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THE DESIGN OF SINGLE POINT MOORINGS

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ABSTRACT

Single point moorings (SPMs) are now being designed for deepwater ports off the coasts of the United States, and other SPMs are being designed for deeper depths and more severe environments such as the North Sea. The paper addresses the important aspects of designing an SPM, including: what parameters must be considered, how mooring loads vary with key parameters, how model tests should be conducted and their results analyzed to determine mooring loads, what factors determine limiting loads and environments, and what criteria should be observed in mooring system design.

The SPM designer must consider all pertinent design parameters including the site, environment, tankers which will be moored, and operating parameters of the mooring. Computer simulation and analytical techniques are now used for design studies and to predict design loads. However, model testing is still usually used to establish final design loads and to verify designs. The maximum mooring loads measured in a single model test are not sufficient to establish realistic design loads; therefore statistical methods are applied. The designer can now refer to recognized standards when designing the SPM structure. High-strength SPM components, such as chains and synthetic ropes, are now available. The capacities of mooring equipment on the vessels to be moored may impose limitations on loads and environments unless the SPM will serve only a few specially modified vessels.

INTRODUCTION

In the past fifteen years the SPM has developed from a curiosity to a widely applied means of mooring very large tankers and handling their cargos. In that time the design of SPMs has become a highly specialized engineering practice. The SPM designer must understand how the site, environment, tanker, and operating procedures, as well as the physical design parameters of the mooring will effect the mooring loads and the performance of the SPM system. Exxon Research and Engineering (ER&E) has been investigating and designing SPM systems for over ten years. This paper discusses some of the principals of SPM design which have been learned.

IMPORTANT DESIGN PARAMETERS

The designer of the SPM must consider all pertinent design parameters. The major site and environment parameters and the methods by which they should be determined are discussed in the American Bureau of Shipping Rules for Building and Classing Single Point Moorings. The tankers which will be moored and the procedures by which the mooring will operate are also important in establishing the design loads. The physical design parameters of the SPM system have a major influence on mooring loads.

The Environment

The most important design parameters are the operational and survival environments that the SPM will be subject to. The operational environment consists of the maximum wave, wind, and current conditions in which a vessel will remain moored. The survival environment normally consists of the most extreme wave, wind, and current condtions that the SPM will be subject to. In most cases the operational environment will dictate the design mooring loads.

Waves at typical SPM sites are irregular and therefore should be defined in terms of significant wave height (the average of the highest one-third wave heights), type of wave spectrum, and mean wave period. The significant wave height defines the relative magnitude of the waves. The wave spectrum represents the frequency distribution of energy in the irregular waves.

For a given significant wave height, a narrow wave spectrum, such as a Pierson-Moskowitz spectrum where most of the energy is concentrated in a relatively narrow frequency band, will influence the response of a vessel moored to the SPM differently than a wide wave spectrum, such as a Roll-Fischer spectrum. Wave height and wave period are not sufficient to establish the distribution of wave periods. For a fully-developed sea the mean wave period of irregular waves can be derived from knowledge of the significant wave height and type of wave spectrum.

The magnitudes and directions of operational wind and current conditions are two other important environment parameters that must be included in the design analysis of an SPM. The relative directions at which waves, wind, and current approach the mooring cannot be disregarded. If wind and current are within about 15 degrees to the direction of waves, they may be assumed to act co-linear with wave direction and may be considered as such in the design analysis with little affect on results. However, if wind or current approach the mooring at large angles to the waves, they may substantially alter the response of the moored tanker and therefore their directions must be treated in the design analysis.

In cases where the maximum waves, wind, and current in which tankers will occupy the mooring will be in the same direction, it still may be necessary to consider the effects of lesser environments having wind or current at angles to waves. Higher loads may be experienced in lower non-parallel environments than in the higher parallel environment.

The Tanker

Normally the largest vessel which will moor to the SPM is chosen as the design-basis vessel. However, where a large range of tanker sizes is to moor at a SPM, consideration must be given to the influence of various tanker sizes on mooring loads. An SPM design may be optimum for mooring one class of tanker sizes, but less than optimum for larger or smaller tankers. ER&E has found that very-large tankers, in the order of 500,000 dwt, may actually exert lower peak mooring loads than intermediate size tankers, in the order of 250,000 dwt, on the same SPM in identical environments. Small tankers exert lower mooring loads, but because mooring fittings on small tankers are not as strong as those on large tankers, special consideration may have to be given to the mooring loads which smaller tankers can tolerate in establishing operating criteria.

