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MONO-MOORING TERMINALS

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I. INTRODUCTION

The need for deepwater terminals in the U.S. to accommodate and unload large tanker vessels in the 200,000 DWT to 500,000 DWT class has been discussed extensively during the last few years, and many studies have been carried out by various agencies to determine the best and safest way to accommodate such vessels.

It is generally recognized that the savings in transport cost that can be achieved by importing crude in very large crude oil carriers or VLCC's are substantial, but equally important, or perhaps more important, is the reduced risk of pollution of U.S. harbors and beaches that will be associated with VLCC transport as compared with transport in large numbers of smaller tankers.

The reduction in pollution risk is achieved by locating discharge terminals in offshore areas far removed from onshore harbor and beach areas and by keeping approach lanes to such terminals well away from congested nearshore sea traffic lanes.

The only alternative solution for satisfying the need for increasing crude oil import would be to keep on as we are and meet oil import needs by ever-increasing numbers of port calls by small tankers. However, aside from the unfavorable economic aspects of this solution, this definitely means more risk of pollution of U.S. harbor and beach areas. The greater the concentration of traffic, the greater the risk of collisions and groundings.

As a result of these considerations, there now seems to be a growing tendency to general agreement between controlling government agencies on the following basic points:

- 1. Transport of large quantities of crude oil is safer when handled in a few Very Large Crude Carriers (VLCC's) than if the same quantity of crude must be handled in a large number of smaller vessels; all provided that the large vessels are isolated from congested coastal shipping routes.
- 2. Berthing facilities for VLCC's should therefore be located in offshore areas remote from crowded traffic lanes and harbor approaches.
- 3. A basic criteria for planning of such offshore VLCC terminals will be the requirement that the environmental disturbances caused by construction and operation of the facilities must be reduced to a minimum.

Given these requirements, mono-moorings have come to be recognized as the optimum solution for berthing and discharging VLCC's in the U.S. coastal areas. The U.S. Army Corps of Engineers has carried out extensive studies to ascertain the environmental impact of various alternative plans for deepwater ports in U.S. waters. In a recently published report, the following general conclusions are made:

"Monobuoys will have little direct impact on the marine environment. Of the alternatives considered, these structures offer the least potential damage to the environment. Monobuoys displace only a small area in comparison to artificial islands and thus will not significantly affect current or circulation patterns other than in the immediate area. Since a very small area is needed for anchorage of a monobuoy, there will be little impact upon the bottom habitat and its associated biotic communities. Like artificial islands, monobuoys will probably attract fin fishes, but in much smaller numbers. In general, impacts of monobuoys on the marine environment and its associated biota will not be of great importance."

II. MONO-MOORING SYSTEMS

The first mono-mooring designed to accommodate a relatively large tanker vessel was completed in 1959. There are now more than 150 mono-mooring facilities in service around the world. At least 45 of these will accommodate tankers in excess of 200,000 DWT. None of these facilities are located in the U.S.

There are three basic mono-mooring systems which have proven their reliability in general service for loading or discharge of tankers.

- 1. Catenary Anchor Leg Moorings (CALM) (See Fig. 1)
- 2. Single Anchor Leg Moorings (SALM) (See Fig. 2 & 3)
- 3. Single Point Mooring Towers (See Fig. 4)

Common to all mono-mooring systems is the characteristic that the berthed vessel is moored with bow lines only to a single point around which the vessel can rotate or "weathervane" 360 degrees and will align itself to head into wind, wave and currents causing the mooring forces to be minimized. Consequently, the structural strength and anchoring capacity required is minimal compared to fixed berth facilities.

The moored vessel being oriented in this way will also exhibit relatively small heave, pitch and roll motions even under rough sea conditions, and this is a basic reason that such facilities can safely be operated in open waters under fairly rough sea conditions. Mono-moorings permit enormous flexibility in locating an offshore terminal. The basic restrictions are adequate water depths and adequate clearances for safe approach to the mooring from all sides.

Floating hoses of steel reinforced rubber construction are commonly used to connect the vessels cargo piping system to a distribution swivel on the mono-mooring facility. The distribution swivel permits the discharge hose to rotate with the weathervaning ship and channels the discharging vessels cargo to a submarine pipeline running along the ocean floor to shore.

Mono-mooring systems which can accommodate 500,000 DWT tankers are already in service and systems are currently being designed for tankers up to 750,000 DWT.

III. PRODUCT HANDLING CAPACITY OF MONO-MOORINGS

Typical maximum discharge rates used for design of tanker unloading facilities range up to 140,000 BPH for 300,000 DWT vessels and correspondingly higher discharge rates for larger vessels.

A discharge rate of 140,000 BPH is practical when using twin 24 inch diameter discharge hose with each 24 inch hose leading into two 16 inch sections of hoses at the tanker rail for connection to the tanker manifold flanges. At present, the maximum size of tanker manifold piping is 16 inches and this is generally only found in tankers above 250,000 DWT.

Larger discharge rates may be achieved by using larger diameter discharge hose. Hose manufacturers are already offering 30 inch diameter hose for such use.

Multi-Product Handling

Mono-moorings may also be designed to handle two or more separate products simultaneously. In this case a special multi-product distribution swivel is required to transfer the separate products from the mono-mooring piping to the separate discharge hoses.

