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THE LOOP DEEPWATER PORT: DESIGN AND CONSTRUCTION OF THE SINGLE ANCHOR LEG MOORING (SALM) TANKER TERMINALS

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ABSTRACT

This paper discusses the design and the major components of three (3) Single Anchor Leg Mooring (SALM) terminals which will be used to moor and unload tankers up to 700,000 DWT at the first domestic port capable of accommodating deep draft vessels.

The extensive model tests and basic rationale used for selecting the SALM (vs. the CALM) are discussed as are the design criteria and mooring forces which were determined through model test analysis and supplemental calculations.

The major SALM components are described with emphasis on unique features which were incorporated to improve safety, increase operational efficiency and reduce maintenance requirements.

Special emphasis is placed on the sophisticated equipment incorporated into these SALM systems to allow remote load monitoring and shut-in control of oil flow during the unloading operation and thus provide maximum protection against mooring breakouts and potential environmental damage.

The LOOP SALM terminals will be classified per American Bureau of Shipping's (ABS') "Rules for Building & Classing Single Point Moorings". This paper discusses briefly the involvement and role of ABS in reviewing overall project plans, mooring forces, structural design, and installation plans, and the providing of site inspection during fabrication and installation.

INTRODUCTION

The Louisiana Offshore Oil Port (LOOP) will be the first domestic facility capable of accommodating deep draft tankers. This facility will greatly improve the efficiency with which crude oil is transported from exporting nations to the United States and will allow full realization of the economics offered by Very Large Crude Carriers (VLCC). These terminals, each designed to safely moor and unload tankers up to 700,000 DWT, will be located approximately 18 miles south of Grand Isle, Louisiana in about 110 feet of water.

The LOOP deepwater port will allow fully loaded VLCC's to unload crude oil directly into underground storage and thence to major pipeline systems and will thus reduce the current requirements for lightering and transshipment. Unloading oil via SPM is ecologically preferable to open ocean lightering because the possibility of spills is greatly reduced. Additionally, the offshore location of the deepwater port provides for environmental safety because it reduces the probability of tanker collision or grounding which are by far the major causes of oil spills.[1,2]

In its initial stage the LOOP terminal will consist of three (3) SALM-type (Fig. 1) Single Point Mooring (SPM) terminals arranged equidistantly along an 8000 foot radius semi-circle with the pumping platform complex at its center (Fig. 2). Ultimately, expansion plans may add up to three (3) additional SALM's for a total of six (6). A fifty-six (56) inch diameter pipeline will connect each SALM to the central offshore pumping platform and a 48 inch diameter pipeline will connect this pumping facility to a shoreside booster station. From here, the oil will move inland to the underground salt dome storage facility where it will be temporarily stored. Oil will be transferred from storage to the St. James terminal of CAPLINE which feeds refineries in the East and Mid-West, and to other pipelines which supply Louisiana refineries. The LOOP terminal which will initially have an import capacity of 1.4 million barrels per day, will ultimately be joined to about twenty-five (25%) percent of the total U. S. refining capacity.

The LOOP deepwater port will be the first application of Single Point Mooring (SPM) technology for crude oil import in the United States. SPM's are

References and illustrations at end of paper.

Hs	Wind	Current
12 ft. @ 180°	35 kt @ 135°	1 kn @ 90°
12 ft. @ 135°	35 kt @ 180°	1 kn @ 90°
4 ft. @ 135°	10 kt @ 180°	.5 kn @ 90°

The total Test Study III consisted of 29 tests for CALM with Lazy-S, 9 tests for CALM with Chinese Lantern and 29 for SALM.

In addition to tests in the selected environments three other tests of interest were conducted:

1. Behavior of ship in wind and current only

2. Behavior of floating hose string when the buoy was unoccupied during a reversal of current direction

3. Tanker collision with buoy

Principal variables were underbuoy hose configurations, tanker size and tanker loading condition. Note: All model tests were conducted at a scale of 1:53 in a water depth of 115 feet.

A total of 82 model tests were conducted during the study of the SALM; 129 tests were required for the CALM study. (More tests were conducted with the CALM because two distinctly different hose configurations were tested and each test required several PLEM-buoy orientations). Several observations of particular interest were made during these model tests:

1. For the SALM with tankers 350 MDWT - 700 MDWT optimum hawser length is 60m. With the 165 MDWT tanker, optimum length was 55m. During the tests, hawser lengths were varied from 40m - 90m and it was observed that increasing the length of the bow hawser beyond the "optimum" resulted in an increase in slow motions of the ship in the horizontal plane and in larger peak bow hawser loads.

2. The largest mooring forces were experienced with the tankers in the light ballast (30%) condition, lowest forces occurred with the tanker fully loaded.

3. In general, no appreciable differences in mooring forces were experienced when the tanker size increased from 350 MDWT to 700 MDWT with tankers in the loaded condition. For the ballasted condition (normal ballast = 43%) forces were slightly larger with the larger vessel.

4. The behavior of both types of mooring systems in waves, wind and current is dominated by large, slow (10-20 minute cycle period) oscillations of the ship in horizontal plane. The oscillations are largest with the ballasted tanker and maximum values of bow hawser force are attained at both extreme positions and at an intermediate position. Forces at the intermediate position are normally much larger than at the extreme positions. Additionally, high frequency oscillations of the buoy and ship with periods about the same as wave periods will contribute somewhat to bow hawser force (typically 10% - 20% for the SALM).

