b) hydromatic drive

2. Electric

3. Steam

4. Hydraulic.

Type 1(a) can not be recommended since the system tends to lack the flexibility required, while types 3 and 4 are not so convenient unless a source of steam or hydraulic power is readily available. The choice then is generally between type 1(b) and type 2.

Considerable power is required to give adequate performance. For example 100 h.p. winch operating at 100% efficiency (a more usual figure is 60-80%) can pull in the cable at a rate of only 33 feet per minute against a pull of 100,000 lbs. Typically, motor horse power is in the 200-400 h.p. bracket.

Winch drums must be of adequate size in order to give the necessary storage capacity and should have an independent braking system

A cable footage counter is highly desirable as is some form of tension gauge. The latter should have a remote reading device in order that the tension on all mooring cables can be monitored (and recorded) simultaneously.

CONCLUSION:

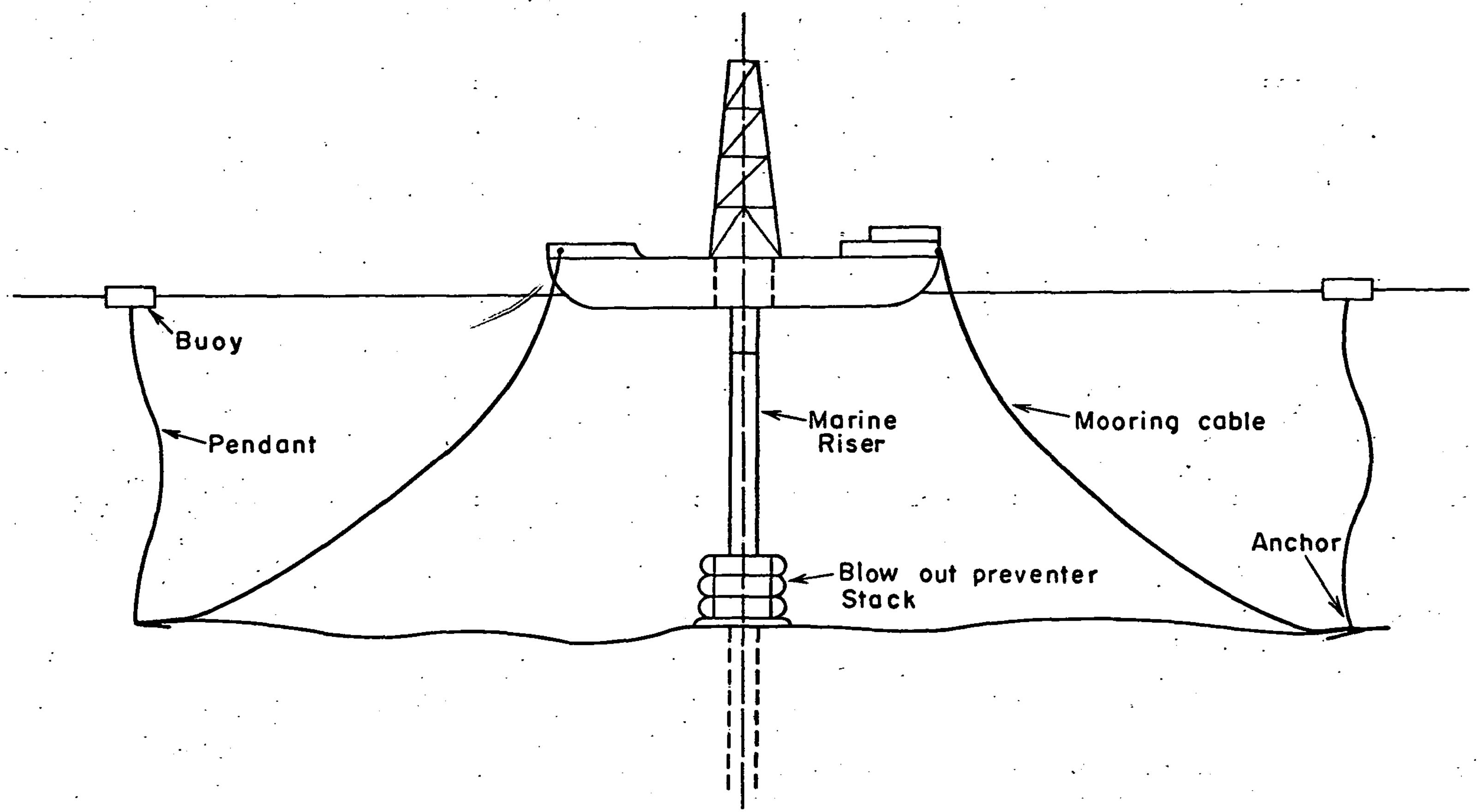
The efficient mooring of off-shore drilling vessels requires a variety of skills and equipment above those required for the mooring of a conventional ship in an anchorage. Many different factors must be considered before a mooring programme for a particular set of conditions can be decided upon.