In addition to the range of tanker sizes which will be moored, the loading condition in which these tankers will most probably be in when exposed to the maximum operating environments must be considered in establishing mooring loads. If tankers are to discharge cargo, they usually moor in the loaded condition in relatively mild environments. However, when completing the discharge of cargo they may be subjected to the maximum operating environment in ballasted or light condition. Operating procedures may require that the tanker take on ballast while discharging cargo to preclude being exposed to severe environments while in a light condition. These operating aspects must be considered in establishing the tanker loading conditions which in turn influence design loads.

The Mooring System

The physical design parameters of the SPM system have a major influence on mooring loads. For a given tanker and environment, mooring loads may be much different at one type or design of SPM than at another because of the different elasticity characteristics of the mooring system. Therefore, parameters which affect the elasticity characteristics of the mooring system are of prime importance.

For a fixed-tower type of SPM, the mooring line elasticity is the primary consideration. The length and size of the mooring line as well as its material and construction determine its elasticity characteristics.

For buoy-type SPMs, the elasticity of the mooring line acting in series with the load-deflection characteristics of the buoy anchoring system determines the overall elasticity of the mooring system. For the SALM (single anchor leg mooring) the net buoyancy of the buoy (the difference between buoy displacement and buoy weight) and the length of the anchor leg, which is a function of the water depth at the site, influence the over-all elasticity of the mooring. For the CALM (catenary anchor leg mooring), the number, size, length, and pretension of the anchor chains influence elasticity. The size and weight of the CALM buoy has a secondary but still important influence on mooring loads.

At any type of SPM the length of the mooring line has another influence on tanker response besides the influence on mooring system elasticity. If the mooring line is too long the moored tanker may have too much freedom of motion, and may gain excessive inertia which results in very high peak mooring loads. A general rule of thumb is the length of the mooring line should be approximately equal to the beam of the moored vessel.

All of the above mentioned environment, vessel, and mooring-system parameters have an influence on mooring loads and must be adequately considered in the design of the SPM system. If a critical mooring-system parameter is not adequately taken into consideration in determining mooring loads or if it is altered substantially after the mooring loads have been determined, the mooring system design may be inadequate.

SPM MODEL TESTING

A properly planned and executed model test program for the purpose of establishing SPM design loads must take into account the important design parameters discussed in the preceeding section. Although advance are being made in SPM design analysis by means of com-computers, and in other analytical methods for SPM design, principal reliance is still placed on the results of model testing to establish the mooring loads and verify the performance of the system.

The Model-Test Facility

The qualifications of the model test facility used to conduct the tests are very important. The model-test facility must be capable of accurately modeling all important parameters of the environment.

Model tests of SPM systems must generally be conducted in irregular waves with wind and current. Unless the operating environment at the site is such that waves, wind, and current will approach from nearly the same direction, the model-test facility must be capable of creating wind and current at various angles to the direction of waves. Wind and curr effects on a vessel moored to an SPM cannot be adequa ly modeled by lines over pulleys to weights.

The competence and experience of the researchers nd technicians conducting the model tests are also mportant considerations. Skill must be exercised in onstructing the models and in setting up the model ests. Care must be taken in conducting each test. nstrumentation must be properly calibrated at the tart of the test program and should be recalibrated eriodically during the test program. Electronic nterference can distort measurements, as can improper rocessing of data. Data analysis and reduction are specially critical. The assistance of skilled and xperienced model-test researchers can be of much value o the SPM designer in interpreting and analyzing odel test results.

odeling Considerations

The model test facility should be large enough to ermit the use of large models in order to avoid, as uch as possible, problems associated with scale ffects. SPM model tests in waves should be conducted sing Froude's law scaling in order to properly model ravity effects. Current forces on the moored vessel re a combination of gravity and viscous-drag effects. owever, at angles other than near bow-on the gravity ffects govern and Froude's law scaling of current elocity is adequate.

Wind forces on the moored tanker are influenced y viscous drag. Viscous drag effects are accurately odeled using Reynold's law scaling but are distorted sing Froude's law scaling. It is impractical to cale wind by Reynold's law in the model basin. To etter model wind effects, the wind velocity should e adjusted to produce forces on the tanker proportion- l to full-scale wind forces scaled by Froude's law. nis may lead to the use of model wind velocities dif- erent than those calculated by Froude's law scaling.

Model construction is another important factor in stablishing model scale. The accuracy with which any components of the mooring system are modeled is rucial to the accuracy of the model test results. t is very difficult to construct accurate models of ome key components, such as swivels and hoses, at mall model scales, because such components must be odeled not only with respect to size and weight, but lso with respect to friction in the case of swivels r to bending rigidity in the case of hoses. Certain mall components become very fragile when modeled at o small a scale and distortion can cause inaccu- acies.

Force and moment measurements are much more ccurate at larger model scales because the measured alues are higher. There is a practical limit to ow accurate force and moment transducers can be abricated and calibrated. At small scales the pre- ence of a relatively large or heavy transducer can nfluence the response of the model and in turn produce rrors in the results.

alysis of Test Results

A maximum force measured in a single model est will not be sufficient to establish realistic esign loads for a mooring system. The statistics f the measured forces from a number of similar model ests must be analyzed to establish realistic design ooring forces.

An individual model test is run for a limited duration, typically corresponding to about 30 minutes of prototype time. The maximum mooring force measured in an individual model test is not necessarily typical of the maximum mooring forces that might be expected at the SPM. Mooring forces are analogous to wave heights in that they have stochastic properties; therefore, mooring force records should be statistically analyzed in order to properly interpret them. One statistical parameter that is normally calculated is the significant mooring force; the average of the highest one-third mooring forces in the record. The significant mooring force is a statistical value which remains constant regardless of the length of the record, providing the record is of sufficient length. Although the maximum mooring forces may vary substantially in comparisons between identical model tests conducted with the same tanker at the same mooring system in the same environment, the significant mooring forces will show close agreement.

Statistical correlations of the ratio of maximum mooring force to significant mooring force can be developed through analysis of data from a number of model tests conducted in similar, though not necessarily identical conditions. The ratio of maximum to significant mooring forces from individual tests may be ranked and plotted as a probability graph to develop probability ratios of maximum mooring force to significant mooring force. If the data represents tests of 30-minute duration, such a probability plot can be used to determine the probability of a given ratio of maximum load to significant load being exceeded during 30 minutes. Statistical procedures can then be applied to determine the probability of the given ratio being exceeded during longer durations. Figure 1 is an example of model test data plotted on probability paper and extrapolated for longer durations.

LOAD-PREDICTION TECHNIQUES

SPM load-prediction techniques and SPM dynamic computer programs are considered, at least at this time, secondary to model testing as a means of establishing design loads for an SPM. ER&E uses these techniques to conduct general studies and to establish preliminary design loads. However, ER&E continues to rely primarily on the results of model tests to establish final design loads for SPM designs.

Dynamic Analysis on the Computer

In recent years there has been much effort devoted to developing computer programs which simulate the dynamic response of a vessel moored to an SPM. ER&E is developing such a computer program as an adaptation of a program recently developed to model tankers moored at conventional piers. The SPM dynamic computer program being developed by ER&E is capable of modeling the combined effects of waves, wind, and current.

ER&E's experience in developing this and other programs has shown that simple computer programs are not adequate for modeling a tanker at an SPM. An example of the complexity of response at an SPM under the influence of wind or current is discussed later. Assumptions and short-cuts should be avoided wherever possible in developing dynamic SPM computer programs. The principal advantage of the dynamic SPM computer program will be to analyze a number of SPM designs in a much shorter time than that which is now required to conduct a model test program.

Empirical Design Techniques

Several methods for predicting mooring loads at SPMs have been developed through ER&E's continuing SPM research program. These methods are empirical, based on the analysis of hundreds of model tests. The methods are capable of predicting mooring loads in both shallow and deep water (up to at least 600 feet) and in various combinations of waves, winds, and current.

These emperical techniques are essentially interpolation and extrapolation methods of model test data which enable the SPM designer to predict mooring loads for an SPM system which has not been model tested from the mooring loads measured in the model tests of other generally similar SPM systems. For SPMs which are somewhat different than those which have been model tested, and for major SPM projects, ER&E uses these methods only to establish preliminary design loads, and then conducts model tests to validate or more accurately establish the final SPM design loads.

The Energy Theory

A key element of these emperical load-prediction techniques is the energy theory. A relationship between the area under the mooring elasticity curve up to the significant mooring force and the environment and tanker size parameters has been found through the analysis of many model tests of tankers moored to SPMs. The area under the mooring elasticity curve represents energy stored in the system and thus this relationship is known as the energy theory. Through the energy theory, the significant force for an SPM system can be predicted from the significant force measured in tests of another SPM system having different mooring elasticity characteristics.

