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THE WORLD'S LARGEST SINGLE POINT MOORING TERMINALS: DESIGN AND CONSTRUCTION OF THE SALM SYSTEM FOR 750,000 DWT TANKERS

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ABSTRACT

This paper will discuss the design, fabrication and installation of two (2) identical Single Anchor Leg Mooring (SALM) Terminals which serve as crude oil export terminals. Both are designed to safely moor and load tankers as large as 750,000 DWT in environmental conditions that will be occasionally severe.

The determination of mooring forces via calculation and model tests and the design and fabrication of the components which transfer these loads will be discussed. Of particular interest is the design and fabrication of the "heart" of the systems, the fluid swivel assemblies which include several innovative features with respect to operation and maintenance. These fluid swivels are the largest ever built for SPM applications and are designed to transfer crude oil and bunker fuel oil simultaneously and to absolutely preclude the possibility of commingling of the two fluids. Model tests that were conducted on the fluid swivel/loading hose system will be discussed.

The foundation design and the optimization of this design with respect to available offshore construction equipment will be outlined as will the installation methods employed.

INTRODUCTION

The safe, efficient and economical transportation of crude oil from typically remote producing areas to the consuming areas of the World presents several difficult problems. Solutions to any of these problems offer attractive cost savings for crude oil feed stocks.

A major step in optimizing crude oil transportation has been the development of the Very Large Crude Carrier (VLCC). Unfortunately, the development of the VLCC has threatened to outpace the development of terminals suitable for loading/unloading these giant, deep draft vessels. One solution to this problem that has gained wide acceptance in recent years is the Single Point Mooring (SPM) or "monobuoy" type of terminal.

The SPM terminal solves several problems that are inherent to other types of tanker loading/unloading facilities (harbors, jetties, sea islands, multiple buoys and fixed towers):

1. It can be readily placed far offshore in the deep water necessary to accommodate deep draft tankers.

2. It can operate efficiently in rough seas and is not sensitive to directional changes of wind, waves and currents. With the tanker moored via bow lines only to a single buoy, the tanker is free to "weathervane" about the buoy and stay head-on to the weather, thus reducing mooring forces and increasing terminal utilization.

3. It reduces operational dependency on support vessels such as tugs.

4. It is generally less expensive to construct and/or operate than the other types of loading/unloading facilities.

This paper describes the ARAMCO - Ju' Aymah SALM Terminals (Arabian Gulf) which are the largest export SPMs ever built, and discusses the unique design features that were incorporated into these systems to make them safer, more efficient and more economical to operate than previous SPM designs. Included are discussions on the determination of the mooring loads, the design of a dual product fluid swivel which absolutely segregates two fluids, the incorporation of features to reduce maintenance requirements including an emergency sealing system which will prevent panic shutdowns due to leakage in the fluid swivel, and the design of the hose system for optimum performance. Model tests data is referred to where applicable with respect to mooring loads and hose system design. Foundation design and installation techniques are also outlined.

References and illustrations at end of paper.

DESIGN PROCEDURE

The Ju' Aymah SALM Terminals are designed to provide reliable export facilities which will be available for continuous use with an absolute minimum of outage time. The following specifications describe the tanker size and environment utilized for the prediction of the maximum mooring forces which determine the design of load transfer components and the sea floor foundation.

Water Depth (typ.)	=	125 Ft.
Tanker Size (max.)	=	750,000 DWT
Tanker Length	=	1,480 Ft.
Tanker Beam	=	250 Ft.
Tanker Draft (loaded)	=	100 Ft.
Significant Wave Height (operating)	=	15 Ft.
Wind Speed (operating)	=	45 Knots
Current (operating)	=	3 Ft./Sec.

The basic characteristics of the Ju' Aymah SALM Systems are illustrated in Figure 1.

The primary design philosophy for an SPM system is to provide a mooring having sufficient elasticity to minimize mooring forces while retaining adequate stiffness to control tanker excursions.

The elasticity of the SALM's inverted pendulum configuration is primarily a function of buoy net buoyancy and anchor leg length in series with the elasticity of the bow hawser. In a simplified system considering buoy net buoyancy (F_b) and the horizontal force (F_h) required to displace this net buoyancy, the relation of the variables may be expressed as:

$$F_h/F_b = \tan\gamma \quad . . . . (1)$$

where γ = angle of inclination with the vertical of the Single Anchor Leg.