Considerable amount of preliminary work such as meteorological and oceanographic studies are often required if expensive delays to the drilling vessels during mooring operations are to be avoided.

Figure 1

GENERAL ARRANGEMENT

(not to scale)



B.M.R. Petroleum Exploration. February 1968.

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Figure 2

DUPLICATED MOORING SYSTEM

(8-cables)

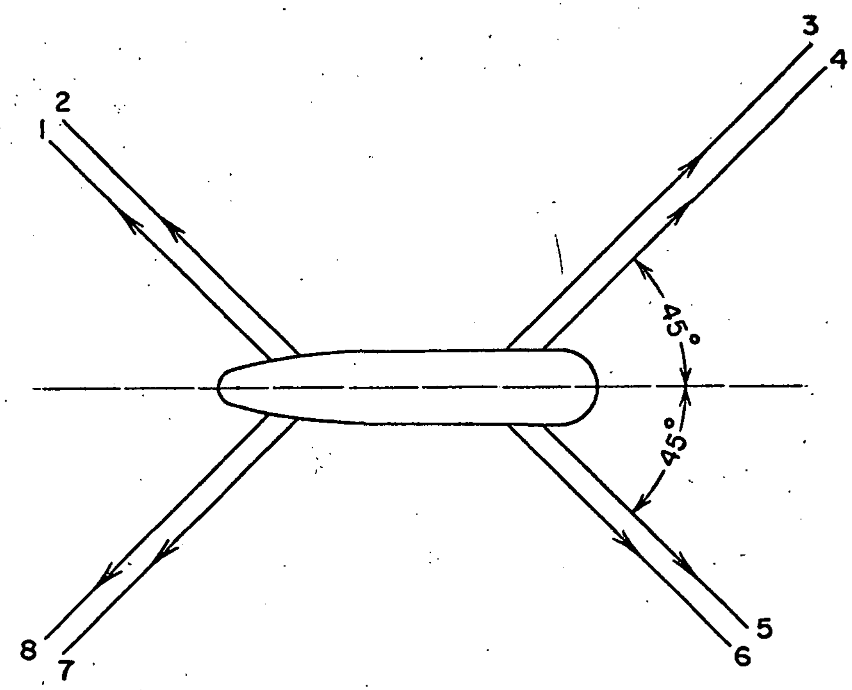

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Figure 3

BALANCED MOORING SYSTEM

(8 - cables)