Figure 2 shows mooring elasticity curves for two mooring systems, SPM A and SPM B. If a given tanker is moored in a given environment to SPM A, a significant mooring force, F_a, would be experienced. If the same tanker were to be moored in the same environment to SPM B, a different significant force, F_b, would be experienced. The area under the elasticity curve for SPM A up to force F_a is equivalent to the energy stored in the system when it is elongated by the significant force F_a and therefore, it is refered to as the significant energy E_a. Significant energy E_b may be defined for SPM B in the same manner.

The analysis of many model-test records has shown that for a given tanker size and a given environment, the energy under the elasticity curve up to the significant force is essentially equal in different SPMs of fairly similar design. For the example given here, energy E_a would equal energy E_b because the tanker size and environment are the same even though the moorings are different.

For other tankers or other environments at SPM A different significant mooring forces and thus different significant energies would be determined. However, the same corresponding significant energies would be expected at SPM B under the same conditions. Thus from measurements of significant forces at SPM A with various tankers and environments, predictions of the corresponding significant forces at SPM B can be made.

The energy technique as described above can be used with caution to relate the mooring loads at one SPM system to those at another SPM system of generally similar design. Other aspects of ER&E's emperical load-prediction techniques account for the effects of bow hawser length, water depth, buoy size, wind, and current on mooring loads.

THE INFLUENCES OF DESIGN PARAMETERS

Variations in environment, operational, and mooring system design parameters can have a pronounced effect on mooring loads at SPMs. The SPM designer must have a general knowledge of these effects in order to select the most important design parameters and intelligently analyze their influences on the SPM system.

Certain rules of thumb relating the influence of various parameters on the mooring loads have been developed from observation and analysis of many SPM model tests. These rules are not precise enough for design purposes, but they can be helpful in assessing the effect which a change in a parameter will have on mooring load.

The Influence of Waves

Wave height is generally the most important parameter in influencing SPM mooring loads. Bow hawser loads have been found to increase roughly in proportion to the square of wave height in the absence of wind and current. This holds even in moderate wind and current nearly in-line with waves. However, as wind and current effects become more prominent the influence of a change in wave height on mooring loads is not as strong. This rule of thumb assumes that in addition to the tanker size and load condition remaining constant, the type of wave spectrum remains the same and the wave period changes commensurate with wave height.

Changes in wave period and wave spectrum also influence mooring loads, though in general their influence is not as great as wave height. A change of wave period with constant wave height implies a change in the band of frequencies in which wave energy is concentrated. For a constant significant wave height, mooring loads generally increase with a decrease in wave period. Of course if the natural period of the buoy or some mode of response, for example roll, of the moored tanker is very near the dominant wave period, then system response and thus mooring loads may be higher than if the natural frequency of the system is out of resonance with the periods present in the waves.

The Influence of Wind and Current

Until recently it had been assumed that wind or current acting on a vessel moored at a SPM produced an essentially constant force on the vessel, and that the wind or current flowing past the vessel would tend to stablize the action of the moored vessel. Yaw and sway of the vessel were believed to be caused primarily by wave action. When the moored vessel would yaw and sway due to wind or current alone in model tests, this was attributed to vortex shedding which would not occur on the prototype.

Now a more full understanding of the effects of wind and current has been reached through theoretical analysis, computer simulation, and model testing. It has been discovered that sustained combined yaw and sway motions can be caused by alternating wind or current lift forces on the vessel hull.

This phenomena can be explained by referring to Figure 3. The vessel may start in position 1 with a slack bow hawser and a slight yaw to the direction of wind. In this position the vessel is unsymetrical to the flow of air and the hull acts like an airfoil or wing in the wind field. The lift created as air flows around the hull causes the hull to sway to port. The vessel will continue to sway until the bow hawser becomes taut in position 2.

As the tension in the bow hawser increases, it retards the motion of the bow to port, but the vessel then begins to yaw about the bow due to its inertia of movement and to swing to position 3. The elastic bow hawser then relaxes as the vessel swings about its bow. The rebound of the bow hawser pulls the vessel forward toward the mooring buoy and the bow is again unrestrained.

The angle of the vessel hull to the wind field has now reversed in position 3, and the flow of air around the hull now lifts the hull to starboard. The vessel will sway to starboard through the center position 4 to the opposite side of the mooring. It will pass through positions 5 and 6 and return to position 1, thus completing the cycle.