The same principle may be used for transferring bunker oil to a tanker vessel simultaneous with the crude oil discharge operation. This will permit the tanker to get underway on its return trip immediately upon completion of the crude oil discharge operation.

Handling of Slurry Cargo

The principal use of mono-moorings to date has been as loading or discharge terminals for crude oil or finished petroleum products. However, the mono-mooring concept also offers potentials for loading and discharge of solid minerals converted to slurry form. Excess water may be decanted over the ship's side during loading and water again added to the cargo at the discharge terminal to reconvert the cargo to slurry form during the unloading procedure. The range of products that may be handled this way include iron ore, bauxite, coal, salt, limestone, zinc phosphates and other commodities.

This concept may be particularly attractive for handling such minerals at remote source locations where other suitable port facilities cannot be economically established.

IV. OPERATIONAL PROCEDURES

Efficient planning and layout of mono-mooring facilities require a basic knowledge of operational procedures to be followed during mooring and deberthing of a tanker vessel at such facilities.

To facilitate the mooring operation, at least one, and preferably two, sea-going service vessels should be available to assist during the mooring operation.

The basic operational procedures to be followed during a mooring operation may be briefly outlined as follows:

- 1. Prior to the arrival of a tanker to be moored, the service vessels should make a general inspection of the mooring facility and particularly assure that the mooring hawser pick-up lines are ready to receive messenger lines from the approaching tanker.
- 2. The approaching tanker must approach the mooring from a direction heading into the wind, wave and currents. In case onshore wind and waves are prevalent, it may be necessary to go in a wide circle around the mooring in order to approach on the best heading. The pilot or master's decision as to his final approach heading must be radioed to the service vessels waiting to assist in the mooring operation.
- 3. If the floating hose string is streamed out in a direction which may interfere with the approaching tanker, one service vessel should pull the hose string out of the way off the approaching vessel.
- 4. During final approach, the tanker should take a course which would pass to starboard of the mooring so that if the tanker moves too far forward it will safely pass the mooring without impact on the mooring.
- 5. As the tanker approaches the mooring, a messenger line will be passed to the line handling service vessel. The service vessel will proceed ahead and make the messenger line fast to the mooring hawser pick-up rope.

At this point, the tanker should have only enough headway to carry the bow of the tanker to within approximately 200 feet of

the mono-mooring. As soon as the service vessel is clear, the messenger should be winched aboard followed by the hawser pick-up rope and the mooring hawser chafing chain. The chafing chain must be brought part way through the bow fairlead and secured to mooring fittings on the tanker forecastle.

6. As soon as the tanker is securely moored, the hose launch may tow the end of the floating hoses to a position below the tanker manifold. The hoses may then be picked up one by one by the tanker's hoisting gear and flanged up to the tanker's manifold.

Leaving the mono-mooring may be accomplished simply by releasing the mooring lines and lowering the hawser and chafing chains to the sea surface. If there is heavy strain on the hawsers due to rough weather, the tanker should apply slow ahead power to relax the hawser pull before the above release operation is performed.

Once the lines are dropped, the tanker may drop astern until clear after which the vessel may proceed forward and to starboard of the buoy.

V. SITE SELECTION AND LAYOUT

Selection of a suitable site for a mono-mooring terminal is a relatively easy task compared to siting and layout of a fixed berth terminal.

The basic requirements are:

- Minimum water depth within the tanker swing circle. -The minimum water depth within this circle at LLW must not be less than the loaded tanker draft plus a clearance which will depend on the degree of exposure of the site to rough weather. This clearance should not be less than 10-15 feet and preferably more. Clearance over pipeline and pipeline end manifolds, as well as over the base structure for SALM terminals, must also be considered.
- Minimum water depth within the maneuvering area. Water depth of LLW within this area should not be less than
 the loaded tanker draft plus a clearance of at least 6 feet.
- 3. Minimum radius of maneuvering area. -The distance to the nearest limiting depth as specified above or to other moorings or fixed platforms or other obstructions should not be less than three to four times the overall length of the maximum size tanker for which the mono-mooring is designed.

The selection of an optimum site and terminal layout must, of course, also include consideration of the following factors:

- Suitable approach routes and the need to keep these routes remote or isolated from congested shipping lanes and other navigational hazards.
- Possible beneficial effects of partial shelter at potential sites.
- Distance to potential tank farm sites onshore.
- Water depth, soils conditions and bathymetry along potential pipeline routes.

VI. BASIC DESIGN CRITERIA

The basic design criteria which will govern the engineering design of a mono-mooring facility includes a number of parameters which are summarized below. Typical ranges of values for the listed parameters are also indicated:

Parameter

Typical Range

Vessel Dimensions

- Class	50,000 DWT -	700,000 DWT
- Length	743 Ft	1480 Ft.
- Beam	102 Ft	250 Ft.
- Depth	50 Ft	130 Ft.
- Draft Loaded	40 Ft	95 Ft.
- Draft Light	12 Ft	38 Ft.