5. The movement of the SALM underwater hose system was less than both the optimum Lazy-S and Chinese Lantern hose systems selected for the CALM in operating and hurricane survival conditions, and during periods of current reversal.

6. No significant advantages were observed whether the SALM hose system was in its normal configuration or submerged on the seafloor during hurricane conditions.

7. Peak forces in the SALM's anchor leg occurred during maximum operating conditions, <u>not</u> during the maximum hurricane.

8. The SALM's single anchor leg chain experienced substantially lower stresses than the most heavily loaded chain of the CALM.

9. The SALM illustrated superior survival characteristics during tanker collision tests.

Based on analysis of these comprehensive model tests and weighed with the personal experience of the various member oil companies, the SALM was selected by <u>both</u> LOOP and SEADOCK for use in their Gulf Coast superports.

The decision to use the SALM instead of the CALM placed major emphasis on performance under routine operating conditions. Of special importance was the consideration of hose maintenance. The model tests showed that the motions of the CALM buoy induced higher forces in the floating and underbuoy hoses than were experienced in the SALM hose system. It was believed that these larger forces would lead to increased maintenance frequency.

NSMB also concluded from the model tests that the SALM system offered the best capability for hurricane survival. Additionally, it was believed that the SALM system would be less likely to experience damage than would the CALM in the event of a tanker overriding the buoy during a berthing approach because no critical SALM components were susceptible to damage from tanker-buoy collision and the SALM had no radial anchor chains or PLEM to buoy hoses that could be fouled by the tanker's bow.

<u>SALM DESIGN</u>

The LOOP SALM terminals are designed to provide reliable import facilities which will be available for continuous use with an absolute minimum of downtime.

The design environment and maximum tanker were selected to insure an operating condition (berth occupied) which would have only a small probability of exceedance and would represent a realistic maximum mooring condition.

Water Depth (maximum)	114 ft.
Tanker Deadweight Tonnage (max.)	700,000 DWT
Tanker Length	1400 ft.
Tanker Beam	250 ft.
Tanker Draft (maximum)	95 ft.
Significant Wave Height	15 ft.

Wave Period	9 Sec.
Current (Parallel to wave)	3 Ft/Sec
Wind (1 minute mean)	50 mph
Maximum Wave (survival)	70 ft.
Maximum Wind (survival)	166 mph
Maximum Current (survival)	4.4 Ft/Sec

As previously noted, testing has shown that the operating environment will determine the design loads, not the hurricane survival condition.

Typical planned operating parameters for the LOOP terminals are:

1. Place tanker onto mooring w/Hs less than 6 ft.
2. Suspend loading with Hs approximately 12 ft.
3. Depart mooring with Hs greater than 15 ft.

The load monitoring system will reduce the judgement factor required to make decisions regarding items 2 & 3.

The required anchoring capacity and structural component strength for the LOOP SALM's are based on two governing conditions i.e., operating mooring loads and ultimate structural capacity loads.

The operating loads were basically established during the model test program but were modified by SOFEC to reflect final design environmental conditions that were somewhat different with respect to operating current than the model tests conditions (Fig. 4):

Item	Model Test	Final Design (SOFEC)
Buoy Size	25 ft dia x 38 ft high	21 ft dia x 46 ft high
Net Submerged Buoyancy	386 s. Tons	350 s. Tons
Current	1 kt 90° to waves	1.76 kt in line w/waves
Bow Hawser Force	386 s. Tons	410 s. Tons
Anchor Leg Force	689 s. Tons	650 s. Tons
Anchor Leg angle (w/vertical)	30°	33°

The operating load dictates the mooring hawser assembly which in turn, dictates the ultimate load-the force required to break the hawser assembly's chafing chain at the tanker's bow. The United States Coast Guard's "Guidelines for Deepwater Port Single Point Mooring Design"[4] recommends 1.75: 1 = chafing chain breaking strength ÷ maximum hawser operating load. This exceeds American Bureau of Shipping's requirements per ABS "Rules for Building & Classing Single Point Moorings" and was thus selected for the LOOP design.

HAWSER SELECTION

The use of a single bow hawser has become popular at some SPM installations in recent years because of ease of handling and hook-up and lack of tangling problems common to twin hawser systems. A single hawser system for LOOP per U.S.C.G. guidelines would require an 18 inch grommet-type hawser (STROP) having a new breaking strength of 846 s. Tons and a chafing chain with a breaking strength of 718 s. Tons. This dictates a Grade U3 chain approximately 3-3/4 inch diameter, larger than the 3 inch chocks commonly found on VLCC class tankers. Additionally, OCIMF standards[5] for tanker deck fittings set maximum working loads well below the maximum probable bow hawser force:

Vessel Size	OCIMF Minimum SWL for bitts, and Smit Brackets
Less than 100,000 DWT	1 x 110 s. Tons
100,000 - 150,000 DWT	1 x 220 s. Tons
150,000 - 350,000 DWT	2 x 220 s. Tons
greater than 350,000 DWT	2 x 275 s. Tons

For these reasons, a dual hawser system was recommended for the LOOP SALM's. Each assembly consists of a 180 ft. long, 15 inch circumference nylon grommet. The grommet was selected instead of a 21 inch single line because the "eyes" at either end are easier to handle.