Sustaining the motion depends on the vessel yawing far enough while the bow hawser is taut to reverse the angle of the hull to the wind, and then on the vessel swaying to the other side of the mooring before the bow hawser becomes taut again. The action thus depends on proper phasing of the periods of surge, sway, and yaw of the vessel on the mooring. Under the proper combination of wind (or current) velocity, vessel size, mass, and freeboard, bow hawser length, and mooring system elasticity, the action will grow to a certain amplitude and continue indefinitely.

The Influences of the Tanker and the Mooring

Mooring loads increase with tanker size, approximately in proportion to the square-root of tanker size. However, very large tankers tend to respond less than smaller tankers, and tankers of 500,000 dwt and larger may experience lower peak mooring loads than tankers of 200,000 dwt to 400,000 dwt. A range of tanker sizes, not just the largest and smallest tankers, should be considered in the design of an SPM which will serve a wide range of tanker sizes.

Variation of mooring system design parameters which affect the elasticity of the mooring system also affect the mooring loads. If the mooring system is very soft, the tanker may respond too freely, building up momentum as it moves under the influence of waves, wind, and current, exerting large loads on the mooring as it comes to the limits of mooring system elasticity. Excessive mooring line length can result in excessive freedom of tanker movement, especially in the case of a ballasted or light tanker moored in high winds, resulting in very high peak mooring loads.

A near-optimum mooring-system elasticity may be established through preliminary design studies and model testing. In the CALM, the length and size of mooring lines, the number and size of anchor chains and the anchor-chain pretension all affect mooring system elasticity. In the SALM, the length and size of mooring lines, the length of the anchor leg, and the net buoyancy of the mooring buoy affect mooring system elasticity. In either SPM system a substantial change in design water depth after the near-optimum design parameters have been established may cause an increase in mooring loads. A revised set of near-optimum design parameters may be established through re-analysis based on a thorough knowledge of how variations in key parameters affect mooring loads. However, a new model test program may be necessary to establish revised mooring loads.

DESIGNING THE SPM

The preceeding sections have addressed the manner in which mooring loads may be determined. However, the SPM must be designed for a defined maximum mooring load. The bow hawser, the buoy, and the anchoring system must be designed by reasonable standards to withstand the maximum mooring load. The established operational environment and the determined maximum design load must be commensurate with tanker and operational limitations.

Determination of Maximum Loads

The design mooring loads for the SPM should be developed using mooring-load probability data in a manner similar to that described above. The operating criteria must be considered in establishing a reasonable duration of exposure on the mooring for given tanker sizes in given environments.

A reasonable chance-of-exceedence of design load must also be established. Statistically, a zero percent chance-of-exceedence cannot be achieved. A ten percent chance-of-exceedence in a six hour duration may be acceptable with the philosophy that the probability of the full operational environment lasting for six hours combined with the probability of the most critical design vessel being moored in its most critical loading condition is extremely small, and should this event occur the design safety factors will permit occasional loads in excess of the design mooring load.

Based on the selected chance-of-exceedence and durations, the ratio of maximum to significant mooring load is determined from a probability curve such as Figure 1. The significant mooring load from model test data for the design tanker in the design storm is multiplied by the maximum-to-significant force ratio to determine the design mooring force. This design mooring load may differ substantially from the maximum mooring load measured in an individual model test. The design-load determination exercise may be performed for several different tanker sizes, loading conditions, and environments, especially if different operating criteria are established for different tanker sizes.

Design Criteria For SPMs

The American Bureau of Shipping (ABS) Rules for Building and Classing Single Point Moorings include design criteria and construction requirements for the various components of SPMs. These rules are the most comprehensive and complete criteria for SPM design available; however, other criteria and standards may be used to supplement them.

The structural design rules incorporated into the ABS SPM rules cover various types of loading and combinations of loading conditions. In general the rules limit tensile stress in structural components to less than 80 percent of yield strength under combined conditions of gravity, wave, wind, current, and mooring loads. The criteria and methods of analysis given in the rules follow from the ABS rules for ship hulls.

Although generally intended to apply to buoy hulls, the rules are broad enough to apply to mooring bases and to mooring towers. In addition to covering structural design and welding standards, the rules cover cargo system, mooring line, and anchoring design. The ABS rules call for cargo piping to conform to ANSI B31.3 for manned SPMs and to ANSI B31.4 for unmanned SPMs. The ABS rules are supplemented by the Oil Companies International Marine Forum (OCIMF) Hose Standards and Hose Guide.

The ABS rules call for anchor legs of buoy-type SPMs to be designed with a factor of safety of 3 on the breaking load. In the case of moorings employing piles, the ABS rules recommend that pile foundations be designed in accordance with the American Petroleum Institute (API) RP2A Recommended Practice for Planning, Designing and Construction, Fixed Offshore Platforms.

One or two mooring lines are usually used between the tanker and the SPM. If two mooring lines are used they should pass through the same fairlead or fairleads as close together as possible at or near the center of the tanker forecastle. If two mooring lines run to widely separated fairleads first one line and then the other will take almost all the mooring load as the tanker yaws and sways at the mooring.

The ABS rules recognize this by requiring a higher factor of safety when two separate mooring lines are used which may be brought through separate fairleads. The combined rated breaking strength of the two mooring lines must be 2.5 times the maximum mooring load. Where a single mooring line is used there is no concern about sharing of the load, and the breaking strength must be at least 1.67 times the maximum mooring load. These criteria are based on the philosophy the maximum mooring load will seldom be approached and has only a slight probability of being exceeded and that mooring lines should be frequently inspected and periodically replaced.

The Strength of Components

The sizes and strengths of synthetic ropes, chains, and other mooring system components for SPMs have increased substantially in the past ten years. For example, in 1966 the largest chain available was 4-3/4 inches in diameter and the largest synthetic rope was 12 inches in circumference. Now 7 inch diameter chain and 30 inch circumference synthetic rope are available.

The basis of published rated loads of synthetic ropes may vary. Some manufacturers list ideal breaking strengths for ropes in their catalogs. These are the breaking strengths which would be achieved if the rope were tested without intermediate or eye splices. The rated breaking strengths should be appropriately reduced if they are not based on tests of typical spliced samples. Some manufacturers publish average breaking strengths while others publish minimum breaking strengths.

An endless grommet rope of a given size would appear to be twice as strong as a single rope of the same size with eye splices at each end. However, assuming the radius of the thimble provided on the grommet is the same as that on the eye splices, the strength of the grommet may be only 1.7 times that of the single rope with eye splice.

Limitations on Loads and Environments

Designing the load-carrying members of the SPM for the mooring loads which can be expected for a range of vessel sizes in certain specified environmental conditions is not sufficient to insure a safe mooring. SPMs may be designed for very-severe environments and very-high mooring loads if tankers which are to moor at the facility are specially modified. However, a number of technical and operational factors may limit the mooring loads and environments which can be tolerated at a SPM which must moor a general tanker fleet. A wide variety of tankers may be expected to moor and the capabilities of tanker-mounted mooring equipment vary from vessel to vessel.

The adequacy and strength of the mooring fittings on the tanker are important considerations in establishing limiting SPM mooring loads and environments. Since the adequacy and strength of these tanker fittings is beyond the control of the SPM designer, the only steps he can take are to design a mooring which experiences low loads in a given environment and to clearly point out to the operator what loads may be experienced for various vessel sizes in specified operating environments. The operator in turn may have little control over which vessels moor at the facility. However, with reference to mooring load data and an assessment of the adequacy and strength of tanker-mounted mooring fittings, the operator can limit the environments in which the tanker shall remain moored.

Most tankers of the VLCC (very large crude carrier) class (generally 140,000 dwt and larger) are equipped with special fittings on their forecastle to fasten mooring lines from SPMs. The Smitts bracket is the most common type of tanker-mounted SPM fitting, although specially adapted chain stoppers are now being fitted on some VLCCs. These fittings are limited as to the size of chain which they will accept. In general, the maximum chain size which can fit a tanker-mounted SPM Smitts bracket or chain stopper is 3 inches in diameter. Smaller VLCCs generally have one such fitting, although some smaller VLCCs and almost all large VLCCs now have two such fittings. The mooring load levels to which these fittings are designed varies.

Some smaller VLCCs and many smaller tankers have no special fittings on the forecastle for receiving SPM mooring lines. When such tankers call at a SPM, special arrangements must be made to fasten the ends of the mooring lines to bollards or other strong points on the forecastle. Usually a wire line or synthetic rope strop is passed through the end link of the SPM mooring line and looped or figure-eighted about bollards. The strengths of the wire line or synthetic rope strop and of the bollards are sometimes questionable.

Limitations on the maximum environments in which cargo transfer may take place at an SPM may depend on the stresses induced in the cargo hoses or on the maximum environment in which hoses can be safely disconnected and lowered. Cargo transfer should be discontinued and the hoses disconnected and lowered at mooring loads and environments below the maximum for which the mooring is designed in order to preclude the possibility of a vessel break-out causing overstressing the hoses and resulting in a spill. The cargo hose when lifted out of the water, over the rail, and attached to the tanker manifold, is subjected to cyclic loading by waves. These loads increase with higher wave heights. Although wave-induced loads in the tanker-end cargo hoses are not so severe as to cause immediate failure, they can reduce the life of the hose and lead to early failure.

Severe wind and wave environments can limit or impede the functions of the tanker crew on the forecastle and main deck and also the operations of launches serving the mooring. It is prudent to discontinue cargo transfer and lower hoses before the environment becomes so severe that the crew cannot safely work around the tanker manifold. Likewise, it is prudent to disconnect the mooring lines from the forecastle of the vessel before it is unsafe for the crew to work on the forecastle. If launches are required to aid in lowering cargo hoses or otherwise assist the tanker in leaving the mooring, these operations should be carried out before the environment hinders launch operations.

CONCLUSIONS

Although SPM design has progressed beyond the stage of being an art, it is still an emerging science. The various design parameters which influence the performance of an SPM are now well understood. Computer analysis, and theoretical and empirical techniques are being used to conduct design studies. However, model testing is still usually relied on to establish final design loads. Standards and rules are available to guide the design of the SPM structure and the various SPM components. Communication of ideas among SPM designers has helped to bring the science of SPM design to the stage it is today, and hopefully will continue to advance the science of SPM design.

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REFERENCES

1. Rules for Building and Classing Single Point Moorings, American Bureau of Shipping, 1975, New York.

2. Flory, J. F., Mascenik, J., and Pedersen, K. I., "The Single Anchor Leg Mooring" Paper No. OTC 1644, Offshore Technology Conference, Houston, 1972.

3. Flory, J. F., and Synodis, S. T., "Development of The Single Anchor Leg Mooring" ASME Paper No. 75-PET-44, American Society of Mechanical Engineers, Petroleum Engineering Conference, Tulsa, 1975.

4. Haring, R. E., Adams, R. B., Beazley, R. A., and Kipp, K. L., "Design of Single Point Mooring Systems for the Open Ocean", Paper No. OTC 1022, Offshore Technology Conference, Houston, 1969.

5. Langeveld, J. M., "Design Criteria for Single-Point Mooring Terminals" ASCE Paper 10931, Journal of the Waterways, Harbors and Coastal Engineerig Division, Vol. 100 No. WW4, American Society of Civil Engineers, New York, November, 1974.

6. Maari, R., Offshore Mooring Terminals (Single Buoy Moorings Inc.), Monaco, 1975.

7. Maari, R., "Design Aspects of Single Point Moorings", Ocean Industry, March, 1976.

8. Madox, N. R., "An Energy Basis for the Design of Open-Ocean Single-Point Moorings" Paper No. OTC 1536, Offshore Technology Conference, Houston, 1972.

9. Pinkster, J. A. and Remery, G. F. M., "The Role of Model Tests in the Design of Single Point Mooring Terminals", Paper No. OTC 2212, Offshore Technology Conference, Houston, 1975.

10. Wichers, J. E. W., "On the Slow Motions of Tankers Moored to Single Point Mooring Systems", Paper No. OTC 2548, Offshore Technology Conference, Houston, 1976.

11. Wilbourn, J. P., "SPM Model Testing for Proposed U.S. Superports", ASCE Preprint 2685, ASCE National Resources and Ocean Engineering Conference, San Diego, 1976.

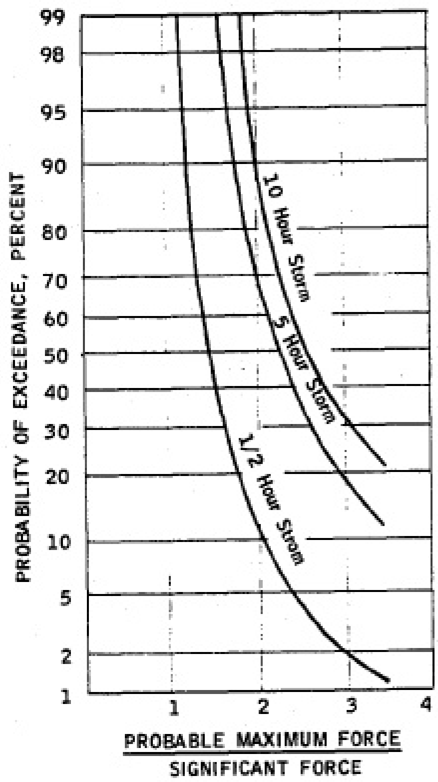

Fig. 1 - Example mooring force probability curve.