2. Throughput Characteristics

- Specific Gravity of Product	. 80 -	. 90
- Viscosity	10 SSU -	150 SSU
- Discharge Rate	40,000 BPH -	150,000 BPH
- Pressure at Tanker Rail	125 psi -	150 psi
- Surge Pressures	300 psi -	450 psi

3. Site Conditions

- Water Depth

70 Ft. - 500 Ft. or deeper

- Soils Characteristics

From borings and lab tests
(May range from soft clay to hard rock)

- Sea Bottom Bathymetry

From sounding survey (Should preferably but not necessarily be level)

4. Environmental Conditions With Tanker Berthed

- Wind Velocity

30 MPH - 50 MPH

- Current Parallel to Wind

1.0 knots - 4.0 knots

- Current Perpendicular to Wind

0.5 knots - 3.0 knots

- Wave Height (Max. Significant)

10 Ft. - 20 Ft.

- Wave Period

6 sec. - 10 sec.

- Tidal Range

0 - 8 Ft. or more

5. Storm Survival Conditions (No Tanker at Berth)

- Wind Velocity

100 MPH - 230 MPH (Hurricane

Winds)

- Current Parallel to Wind

3 knots - 6 knots

- Current Perpendicular to Wind

2 knots - 4 knots

- Wave Height (Max. Single Wave)

35 Ft. - 93 Ft. (North Sea)

- Wave Period

12 sec. - 16 sec.

- Max. Storm Tide

0 - 10 Ft.

VII. GOVERNING DESIGN FORCES

Maximum load conditions for individual mooring system components may occur during either of the following two conditions.

- Operating condition with the maximum size tanker moored to the mono-mooring.
- Maximum storm wave condition with no tanker moored.

Examples of design forces governed by the operating conditions are:

- Peak loads acting on the mooring hawser during the most unfavorable combination of wind, wave and current conditions. The peak load in turn will govern the design of the structural linkages leading to the anchorage at the sea bottom and the anchorage system itself.
- Forces and strains on CALM underbuoy hoses due to displacement of the mooring buoy during peak mooring loads.
- 3. For an SPM Tower Mooring, the governing design force for the tower structure will usually be the impact force due to accidental impact from a moored tanker riding up to the tower or from an approaching tanker loosing control during the mooring operations.

Examples of governing design forces which may be caused by dynamic response effects during storm conditions are the following:

For CALM Systems

- Forces and strains on underbuoy hoses due to dynamic response movements of the buoy and the hoses.
- Forces and strains on floating hoses, particularly where the floating hose is attached to the swiveling pipe arm on the mooring buoy.

2. For SALM Systems

- Forces and strains on submarine hose and floating hose.
- Dynamic response forces due to forced oscillations of the riser shaft for deepwater SALM's.

3. For SPM Towers

- Forces and strains on floating hose, particularly where the floating hose is attached to the tower turntable.
- Wave and current forces acting directly on the tower structure.

Evaluation of Design Forces

Operating Conditions (Tanker Moored)

A single mono-mooring system, with a tanker moored and exposed to the wind, waves and currents, constitutes in effect a large spring/mass system which is subject to external load impulses from the wave action and varying wind and current forces. The peak forces developed in the mooring, are basically dynamic forces developed as the tanker oscillates with slow sway, yaw and surge motions.

The maximum forces developed are to a large extent governed by the elastic and dynamic response characteristics of the mooring system. For a CALM or SALM system, the elastic characteristics are in turn governed by the force vs. displacement characteristics of the buoy, combined with the elastic characteristics of the mooring hawser. For an SPM Tower Mooring, only the mooring hawser contributes to the elasticity of the system.

Evaluation of the maximum mooring forces are commonly based on scale model tests of systems modeled as close as possible to simulate the dynamic response of the actual systems. One important fact that has been established by model testing is that currents acting in a direction perpendicular to the direction of wind and waves will usually cause higher peak loads in the mooring system. This is due to the effect caused by lateral current forces pushing the tanker into a quartering exposure to wave action.

Methods have been developed by which peak mooring forces may be evaluated by analytical means. Notable is a method developed by Exxon Research and Engineering Company and Exxon Production Research Company. This method relates peak mooring forces to energy absorbed by the mooring system while a vessel is moored to a single point mooring during storm conditions. The energy absorption capacity required for varying tanker sizes and wave conditions has been established by an extensive series of model tests with tanker vessels ranging in size, up to 500,000 DWT. The basic concept of the method is described in further detail in OTC Paper No. 1536 by N. R. Maddox.

Evaluation of the peak mooring forces may also be accomplished by computer simulation analysis; however, although several attempts have been made to program a reliable simulation analysis which can be correlated with known model test data, no such program is generally available at this time.

2. Storm Wave Conditions (No Tanker Moored)

During severe storm conditions, substantial dynamic force reactions may be developed at the connections between the moving components of the system as outlined previously. The potential maximum magnitude of these forces can be evaluated by theoretical analysis of the dynamic response of the oscillating system; however, determination by model tank testing is preferable.

VIII. THE CATENARY ANCHOR LEG MOORING (CALM) - (See Fig. No. 1)

This system has been in use since 1959. The system evolved naturally from the similar concept of "Telephone Buoy" moorings commonly used for free swinging mooring of Navy vessels. Through the years the system has undergone continuing development based on the operational experience gained as the size of the buoys and throughput capacities were expanded to correspond to the increase in tanker sizes that have occurred during the same period. Probably more than 90% of existing mono-moorings are of this type.