The two hawser assemblies are completely autonomous. There are two sets of mooring brackets on the buoy deck, each with its own quick change hawser coupler and strain gauged mooring pin, and twin chafing chains 25 ft. long at the tanker end, each connected to its hawser via quick change thimble.

The structural components of the SALM are designed to assure that a load of 1.75 x max. operating hawser load or approximately 720 s. Tons will not cause yielding in any component which might affect the integrity of the product swivel or other critical members. Twin 3 inch chains (Gr. U3) acting in unison through closely spaced bow chocks could exert as much as 970 s. tons. Thus, the chafing chain assemblies were designed to incorporate an overload stress control link. These machined links have a breaking strength of 360 s. tons each and will be placed in each chafing chain just outboard the bow fair lead. Should a failure occur at this location (which would require loads substantially in excess of the maximum predicted load) the nylon hawser would spring back toward the buoy and would not endanger tanker personnel. It is noted that the hawsers themselves which are vulnerable to attrition from salt water wetting and cyclic loading each have a new breaking strength of 600 s. tons for a combined strength of about 3 times the maximum predicted load.

In the case of widely spaced bow chocks (10 ft. or more apart) the hawsers will be unequally loaded a majority of the time. In the extreme yaw position, the angle between the hawser and the ship's longitudinal axis may be as large as 60°. In this position with the maximum loaded hawser at its limit i.e., 360 s. tons with chafing chain overload safety link, the least loaded hawser will be elongated about 8.7 feet less and will pick up about 140 s. tons for a total combined capacity of 500 s. tons.

The evaluation is based on the elastic characteristics of nylon hawsers which have been in use for some time. Newer hawsers would have substantially higher elasticity and consequently smaller load differentials would result between the two hawsers. In considering the probability of a condition which could overstress the chafing chain, it should be recalled from the discussion of model tests that the extreme yaw position does not create the peak hawser loads. Rather, the peak forces occur at an intermediate position where the load distribution between the two hawsers will be nearly equal.

Considerations for Fatigue

Design of welded joints and structural components subject to significant stress variations was based on consideration of fatigue effects. Previous SOFEC research has established allowable stress ranges for various components of the SALM terminal based on consideration of the cumulative effects of the predicted stress history during service life of the facility.

Basically, peak load stresses due to both mooring loads and dynamic (hurricane) loads were computed and a complete stress range history for a 20 year service life was established. The number of stress cycles within each of a series of stress range groups was then determined on the basis of wave statistics and predictions of the average interval of occurrence of peak loads during both mooring and survival conditions. The cumulative effects of the computed stress ranges were evaluated using a "damage factor" technique.[6] Using this method, ratios of actual stress cycles to stress cycles required for failure for a given stress range are developed and a summation of these ratios is then compiled. Values for the stress cycles required for failure at a given stress level in welded joints and structural components were derived from published data and were used in establishing the final design criteria.[7,8]

DESCRIPTION OF MAJOR SALM COMPONENTS

Mooring Base & Pilings

The SALM mooring base is a compact, pile anchored seafloor foundation. It is an "open" square, steel structure 40 ft. outside x 30 ft. inside dimensions with a 13 ft. overall height. The sides of the square are stiffened box beams 5 ft. wide x 7 ft. high which connect to 6' o.d. pile sleeves at each corner. Four (4) 5 ft o.d. x 90 ft. long piles will be driven to 77 ft. penetration to anchor the base to the seafloor. Connection between pile and pile sleeve will be achieved by pressure grouting.

The entire base will be recessed into the seafloor 7 feet. The mooring base is designed to form an externally flush sealed unit when the fluid swivel is in place. This design completely encloses the structural connections and the fluid swivel piping thereby protecting them from silt build-up.

The mooring base cover plate is flush with the mud-line and is intended to be "self cleaning" by the action of bottom currents as the absence of exposed structural members and piping will prevent excessive silt build-up around the base. The structural connection between fluid swivel and base, and the twin 30" outlet piping may be readily accessed by divers through large manways. While the environment is wet, it is protected from silt build-up and jetting will not be required in order to inspect these components.

The rotating crude oil inlet chamber is located just above the mud-line. To prevent silt from building up against this swivel, a simple labyrinth-type exclusion device was designed. This device utilizes an air-pocket seal and has no running parts to contribute to torque build-up.

Fluid Swivel Assembly

The fluid swivel allows the hose assembly to rotate 360° and follow the tanker as it swings around the mooring in response to directional weather changes. The fluid swivel is designed as a complete separate modular unit which is set into the mooring base and connected with sixteen (16) high strength bolts. This arrangement presents a very low profile so that the entire fluid swivel including the lower universal joint projects a total of only about 10 feet above the mud-line.

The underwater location of the SALM's fluid swivel dictates a design that provides long-life maintenance free operation. SOFEC-SALM fluid swivels do not require periodic lubrication and the design positively insures that no mooring forces are transferred into the swivels.

The fluid swivel assembly incorporates the stationary crude oil outlet chamber i.e., the chamber is built into the fluid swivel assembly unit and is not an integral part of the mooring base. This allows the connection between the fluid swivel and the mooring base to be strictly structural and thus not required to maintain any kind of seal in conjunction with its structural load-carrying function. This type design allows every pressure sealing connection to be readily removed and brought to the surface in the event maintenance is required.