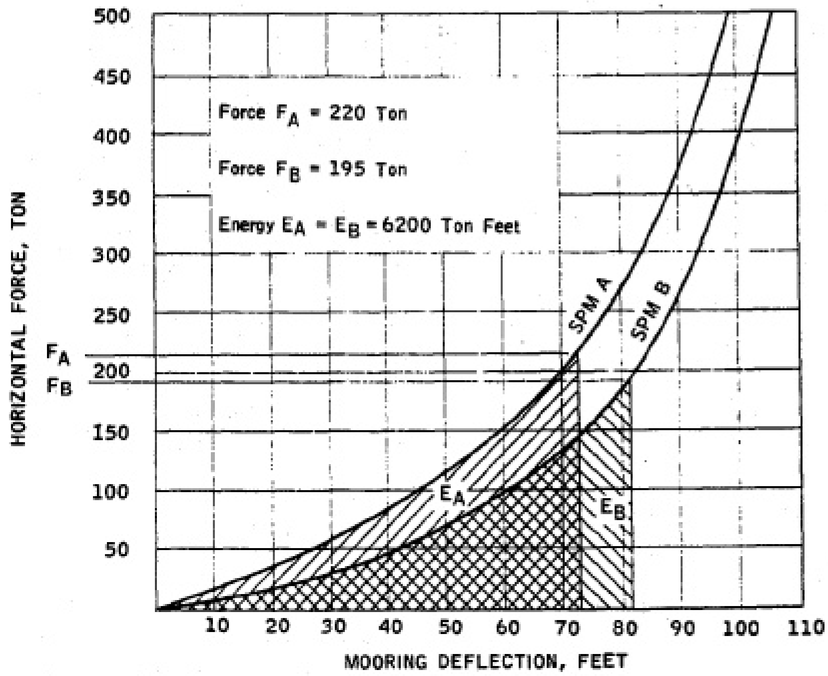

Fig. 2 - SPM elasticity curves showing application of energy theory.

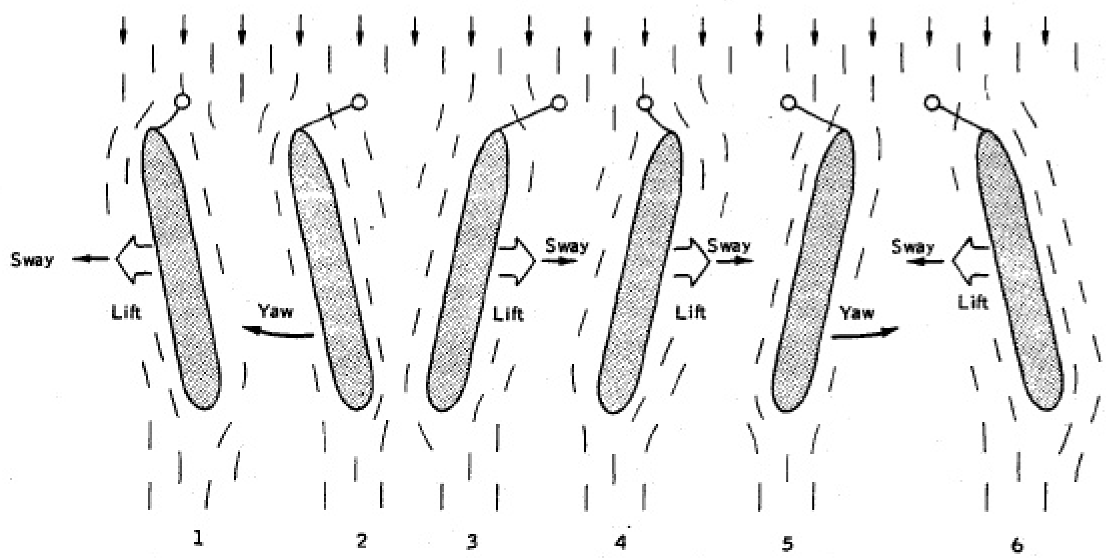

Fig. 3 - Motion of vessel due to wind or current at SPM.