The Buoy Hull

The main component of the CALM system is the mooring buoy. For a CALM terminal designed for large vessels in the 200,000 DWT to 300,000 DWT class, the buoy may be 40 Ft. or more in diameter and approximately 15 Ft. high. The hull is generally subdivided into four, six or eight compartments by vertical bulkheads. This insures that the buoy will continue to float in the event of hull damage in one or two compartments. As an extra safety measure, some or all of the compartments may be filled with closed cell plastic foam material.

The Catenary Anchor Legs (Mooring Chains)

The buoy is anchored to the sea bottom by four to eight anchor chains radiating out from the buoy and fastened to anchor piles driven into the sea bottom or set into predrilled holes and grouted in place. Alternatively anchorage may be provided by large ship type anchors set into the sea bottom. The anchor legs are fastened to the buoy in a chain stopper arrangement which permits adjusting the length of the anchor legs so that the optimum amount of tension on the catenary chain legs can be maintained. The chains must be tensioned enough to prevent the buoy from being displaced excessively when subject to maximum mooring loads from the moored tanker. Excessive displacement may cause damage to the underbuoy hose system. On the other hand the chains must not be tensioned too much as this will result in a "stiff" mooring system with little capacity to absorb the surge and sway motions of the tanker and consequently the peak mooring loads will be unacceptably high.

Typically, the catenary anchor legs are of total length equal to 6 to 8 times the water depth. With the mooring buoy in neutral position and no mooring force acting on the buoy, there will only be a chain length of 1-1/2 to 2 times the water depth suspended from the buoy. The total length of chain is chosen so that during maximum mooring load conditions, the direction of pull at the outer end of the maximum loaded chain will not deviate appreciably from a horizontal pull.

The Rotating Buoy Deck

A rotating turntable is mounted on top of the buoy. The turntable may be of different configurations depending on the manufacturer's special design, but it will always contain three distinct sectors, each sector containing special features which are essential for the proper function of the CALM buoy.

1. The Mooring Bracket Sector -

This sector will have brackets for attachment of the special designed mooring hawsers. Bollards for mooring small tanker vessels or maintenance workboats are also located in this sector. The entire turntable will rotate in response to the mooring line pull of a weathervaning vessel moored to the facility.

The Piping Manifold Sector -

This sector contains the rotating pipe arm leading from the edge of the buoy to the product distribution swivel in the center of the buoy. The piping manifold sector is usually offset approximately 90° with respect to the mooring bracket sector. The 90° offset helps keeping the floating hose string from getting in contact with the hull of the moored tanker.

3. The Counterweight Sector -

This sector is located diametrically opposite the mooring bracket and piping manifold sectors, and its function is simply to balance the off-center weight of the mooring bracket sector and the piping manifold and assure that the buoy will float on an even keel.

The Product Distribution Swivel

The turntable has an open well in the center and in this well is mounted the product distribution swivel. The lower part of this swivel unit is bolted to the stationary buoy hull while the upper rotating part is connected to the turntable manifold piping through a flexible connector. The stationary part of the swivel is flanged up to internal piping in the buoy leading to flange connections for underbuoy hoses under the buoy.

The Underbuoy Hose System

The underbuoy hose system transfers crude oil or other cargo between the buoy and the pipeline end manifold anchored to the sea bottom directly below the buoy.

The underbuoy hose configuration is one of the most critical design considerations of the CALM system. The hoses must have adequate slack

to accommodate the maximum range of motions of the buoy without overstraining the hose. Dynamic response due to the constant motions of the buoy and hose when subject to wave action varying from near calm to storm conditions must be considered carefully. The optimum configuration and length of hose should preferably be determined by model tests.

There are two basic underbuoy configurations in general use, the "Chinese Lantern" configuration and the "Lazy S" configuration. The Chinese Lantern configuration will generally be found most suitable for relatively shallow water depths whereas the Lazy S configuration is preferable for deep water installations. The desired configurations are achieved by proper orientation and location of the manifold flanges under the buoy and on the pipeline end manifold, and by use of flotation units attached to the underbuoy hose at suitable locations. In addition, adjustable buoyancy tanks may be provided at joint between the hoses to provide a means for convenient adjustment of the hose profile.

The Floating Hose System

Tanker piping manifolds are traditionally located at midships and the floating hose system used for transfer of cargo from the tanker must therefore reach from midships to the rotating pipe arm on the mooring buoy with adequate slack to accommodate any possible yaw, sway, surge or ride-up of the tanker. For a 300,000 DWT tanker, the total length of floating hose will be approximately 1000 Ft. As mono-moorings become the generally accepted terminal system for VLCC's it seems probable that such vessels will be fitted with an auxiliary manifold near the bow which would permit shortening the floating hose string a very appreciable amount.

Depending upon the discharge requirements, the floating hose system may consist of a single hose string or may contain two or more hose strings in parallel.

The hose strings are made up of individual lengths of hose connected with bolted flange connections. Each length of hose is usually 30 - 35 Ft. long. The hoses are made from many plies of rubberized fabric and reinforced with helical wrappings of steel wire imbedded in the rubber cover. To provide adequate flotation to float the hose while carrying oil cargo or sea water (during installation) there are two systems in general use: The flotation collar system with separate two piece collar shaped floats clamped onto the hose carcass at suitable intervals and the integral float system which has the lightweight flotation material built into the cover of the hose. The integral float hose is most widely used today for large diameter hose.