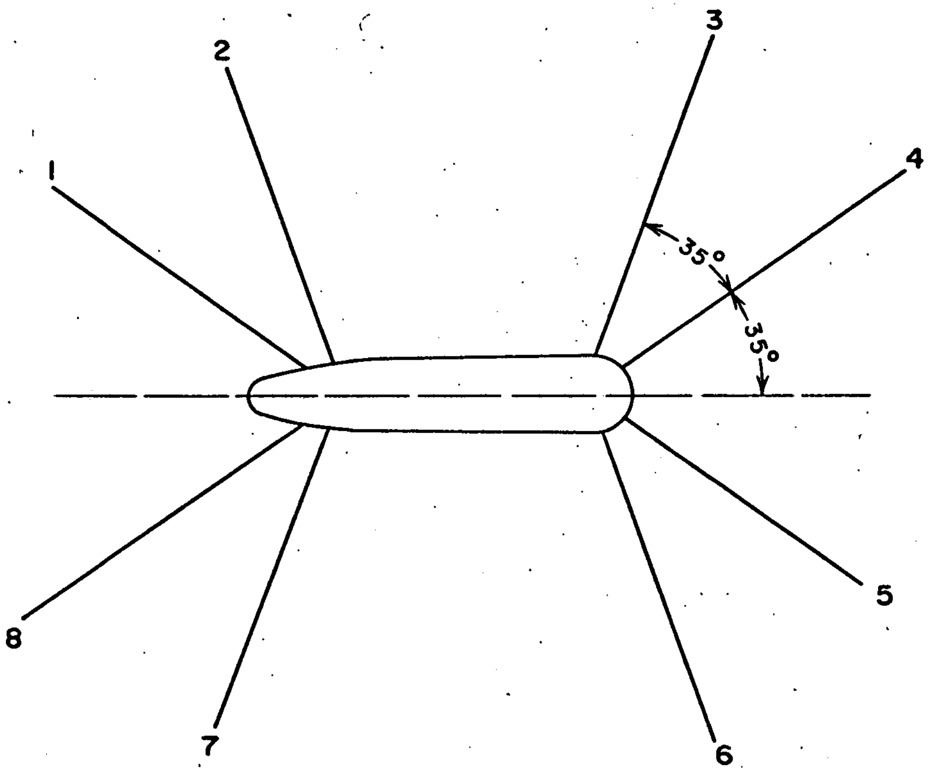

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Figure 4

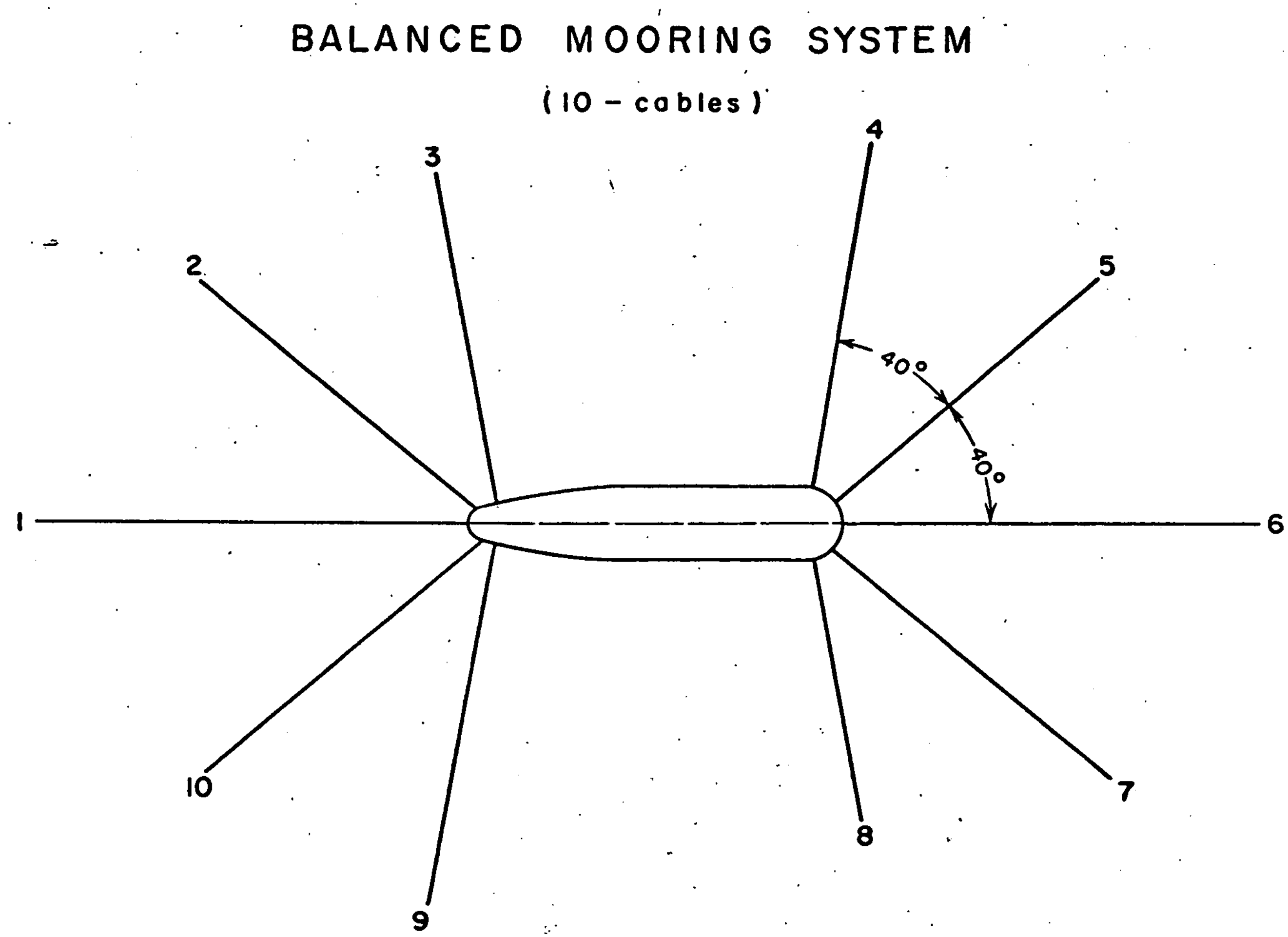