The rotating crude oil inlet chamber is mounted on two (2) rotary fluid swivels. Each swivel incorporates five (5) large volume seals; three (3) on the crude oil side and two (2) on the seawater side. The primary oil seal is a very large cross-section, multiple contact, self-energized seal which is actually three seals in one. The secondary seal is a large U-type pressure energized seal. Additionally, on the oil side an "emergency" seal is incorporated which may be brought into service in the event of primary and secondary seal failure.

This seal is normally in a passive (retracted) position and may be energized and externally set with hydraulic pressure. Once set, this seal will allow the swivel to continue to operate as usual until maintenance can be scheduled thus preventing an unanticipated shut-down of the system.

The fluid swivel is designed to accommodate crude oil flow rates of 175,000 barrels per hour at operating pressures up to 275 psig.

Another important fluid swivel design consideration is torque resistance. The LOOP fluid swivel assemblies are designed to rotate under the influence of the torque created by small currents acting on the hose string. Thus, in periods of current reversal such as tide changes when the terminal is unoccupied the swivel will rotate and prevent the hoses from wrapping around the SALM buoy.

In order to insure the performance characteristics and integrity of SOFEC-SALM fluid swivels, the units are completely tested during three phases of manufacture:

1. The individual rotary fluid swivels are tested prior to installation in the fluid swivel assembly. Torque-pressure curves are developed during these tests. Two separate series of tests are conducted; one series tests the emergency seal system only, the second series tests the primary and secondary sealing system.

2. The completed fluid swivel assemblies are hydrostatically and rotationally tested to develop torque-pressure characteristics. A total of eighteen (18) separate rotational tests are conducted at different pressures during which 312 torque readings are recorded.

3. After installation into the mooring base the swivel along with all associated base piping is again hydrostatically and rotationally tested.

The final acceptance testing which is a full rotational and hydrostatic test series is conducted subsequent to the installation and prior to commissioning of the SALM.

In order to allow comprehensive maintenance, a series of test ports are designed into the system. Access to these ports is provided in a convenient location so that a diver can easily conduct maintenance checks and on-site tests, if required.

Mooring Buoy

The SALM mooring buoy provides the Single Mooring point to which the tanker is attached via bow hawsers. The buoys' hull is 21 ft. o.d. x 46 ft. high. It has a submerged net buoyancy of 350 s. tons. The buoy is designed to maintain positive tension on the anchor leg at all times including the event of the maximum hurricane wave.

The buoy is designed as an externally loaded ring-stiffened pressure vessel with a minimum design factor against buckling of 2.5:1 at the maximum design submergence of 70 ft.

The interior of the buoy is divided into eight (8) watertight compartments by a horizontal deck at mid hull plus 2 vertical bulkheads 90° apart. In an emergency, any four of these compartments could be flooded without causing the buoy to sink.

The exterior of the buoy is completely enclosed by a structural framework which serves three (3) important functions:

1. It provides structural protection for the buoy hull to prevent damage by tanker-buoy collision.

2. The framework serves as external ring-type hull stiffeners.

3. The framework provides a series of evenly spaced flat surfaces on which to mount elastomeric fenders. This type mounting assures full utilization of the fenders energy absorbing capabilities.

Anchor Leg Assembly

The SALM's single anchor leg assembly utilizes 6-1/2 inch grade ORQ (Oil Rig Quality) stud link anchor chain with a breaking strength of 1985 short tons. At the maximum predicted operating load, the anchor chain is stressed to less than 33% of its breaking strength. It is important to note that the proper SALM design insures that this chain is always in tension i.e., it is not subjected to impact loads even in the event of the maximum hurricane wave passing the buoy.

The assembly incorporates a universal joint at each end and a chain swivel at one end. With this arrangement, the universal joints accommodate lateral displacements of the buoy and the chain swivel allows rotational motion. Thus, relative movement between the chain links and subsequent chain wear cannot occur.

The SOFEC universal joints utilize full monel overlay on the load carrying pins and on facing surfaces. Permanently lubricated aluminum-bronze bushings and thrust washers are employed and the joints have proven to provide long, maintenance free life.[3]

Each chain swivel will employ five (5) rows of angular contact ball bearings. The units will be pull tested to 1000 tons and rotational tests will be conducted at incremental loads to develop load-torque curves. Following testing, the swivels will be completely disassembled and inspected prior to acceptance.

The swivels are grease filled and sealed against intrusion of sea water. They do not require periodic lubrication. Swivels of this design are proven, low torque units which offer exceptionally long life.[3]

The SOFEC-SALM design, which places the chain swivel directly in the anchor leg assembly, insures that no torque loads are transferred into anchor leg components.

Hose System

The hose system for the LOOP SALMs consists of two parallel 24 inch i.d. hoses with a total horizontal length from the buoy's static center line to the tanker's mid-ship manifold of about 1100 feet.

The hose system consists of a submerged section, a short transition section and a long floating section.

The floating section will be made up of about 24-40 ft. lengths of integral float-type hoses such as are in common use on SPM's throughout the world.

The submerged section of SALM hose system will consist typically of 5 - 40 ft. lengths of specially reinforced submarine hose. The stiffness or rigidity is calculated via iterative technique and must be sufficient to cause this portion of the hose string to assume a configuration that provides a "moment arm" adequate to rotate the fluid swivel when the floating hose string is acted upon by nominal surface currents. Each hose manufactured will be subjected to a bending test (along with other extensive pressure and vacuum tests) to insure that it meets the stiffness requirements.