The Mooring Line System

The mooring line system for a mono-mooring facility usually consists of three components:

- 1. The Mooring Hawser
- 2. The Chafing Chain
- The Pick-up Rope

The mooring hawser is attached to the mooring bracket on the buoy with special, thimble fittings, chain links and shackles. At the tanker end of the mooring hawser, which is usually 150 - 200 Ft. long, a length of chain is attached. This chain, usually 20 - 25 Ft. long, is brought through the ship's fairlead and serves to prevent chafing on the nylon hawser while also providing the linkage to the ship's mooring fittings.

To assist in picking up the heavy chain and hawser during mooring operations, a 300 - 400 Ft. long pick-up line of self-floating polypropylene rope is attached to the tanker end of the chafing chain. During mooring operations, the tanker's messenger line will be attached to the pick-up rope for hauling the mooring line assembly aboard the tanker.

The mooring hawser usually consists of braided nylon rope of diameter from 4 to 7 inches. For large force capacity requirements, double line hawsers are used. A double line hawser made from 7 inch diameter braided nylon will have a breaking strength in excess of 2,000,000 lbs.

IX THE SINGLE ANCHOR LEG MOORING (SALM)

The first Single Anchor Leg Mooring was installed in 1969 by Esso Libya Inc. at Marsa el Brega, Libya. The SALM system was developed as a deliberate attempt to improve the performance of the Catenary Anchor Leg Mooring system. There are now three SALM terminals in general use with four additional terminals under construction or in active final design stages in overseas areas.

The basic characteristics of the SALM system are as follows:

A relatively small mooring buoy is anchored to a mooring base on the sea bottom with a single anchor leg under constant tension. On the buoy deck is located mooring brackets for attachment of the mooring hawsers and navigational aid features. Navigational aids will always include a long range beacon light and may include radar reflectors and a fog horn.

The product distribution swivel is of a special design suitable for submarine service and is mounted well below the loaded draft of the maximum size tanker for which the SALM terminal is designed. Depending upon the water depth at the terminal site, there are two basic versions of the SALM system. For shallow water depths the product distribution swivel is

mounted directly on top of the mooring base (Fig. No. 2) while for depths in excess of say 120 Ft. an articulated riser shaft is inserted between the mooring base and the product distribution swivel (Fig. No. 3).

One safety feature of the SALM is the ability of the system to allow a tanker to completely override the buoy without significant damage to the buoy and no contact with the oil carrying swivel or piping components.

The floating discharge hose is not attached to the moving surface buoy, but is directly attached to a submarine hose string which dips gradually below the surface and is carried in a gentle curve to the rotating hose arm on the product distribution swivel. For deepwater SALM terminals, the discharged product is carried through piping in the riser shaft to a flexible base hose connection, which allow the riser shaft to oscillate freely and align itself in response to the mooring line pull from the moored tanker. In the shallow water SALM, the product is lead directly from the product distribution swivel into the submarine pipeline.

The SALM Mooring Buoy

When the moored tanker exerts a peak load pull on the mooring buoh, the entire buoy will be pulled below the surface and in fact, for full design loads the buoy may be submerged 50 - 60 Ft. or more. The SALM buoy is accordingly designed as a cylindrical pressure hull with the governing criteria being adequate safety against buckling of the cylindrical shell. Interior or exterior ring stiffeners are provided as required.

The buoy is divided into four to eight watertight compartments by vertical and/or horizontal bulkheads to provide a safety margin against excessive loss of buoyancy in case the buoy hull is damaged. Rubber fender buffers are provided all around the buoy to reduce impact loads in case of tanker contact with the buoy.

Universal Joints

The anchor leg is attached to the bottom of the buoy and to the top of the distribution swivel with large universal joints. For deepwater SALM's a third universal joint is located at the connection between the riser shaft and the mooring base. The universal joints are usually fabricated as heavy plate weldments with self-lubricating bronze bearings. Pin diameters of the universal joint bearings may range from 12 inches to 16 inches depending upon the magnitude of the maximum design mooring force. The large diameter is basically governed by the need to keep bearing pressures low and assure a 10 year life or more of the facility without detrimental wear and need for replacement of these units.

The SALM Anchor Leg (Anchor Chain)

The connection between the upper and lower universal joint is provided by a length of heavy anchor chain which includes a special large capacity anchor leg swivel. The anchor leg swivel permits the mooring buoy to , rotate freely in response to the weathervaning tanker moored to the buoy. The anchor chain is typically a 6 inch chain with a minimum breaking load capacity of 3, 400, 000 lbs. The anchor leg swivel is of roller bearing construction sealed for permanent service in the submerged seawater environment.

The SALM Product Distribution Swivel

The SALM product distribution swivel unit performs two basic functions. It permits transfer of one or more products to be transferred from a rotating hose arm to the stationary piping built into the mooring base or into the riser shaft for deepwater SALM's as the case may be. It also allows transfer of mooring forces from the universal joint mounted on top of it to the mooring base or the riser shaft. The transfer of forces is accomplished through a large diameter center shaft around which the swivel housing is rotating in a vertical plane. Mooring forces are carried directly through the center shaft to the base or the riser shaft. No strains due to mooring loads are exerted on the swivel bearings.

The submarine section of the discharge hose system is attached to a hose arm mounted on the swivel housing. The hose arm is hinged in a vertical plane to minimize strains on the hose when the hose moves in response to storm waves or direct pull on the hose string. The hose arm also provides a lever arm to facilitate horizontal rotation of the product distribution swivel in response to the weathervaning tanker and hose string.

The SALM Riser Shaft

The riser shaft on existing deepwater SALM's is a simple cylindrical steel shaft internally reinforced with ring stiffeners. For very deep water installations the riser shaft would be designed as a four legged pipe truss in order to minimize the oscillating mass and the hydrodynamic inertia forces acting on the shaft under storm conditions.

The shaft contains the piping required to transfer the discharge products from the product distribution swivel to the base hose attached to the submarine pipeline. Buoyancy chambers built into the shaft near the top will provide vertical stability during installations and during dismantling of the buoy for maintenance overhaul.

The governing design forces for the structural design of the riser shaft are the horizontal components of the dynamic reaction forces, developed and the resulting bending moments in the shaft when the shaft and buoy oscillates during storm conditions.

The SALM Mooring Base

The general configuration and detail design of the SALM mooring base depends to a large extent on the soils conditions at the SALM site.

Two existing SALM terminals utilize a hexagonal "torus" shell with the corners of each shell segment connected to the center of the base by radial plate girders. The installed bases are ballasted with sand fill inside the 8 to 12 Ft. diameter torus shell and are pinned to the sea bottom with 26 inch to 30 inch diameter piles driven through pile sleeves fitted into the torus shell. The structural connection between the pile sleeves and the piles is provided by cement grout placed by pressure grouting from the surface.

A third SALM facility now in service in 300 Ft. of water utilizes a gravity base. The basic feature of this design is a large cylindrical steel "can" 80 Ft. in diameter and 12 Ft. high. Eight buoyancy chambers are mounted radially inside the "can" and serve both as structural girder members and as buoyancy tanks during transport and installation. The provided buoyancy is adequate to keep the structure afloat during transport and installation should the bottom of the "can" be accidentally punctured. A large pedestal in the center serves for attachment of the universal joint connection to the riser shaft.

The installed base structure was filled with crushed rock by dropping the crushed rock material from the surface in a 20 inch diameter chute. The total submerged weight of the steel structure and the rock ballast provide adequate mass to resist mooring loads in excess of the breaking load of the mooring hawsers, in this case a force of 2,300,000 lbs.

The Submarine Hose System

The submerged hose system extends from the floating hose to the hose arm on the product distribution swivel. Generally, this hose is equipped with floatation collars along the length of the hose to provide just enough buoyancy to make the oil filled hose neutrally buoyant. Additionally steel buoyancy tanks are provided at joints between the hoses. The contribution of these tanks to the net buoyancy of the system can be adjusted by ballasting the tanker partially with water or by blowing water out of the tanks. This adjustable feature is needed as a means of providing a final adjustment of the hose profile during installation and later if readjustment become necessary

Floating Hose System and Mooring Hawser

Details of the floating hose system and the mooring hawser system used for the SALM terminal are basically identical to the features already described for the CALM system. Again it may be pointed out that there is no floating hose connection to the mooring buoy.

X. THE SPM MOORING TOWER - (See Fig. No. 4)

SPM Mooring Towers have been in use since 1964 when the first SPM tower mooring for large tankers was placed in operation by Esso Libya, Inc. in the same offshore area where the first SALM was later installed. This facility utilizes a submerged trussed pipe arm in lieu of floating hose to transfer the fluid cargo between the tanker and the tower structure to which the ship is moored. The incentive to use the trussed pipe arm was provided by the need for larger throughput rates than could be provided by available floating hose sizes at the time the facility was designed. This tower mooring has performed well over the years since it was built and is still in service. The trussed pipe arm concept may well be considered again for future tower moorings as needed throughput rates for economic offloading of VLCC's tend to exceed the capacity of available hose sizes.

At least four additional SPM Mooring Towers have been built to date. These facilities all utilize floating hose for cargo transfer between the tanker and the mooring tower.

The Tower Structure

SPM tower structures for VLCC moorings are conveniently built as template structures much in the same manner as offshore drilling platform structures are fabricated and installed. After the prefabricated template structure has been transported to the site and placed on location, anchor piles are driven through the template legs into the seabed to anchor the structure securely against maximum mooring loads and accidental tanker contact.

The Fender System

In order to protect the tower from damage by accidental impacts, a highly efficient fender system with large energy absorption capacity is provided all around the tower. The fender system is generally designed for impact velocities in the order of 0.5 Ft. per second.

The Rotating Superstructure

The tower extends above the waterline to an enclosed control room platform located high enough to be out of reach of storm waves. Above the
control room level is mounted a rotating turntable on which mooring
brackets and a rotating pipe arm is mounted much in the same way as
on the CALM turntable. The pipe arm is cantilevered out beyond the
tower fender system and extends down to the sea level for attachment
of the floating hose system.

The Product Distribution Swivel

A product distribution swivel is mounted in a well in the center of the turntable. This swivel is of similar design as the CALM swivel and permits transfer of discharge product from the pipe arm to a vertical pipe riser leading from the swivel to the submarine pipeline on the sea bottom.

Floating Hose System and Mooring Hawser System

The floating hose system and the mooring hawser systems are basically identical to the arrangements described for the Catenary Anchor Leg Mooring System.

Suitability of SPM Tower Systems

The SPM Tower System is particularly suitable where storm conditions are not severe so that the control platform and turntable structure can be kept well above the maximum storm wave height. The fender system should also preferably be above the reach of most storm waves.

XI. COMPONENT FABRICATION

The major component of a mono-mooring facility will usually be built in a shippard. Such major components include, for a CALM system, the mooring buoy and turntable stucture; for a SALM, the buoy, mooring base and riser shaft, and for an SPM Tower the tower structure and turntable, etc.

As a minimum requirement the shipyard selected to fabricate these components must have facilities and labor capabilities as generally required for fabrication of barge hulls and/or drilling platforms. From the point of view of minimizing transport costs and risks during transport from the fabrication yard to the installation site it is of course advantageous if the shipyard is located not too distant from the installation site; however all the components can be transported to the site as deck cargo on barges or in some cases where transport routes are not too long and hazardous, the major hull components may be towed directly in the self buoyant mode.

Heavy weldment components and machined components such as product distribution swivel units and universal joints, etc. may also be fabricated in the shipyard if the yard has adequate machine tool capacity. However, it will often be found advantageous to have these components manufactured by a machine shop with special capabilities in this area.

Standard manufactured items such as floating hoses, chains and swivel bearings, etc. are purchased directly from vendors of these items. It will generally be found that these components are the long lead items which must be ordered during an early stage of final planning if the total construction schedule is to be kept to a minimum.

Installation procedures will of course vary for the various mono-mooring systems here discussed. However, in each case the installation procedures must be carefully planned in consideration of the special conditions existing at the installation site and the construction equipment available.

The design of individual components must also include consideration of the equipment which will be available for installing the system. This is particularly true for the SALM terminal system and for SPM Tower installations.

XIII. SUMMARY

Summing up - There are at least three basic mono-mooring concepts which have been proven in actual service for mooring and discharge or loading of large tankers in offshore areas.

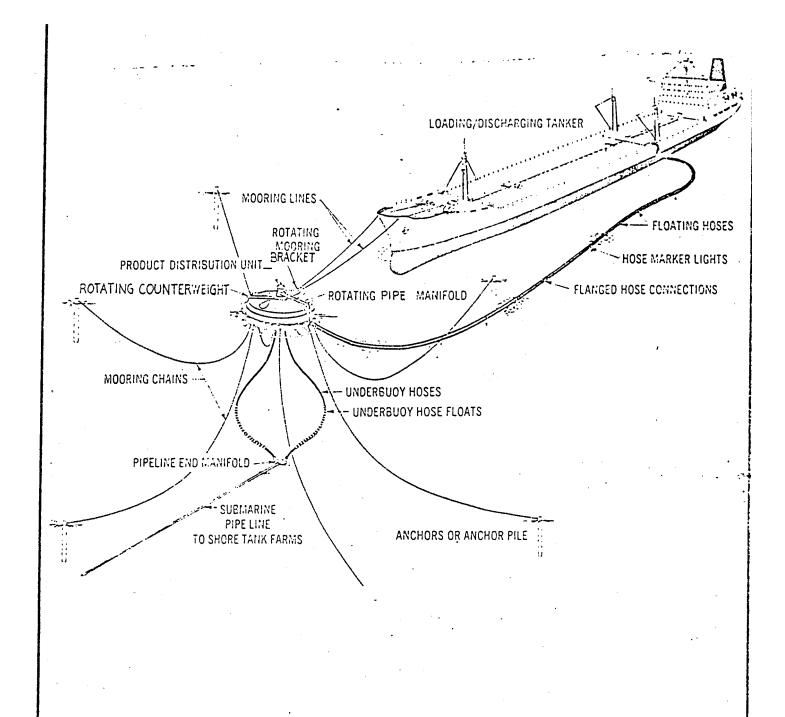
The basic requirements for a specific mono-mooring terminal location must be carefully studied in order to select the basic system best suited to the particular application.

Detailed information regarding environmental conditions and other characteristic site conditions should be obtained at an early stage of the planning effort and must be available for detailed planning and design of a monomoring system.

For environmental conditions and basic requirements similar to monomorings already in service the planning and design of a mono-mooring terminal can safely be carried out based on available design data. In cases where unusual design features are considered or where extremely severe environmental conditions prevail it may be necessary or recommendable to carry out scale model testing to simulate conditions for the proposed facility.

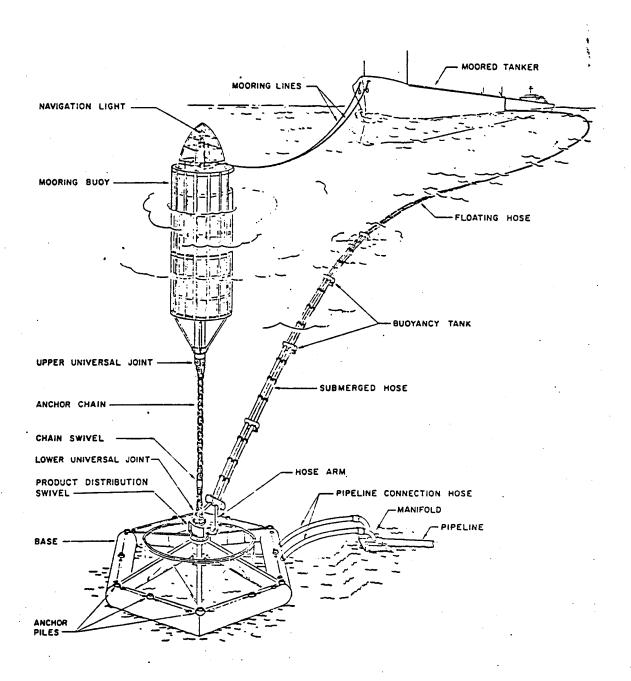
With respect to time requirements for planning, fabricating and installing a mono-mooring facility, it must be borne in mind that a reasonable amount of time must be allotted to obtain adequate field data and to carry out necessary preliminary studies in order to select the optimum system for a particular application. Although the mono-mooring systems that have been discussed here appear to be fairly well standardized experience has shown that there will rarely be two installations with identical or even near-identical requirements.

In view of the pressing need for deep water ports in the U.S. and elsewhere and the realization that mono-moorings provide safe and economical solution in satisfying this need it may be expected that mono-mooring terminal systems will experience a rapid growth in the next few years.

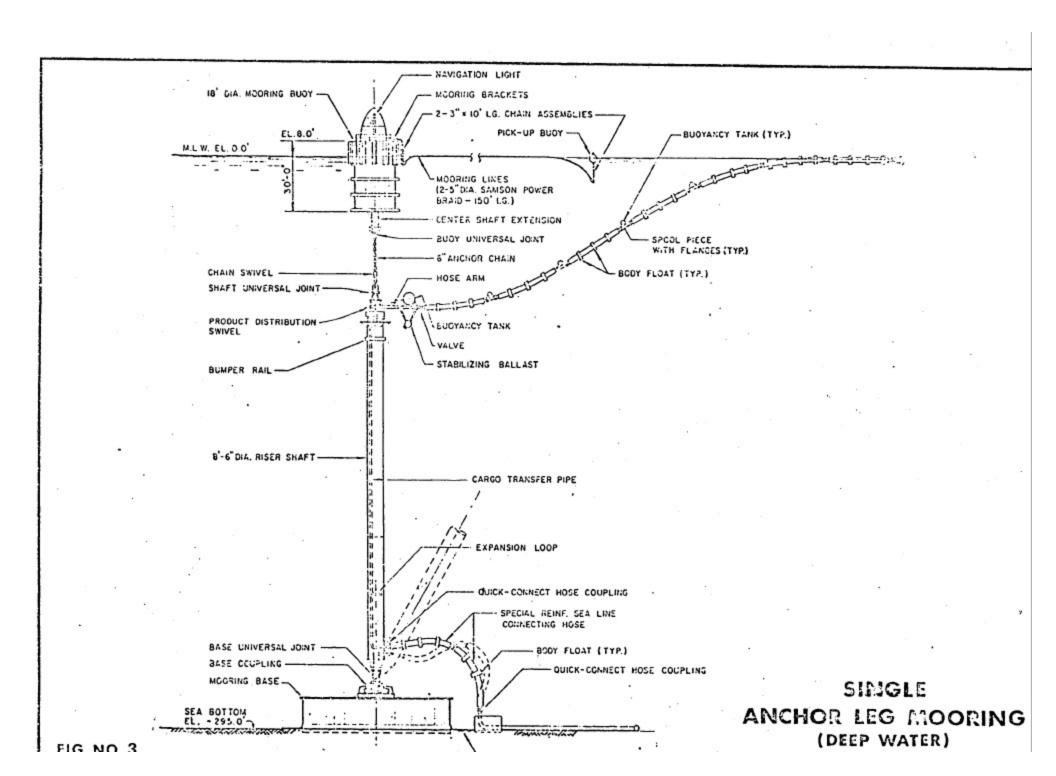


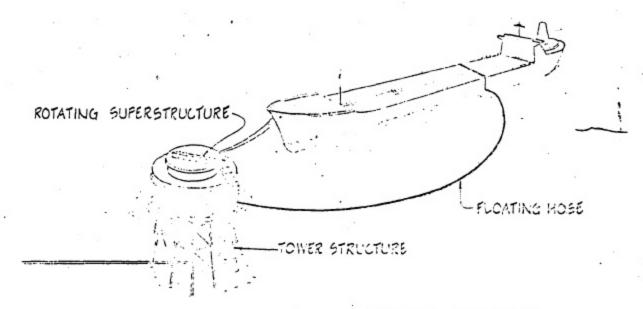
CATENARY
ANCHOR LEG MOORING

FIG. NO.1

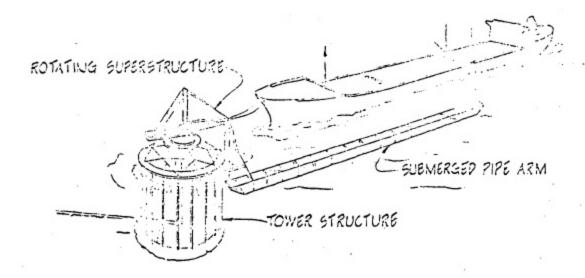


SINGLE ANCHOR LEG MOORING (SHALLOW WATER)





SINGLE POINT MOORING TOWER (FLOATING CARGO HOSE)



SINGLE POINT MOORING TOWER
(SUBMERGED CARGO ARM)