In the analysis of an actual SALM, the uplift force exerted by the bow hawser, the non-linearity of the hawser and the mass and buoyancy of the components must be considered. Problem solution yielding static forces and deflections at each junction in the mooring system is achieved via iteration techniques with a computer.[1]

SOFEC's method for predicting mooring forces is based on an empirical technique developed by Exxon Research and Engineering Company and Exxon Production Research Company. This technique relates peak mooring forces to the energy stored in the mooring system as it is displaced by the tanker and has been experimentally verified by approximately 1000 model tests. The model tests have been conducted with tankers ranging in size from 28,000 DWT to 700,000 DWT in water depths from 100 ft. - 600 ft. and in waves (operating) to 23-1/2 ft. significant and survival waves approaching 80 ft. (maximum wave height).

The effects of currents both parallel and perpendicular to the direction of the waves and of wind have been studied in these tests and are taken into account during SALM design.

The method allows design treatment for the effects of cross-currents (perpendicular to waves) by treating these currents as wave energy modifiers which increase the effects of a given significant wave by causing reorientation of the tanker so that it assumes a quartering (rather than head-on) exposure to the waves.

An explanation of Exxon Production Research Company's application of the "Energy Method" for prediction of mooring forces is given in Reference 2.

SOFEC has extended the basic "Energy Method" to allow better determination of the actual effects of winds and currents by considering the equilibrium position assumed by the vessel in a given loading condition, water depth and environment.

Mooring forces predicted via calculation procedure have been correlated with mooring forces observed in model tests with excellent results which indicate the calculation procedure to be slightly conservative.

For the Ju' Aymah Project, two separate series of model tests were carried out at the Netherlands Ship Model Basin. The first series was for the purpose of assessing the performance of the SALM System in general, selecting an optimum hose system design and verifying mooring forces. The second series was conducted to study on a large scale the performance of the SALM hose system in waves and currents. Results of these tests will be discussed as applicable in the following sections.

DESIGN OF SALM COMPONENTS

The design of the Ju' Aymah SALM Terminals considered several parameters which governed the design of the various components, specifically the mooring base which had to be designed around available construction equipment and the fluid swivel/hose system which had to ensure very low swivel and hose maintenance and offer provisions for emergency sealing of the fluid swivel.

The mooring base is a sea floor foundation which transmits the mooring forces into the anchor piles. It is subjected to occasionally heavy lateral loads from operating conditions but is designed to withstand the ultimate load that may occur should a tanker remain on the mooring for a sufficient time during peak environmental conditions to experience an extreme event. Components design must insure an acceptable factor of safety even in the event that this ultimate load should occur. Maximum* forces are predicted by application of probability theory similar to that described in Reference 5. The ultimate force that could result is defined as the breaking strength of the bow hawser in new condition (for the 7-inch grommet-type hawser utilized for the Ju' Aymah design breaking strength = 2200 kips). Predicted peak forces were very closely verified by the model tests.

The mooring base was designed to accommodate construction equipment and techniques available in the Arabian Gulf. Soil conditions at the proposed

* Peak operating force

installation site and requirements for tanker under-keel clearance (vertical distance from highest fixed point on sea floor to keel of fully loaded design tanker) dictated a pile anchored structure in favor of a gravity-type structure. Several alternatives were investigated which involved structures having 12, 6, 4, 3 and even 1 pile and the four (4) pile base was selected as the best design because it involved the minimum number of pilings of a size that could be installed with the available construction equipment.

Soil conditions were determined by two undisturbed sample borings drilled to a nominal penetration of 100 ft. below the sea floor. Field and laboratory soil tests were performed on representative samples from the borings to develop ultimate tensile pile capacity and soil resistance-pile deflection (p-y) data for the proposed pilings. The soils encountered in these borings consisted of sand, clayey sands, clayey silts, clays and seams and layers of gypsum. The sands and silts were dense to very dense and the clays very stiff to hard.

Based on the soil conditions encountered, it was determined that the best scheme for installing the pilings would be to either pre-drill undersized pilot holes and then drive the piles or to drill oversized holes and grout the piling into place. Final selection of the pile installation method was determined by installation economics.

The mooring base is a "hollow" square (Figure 1) with 45 feet outside dimension and 27 feet inside dimension. Each leg of the square is a 9 feet diameter, internally stiffened cylinder. Bulkheads at each corner separate the base into four watertight compartments so the entire structure is self-floating. Two of the compartments are designed to be flooded for submergence of the base during installation and two are designed to remain dry under full hydrostatic pressure which reduces hook loads during the lowering of the base from the surface to the sea floor.