The profile of the submerged hose string is achieved and maintained by integral in-line buoyancy tanks mounted between the hose flanges. Each hose length is additionally supported by hose flotation beads mounted onto collars that are made into the hose carcass. This type of support provides a very stable hose profile which, due to its complete separation from the mooring buoy, is not subjected to large external forces and provides very long service life. Forces exerted by sea action on the floating hoses are gradually dampened as they travel along the slightly stiffer submerged hose section and the resultant motions (and forces) which occur where the hose attaches to the fluid swivel are relatively minor.

To add additional protection to the hose string, the LOOP SALM's will incorporate a specially designed elastomeric joint at the juncture point of hoses to the fluid swivel assembly. These flexible joints are designed to provide a transition between the hose and the rigid piping.

Equipment for Operational Monitoring & Control

The LOOP SALM terminals will be equipped with remote valve control systems and with a unique system for monitoring forces in the bow hawsers which attach the tanker to the buoy. This equipment will allow remote observations of the tanker-buoy interaction during unloading operations and will permit remote shut-in of the crude oil transmission system between the tanker and the pipeline to the central control platform. Thus, the remote systems provide maximum command over two potential operational hazards; tanker breakouts and oil spills. A third type of potential operating danger, tanker/buoy damage due to collision, is eliminated by the inherent safety of the SALM design which places critical fluid carrying components below the keel of the tanker and allows the buoy to be readily pushed aside by tanker contact.

Valve Control System

During unloading operations oil is pumped from the tanker through the twin 24 inch i.d. hoses into the SALM's fluid swivel. The oil departs the fluid swivel through two thirty inch headers which lead to the main fifty-six inch pipeline that connects each SALM to the central pumping platform. Ball valves are provided at the inlet and outlet of the fluid swivel. Additionally, thirty inch check valves are provided at the swivel outlets. Twenty-four inch valves on the inlet side are locally controlled via direct hydraulic operators. The 30 inch ball valves on the outlet side are controlled via hydraulic operators which are actuated from the central control platform 8000 feet away.

The primary considerations for selection of the valve control system were reliability as proven by actual sub sea experience and response time.

Three basic types of control systems were considered:

1. Electro-hydraulic - sub sea accumulators provide fluid to valve operator through a solenoid operated control valve which is electrically controlled from the main platform.

2. Hydraulic- piloted - same as (1) except pilot control valve is hydraulically actuated from the platform.

3. Straight hydraulic - valve operator only is located at seafloor connected via hydraulic hose bundle to accumulators and controls on platform.

System 1, electro-hydraulic- has the advantage of very fast response time, less than 10 seconds, but has the disadvantage of dependence on electrical circuits in a sub sea environment. System 2, hydraulic piloted, sacrifices response time (aprox. 30 seconds required to initiate the valve operator) but its hydraulic components offer improved reliability and have a substantial sub sea experience record. System 3, straight hydraulic, offers the best reliability (although actual experience is lacking) because all major components except the valve operator are located on the platform. The disadvantage of this approach is longer response time

Additionally, difficulty was encountered in accurately predicting response times due to a lack of actual recorded test results of various hoses or tubing products with different hydraulic fluid mediums.

After thorough investigation of advantages and disadvantages of each system and how the systems operation would relate to terminal operation, the straight hydraulic concept was chosen as the most suitable for the LOOP project. It's key advantage was simplicity and the absence of sub sea components.

Surface equipment required for the straight hydraulic system consists of a hydraulic power unit, (HPU), main control panel and remote control panel, all located on the main platform. Provision is made to integrate the control functions into the platform programmable controller. The HPU provides hydraulic fluid at 3000 PSI for sub sea utilization. Special features are incorporated to insure that this fluid is free of impurities. Hydraulic fluid flows to the sub sea SALM valve operators approximately 8000 ft. distant via a sub sea hydraulic transmission bundle. Two lines are used for operating each valve operator, alternating as feed and return lines to form a closed loop and return all hydraulic fluid back to the main platform.

The sub sea components utilized in this project will be extensively tested and proven operational in a sub sea environment prior to installation. The completed assembly will be set up and functionally tested, and all necessary adjustments made prior to being installed offshore.

Load Monitor System[9]

The load monitor system will measure, compare and automatically transmit to the control platform 8000 feet away the peak loads which occur in each of the two mooring hawsers during a preselected time interval.

Knowledge of the mooring loads allows the operator to observe the effects of worsening sea conditions as the tanker unloads and thus provides him with a means to make a reasoned decision to:

1. Cease loading operations but leave tanker on buoy.
2. Cease loading operations and instruct tanker to depart buoy.

Additionally, a permanent record of the mooring loads will show how many load cycles each hawser experiences at different percentages of rated breaking strength. This data which will provide a rational basis for hawser replacement decisions will be stored in the LOOP main computer, available for call back and comparison at any time.