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Figure 5

BALANCED MOORING SYSTEM

(8-cables) designed for 30° swing

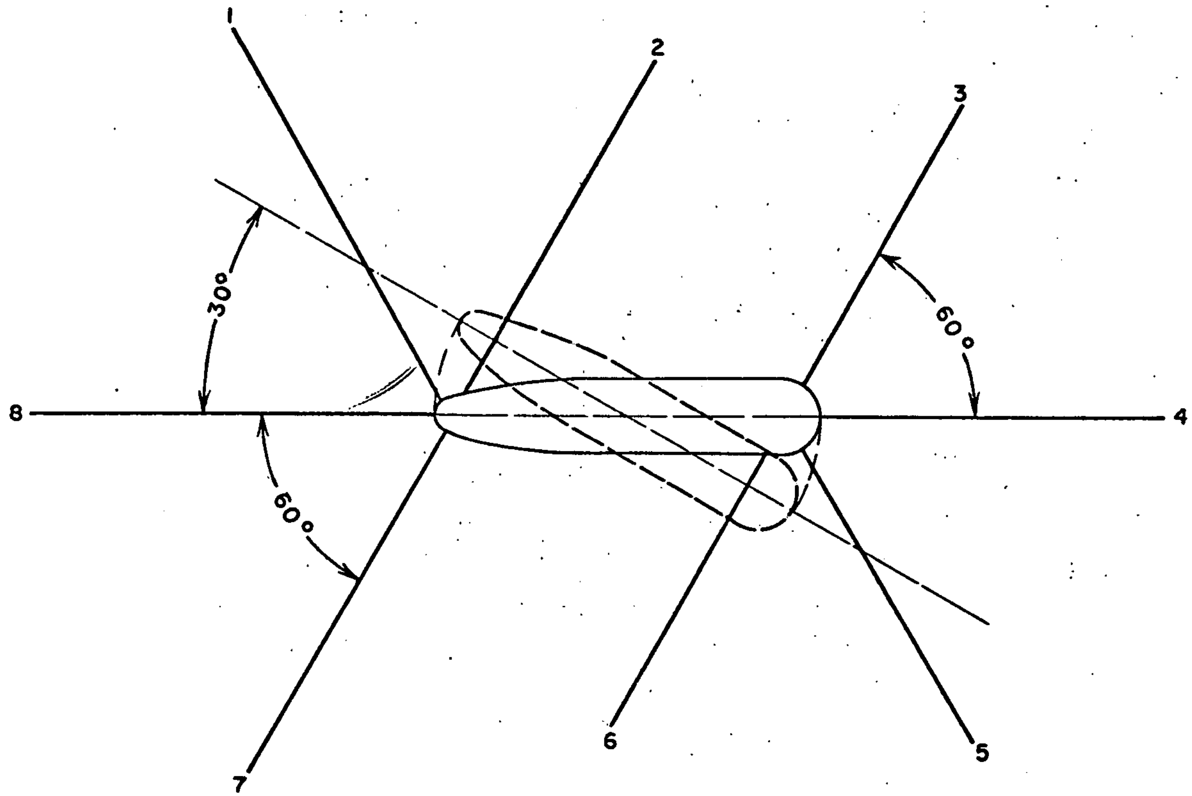

Figure 6

DETAIL OF ANCHOR SYSTEM

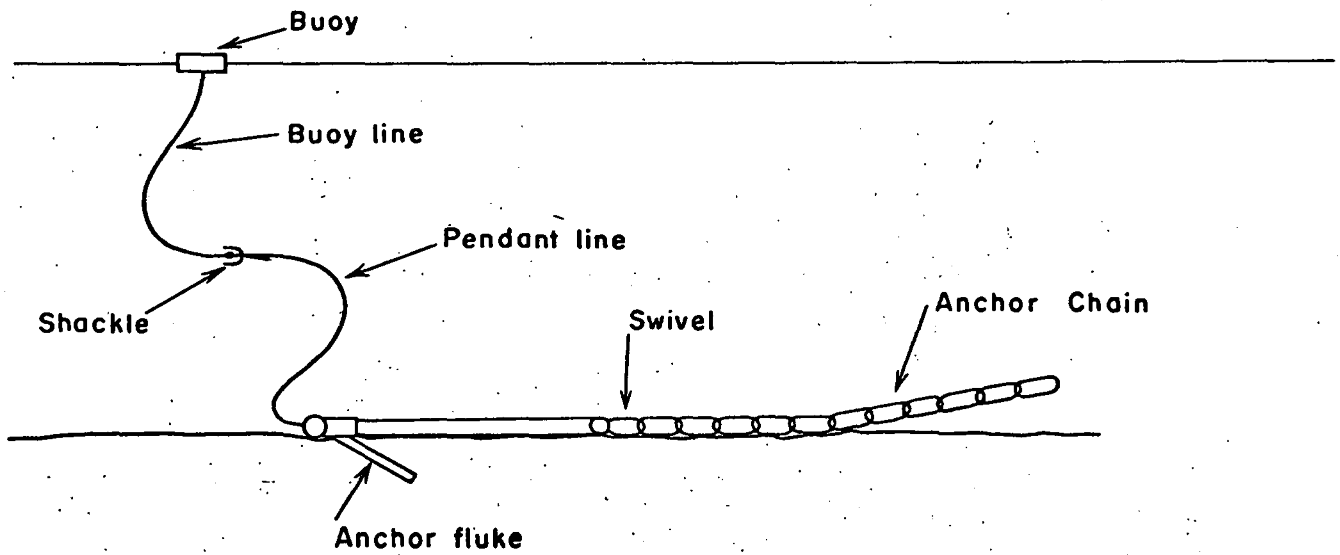

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Figure 7

PILE MOORING

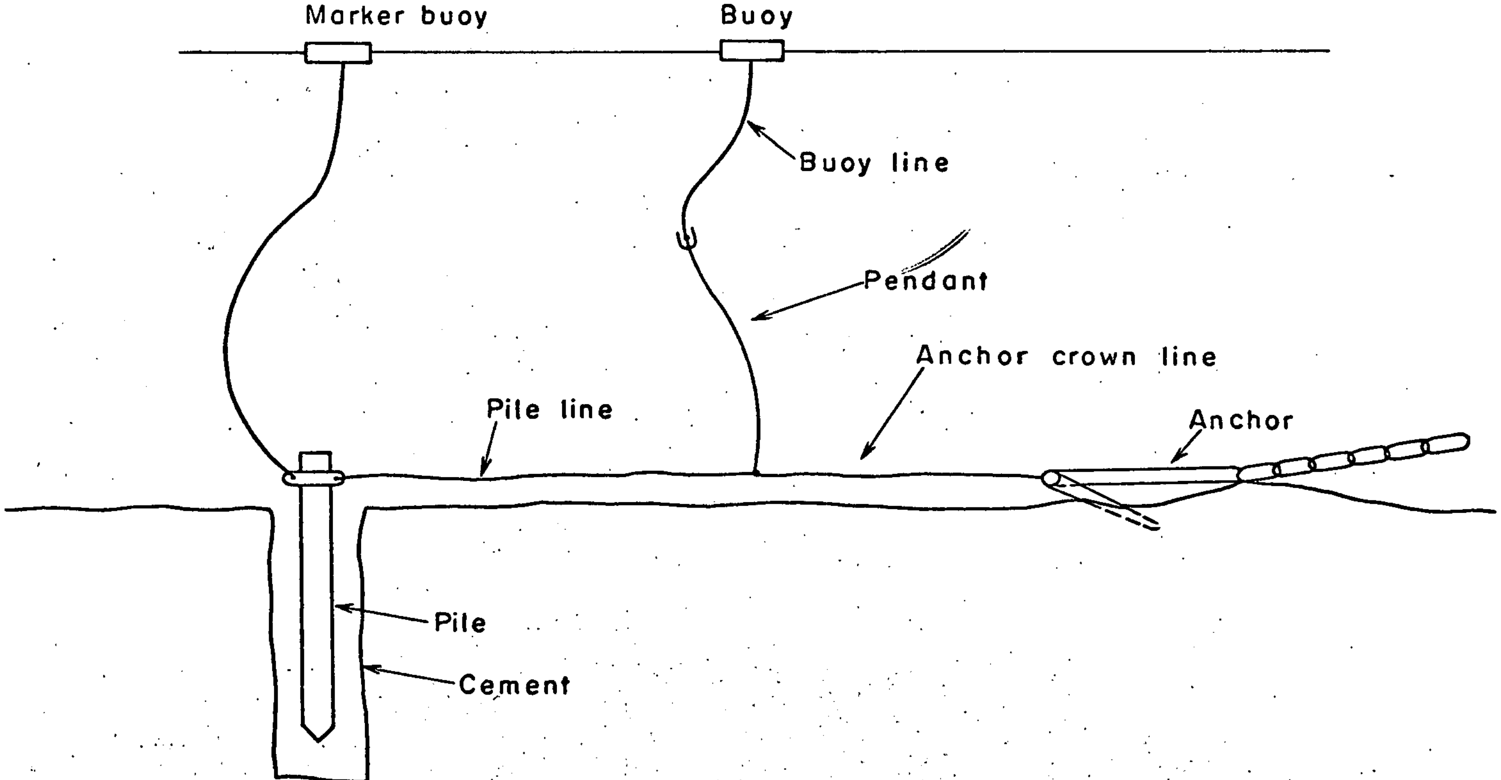

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Figure 8

CABLE CATENAY

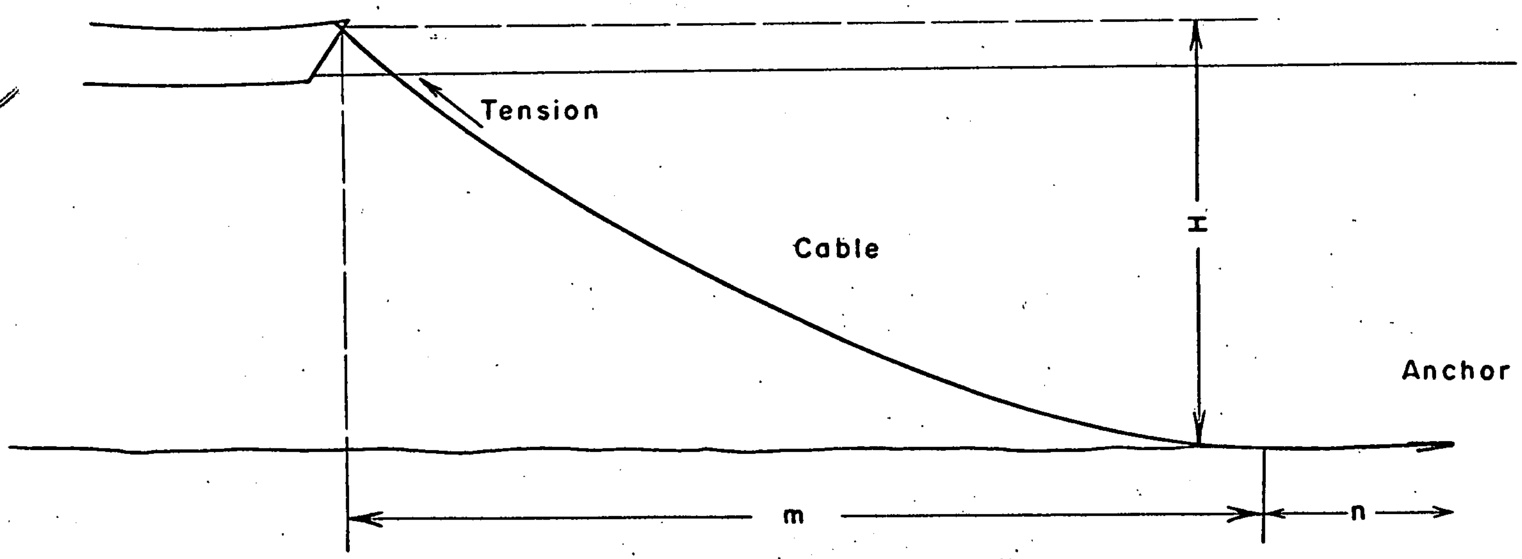

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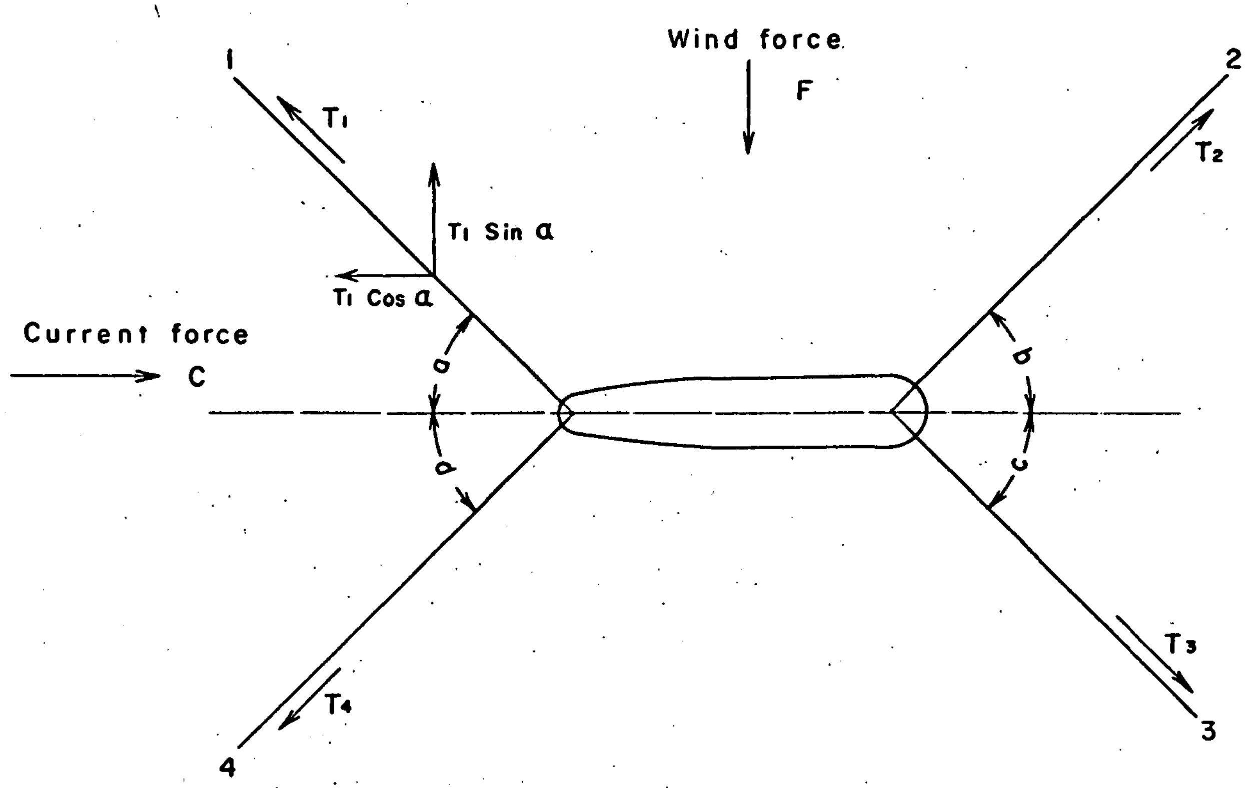
Figure 9

MOORING FORCES



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