All legs are flooded once the base is on the sea floor. They are then filled with cement which acts as ballast and prevents the pile system from being constantly in tension. The in-place weight of SALM base plus piles plus ballast offsets the uplift forces imposed during nominal operating conditions. Each Ju' Aymah SALM mooring base has an in-place weight of about 600 tons.

The corner bulkheads which also serve as shear plates for transferring loads from the SALM base into the anchor piles are tied through integral 76-inch i.d. pile sleeves to the short, deep heavy section plate girders which form the brackets for mounting the fluid swivel assembly.

The four (4) anchor piles are each 60-inch diameter x 90-foot long and are tapered with wall thicknesses from 1-1/2-inch in the upper section to 3/4-inch in the lower end. Centralizers are provided at the upper end to center the piles in the pile sleeves and thus insure uniform grout distribution and maximum grout bond strength is insured by shear keys welded to the i.d. of the pile sleeves. Specially designed extensions of the pile sleeves which penetrated the sea floor were utilized for grout seals.

All foundation design was consistent with API RP-2A - Recommended Practice for Designing and Constructing Fixed Offshore Platforms.

The fluid swivel is the "heart" of any SPM system and must be designed for maximum integrity to avoid costly downtime.

The SALM, whose fluid swivel is located underwater, dictates that fluid swivel design be for long life, maintenance free operation. SOFEC-SALM fluid swivels do not require periodic lubrication and actual field histories indicate that seal replacement requirements are very infrequent -- on the order of 7 years or more. Thus, the underwater location of the swivel becomes a positive advantage as it is removed from the harsh surface environment to the quiet zone near the sea floor and is also well below tanker draft and safe from damage by collision should the tanker override the buoy. Additionally, the underwater swivel allows separation of the mooring function and the cargo transfer function. There are no hoses attached to the SALM buoy and thus the hose system is not subjected to forces (and potential damage) caused by motions of the buoy.

The Ju' Aymah fluid swivels (Figure 2) and associated fluid transfer components i.e., the hose arm and the submarine portion of the loading hose, were designed as an entire system with the intent of achieving very low and infrequent maintenance requirements for these critical components.

The fluid swivel assemblies are each designed to transfer two (2) fluids simultaneously, crude oil and bunker fuel oil. The SOFEC design segregates these fluids via structural separation i.e., no elastomer or other type of seals are utilized. Maximum design throughput for the crude oil swivel is 210,000 BPH; bunker fuel maximum design flow rate is 20,000 BPH.

Each fluid swivel assembly is designed around a heavy wall tubular center shaft. Two fluid distribution chambers are swivel mounted concentric with the center shaft in a manner that prevents mooring forces from being transferred into the rotary fluid swivels.

The lower end of the center shaft is integral with the main fluid gathering chamber allowing the attachment between the fluid swivel assembly and the mooring base to be strictly structural. Thus the sea floor connection between the fluid swivel and the mooring base is not required to maintain a pressure-tight seal in conjunction with its structural load-carrying function and there are no pressure sealing connections that cannot be readily removed and brought to the surface (in earlier SALM designs, the gathering chamber was integral with the mooring base and sealing surfaces were subject to damage). The attachment between the fluid swivel and the mooring base is a structural flange which is integral with the center shaft and attaches to the mooring base with sixteen (16) high strength 3-1/2-inch diameter bolts. The crude oil inlet to the fluid chamber is a single 42-inch line and the bunker fuel oil flows through a single 12-inch line. Piping to the fluid swivel is contained in the mooring base and is designed to provide maximum redundancy with spool pieces utilized to insure easy replacement should damage occur to piping or flanges.

The upper end of the center shaft incorporates an internal lug-type connector for attachment of the lower universal joint. This simple, high strength connector replaced a previous design which utilized 48 bolts.

The rotary swivels on which the fluid distribution chambers are mounted each incorporate five (5) large volume seals; three (3) on the oil side and two (2) on the side exposed to seawater. On both the oil and seawater sides, the primary seal is a very large (2-inch) cross-section multiple contact self-energized type seal and the secondary seal is a large pressure energized type. Additionally, on the oil side an "emergency" seal is incorporated. This seal is normally in a passive or retracted position and may be energized and set externally with hydraulic pressure. