OFFSHORE OIL LOADING FACILITIES

by

K. I. Pedersen
Van Houten Associates, Inc.
New York, N. Y.

A. S. C. E. SEMINAR

on

MARINE CONSTRUCTION

February 1977

OFFSHORE OIL LOADING FACILITIES

K. I. Pedersen
Van Houten Associates, Inc.
New York, N.Y.

INTRODUCTION

In spite of attempts to reduce energy consumption, the amount of oil being produced and transported from overseas producers to consumers in the western world is near all-time records, and the size of new tanker vessels for sea transport of oil are constantly increasing.

The proliferation of larger and larger tanker vessels, for which natural sheltered port areas are hard to find, have led to the development of offshore loading facilities which permit loading and discharging of such vessels in open deep water areas.

Recently offshore loading facilities have also come into use for loading of tankers in offshore production fields. This development is spurred by the need to expedite early production and financial returns on new offshore fields while pipelines for full-scale production are built or, in some cases, an offshore loading system is used for full-scale production in fields where attainable production rates are too low to justify expenditures for long pipelines to shore.

This discussion will deal exclusively with offshore loading facilities which are suitable for open sea locations and to systems which are now in service. The history of development of such facilities will be outlined and basic facility characteristics and requirements will be discussed. Details of design and construction of systems which are in general use today will also be discussed.

DEVELOPMENT HISTORY

The history of the development of offshore oil loading facilities dates back to before the second world war when oil companies first started to use submarine pipelines for transfer of oil between shore-based storage facilities and tankers anchored off the coast in relatively unprotected open waters. The system then developed is still in limited use today and is generally referred to as a "Conventional Buoy Mooring" or, more descriptive, as a "Multi-Buoy Mooring" (see Figure 1).

A tanker vessel moored at a Multi-Buoy Mooring is simply anchored in a relatively fixed position with respect to the seaward end of the pipeline by mooring lines radiating from the bow and the stern of the tanker. The bow anchorage is usually provided by the ship's own anchors while the stern mooring lines are attached to permanently deployed mooring buoys. Flexible hoses, 10 to 16 inches in diameter, provide the cargo transfer connection between the ship's manifold and the submarine pipeline. The hoses simply rest on the sea bed when not in use.

With maximum tanker sizes up to the end of World War II in the order of 17,000 DWT and the maximum loaded draft less than 30 feet, it was not too difficult to find semi-sheltered offshore areas where the above described tanker loading system could be safety employed. Besides, there were numerous locations where more efficient onshore berth facilities could be established with approach channels suitable for these vessels.

However, with the rapid increase in world demand for petroleum products after World War II, and the resulting need for expanded oil transport capacity, the size of new tanker vessels began to increase until by 1955 the supertankers of the day were in the 50,000 DWT class. That was the maximum size vessel which could pass through the Suez Canal at the time, and it was thought that this criteria would provide a practical limit for economically viable tanker sizes. The first closing of the Suez Canal in 1956 changed this picture completely, although this closing lasted only a few months. This event triggered the astonishing rapid development of the very large tankers, which now are generally referred to as VLCC's (Very Large Crude Carriers).

By the mid-sixties, the maximum size tanker being built was in the 200,000 DWT class, and the second closing of the Suez Canal in 1967 gave added impetus to the development of VLCC's. Today there are more than 600 VLCC's in the world with capacity in excess of 200,000 DWT. The largest tanker in service today (Jan. 1977) is the Globtik Tokyo with 477,000 DWT capacity. A tanker of this size has an overall length of 1250 ft., a beam of 205 ft. and a loaded draft of 90 ft. 700,000 DWT tankers with a loaded draft of 100 ft. are expected to be in service within the next few years.

In the U.S., there are, at the present time, only three or four tanker terminals which can handle tanker vessels larger than 60,000 DWT and only two which can handle 100,000 DWT vessels. In other parts of the world where VLCC's are presently being loaded and discharged, suitable sites for conventional fixed berths for mooring of VLCC's are also scarce.

The scarcity of suitable near-shore sites with adequate water depths for VLCC's have led to the development of a number of offshore terminal systems which can be located in open and unprotected deep-water areas.

Multi-buoy moorings as previously described are still used for offshore loading of tankers up to 100,000-150,000 DWT. However, such facilities are only suitable for relatively sheltered areas or where the directions of the wind, wave and current are aligned along one prevalent direction.

The one general concept which has proven successful for offshore tanker loading facilities is the Single Point Mooring concept. The common characteristic of single point mooring facilities is that the tanker is moored to the facility with bowlines to a single point only, allowing the vessel to rotate, or "weathervane," freely around the mooring. A flexible or articulated oil conduit system, which pivots around the same point, is provided for transfer of oil to or from the moored tanker. This permits the vessel to align itself to head into wind, wave and current, reducing mooring forces so that, compared to fixed berth facilities, minimal structural strength and anchoring capacity is required. A vessel moored in this way will exhibit relatively small heave, pitch and roll motions, even under rough sea conditions. Therefore, such facilities can be safely operated in open waters under fairly rough sea conditions.

Four distinct versions of the single point mooring concept are in use today:

1. Catenary Anchor Leg Moorings
2. Single Anchor Leg Moorings
3. Fixed Tower Moorings
4. Articulated Tower Moorings

The first oil loading facility built in accordance with the single point mooring principle was a Catenary Anchor Leg Mooring. It was installed in Sweden in 1959 and, although it was of very modest size, designed for 3,000 DWT vessels, it was followed within two years with facilities designed for 100,000 DWT vessels. Fixed Tower Moorings were introduced in 1964, Single Anchor Leg Moorings in 1969 and Articulated Tower Moorings in 1976.

There are now more than 180 single point mooring facilities in service around the world. At least 65 of these will accommodate tankers in excess of 200,000 DWT. None of these facilities are located in the U.S.

Single point mooring systems are usually located one or more miles off the coast in water depths ranging from less than 100 ft. to more than 500 feet. Further discussions of specific systems will be limited to the above four single point mooring systems.

OPERATIONAL CHARACTERISTICS OF SPM FACILITIES

Regardless of whether a single point mooring is used in an export or import terminal or as an offshore production field facility, the basic functional characteristics are similar. However, there are substantial differences in operational performance requirements and usually also in the environmental conditions governing the design of systems suitable for the two distinct purposes.

- Export or Import Terminals

An offshore export/import SPM facility will usually be located in water depth just adequate to accommodate the largest vessel to be moored. For VLCC loading, this means a water depth in the range of 100-110 ft.

Selection of a suitable site for an SPM terminal is a relatively easy task compared to siting and layout of a fixed berth terminal.

The basic requirements are:

1. 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 feet and preferably more. Clearance over pipeline and pipeline end manifolds must also be considered.

