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SCOPE

This Design Practice, along with the references, provides criteria and guidelines for planning and design of offshore berths. Included in the scope are multiple buoy moorings (MBM) and single point mooring systems (SPM). The single point mooring systems covered include catenary anchor-leg mooring systems (CALM) and single anchor-leg mooring systems (SALM). Also included are the associated offshore pipeline and hose systems.

This design practice provides an overview of the various offshore berths and their components, including the pipeline and hose systems. Issues that must be considered in the design and their impact on the design are discussed. Information is provided to assist with the selection of the appropriate berth type and to locate and evaluate the design of the system. Design requirements for offshore pipelines and requirements for specification and supply of offshore hose systems are also included.

Fabrication and installation considerations for SPMs are addressed and installation methods for offshore pipelines are discussed. Certification and classing considerations for SPMs are also provided.

The information included herein is intended for the planning and design of new facilities. The information can also be used for replacement of individual components on existing systems or for evaluation of existing systems.

Deepwater mooring systems for production facilities are not covered in this design practice.

Because the basic units for this technology are metric, the usual convention of using customary first has been reversed for the units.

REFERENCES

DESIGN PRACTICES

- DP XXIII-A Basic Loading System
- DP XXXI-I Minimum Safety Requirements for Marine Terminals

GLOBAL PRACTICE

- GP 19-1-1 Paint and Protective Coatings

OTHER REFERENCES

American Bureau of Shipping

- ABS 2, *Rules for Classifying and Building Steel Vessels*
- ABS 8, *Rules for Building and Classing Single Point Moorings*
- ABS 39, *Certification of Offshore Mooring Chain*

American Petroleum Institute

- API RP 2A, *Recommended Practice for Planning, Designing, Constructing Fixed Offshore Platforms*
- API 2SK, *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures*
- API RP 14F *Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1 and 2 Locations*

American Society for Testing and Materials

- ASTM A36 / A36M, *Standard Specification for Carbon Structural Steel*
- ASTM A153-01, *Standard Specification for Zinc Coating (Hot Dip) on Iron and Steel Hardware*

American Society of Mechanical Engineers

- ASME B31.3, *Process Piping*
- ASME SEC VIII D2, *SISI Units (Boiler and Pressure Vessel Codes)*
- ASME SEC IX, BPVC SECTION IX, *Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators Addenda - 1995; Addenda - 1996; Interfiled (Boiler and Pressure Vessel Codes)*

Crane Manufacturer's Association of America, CMAA 70, *Specification for Electrical Overhead Travelling Cranes*

Det norske Veritas (DnV)

- Rules for the Design and Construction and Inspection of Offshore Tanker Loading Systems*
- Rules 2 pt 3 ch 2 F100*

Lloyds Register of Shipping, 2000, *Rules and Regulations for the Classification of Ships*

NACE RP0394, *Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating; Errata*

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Naval Facilities Engineering Command (NAVFAC) Design Manual 26.5, *Fleet Moorings - Basic Criteria and Planning Guidelines*

Oil Companies International Marine Forum

OCIMF-2, *Buoy Mooring Forum Hose Guide*

OCIMF-3, *SPM Hose Ancillary Equipment Guide*

OCIMF-4, *Buoy Mooring Forum SPM Hose System Design Commentary*

OCIMF-6, *Standards for Mooring Equipment Employed for Ships at Single Point Moorings*

OCIMF-7, *Hawser Test Report*

OCIMF-10, *Guide to Purchasing Hawsers*

OCIMF-11, *Procedures for Quality Control and Inspection During the Production of Hawsers*

OCIMF-14, *Predictions of Wind and Current Loads on VLCCs*

OCIMF-19, *Single Point Mooring Operations and Maintenance Guide*

OCIMF-20, *Guide to Purchasing, Manufacturing and Testing of Loading and Discharge Hoses for Offshore Moorings*

Society for Protective Coatings

SSPC SP 5, *Joint Surface Preparation Standard White Metal Blast Cleaning*, NACE No. 1: 1999 (Steel Structures Painting Manual, Ch 2 - Surface Preparation Specs.)

SSPC SP 10, *Joint Surface Preparation Standard Near-White Metal Blast Cleaning*, NACE No. 2: 1999 (Steel Structures Painting Manual, Ch 2 - Surface Preparation Specs.)

GENERAL

TYPES

Multiple Buoy Moorings (MBM)

There are two main categories of Multiple Buoy Moorings (MBM) (Refer to **Figure 1**):

- Conventional Buoy Berth (CBB) - Offshore berths in which the ship's bow is held in position by the ship's own anchors while 3 to 7 mooring buoys are used to secure the stern. CBBs are the most common type of MBM.
- All Buoy Berth (ABB) - Offshore berths in which both the ship's bow and stern are held in position by a total of four to eight mooring buoys. ABB's are generally located where bottom conditions prevent the use of ship's anchors or where additional mooring restraint is needed for the expected environmental conditions.

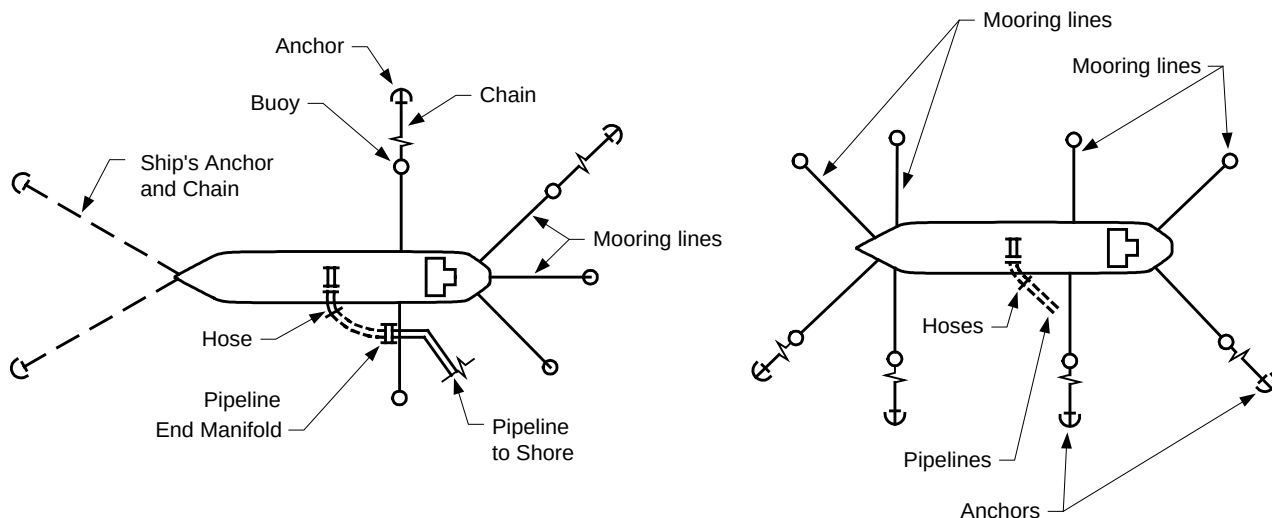
At buoy berths, submarine pipelines run from shore tankage to the area of the buoys. Loading or unloading operations are accomplished through a system of flexible hoses that are connected between the submarine pipeline end manifold and the ship's manifold.