The load monitoring system provides hawser forces to the control platform operator and to the mooring master on the tanker. The actual load on each of the two mooring hawsers on each SALM buoy will be continuously monitored by this system which includes a primary data transmission system and a back up secondary transmission system. The load sensors will consist of rugged strain gage arrangements built into each of the two specially designed mooring pins located on the buoy deck. The mooring pins are stationary (non-rotating). Wire leads from the strain gages are carried in watertight rigid conduits to a watertight compartment containing signal amplifiers and acoustic telemetering equipment. Acoustic transponder units mounted under the mooring buoy will transmit signals from each strain gaged mooring pin to seafloor relay units via acoustic pulses. From the seafloor relay unit, which is located on the SALM mooring base, signals will be transmitted to the control platform via armored underwater cable. All electrical connections in the sub sea environment are made with metal shell underwater mateable pin connectors. At a control room console all strain gage signals will be converted to calibrated load read out data, displayed on analog meters, and plotted by strip chart recorders. A signal comparator will compare monitored loads from each separate hawser with a preset load limit value and will trigger audio and visual alarms if the preset load limits are exceeded. By command from the platform, the buoy mounted sensors can be caused to transmit a signal on a selected time interval ranging from two seconds to 60 seconds. The signal which is then transmitted will be the maximum load which was measured during that interval. This will allow for limited access (and therefore limited usage of stored battery power, strip chart paper, etc.) during periods of consistantly low mooring loads, but closer, more exact monitoring as loads increase in poor weather conditions.

This load monitoring system design was selected to provide maximum integrity and minimum maintenance. All buoy mounted components are securely mounted and none of the components are subjected directly to the environment or to any severe motions or impact loads. The acoustical link from buoy to seafloor is short which allows for the use of very high frequency signals. Complete redundancy is provided on critical functions of the system.

The processed data will be transmitted by radio link from the control platform to the tanker bridge where loads on each hawser will be displayed on a hand carried receiver which also will contain load limit alarm equipment.

As a back up primary transmission system, the acoustic signal from the buoy mounted transponder may also be received directly aboard the tanker through a small portable display unit which receives acoustic signals directly through a small hydrophone lowered into the water over the side of the vessel. The portable unit provides a complete redundant back up because it can interrogate the buoy directly and is totally independent of the control platform and the sub sea cable. It will be used in the event of sub sea cable damage and as a trouble-shooting tool.

In addition to the basic load monitoring system, a central control computer will collect, sort and record all incoming load data together with the corresponding sea state and wind and current velocities and directions.

Thus, a complete correlation of tanker size and environmental conditions with mooring loads will be achieved which will provide valuable operating data for the LOOP terminal.

SALM Classification - The Role of ABS

The American Bureau of Shipping (ABS) is a technical, non-profit organization; which has published rules and standards for building and classing Single Point Mooring Systems. They have been given the responsibility of classing the LOOP Single Point Mooring Systems, according to these rules. As a pre-requisite to classing these systems, ABS is responsible for review of several areas affecting the design and operation of these systems. The specific areas of ABS are as follows:

1) Review of environmental data and verification of predicted mooring loads.

2) Review of site survey data and layout drawings showing SALM location, spacing, tanker fairways and anchorage locations.

3) Review of all design calculations

4) Approval of design drawings

5) Inspection and certification of various manufacture of these SALMs and witnessing of material physical test where applicable, inspection and observation of fabrication procedures and fabrication work in progress.

6) Review and interpretation of non-destructive testing being performed on a complete fabrication, such as x-ray, ultrasonic examination and mag particle.

7) Witnessing of sub-component functional testing

8) Review of installation procedures and actual witness during offshore installation

9) Issuance of the ABS classification for each Single Point Mooring

It should be noted that there are certain specific areas wherein there are no ABS rules which are applicable to the work being performed, such as valve controls and the load monitoring system. For these areas, independent inspection outside the scope of ABS is being utilized. Additonally, and supplemental to work being performed by ABS, LOOP has employed Engineering Contractors (primarily Fluor Ocean Services and Petro Marine Inc.) assigned the responsibility of quality assurance for all work being performed. Personnel of this quality assurance organization together with sub-contractor inspectors and direct inspection by SOFEC supplement the inspection services of ABS.

CONCLUSIONS

1. The utilization of Single Point Mooring's (SPM's) for the LOOP crude oil import terminal demonstrates the complete acceptance, and the importance of the SPM concept as a vital link in worldwide oil transportation network.

2. The selection of the Single Anchor Leg Mooring (SALM) instead of the Catenary Anchor Leg Mooring (CALM), which has historically dominated terminal applications for the past 20 years, indicates industry's recognition of the importance of the safety and maintenance features inherent in the SALM design for use in the Gulf of Mexico environment.

3. The application of load monitoring and valve control equipment indicates the importance placed on maximum control of the mooring and unloading operation. The load monitoring system will also provide valuable feedback for comparison with model test results and for correlating actual hawser experience with industry test data.