2. Minimum water depth within the maneuvering area. -

   Water depth at low tide 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 four times the overall length of the maximum size tanker for which the SPM is designed.

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

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

Typical maximum loading/discharge rates used for design of export/import facilities range up to 125,000 BPH for 300,000 DWT vessels and correspondingly higher rates for larger vessels.

A loading/discharge rate of 125,000 BPH is practical when using twin 24 inch diameter discharge hoses with each 24 inch hose leading into 20 inch sections of hose at the tanker rail for connection to the tanker manifold flanges. At present, the maximum size of tanker manifold piping is 20 inches and this is generally only found in tankers above 250,000 DWT.

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

SPM facilities 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 internal piping system to the separate discharge hoses.

The same principle may be used for transferring bunker oil to a tanker vessel simultaneously with the crude oil discharge operation, or alternately ballast water may be discharged to shore while crude oil is being loaded.

An export/import tanker terminal often will include several SPM units so that several tankers may be berthed simultaneously. An example of such facilities are the deep water ports planned for construction in the U.S. Gulf Coast area. The SEADOCK terminal off Freeport, Texas is planned to include six SPM units when fully developed. The LOOP terminal off the coast of Louisiana is planned to be of similar scope.

Such terminals will usually include a pile-supported platform complex consisting of one or more pumping platforms and a separate platform for living quarters and control center facilities.

Onshore facilities required for import/export tanker terminals will basically consist of storage tanks and related piping to provide "transit" storage to compensate for discrepancies between pipeline flow and the intermittent loading or discharge of tanker vessels.

Safety control measures for SPM facilities essentially consist of remote controlled emergency shut-down valve systems combined with suitable fire detection and fire fighting systems.

In the U.S. Federal and State laws govern the design and operation of safety systems at SPM terminals.

An essential part of safety and spill control measures to be observed at any oil terminal consist of specific inspection and maintenance procedures carried out at regular scheduled intervals. Special automatic leak control systems are currently being developed. One such system is based on continuous measurement of flow rates at the start and at the end of the piping and hose system. Any difference in flow rate at the gaging points will activate closing valves and shut down pumping pressures immediately.

Regardless of the extent of safety and spill control measures built into the SPM facility hardware and operational regulations, special oil containment booms and spill removal equipment should be immediately available. Such equipment should preferably be stored on service craft stationed in the vicinity of the offshore terminal installations.

- Offshore Production Field Loading Facilities

The operational requirements for an offshore production field loading facility differs in several respects from the requirements for an export/import loading facility.

There are two basic methods of operating loading facilities in offshore production fields. One method involves having a storage vessel moored permanently to the mooring facility. Crude oil is pumped aboard the storage vessel at a constant production rate and is then transferred to shuttle tankers moored alongside the storage vessel at suitable intervals. The crude may have been preprocessed by equipment installed on a production platform or the processing may be carried out on the storage vessel.

The second method of offshore production field loading involves loading the platform processed crude directly into shuttle tankers. When one tanker is full, it departs and is replaced by another tanker. This method is generally used only for offshore fields with relatively low production rates. The method necessitates temporary shut-down of product flow during the changeover interim.

Tanker vessels used for offshore storage and/or shuttle service are usually in the range of 50,000 DWT to 100,000 DWT. However, since the vessels must remain berthed even in very rough weather to avoid shut-down of production, the facility must be designed to allow keeping the moored tanker safely at berth under very extreme environmental conditions.

As a general rule, only production fields in relatively deep water and far from shore, will use production field loading as a means of getting the oil to market. Typical water depths at offshore fields using this method are in the 200 ft. - 500 ft. range.

Because loading rates at these facilities are tied directly to the production rate of the field, and not governed by a desire to load the tanker in a minimum amount of time, the loading rates are very moderate; typically in the order of 2,000 BPH to 10,000 BPH. These loading rates mean that the internal piping and loading hose system will usually consist of a single 8 inch or 12 inch loading line. However, such facilities may also be designed with dual or triple product lines for handling of separate products.

Safety and spill control features to be included in these facilities are basically identical to the requirements outlined for export/import terminals.

CATENARY ANCHOR LEG MOORINGS (CALM)

The basic features of the Catenary Anchor Leg Mooring system are illustrated in Figure 2. Individual components and their functions are further described below.

- 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.

- 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 this 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.

- 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.

2. 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^{o} with respect to the mooring bracket sector. The 90^{o} 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.

- 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 this buoy.

- 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 over-straining 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 joints between the hoses to provide a means for convenient adjustment of the hose profile.

- 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 single point 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.

- Mooring Line System

The mooring line system for a single point mooring facility usually consists of three components:

1. The Mooring Hawser

2. The Chafing Chain

3. The Pick-up Rope

The mooring hawser is attached to the mooring bracket on the buoy with special, timble fittings, chain links and shackles. At the tanker end of the mooring hawser, which is usually 120-150 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.

- Navigational Safety Aids

Navigational aids are usually mounted in the center of the turntable. Such features will always include a long range light beacon and may include radar reflectors and a fog horn. The light and the fog horn will be powered by replaceable dry cell electric batteries which are housed in a watertight container also mounted on the turntable.

- Rigid Mooring Arm

For a permanently moored storage vessel in offshore production field operations, the mooring lines may be replaced by a rigid mooring arm.

The mooring arm is constructed of tubular or box-shaped steel members and in plain view forms an "A" shaped frame which is pivoted on the mooring buoy at the apex of the "A." The legs of the arm are attached with hinged joints on the port and starboard sides of the tanker, about 50 ft. astern of the bow. The hinged joints permit the mooring arm to pivot freely around a horizontal axis. Piping for transfer of oil between the mooring buoy and the storage vessel is carried along one or both legs of the mooring arm.

Advantages of this system as applied to storage vessel mooring are the following:

1. Floating hoses are eliminated.
2. Storage vessel will not ride-up on the mooring buoy in calm weather.
3. Mooring hawser maintenance is eliminated.

- Hose and Hawser Reel-in Features

One special version of a catenary anchor leg moored oil loading system is the spar buoy facility installed by Shell in the Auk production field in the North Sea.

This facility includes large take-up reels for reeling in the loading hose and mooring hawsers when no tanker is moored at the facility. Exposure of these components to severe storm conditions and the resulting deterioration effects are thereby greatly reduced.

To provide adequate stability of the buoy hull to carry the large hose reels on the deck of the buoy, the buoy hull is of a spar buoy configuration. Stability is achieved by solid ballast placed in the bottom of the deep spar buoy hull.

SINGLE ANCHOR LEG MOORINGS (SALM)

The basic characteristics of the SALM system are as follows:

A relatively small mooring buoy is anchored to the mooring base on the sea bottom with a single anchor leg under constant tension. On the buoy deck is located mooring brackets for the attachment of the mooring hawsers and navigational aid features.

A product distribution swivel of a special design suitable for submarine service 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 (Figure 3) while for depths in excess of say 130 ft. an articulated riser shaft is inserted between the mooring base and the product distribution swivel (Figure 4).

One safety feature of the SALM is the ability of the system to allow a tanker to completely override the buoy without contact with the oil carrying swivel or piping components.

The floating discharge hose is not attached to the mooring 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 deep water SALM terminals, the discharged product is carried through piping in the riser shaft to a flexible base hose connection, which allows 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.

- SALM Mooring Buoy

When the moored tanker exerts a peak load pull on the SALM buoy, 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.

- Mooring Base

The general configuration and structural design of a SALM mooring base is primarily governed by the soils conditions of the site.

At locations where the sea bottom has adequate bearing capacity a gravity base will usually provide the most economical solution. However, for shallow water facilities, height restrictions may make a gravity base impractical. In such cases, and where the soils conditions are poor, a pile anchored base may be used.

Ballast material for gravity bases may be sand or stone material or may consist of cement grout or heavy barite material. Barite is available as a fine grained material which may be pumped into base chambers as a water-based slurry. Since weight is essential for a gravity base, it would appear that a reinforced concrete base might be ideal. However, the base structure will usually be built of steel to facilitate transport and installation.

Pile anchoring is achieved by driving pipe piles through pile sleeves in the base. The structural connection between the piles and the pile sleeves is provided by cement grout placed by pressure grouting from the surface.

- SALM Anchor Leg (Anchor Chain)

For shallow water SALM facilities, the connections between the mooring buoy and the base 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 sea water environment.

- Riser Shaft

The riser shaft on existing deep water SALM's is a simple cylindrical steel shaft internally reinforced with ring stiffeners. For very deep water installations the riser shaft may be designed as a four legged pipe truss or intermediate articulations (Universal Joints) may be introduced along the length of the riser.

The shaft contains the piping required to transfer the discharge products from the product distribution swivel to the base hose connected 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.

- SALM Product Distribution Swivel

The SALM product distribution swivel unit performs two basic functions. It permits transfer of one or more products between a rotating hose arm and the stationary piping built into the mooring base or into the riser shaft for deep water 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. 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 about a horizontal axis 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.

- 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 deep water 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 10 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.

- 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 flotation 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 tanks 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 becomes necessary.

- Floating Hose System and Mooring Hawsers

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.

- Rigid Mooring Arm

For mooring of storage vessels in offshore production field operations, a rigid mooring arm of similar design as described for the CALM system may be employed. The connection between the mooring buoy and the hose arm is in this case constructed as a universal joint, eliminating transfer of any torsional strains at this point.

FIXED TOWER MOORINGS (See Figure 5)

At a fixed tower mooring the tanker is moored with bowlines to a rotating turntable mounted on a fixed tower structure. The tower structure is anchored to the sea bottom and contains piping conduits for transferring oil from a submarine pipeline to a product distribution swivel mounted in the center of the turntable. Oil may be transferred between the product swivel and the moored tanker through a rigid submerged arm which "weather-vanes" with the tanker. More commonly, floating flexible hoses are used in lieu of the rigid arm structure, or hoses are suspended directly from the turntable boom to the bow of the moored tanker. In the latter case, it is necessary to apply astern power with the tanker engine during calm weather as the tanker otherwise will drift into the tower structure.

- Tower Structure

Fixed 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.

- Fender System

In order to protect the tower from damage by accidental impacts, a highly efficient fender system with large energy absoption capacity is provided all around the tower.

- 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.

- 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 Fixed Tower Mooring Systems

Fixed Tower Moorings are 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.

ARTICULATED TOWER MOORINGS (See Figure 6)

Articulated Tower Moorings have been in operational use only since the spring of 1976. However, an experimental unit was installed in the Bay of Biscayne off the coast of France in 1968 and has provided substantial engineering and operational data which has been utilized in the design of a unit now being operated by Mobil in the North Sea (Beryl Field).

This system is primarily suitable for large depths and differs from the fixed tower mooring in that the tower structure is slender and is articulated at the bottom in a similar way as a SALM riser shaft.

The tower structure extends approximately 100 ft. above sea level and the upper section of the tower is designed to rotate freely. A 100 ft. long hose boom cantilevers off the rotating head.

Oil is transferred from the submarine pipeline through swivels and internal piping to the end of the hose boom. A loading hose is suspended from the end of the hose boom and is brought over the bow of the moored tanker during loading operations.

The articulated tower mooring is primarily designed for offshore production field loading in relatively deep water.

- Mooring Base

The mooring base for an articulated tower mooring is of similar construction as a mooring base for a SALM facility. At the water depth where articulated tower moorings are used, a gravity base is the preferred design, provided the soils conditions are adequate.

- Universal Joint

On the articulated tower mooring now in service, the articulation between the mooring base and the tower structure is a universal joint of special design which allows flow-through of oil between the base piping and piping built into the tower structure. The oil transfer at this point could also be achieved, as for current deep water SALM facilities, by flexible hose connections.

The connection between the universal joint and the mooring base is designed for convenient underwater installation and will permit disconnection and reinstallation as required.

- Tower Structure

The submerged part of the tower consists of a tubular truss structure with a large buoyancy tank installed approximately 50-60 ft. below sea level. This buoyancy tank provides the stabilizing effect which keeps the tower in a stable vertical position even in heavy seas.

Auxiliary buoyancy tanks are attached near the bottom of the tower structure to facilitate horizontal flotation of the tower during transport and installation of the unit.

The above-water portion of the tower structure is a cylindrical steel shaft which carries the rotating head and hose boom.

- Rotating Head

A large slewing ring bearing, as used for large rotating cranes, supports the rotating head. Product transfer between the tower piping and the rotating head is accomplished through a product distribution swivel similar to a CALM swivel. The product piping is carried to the tip of the hose boom from which the loading hose is suspended.

Diesel engine powered slewing gear permits rotating the hose boom to line up with an approaching tanker. After hook-up of the hose is achieved, the hose boom will be self-aligning under the influence of the pull from the suspended hose.

- Loading Hose

The loading hose may be of size ranging from 10" I. D. to 16" I. D. or more. Under operating conditions the hose drapes freely from the end of the hose boom to the bow of the moored tanker.

At the articulated tower mooring installed in Beryl Field, the tankers being loaded at the facility are assigned as shuttle tankers for this service only. The bow of these vessels have been modified to accommodate the hose and special mooring gear. The vessels are also equipped with bow thrusters for greater maneuverability and control during approach and tie-up operations.

- Mooring Hawser

The mooring hawser system is of similar construction as for other SPM systems, but the articulated tower mooring includes a counterweight loaded take-up arrangement which automatically pulls in the hawser when it is released from a departing tanker.

DESIGN CONSIDERATIONS

Selection of the most suitable oil loading system for a specific project will be governed, not only by operational capacity and safety requirements, but equally by the environmental conditions existing at the proposed site.

The combination of operational requirements and environmental conditions will seldom, if ever, be the same for any two locations, and the selection of the best system and the engineering of the selected system can entail substantial study and design effort in each case.

- Basic Design Parameters

Basic design criteria will include the following data:

1. Maximum tanker size to be moored.
2. Water depth at the site.
3. Wind, wave and current characteristics.
4. Soils conditions at the site.
5. Number and characteristics of products to be handled.
6. Loading or discharge rates required.

The main parameter governing the structural design of the facility components, is the maximum load in the mooring hawser or rigid mooring arm. Actual mooring loads are not static loads but irregular varying forces, which depend on the dynamic interaction between the tethered tanker and the mooring system, as the tanker is acted upon by external forces due to wind, wave and currents.

The maximum peak loads to be expected at a given facility can be determined in terms of probability of occurrence from the results of model tests simulating the actual installation, and the wind, wave and current conditions in accordance with Froudes law of dynamic similitude. Model testing under carefully controlled conditions is the most reliable method for determining peak mooring loads.

Several attempts have been made to develop computer programs which will simulate the dynamic response of a tanker moored to a SPM facility and thus allow an analytical evaluation of the maximum mooring forces. However, to the writer's knowledge, no such program has yet been developed to the extent that it can be used with confidence.

For articulated risers and articulated mooring towers, the bending moments in the riser shaft or tower structure will be governing for structural design. These bending moments are due to wave and current forces acting directly on the structure, and to dynamic effects of the movements of the moored tanker and the articulated riser or tower. Such bending moments may be evaluated with some confidence by computer analysis, but again, model testing under carefully controlled conditions is the preferred method.

- <u>Fatigue Effects</u>

Structural design of components and details which are subject to repetitive cycles of stress variations and reversals must include consideration of fatigue effects. Generally, SPM facilities are designed for an expected service life of 20-25 years. Load cycles will be of varying intensity, but the total number of stress cycles of significant intensity for fatigue effects may be in the order of one to three million cycles during a service life of 20 years.

- <u>Installation Equipment Availability</u>

As a general rule, a very important consideration in the design of a specific facility is the availability, or absence as the case may be, of heavy floating construction equipment in the part of the world where the facility is to be installed. Consideration of this factor during the early planning stages for a given facility is mandatory if unforeseen difficulties or costly design changes are to be avoided.

- <u>Special Features</u>

The design of such facilities also offer great opportunities for savings to be achieved by special built-in features, which will minimize the requirements for floating installation equipment and underwater diver services. An example of such features are built-in buoyancy tanks in the mooring base for single anchor leg moorings or articulated tower moorings. Such buoyancy tanks may make the unit self-floating and also may be used to minimize the submerged weight of such components, thereby facilitating lowering of the unit to the sea bottom. Other examples are special designed hydraulic operated coupling devices for underwater connections and guide wire arrangements to guide components in place during lowering.

- <u>Design Guidelines</u>

In addition to commonly used design standards for structural and mechanical design of oil industry facilities, the following design guidelines are relevant to the design of offshore oil loading facilities:

1. American Bureau of Shipping: "Rules for Building and Classing Single Point Moorings."

2. Buoy Mooring Forum: "Specifications for Rubber Wire-Reinforced Oil Suction and Discharge Hoses for Offshore Moorings."

3. American Petroleum Institute: "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms."

4. Det Norske Veritas: "Tentative Rules for the Construction and Classification of Offshore Loading Systems."

FABRICATION AND INSTALLATION

Lead times required for planning, fabricating and installing an offshore oil loading facility of the types discussed herein may range from 10 months to 24 months or more, depending upon the size and complexity of the system.

- Component Fabrication

The major components of the facilities discussed herein will usually be built in a shipyard. Such major components include, for a CALM system, the mooring buoy and turntable structure; for a SALM, the buoy, mooring base and riser shaft, and for fixed or articulated tower moorings, the tower structure, rotating head and base structure, 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 close to 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 as self-buoyant units.

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 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

Installation procedures will, of course, vary for the various offshore oil loading 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.

Typical for all systems, the installation requires the services of an experienced marine contractor with adequate equipment to handle the components to be installed. The field personnel must include an experienced diving crew to carry out underwater work. Diving services are often subcontracted to a diving company which specializes in this type of work.

Equipment requirements include floating, barge rigs, with adequate hoisting capacity for the heaviest lifts to be handled. Personnel launches and workboats, as well as shore-based support facilities, must also be available. Auxiliary tools and equipment required will include air compressors, marker buoys, temporary mooring anchors as well as support equipment for diving operations.

Prior to actual installation, all components to be assembled under water must be trial assembled in the dry. This trial assembly should preferably be carried out by the same personnel which will carry out the actual underwater assembly

Typical installation sequences and procedures for the systems previously discussed will be briefly outlined.

(A) CALM Installation Procedures

Procedures and sequences of installation for a pile anchored CALM system will be as follows:

1. Locate anchor points for 4 to 8 anchor chains as required. Mark locations on sea bottom and with marker buoys.

2. Set all anchor piles by driving or by grouting into predrilled holes.

3. Attached anchor chain to anchor piles and lay chains along radial lines toward buoy location.

4. Tow mooring buoy to location and attach chains to buoy. Attach chains in opposing pairs to facilitate keeping buoy on location during installation.

5. Tension all chains to desired pretension force.

6. Install pipeline and manifold for connection of underbuoy hoses.

7. Install underbuoy hoses.

8. Install floating hose system.

9. Conduct pressure tests on product piping and hose systems.

10. Install mooring hawser systems.

(B) SALM Installation Procedures

For a SALM facility with a riser shaft, typical installation procedures are as follows:

1. Locate and set deadweight or ship's anchors for guideline control of the mooring base during lowering to the sea bottom.

2. Prepare mooring base for lowering. Connect riser shaft to mooring base with riser guyed in vertical position, or for long risers with the riser shaft floating in a horizontal position at this stage.

3. Lower mooring base to sea bottom letting the riser follow into upright position if not already fixed in that position. Remove any guy lines on the riser.

4. (a) If a gravity base - Fill base with ballast material.

   (b) If a pile anchored base - Set anchor piles by driving or grouting into predrilled holes. Grout annulus between piles and pile sleeves in base structure.

5. Float mooring buoy into location. Ballast with water to lower buoy into position for attachment to riser shaft Connect to top of riser and deballast to achieve desired pretensioning in achor leg.

6. Install pipeline end manifold.

7. Install hose connection between pipeline end manifold and SALM piping.

8. Complete installation as outlined in steps 8-10 for CALM system.

(C) Fixed Tower Installation

Installation of a fixed tower mooring will require procedures very much similar to the installation of a fixed drilling platform using template jacket construction.

Since there are no underwater mooring parts, and underwater connections are limited to the flange-up between the submarine pipeline and a riser leading to the top of the tower, there will generally be less diving work associated with the installation of a fixed tower mooring than with the other systems discussed herein.

(D) Articulated Tower Installation

Installation of the tower structure and the mooring base for an articulated tower mooring generally require the same procedures as for installation of the mooring base and riser shaft of a SALM system. However, the components involved will usually be much larger and heavier than for a SALM facility and consequently heavier equipment will be required.

Installation of above water components of an articulated tower will proceed in a straightforward manner, but will require a floating rig with high reach and large lifting capacity.

- Start-up and Operation

For any offshore loading facility, the installation is generally followed by a start-up period in which operating personnel are made familiar with operating procedures to be followed.

Operating manuals including Inspection and Maintenance instructions, prepared by the designer of the facility, are submitted to the operating personnel for their guidance in continued operation and maintenance of the facility.

CONCLUSION

There are at present four types of oil loading facilities which have been proven in actual service for mooring and discharge or loading of large tankers in offshore areas. Three of those, the CALM, the SALM and the Articulated Tower, are suitable for unprotected open water.

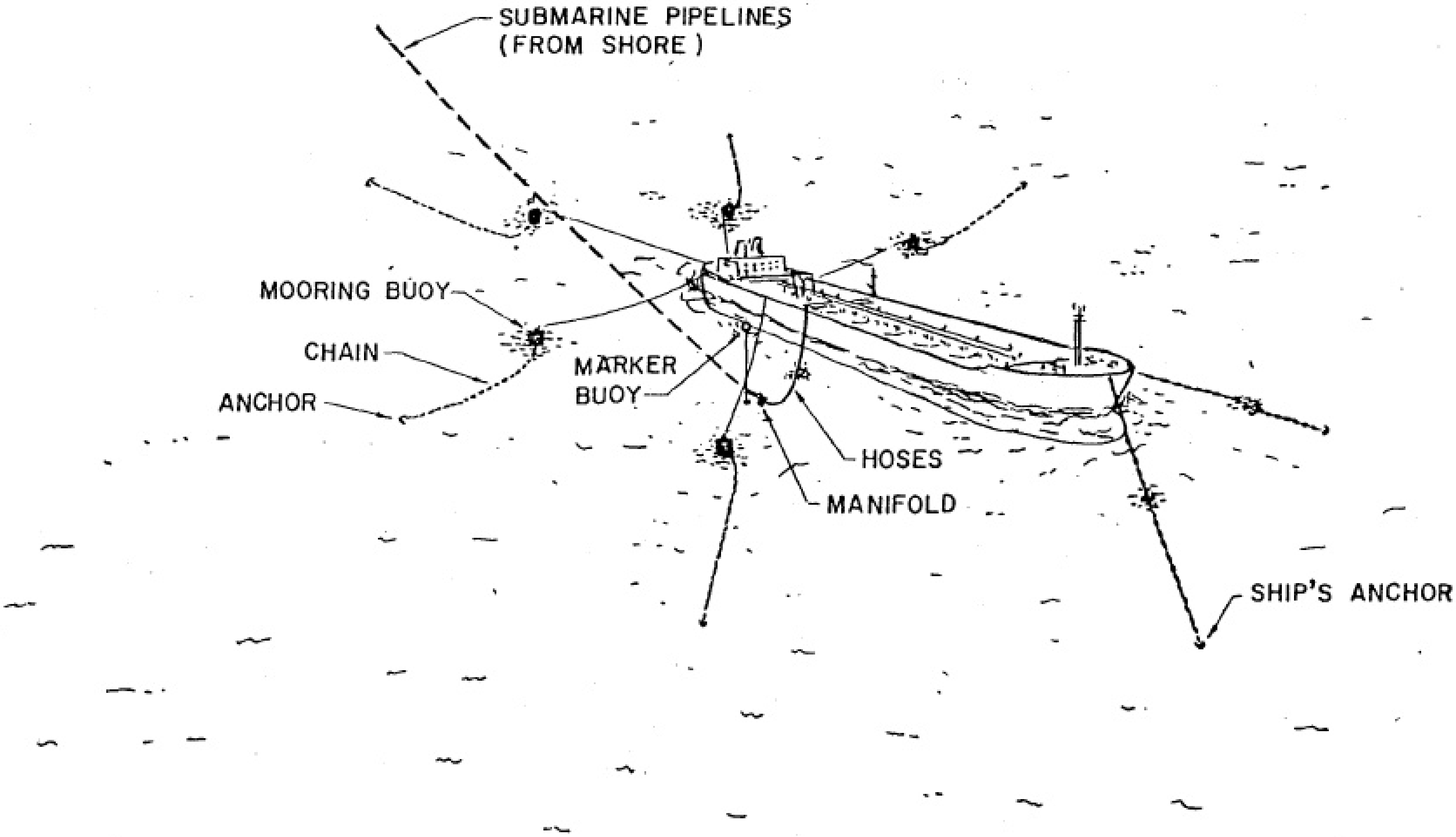
The basic requirements for a specific offshore oil loading facility must be carefully studied in order to select the basic system best suited to the particular application, and location. Detailed information regarding environmental conditions and other characteristic site conditions should be obtained at an early stage of the planning effort and must be available for detailed planning and design.

For environmental conditions and basic requirements similar to facilities already in service, the planning and design of an offshore oil loading facility can safely be carried out based on generally available design data. For special requirements, or where severe environmental conditions prevail, it will usually be necessary to carry out scale model testing to generate adequate design data.

With respect to time requirements for planning, fabricating and installing an offshore oil loading facility, it must be borne in mind that time must be allotted to obtain adequate field data and to carry out necessary preliminary studies, perhaps including model tests, in order to select the optimum system for a particular application. Although the systems that have been discussed here appear to be fairly well standardized, experience has shown that there will rarely be two installations with identical requirements.

In view of the need for deep water oil loading facilities in the U.S. and elsewhere, and the realization that single point mooring systems provide safe and economical solution in satisfying this need, it may be expected that such systems will experience a rapid growth in the next few years.

VAN HOUTEN ASSOCIATES INC.
CONSULTING ENGINEERS NEW YORK



CONVENTIONAL BUOY MOORING

FIG. 1

VAN HOUTEN ASSOCIATES INC.
CONSULTING ENGINEERS NEW YORK

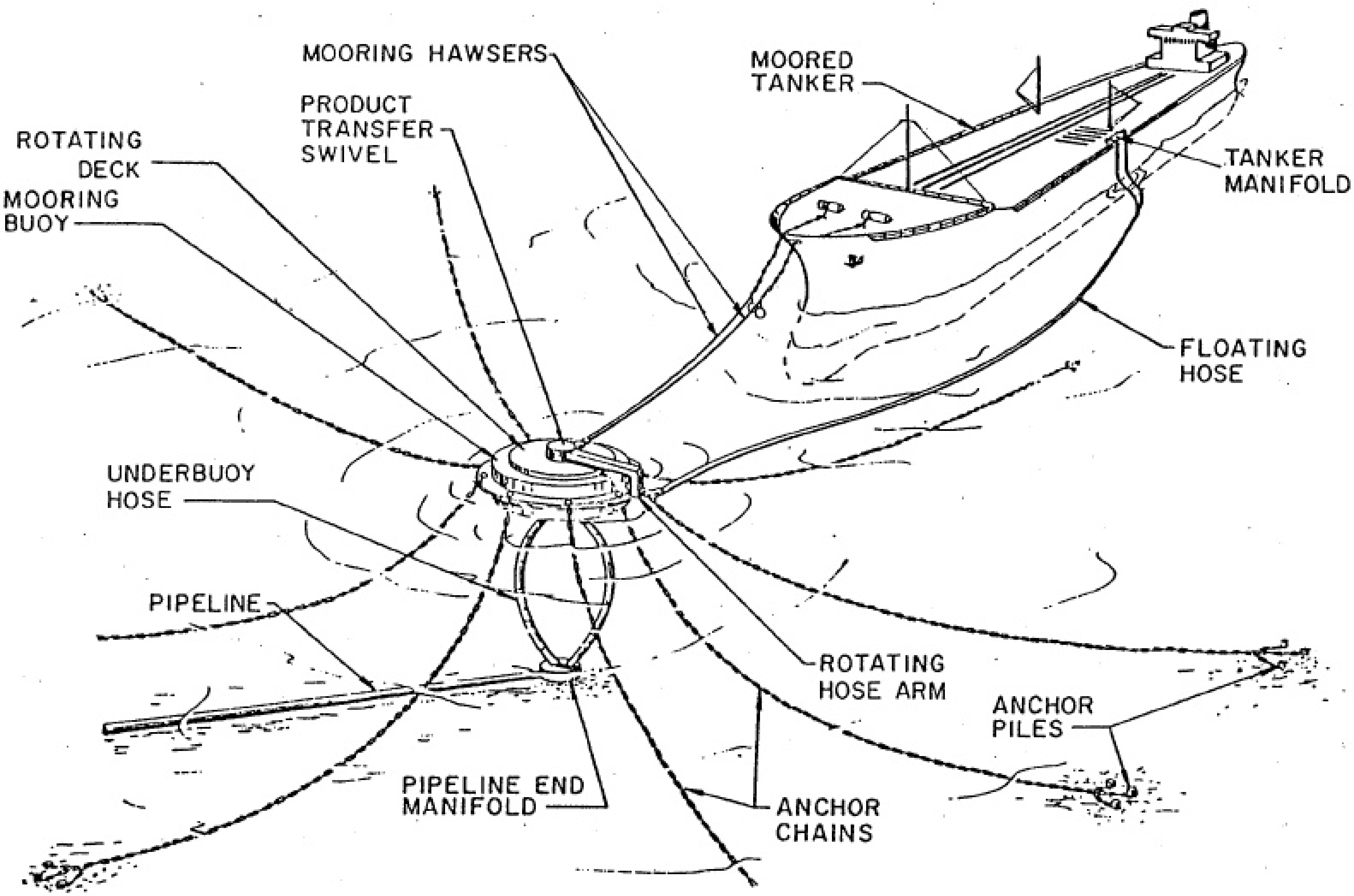


FIG. 2

CATENARY ANCHOR LEG MOORING(CALM)

VAN HOUTEN ASSOCIATES INC.
CONSULTING ENGINEERS NEW YORK

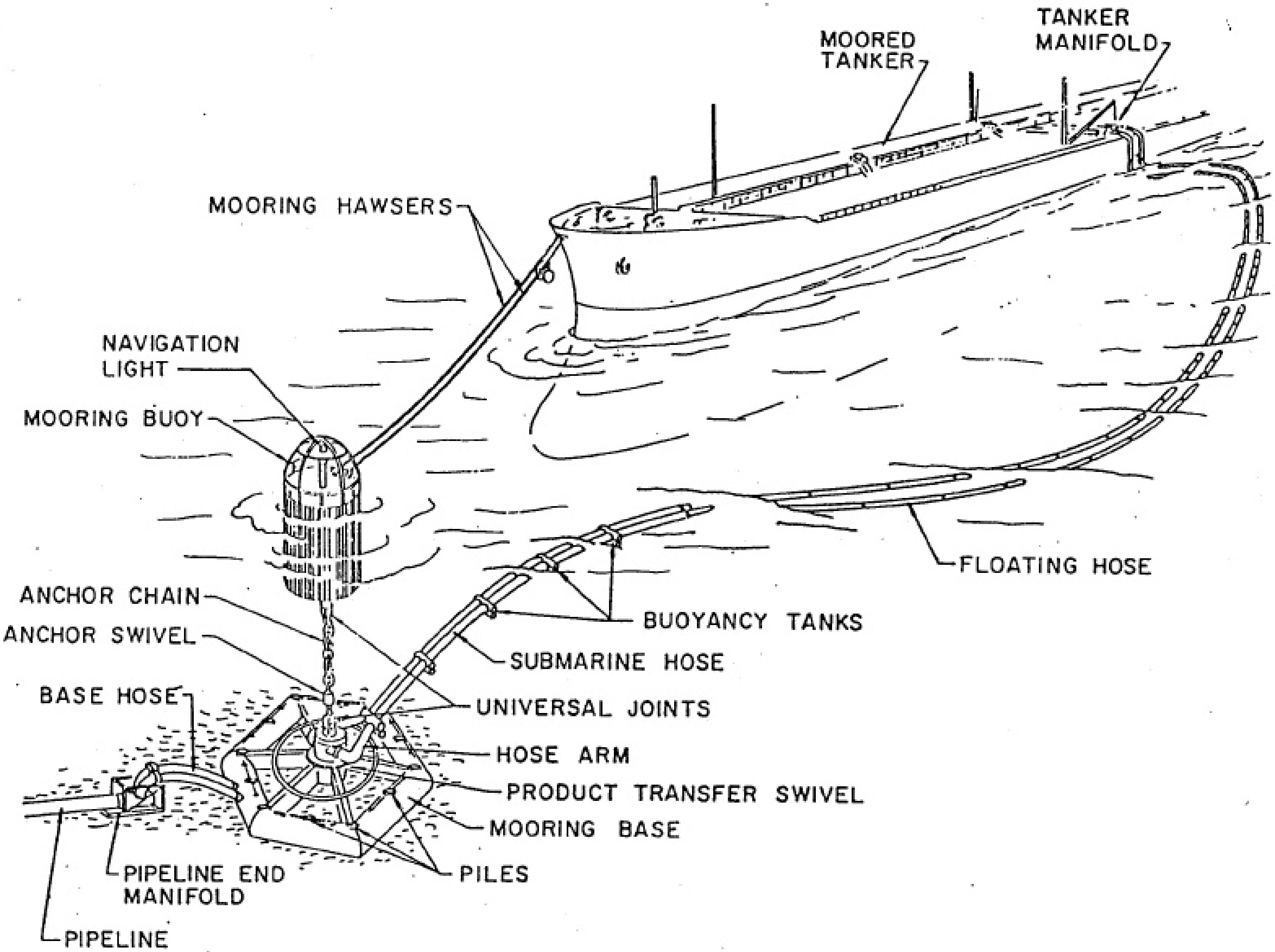
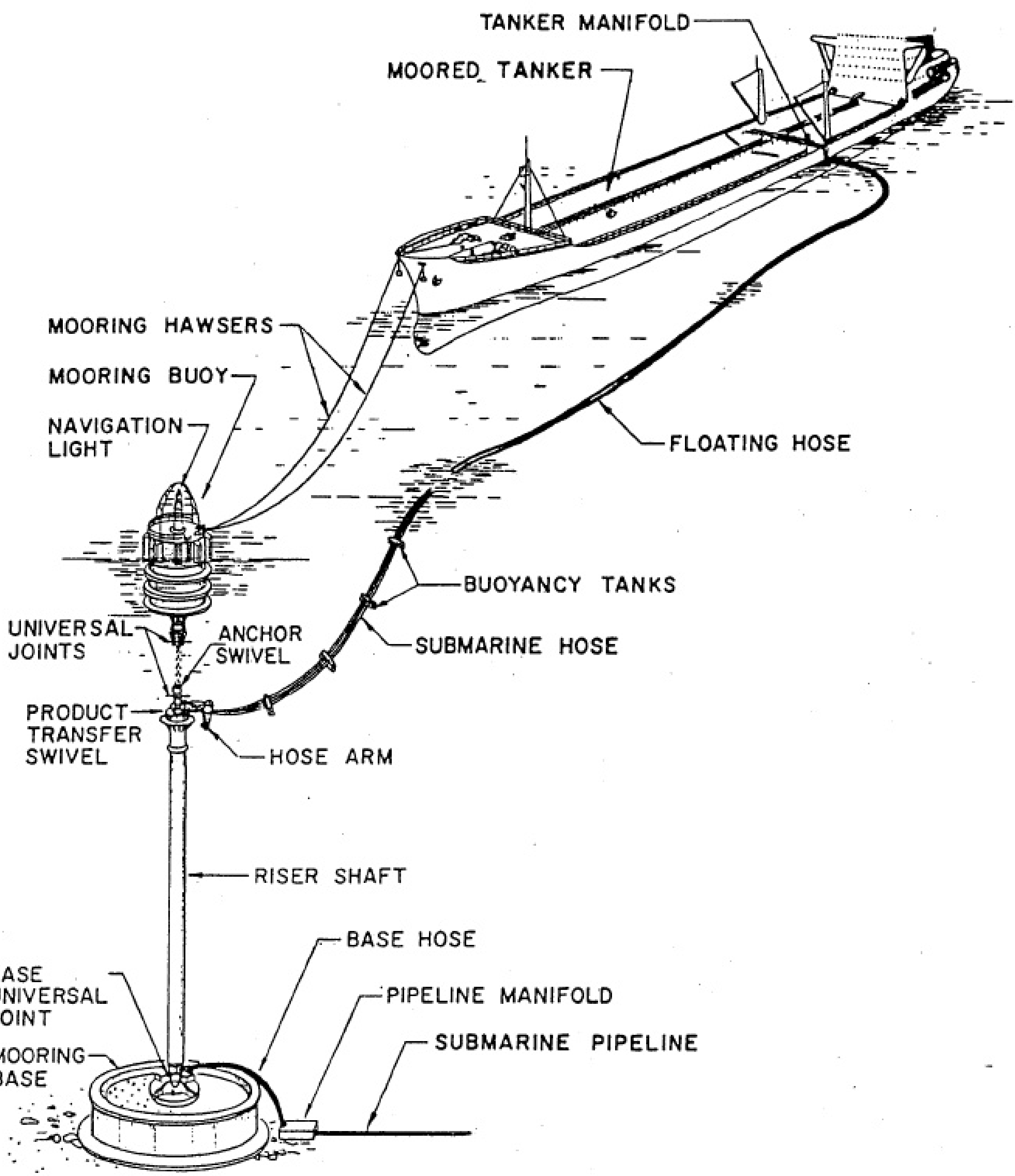


FIG. 3

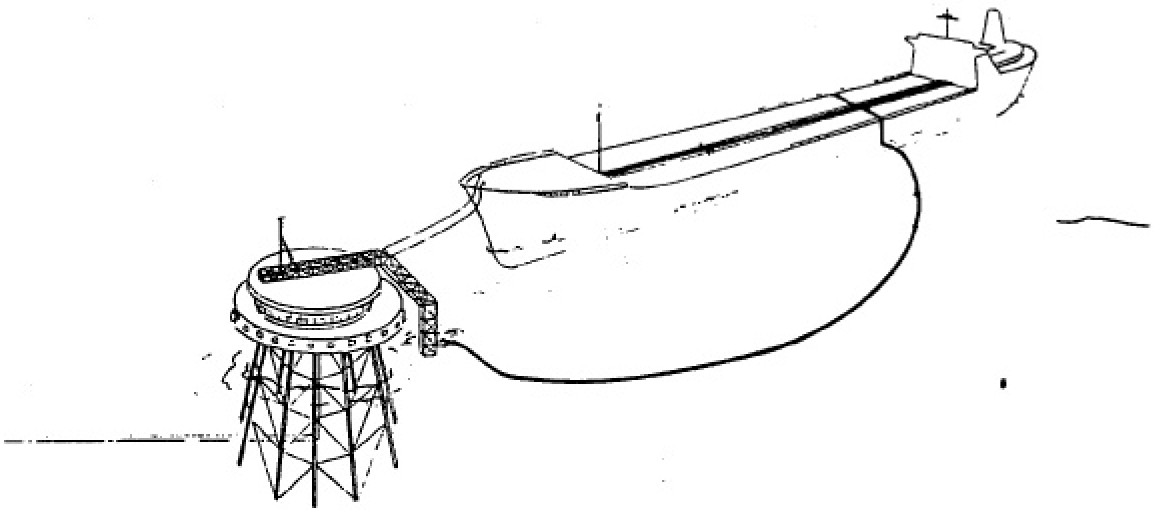
SINGLE ANCHOR LEG MOORING (SALM)
SHALLOW WATER SYSTEM



SINGLE ANCHOR LEG MOORING (SALM)
DEEP WATER SYSTEM

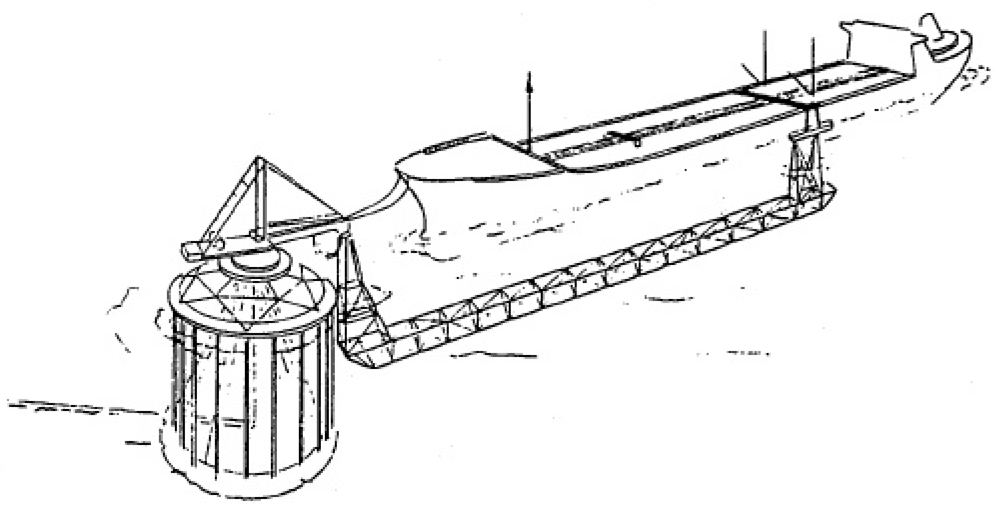
VAN HOUTEN ASSOCIATES INC.
CONSULTING ENGINEERS NEW YORK

FIG. 4



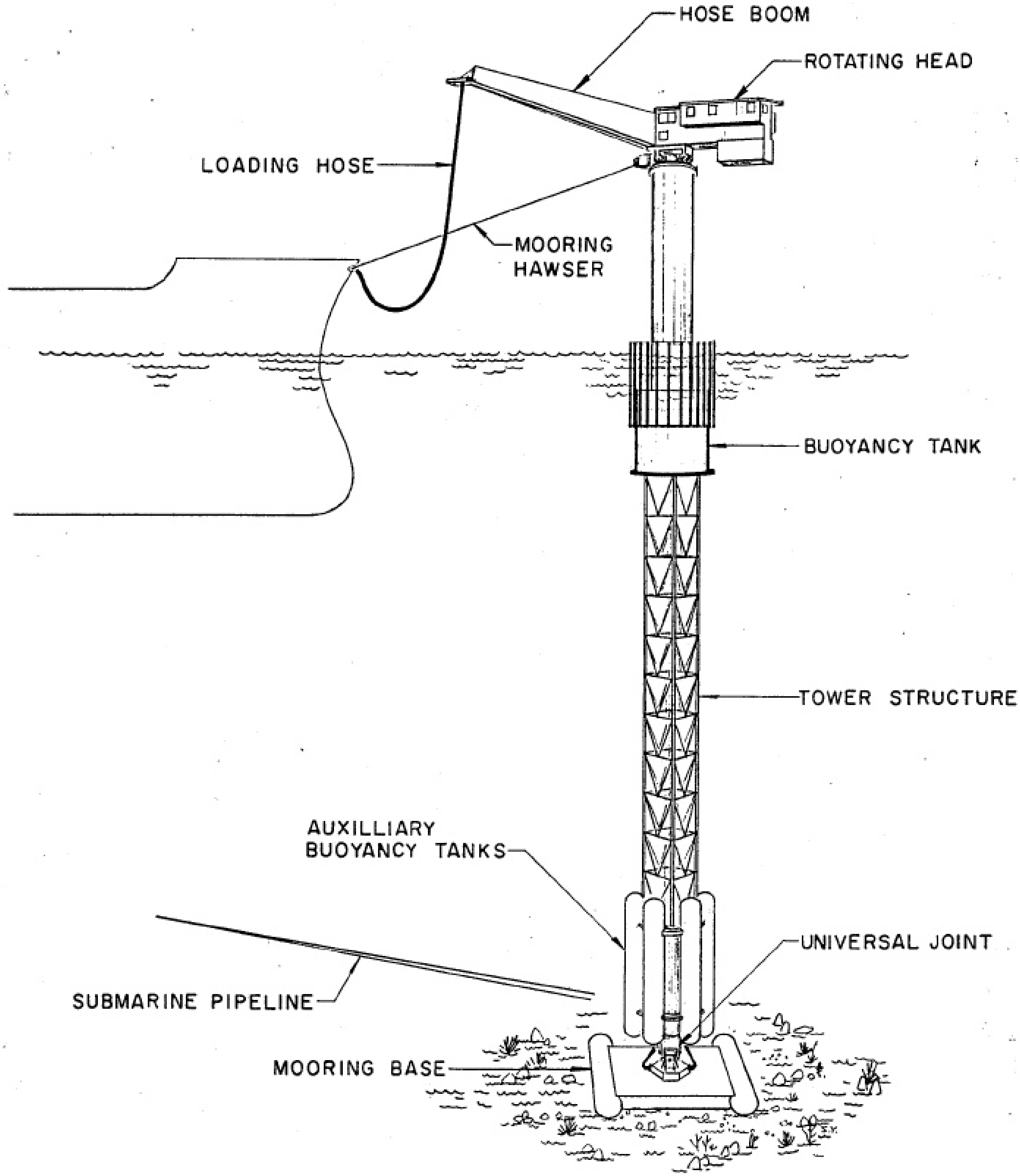
SINGLE POINT MOORING TOWER

(FLOATING CARGO HOSE)



SINGLE POINT MOORING TOWER

(SUBMERGED CARGO ARM)



ARTICULATED MOORING TOWER

FIG. 6