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GENERAL (Cont)

FIGURE 1
TYPES OF MULTIPLE BUOY BERTHS



CONVENTIONAL BUOY BERTH (CBB)
(May have 3,5, or 7 Buoys, Shown Above)

ALL BUOY BERTH (ABB)

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Single Point Moorings (SPM)

At SPMs, ships are moored with only a bowline to a single buoy or tower. Consequently, the ship is free to weathervane around the point to which the bowline is attached. The cargo is transferred by rubber hoses between the ship's manifold and a cargo swivel located on the SPM. The tanker can freely swing around the mooring in response to the environment while simultaneously transferring cargo.

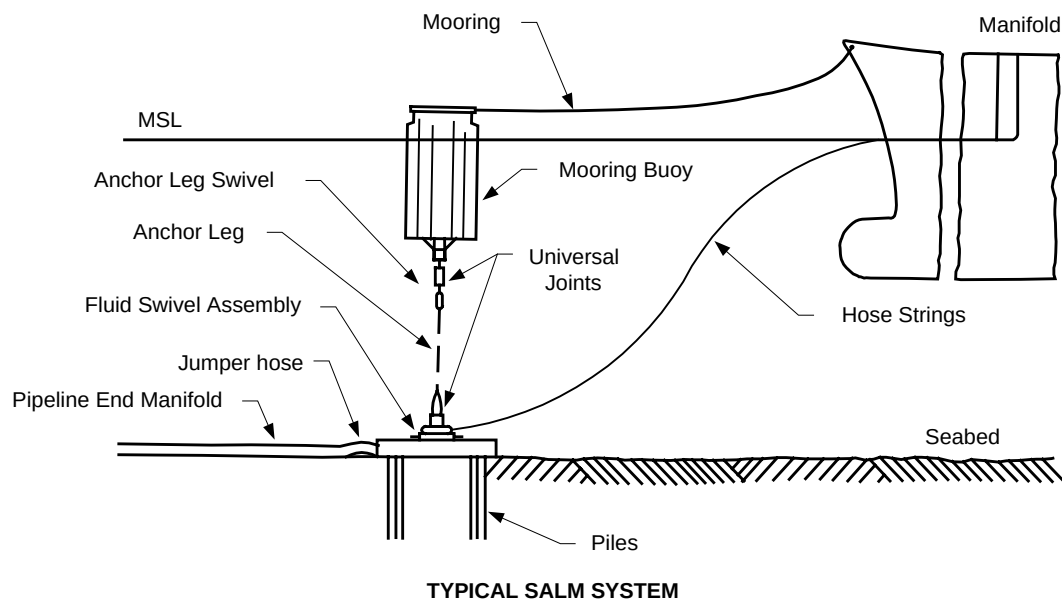
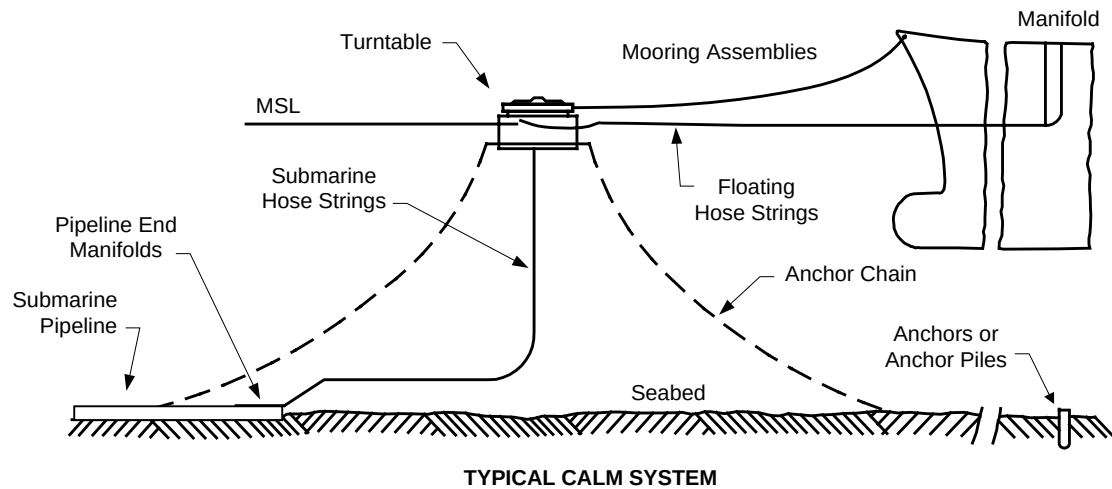
The two most common types of SPM's are (refer to **Figure 2**):

- **CALMs** - Catenary Anchor Leg Moorings are comprised of a single buoy restrained by four to eight conventional chain-anchor legs. The cargo is conveyed between the submarine pipeline and the buoy by submarine hoses. The mooring line is connected to the cargo swivel on the buoy by a lever arm. This device is used to rotate the swivel with the mooring line. Floating hoses connect the cargo swivel on the buoy to the vessel manifold. CALMs are the most common type of single point mooring.
- **SALMs** - Single Anchor Leg Moorings are comprised of a buoy moored by means of one vertical chain or pipe attached to a single base anchored to the seabed. The cargo is transferred from a submerged cargo swivel to the ship's manifold by rubber hoses. The swivel is turned by the cargo hoses. The ship's bow mooring line is attached to the buoy.

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GENERAL (Cont)

FIGURE 2
TYPES OF SINGLE POINT MOORING BERTHS



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GENERAL (Cont)

SELECTION OF SYSTEMS

Buoy moorings in general, and SPMs in particular, provide the flexibility to operate a terminal in areas where the environmental conditions would make it impossible or impracticable to operate a conventional pier. MBM berths are typically operated in areas where wave heights are up to 1.2 m (4 ft). SPMs, requiring the use of tugs and support craft, are typically operated in waves up to 2.5 m (8.2 ft). Other advantages of offshore berths over conventional piers include:

- Fabrication and installation costs are generally advantageous.
- Planning and installation can be completed in a short period of time.
- Design flexibility facilitates application to a variety of circumstances.
- Berthing and unberthing frequently does not require tugs.

Disadvantages to offshore berths are primarily operational. The most significant considerations include:

- MBMs are typically designed to handle a certain class of ship and may not be suitable to handle other classes with different dimensions.
- Deteriorating weather conditions may require shutdown of cargo conditions and in some cases may require the ship to vacate the berth.
- The terminal typically is required to provide a shore based mooring gang to assist with mooring / unmooring and hose hook-up / disconnect.
- The terminal typically is required to provide one or more seagoing mooring launches.
- At SPMs the terminal will be required to provide the hawser, and at some exposed MBM locations the terminal may also be required to provide mooring wires permanently attached to the buoys.
- Offshore pipelines are more expensive to install than onshore piping.
- Offshore pipelines can be long and frequently loading / discharge rates are lower than at conventional piers.
- It may be difficult to clear the pipelines between transfers if more than one product is handled.
- Hose handling can be complicated and time consuming.
- Supply craft are required to provide bunkers and fresh water, unless separate pipelines are provided.
- Access must be provided to/from the moored vessel. This can involve transfer of stores and large quantities of provisions.
- Inspection and maintenance work typically requires specialized craft and divers.

ADDITIONAL REFERENCES

API 2SK *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures* provides rational methods for analyzing, designing and evaluating the SPM mooring systems described in this Design Practice. Additional guidelines for model testing, design and analysis of the SPM hawser can be found in Exxon Report No. EE-17E.T77 *Guidelines for Deepwater Port Single Point Mooring Design*.

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The latest editions of the following OCIMF publications provide additional technical, operating and maintenance background and guidance for offshore facilities. Although most of these documents are specific to SPM systems, some of the design and analysis methodologies, model testing, and anchor leg hardware can be selectively applied to MBM terminals.

- **Single Point Mooring Maintenance and Operations Guide** - Provides guidelines to operators of SPM terminals to assist in the preparation of operating and maintenance manuals.
- **Guide to Purchasing, Manufacturing and Testing of Loading and Discharge Hoses for Offshore Moorings** - This publication gives the minimum specification of acceptable technical requirements to ensure the satisfactory performance of rubber, reinforced, smooth bore, oil suction and discharge hoses for offshore moorings. The specification is divided into two parts: technical requirements for commercial hoses and technical requirements for prototype hose approval. Notes to the purchaser are included listing items which should be specified or agreed with the manufacturer. It includes reference to double-carass hoses, lifting lug requirements, float design requirements, standardization of bead float collars and standards for packing.
- **Guidelines for the Handling, Storage, Inspection and Testing of Hoses in the Field** - Gives guidance on the handling, storage, inspection and testing of hoses under service conditions.
- **SPM Hose Ancillary Equipment Guide** - Gives guidance on common descriptive terminology and technical requirements for the designer and operator of SPM systems.
- **SPM Hose System Design Commentary** - A commentary on the two most common types of SPM (CALM and SALM) reflecting modern practices, providing descriptive terminology together with an outline of present practice in the design of hose systems.
- **Recommendations for Oil Tanker Manifolds and Associated Equipment** - Gives recommendations aimed at introducing conformity in manifold arrangements for all ocean going tankers engaged in the transport of crude oil and bulk liquid petroleum products, including guidance on vapor recovery manifolds.
- **Recommendations for Equipment Employed in the Mooring of Ships at Single Point Moorings** - Gives recommendations aimed at facilitating correct matching between the SPM and the ship. Recommends that mooring equipment available at terminals be brought into line with these standards and that ships be provided with bow stoppers and associated fittings designed to secure and accept standard chafe chains.
- **Hawser Test Report** - Gives a complete description of the first major large rope testing program. This was undertaken to determine the actual new and used strengths and rate of strength reduction of large synthetic ropes similar to those used as SPM hawsers. All the test data and analyses are included together with conclusions and recommendations. It will be of interest to designers and operators of SPMs and to all who manufacture or use large, synthetic ropes for lifting and mooring.
- **Hawser Guidelines** - These three booklets are produced with the intention that rope manufacturers establish complete and detailed documentation of their synthetic fiber products, particularly those primarily intended for use at single point moorings.
Volume 1 - Guide to Purchasing Hawsers
Volume 2 - Procedures for Quality Control and Inspection During the Production of Hawsers
Volume 3 - Prototype Rope Testing

DESIGN CONSIDERATIONS

In planning the design of an offshore berth, the design should consider the site, environment, tanker, mooring operations and physical parameters of the mooring and hose handling system. Planning studies are normally a joint effort among Engineering, Marine Transportation and Operations. A brief discussion follows concerning the major points in planning an offshore berth.

LISTING OF HANDLED PRODUCTS

Most often, offshore berths handle a single product, which requires only one fluid path throughout the system. However, MBM's capable of handling as many as five products have been installed. A complete listing of all products to be handled, including ballast and bunkers, should be developed, along with discharge/receipt operations. This listing is needed in order to determine the compatibility of products using the same fluid pipeline and the number of fluid transfer operations that need to be carried on simultaneously.

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DESIGN CONSIDERATIONS (Cont)

THROUGHPUTS

Throughputs by product and parcel sizes, should be established to evaluate the number and size of facilities required.

TANKER LISTING

A complete listing of tankers by class size, is required. Also required is a breakdown of the arrival frequency on an annual basis.

ENVIRONMENTAL DATA

The effects severe weather can cause exceptional problems, especially with regard to port closure resulting in potential throughput cutbacks and demurrage. Data on wind, current, wave, swell, fog, tides, ice, etc., should be collected and evaluated with regard to buoy operations, including the effects on the various size classes of tankers and support craft necessary to conduct operations.

LOCATION

Nearshore buoy terminals should be sited / located based on the following objectives and considerations:

Pipeline Length

Submarine pipelines often represent the major portion of the berth investment. Therefore, minimizing the length of the pipeline route should be a primary consideration. Routing the submarine pipelines in a straight line perpendicular to shore is not always possible. It is also important that pipelines be routed away from rock outcrops and achieve an elevation profile that minimizes / avoids high and low spots (maintenance and reliability consideration).

Maneuvering

Multi Buoy Mooring Systems - The necessity for providing adequate maneuvering room imposes the largest limitation on CBB layout. The following considerations should be evaluated when locating / siting an MBM berth:

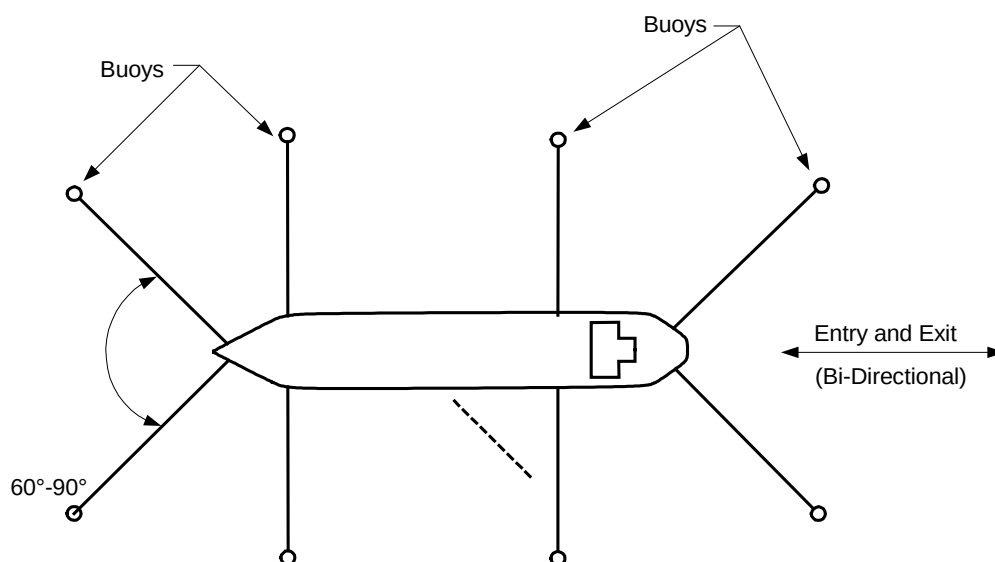
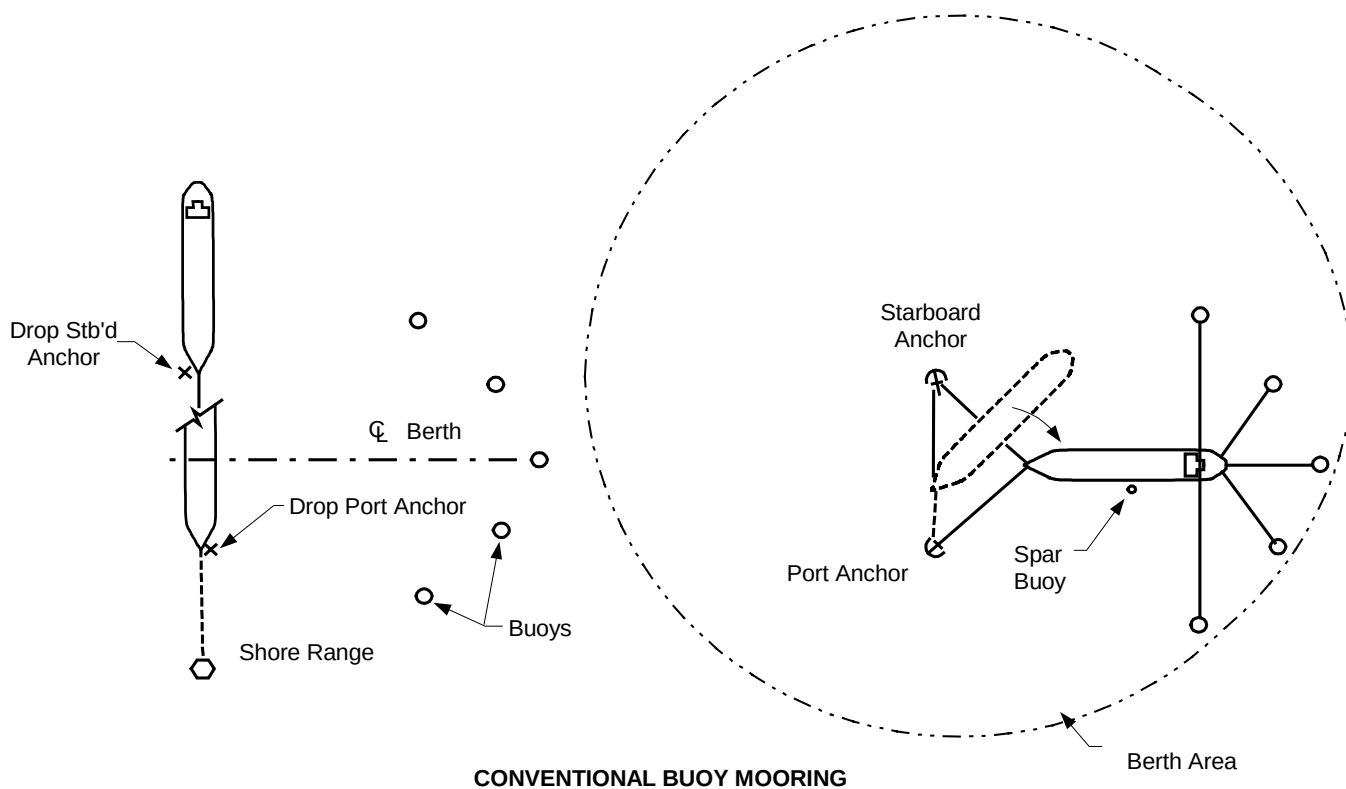
- Adequate room should be provided for maneuvering (safety and operability consideration). For MBM's, it is critical that a nautical advisor defines the vessel approach route(s), distance needed to stop and turn the vessel, level of tug assistance, and maneuvering procedure into the berth. The vessel must be able execute these maneuvers during the expected operational environmental conditions while remaining a safe distance from any obstructions (property lines, anchorage, submarine lines / cables, buoys, etc.) and in an area of sufficient water depth. The role of tugs in determining the appropriate safe distances should be considered. The berth should be situated such that vessels have a safe escape route in the event that the maneuver must be aborted (e.g. due to mooring difficulties). Refer to **Figure 3**.
- The vessel should be able to swing on its anchor without grounding during normal maneuvers and in the event of a vessel break out.
- The vessel should be able to swing clear without fouling the buoys. Impact with a buoy could cause the buoy or its anchor chain to be damaged or the ship's propeller to be fouled and damaged. In order to allow the vessel to swing on its anchor and back into the berth without tug assistance, normally requires that mooring buoys be located at the stern of the vessel only, and far enough from the vessel to insure they will not be struck.



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DESIGN CONSIDERATIONS (Cont)

FIGURE 3
MANEUVERING AT CONVENTIONAL MBM'S



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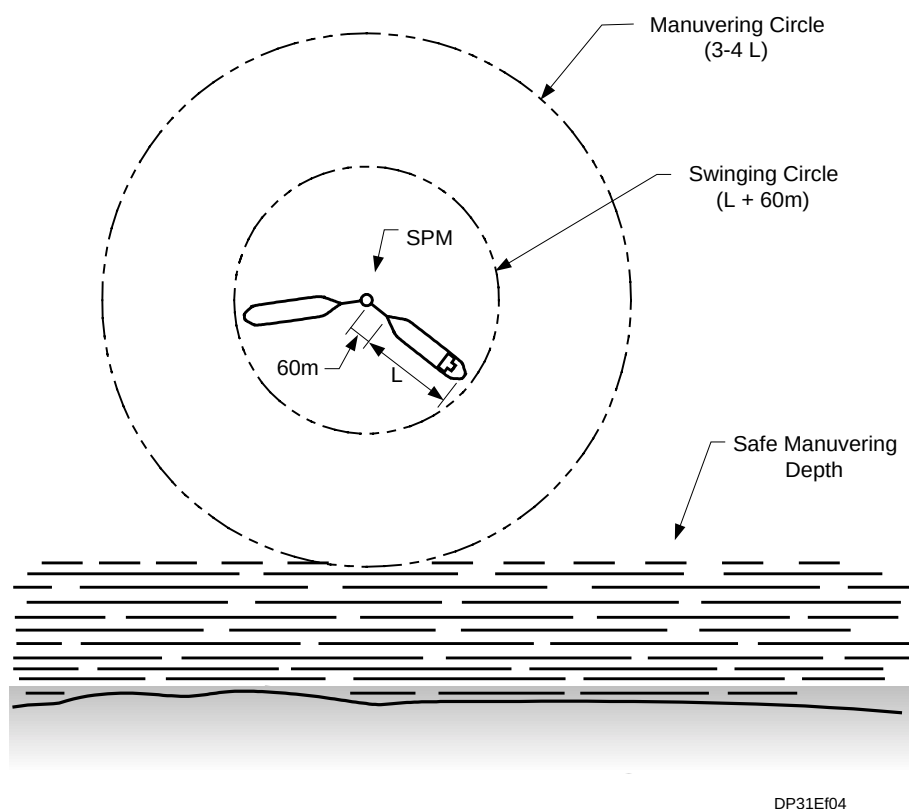
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DESIGN CONSIDERATIONS (Cont)

Single Point Mooring System - Most SPMs are positioned so that the largest tanker expected to use the buoy can approach or leave the buoy from any heading. The minimum water depth within the approach or maneuvering circle is determined as described here. The maneuvering radius is normally established as five ship lengths of the largest (longest) tanker.

For SPM's, the maneuvering area is defined as a circle with a radius equal to 3 to 4 times the vessel LOA. There should be sufficient water depth within the maneuvering area to achieve the required underkeel clearance. Refer to **Figure 4**.

**FIGURE 4
LAYOUT OF SPM'S**



Water Depths

Transit - Water depths are critical throughout the tanker transit from and to deep water. Once the maximum design draft has been established for each leg of the transit, the required water depths can be calculated. This involves consideration of waves, bow sinkage, seabed material, bathymetry inaccuracies and underkeel clearance (UKC) requirements, which are often approximately 15 percent of the deepest draft tanker.

Berth - The offshore berth should be located to ensure adequate water depth is available in the immediate berth area (safety consideration). Methods for estimating the required underkeel clearance at conventional piers are described in Section XXXI-I. A wave response allowance must be added to the requirements in Section XXXI-I for determining the water depth and minimum underkeel clearance for buoy berths. For vessels moored at buoy berths, the maximum wave response for early screening purposes may be assumed equal to 1.9 times the operational wave height limit (expressed as significant height). For planning purposes, a minimum underkeel clearance can be set at 30% of the maximum vessel draft. Additional water depth considerations are listed below:

- For MBM's, the berth should be situated in sufficient water depth to achieve the required underkeel clearance between the vessel hull and obstructions on the seabed, i.e. PLEM, pipelines, cargo hoses, and the seabed when moored during the expected operating wave conditions. The berth area should encompass the range of possible vessel positions while moored. This range should provide an allowance for misalignment and the elasticity of the mooring system for the maximum operating environmental conditions. Refer to **Figure 3**.

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DESIGN CONSIDERATIONS (Cont)

- For MBM's that are not aligned with currents, additional underkeel clearance may be necessary to reduce / limit current-induced loads on the mooring system.
- For SPM's, the berth area should be also be situated in sufficient water depth to achieve the required underkeel clearance between the vessel hull and obstructions on the seabed, i.e., SALM base, PLEM, pipelines, seabed, etc. when moored during the expected operating wave conditions. The berth area is defined as the swinging area (see **Figure 4**) around the buoy. The swing circle can be estimated by using a radius equal to $60 + \text{LOA}$ (meters).

Other Location Considerations

Areas with steep underwater slopes should be avoided (installation consideration). For MBMs, the berth should be located in an area where the water depth is relatively uniform (extending to include buoy anchor legs).

GEOTECHNICAL / GEOPHYSICAL

Soil borings at PLEM and anchor sites should be performed prior to contracting for SPM, and the soils report should be included as an attachment for the bid package. The soils report should provide sufficient information in order to design the foundation for the PLEM and to evaluate anchor and/or piles for the mooring legs.

An underwater hazard survey should cover the planned maneuvering area and the approach channel. The hazard survey report should be made part of the bid package. A hazard survey and documented report normally include the following elements:

1. Sidescan Sonar
2. Shallow Seismic
3. Magnetometer
4. Bathymetry

INITIAL FACILITY SIZING

Once throughputs, fleet composition and environmental conditions have been established, the initial sizing (such as pipeline rates and tankage volume) can take place. This should preferably be done by computer simulation techniques; however, for simple cases, hand calculations may suffice. The entire transportation / storage system should be simulated, since all components are interactive, and any one can affect the others. As the project progresses, and changes are made, the site selected, and layouts developed, additional simulation runs may be required to verify and/or re-establish facility sizes. Refer to [Section XXIII-A](#) for additional loading system considerations.

SUPPORT FACILITIES

The support facilities that should be provided may vary widely, depending upon the berth site in relation to a built-up port and its port's infrastructure, consideration should be given to such items as navigation aids, mooring launches, pilot boats, maintenance craft, etc. Additionally, the potential for environmental pollution should be addressed and contingency plans developed, in order to determine the specialized equipment required to protect the environment.

FACTORS INFLUENCING MOORING LOADS

Certain factors are vitally important in establishing design loads, while other factors have only minor effects. The designer should be aware of the significance of the various factors, and the possible effects that a change in a parameter may have on mooring loads and mooring performance. The basis for a mooring system design depends upon the peak mooring loads that the tanker exerts on the system, and the lateral excursion of the buoy for SPMs. Factors that have the dominant effect on mooring loads include wave height, wave period, wind, current and vessel-mooring system interaction.

At SPM berths, the tanker and buoy are coupled by an elastic mooring hawser. The SPM itself acts as a lateral spring system with a non-linear response. Moreover, the motions of a vessel, moored to an SPM, in waves, wind and current can be exceedingly complex, especially if the three environmental components are not co-linear. Both the moored vessel and the SPM buoy are free to respond in three translational degrees of freedom: surge, sway, and heave; and in three rotational degrees of freedom: yaw, pitch and roll. Altogether, this results in a non-linear system with 12 degrees of freedom, some of them coupled and acted upon by irregular environmental forces. It is a complicated problem to deal with analytically, yet there are ways of breaking the problem down to manageable proportions. For analysis purposes and for an understanding of the relationship of mooring loads to the environment, the effects of waves, wind, and current are often considered separately, as discussed in the following sections.

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DESIGN CONSIDERATIONS (Cont)

Waves

Like ocean waves in general, waves at typical tanker loading sites are usually irregular. That is, they cannot be adequately represented in terms of a regular sinusoidal wave function having a single amplitude and a single frequency. Indeed, it is difficult, if not impossible, to completely describe ocean waves analytically. However, for most practical engineering purposes, statistical properties are used to define the important characteristics of irregular waves in the ocean. These include the significant wave height, peak period, significant period, dominant wave direction and the power energy spectrum.

Wave Height - It is conventional to characterize an irregular sea by its "significant wave height." Specifically, the "significant wave height" is defined as the average of the highest one-third of the peak-to-trough waves in a wave record. For SPM's, the mooring hawser load has been found to increase roughly in proportion to the square of significant wave height in the absence of wind, current and tanker propulsion assistance.

Wave Period - The term "significant wave period" applied to irregular waves has not achieved the degree of agreement as significant wave height. "Significant wave period" refers to the average of the periods of the highest one-third of the waves in a wave record. "Peak wave period" is the reciprocal of the frequency of peak energy in the wave energy spectrum. Generally, peak wave period data are more readily available.

The wave period and the type of wave spectrum can also influence mooring loads. At SPM berths with a constant significant wave height, mooring loads generally increase with shorter wave periods (higher frequency), as shorter period waves tend to excite the mooring buoy motion relative to the moored tanker.

On the other hand, long period wave phenomena can have a major influence on the response of a moored tanker, and thus on mooring loads. Long period phenomena occur in the form of swell and wave groups. Swells result from large storm waves traveling very long distances, even thousands of miles; however, over time and distance high wave frequencies damp out, leaving dominant low frequencies. Wave grouping results from the combining of waves of different frequencies. When they are superimposed, new waves with the sum/difference frequencies of the combining waves result. The envelope of the wave groups are, in fact, the difference frequencies, which can be very low. If those low frequencies approach the natural frequency of the mooring system, then resonance and high mooring loads can occur.

Response to Waves - At SPM berths a vessel moored in waves alone tends to align itself into the waves and responds primarily in surge. In regular waves, the vessel will surge back on the mooring until the force in the hawser equals the mean wave-induced force on the vessel, which will remain essentially in equilibrium at this position. Small variations will occur around the mean hawser tension, as the buoy responds to the waves. Larger variations occur if the wave periods are in resonance with a natural frequency or a harmonic of the mooring system.

In irregular waves, there is a mean wave force, the low frequency wave forces associated with wave groups, and the force of each individual wave. The moored vessel will respond to each of these components.

The tanker / mooring system response will be especially pronounced, if the period of swell or wave grouping corresponds to the natural period of the mooring system in surge. In that case, peak mooring forces will be significantly higher than would otherwise be experienced in waves of the same height.

In planning an offshore berth, a study of oceanographic data should be performed to determine if these long period phenomena exist at the site. If they are expected, they should be accounted for in the analysis, and model testing for SPM's.

Wind and Current

Unlike the loads imposed on the tanker by waves, the static loads imposed by wind and current can be established with relative accuracy. However, due to the nature of the response of the tanker to wind and current loads, the influences of wind and current on SPM mooring loads may be difficult to determine. "Loads" in this case includes both forces and moments. Because moments are imposed when the tanker hull is at an angle to wind or current, the tanker may move to apparently unusual positions under the combined effects of waves, wind and current.

Wind Loads on the Vessel - Wind loads are proportional to the square of the wind velocity and the projected area exposed. Wind force coefficients for Very Large Crude Carriers (VLCCs) have been developed from wind tunnel tests, and are published by OCIMF (refer to **OCIMF-14**). In general, a one-minute average wind velocity, taken at a 10 m (33 ft) elevation, is used to calculate wind forces and moments on the tanker.

Current Loads on the Vessel - Current force and moment coefficients for typical tanker hulls have also been developed and published by the OCIMF (refer to **OCIMF-14**). As with the wind, current loads increase proportionally to the square of the velocity of flow. Current loads will decrease with a decrease in draft. For a fixed draft, current loads will decrease with an increase in the water-depth-to-draft ratio. This effect is important up to a depth-to-draft ratio of about 1.5, and less pronounced beyond that ratio.

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DESIGN CONSIDERATIONS (Cont)

For SPM's, it is possible to see large dynamic responses of a tanker moored in constant wind or current alone. These responses in steady wind or current are due to the variations of moments and forces that occur, as the tanker hull changes its heading to the direction of the steady wind or current field. Changing tanker heading causes alternating induced lift forces from wind and current on the hull, which results in yaw and sway of the tanker.

Additional Considerations for Single Point Moorings

Influence of the Tanker - Variations in tanker size or shape do not affect mooring loads at SPMs as much as do variations in the environment. Nevertheless, where different size tankers are to moor at an SPM, consideration should be given to the influence of tanker size on mooring loads. The larger tankers do not always impose the highest mooring loads.

The state of tanker loading – that is, whether the tanker is loaded or light ballasted – can have a major influence on tanker response, and thus on mooring loads at SPMs. Consideration should be given to the loading condition in which tankers will most probably be exposed to severe environments.

In general, the mooring forces will increase proportionally to the square root of the tanker size. However, mooring loads measured in model tests, for tankers of 500,000 DWT and larger, have generally been no higher than those measured on tankers in the size range of 200,000 to 400,000 DWT. This is because the smaller tankers move around more than the larger ones, and high mooring loads result from the arresting of the tanker momentum. Therefore, not only the maximum size tanker, but also the smaller ones should be considered in designing an SPM.

For a given tanker size, different mooring loads will be experienced in the loaded condition, and in the ballasted condition. The more critical case of ballasted or loaded tanker cannot be assumed; therefore, both cases should be considered.

The use of the tanker's main propulsion or thrusters and/or tying a tug to the stern of the tanker can have a significant effect on mooring loads. This assistance is often used in severe environment locations to reduce the effects of steady environmental forces, or to maintain a steady mooring load and reduce surge loads.

Influence of the Mooring System - The design of the mooring system has a major influence on the mooring loads. The most important mooring system parameters are those that affect the elasticity or stiffness of the mooring system. A very stiff mooring system will severely constrain the response of the tanker to waves, resulting in very high mooring loads. Conversely, if the mooring system is very soft, the tanker may respond too freely. This builds up momentum as the tanker moves under the influence of waves, wind, and current, which exerts high loads on the mooring as it comes to the limits of mooring system elasticity.

Conclusions

In determining design mooring loads of an offshore berth, many influences should be taken into account. The engineer should determine the dominant factors in a given situation and develop design loads accordingly, using the tools at his disposal. Because of the sometimes complicated interplay of forces and responses, it is important that realistic wave, wind and current environments be used in analysis, and model testing for SPM's. Realistic wave spectra should be used. Long period phenomena, such as swell and wave grouping, should also be reflected in the wave record, if they exist in nature at the site. It is also important that the wind, and current be accurately represented as to direction, velocity, and their moment-producing effects on the vessel.

DETERMINATION OF ENVIRONMENTAL DESIGN CRITERIA

Offshore berths should be designed for both survival conditions (tanker disconnected) and maximum operating conditions (tanker moored at the berth).

- Survival conditions should be determined based on the 100 year return period of wind, wave and current conditions resulting in the highest loads on the buoy system with the vessel disconnected. Two sets of criteria are investigated:
 1. The 100 year waves with associated wind and current. Typically the governing load case for the MBM and SPM systems considered in this Design Practice.
 2. The 100 year wind with associated waves and current.



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- Maximum operating conditions are determined from an evaluation of the required frequency of loading / off-loading and the long term weather statistics for the area. The required off-loading frequency is a function of the size of tankers, amount of storage and the product transfer rates. The maximum operating conditions may determine the type of offshore berth, as some are better adapted to rough sea conditions than others. The design environmental criteria should be developed from the environmental information described in this section and may also include a risk analysis where prior experience is limited. The risk analysis may include: historical experience, the planned life and intended use of the mooring, consideration of safety of operating personnel, the estimated cost of the mooring designed to environmental conditions for several average expected recurrence intervals, and the probability of mooring damage or loss when subjected to environmental conditions with various recurrence intervals, and the financial loss due to mooring failure. The typical limiting wave height for MBM operations is about 1.2 m (4 ft) to allow the mooring gang to safely disconnect the lines from the buoys. The typical operating wave height for SPMs is 2.0-2.5 m (6.5 ft).

Acquisition of valid weather statistics may require several years of data measurement.

MULTI BUOY MOORING SYSTEMS

This section includes a description and general requirements for MBM buoys, anchor legs and ancillary equipment. Specific guidelines for MBM layout and orientation are also included. Additional design considerations for buoys, anchor legs, hoses and ancillary equipment are provided in subsequent sections. Orientation and layout considerations should always be discussed with experienced marine personnel before final design to insure the operability of the berth.

ORIENTATION

In general, MBMs should be aligned parallel to the direction of the predominant environment in order to minimize loads on the moored ship and reduce the probability of mooring incidents. Long period wave / swell action is normally the governing condition.

Consideration must also be given to the method of tanker approach and departure from the berth. Normally the tanker should be capable of maneuvering into a CBB without the assistance of tugs. Furthermore, the tanker must be capable of leaving the berth quickly in the event of worsening weather. These criteria usually result in a berth oriented perpendicular to the coast line and heading out to sea.

In locations which experience high currents parallel to the coast, an ABB berth oriented parallel to the coast line may be required. In other locations, where governing environmental conditions vary throughout the year, the berth may be given two orientations.

Specific guidelines that should be considered when locating and orienting the berth include:

- MBMs should normally be sited with sufficient sheltering such that significant wave heights are less than 1.2 m (4 ft) more than 90% of the time. Somewhat higher waves (up to 1.5 - 2 m (5 - 6.6 ft)) may be accommodated if the wave sector is well defined and narrow, and the vessel aligned such that waves strike her bow.
- MBMs, where wave heights do not exceed 1.2 m (4 ft), should be aligned parallel with the direction of the strongest current, if the velocity exceeds 1 knot.
- MBMs, where there are minimal currents or waves, should be oriented such that strong prevailing winds strike the stern of the vessel.

LAYOUT

If local conditions permit, a conventional 3 or 5 buoy berth layout (**Figure 5**) normally results in the most economical and workable scheme. Therefore, the CBB layout is discussed first followed by the ABB layout.