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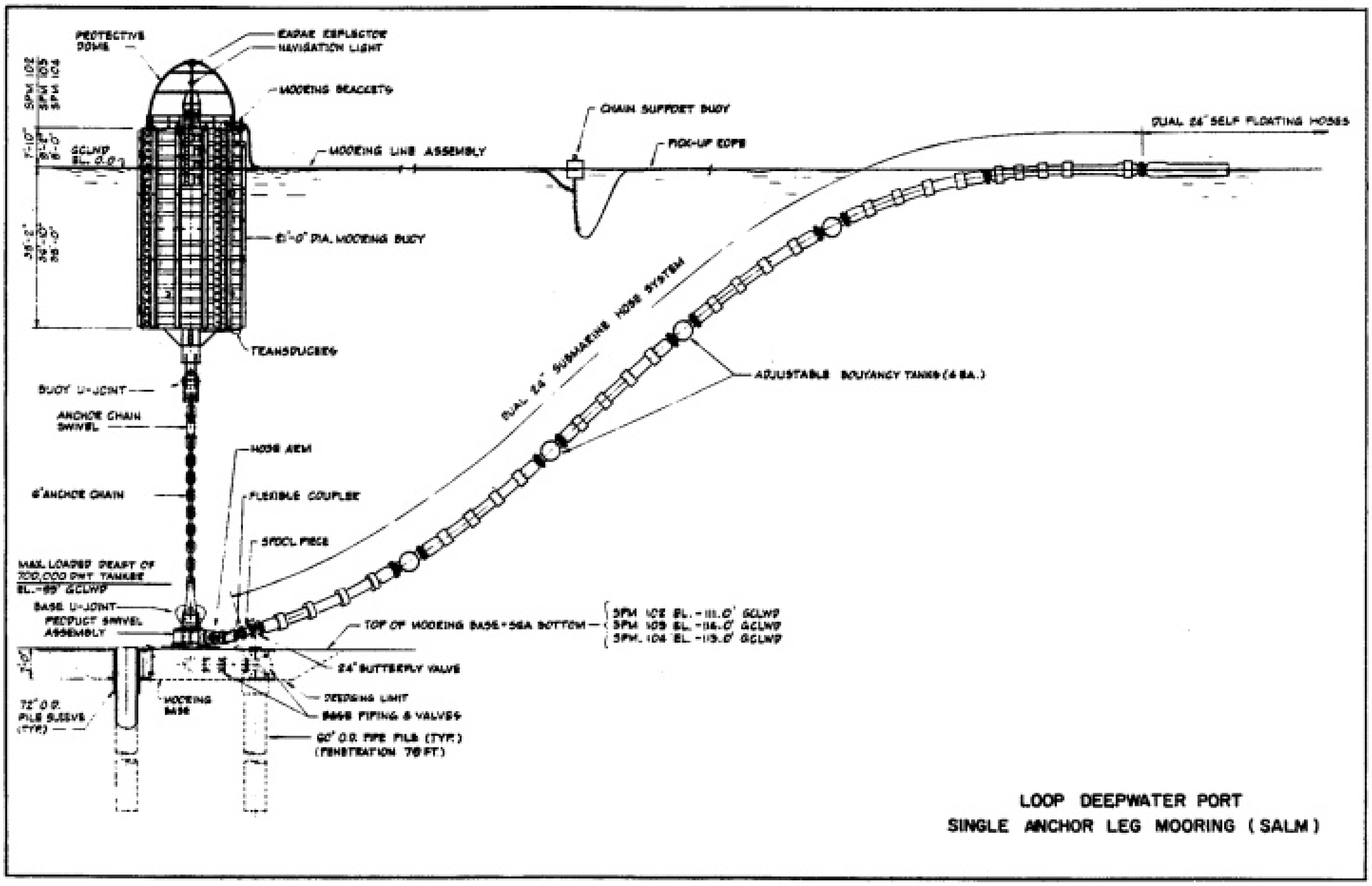

Fig. 1 - SALM elevation.

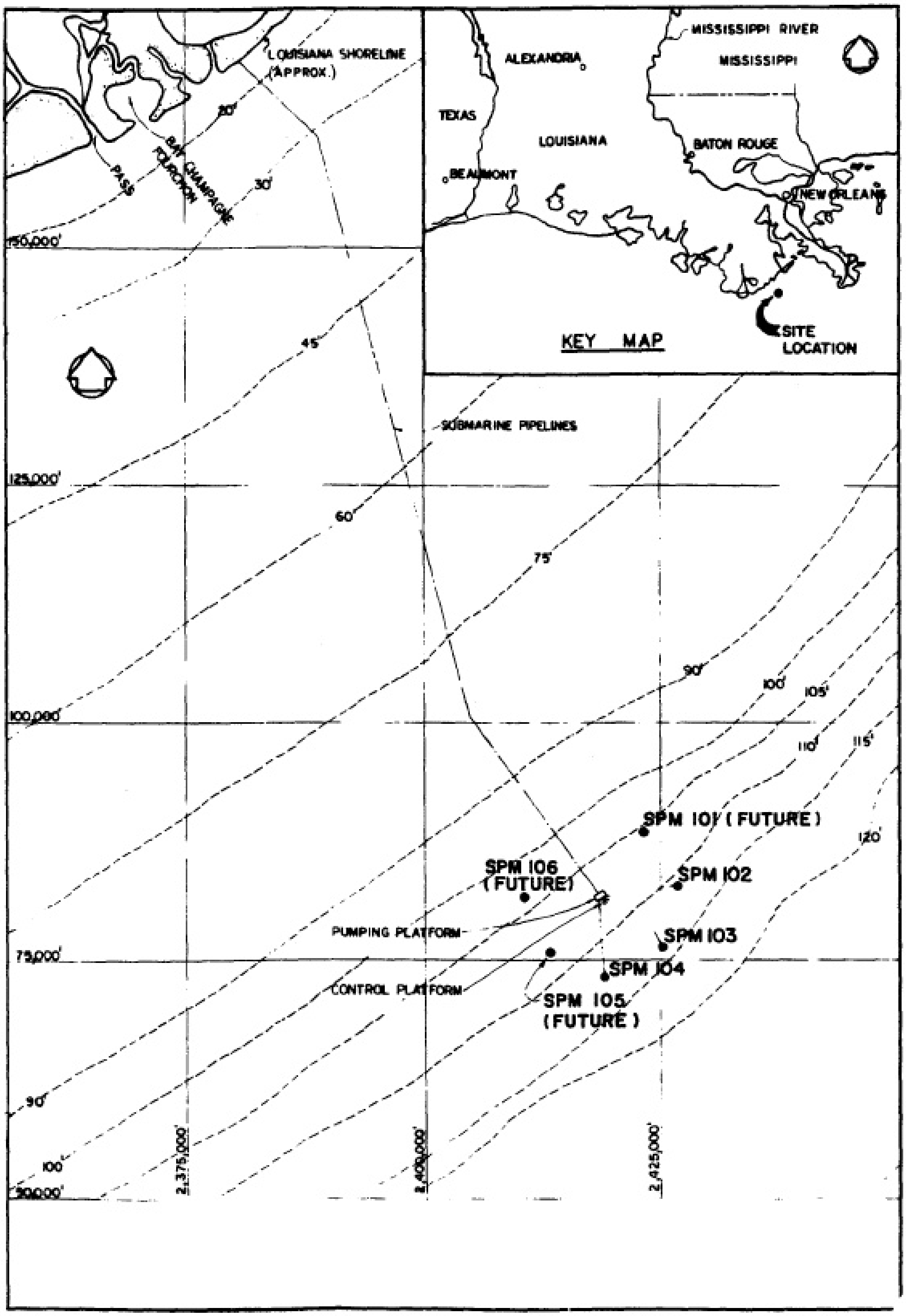

Fig. 2 - LOOP deepwater port: Location map.

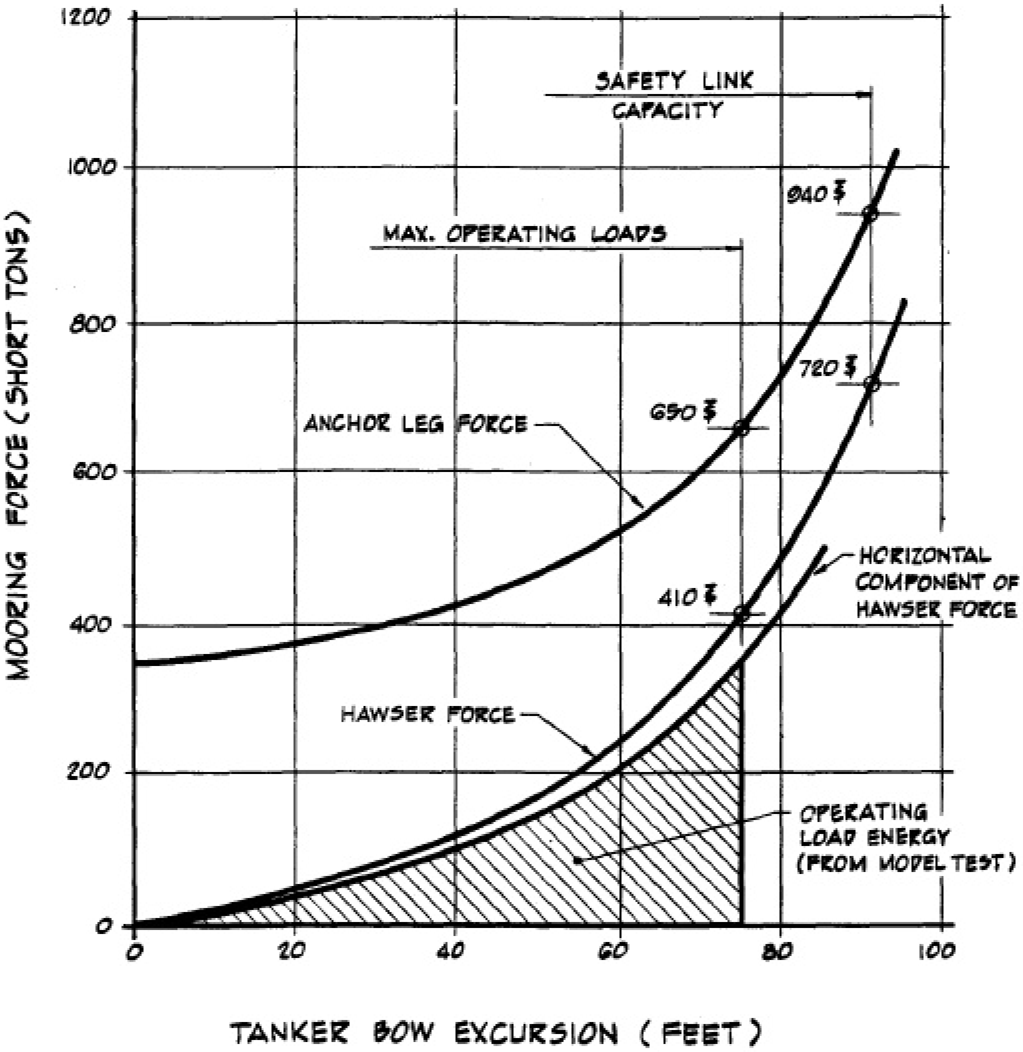

Fig. 3 - SALM design loads.