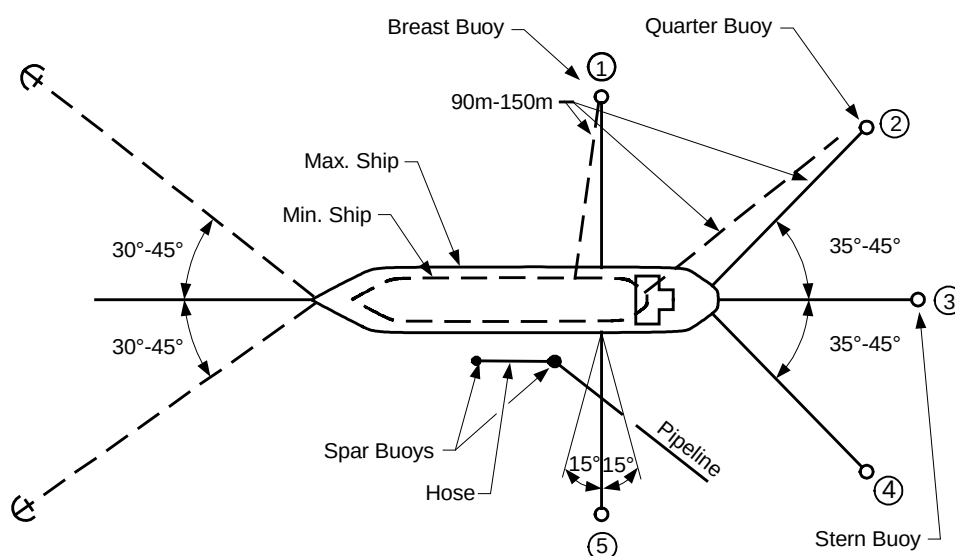
In laying out a CBB, three main factors must be considered:

- Optimum disposition of vessel's anchors
- Provision of adequate maneuvering room
- Accommodation of full range of tanker sizes

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MULTI BUOY MOORING SYSTEMS (Cont)

FIGURE 5
LAYOUT OF MBM'S



3 BUOY BERTH SIMILAR EXCEPT DELETE BREAST BUOYS

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CBB Ship Anchor Layout Considerations

For economical and safe design of a CBB, the vessel's anchors (2) should be utilized to their full capacity. Normally, the ship's anchors are the only moorings holding the bow of the vessel against wave, wind, and current forces. At times, the ship's anchors are the weak link in the mooring system, particularly in areas where the seabed consists of soft materials and the anchors are not capable of developing high holding power. Estimates of the holding power of ship anchors are given in section **MOORING LEG DESIGN**.

To fully develop the anchor's holding power, a sufficient length of chain must be used so that the pull on the anchor will be approximately parallel to the sea bottom. If the chain is too short, the end of the chain will be inclined to the sea bottom and the anchor will tend to pull out and drag before developing its full capacity.

For small tanker berths (< 30 KDWT), the layout should be based on a minimum chain length of 160 - 220 m (6 - 8 shots, where 1 shot = 90 ft). For larger berths or berths located in exposed locations, or in deep water, the layout should consider the full length of chain carried by the ship. The length of chain carried by a ship is specified by ship classification societies (e.g. **Lloyds, American Bureau of Shipping**) according to the calculated equipment number for the vessel. The equipment number is a function of vessel displacement, beam and depth, and wind area of superstructures. The equipment number and the anchor weight and length of chain for some typical size tankers are provided in the table below.

TANKER ANCHOR CHAIN LENGTH

SHIP DWT	EQUIP. NO.	LENGTH*	
		m	ft
25,000	2080 - 2330	300	1,000
50,000	2870 - 3040	330	1,100
100,000	4000 - 4200	360	1,200
250,000	6100 - 6500	385	1,300



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* Length of chain for each anchor

MULTI BUOY MOORING SYSTEMS (Cont)

The angle between the bow anchor chains should be between 60 - 90° (see **Figure 5**). A high angle between anchors is normally preferable, although not always possible, when strong beam or quartering forces must be resisted. If the berth experiences high head seas and very little beam winds or currents, a 60 - 70° anchor spread may be more appropriate. The maximum bow anchor spacing can be limited by the length of chain carried by the vessel (less the water depth) since the ship must pay out the chain from one anchor while maneuvering to drop the second anchor.

CBB Buoy Layout Considerations

The necessity for providing adequate maneuvering room imposes the largest limitation on a CBB layout. To allow the vessel to swing on its anchor and back into the berth with or without tug assistance, normally requires that mooring buoys be located at the stern of the vessel only, and far enough from the vessel to insure that they will not be struck. The vessel should be able to swing clear without fouling any buoys. Consideration must also be given to the possibility of a vessel breaking out of its moorings and swinging on its bow anchors.

There is a difference of opinion among operators as to the need for or desirability of a 5 buoy CBB compared to a 3 buoy CBB. The use of breast buoys limits the available maneuvering room and makes berth entry and exit more difficult. Central American sea berths handling vessels up to 36 KDWT have operated successfully without breast buoys. However, where larger vessels are handled or more severe environmental conditions exist, 5 buoys are normally required. At very large ports, 7 buoys are used.

Once the initial layout is determined, the mooring loads are analyzed. If analysis indicates that the vessel's anchors and/or the stern mooring lines are overloaded for a conventional layout, the following alternatives are available:

- Add buoys
- Add "swamped" moorings
- Use an all buoy berth
- Limit vessel operations

Number of Buoys - The majority of marketing terminals are conventional 3 or 5 buoy berths as shown on **Figure 5**. A minimum of 3 stern buoys is required for tanker berths in open sea areas, although two stern quartering buoys may be adequate for barge berths. The buoys should be located on each quarter and directly astern of the vessel. Stern breast buoys should not be used in lieu of stern quartering buoys in a 3 buoy berth, as this will normally result in an overload of the hawsers attached to the buoy located directly astern of the vessel.

Where larger tankers are handled or more severe environmental conditions exist, the addition of breast buoys in a five-buoy arrangement may be necessary. If the critical environmental condition has a defined direction sector, an additional buoy may also be beneficial.

For berths handling larger crude oil tankers, additional breast buoys and a forward bow buoy may be necessary. The buoy located off the bow of the vessel can be used in conjunction with the ship's anchor as shown **Figure 6**. This buoy leg can be designed for higher mooring loads through the use of a suitable permanent anchorage system and a number of mooring lines from the vessel. Therefore, if the buoy is located on the side of the vessel which is exposed to the highest forces, it may increase the capacity of the berth.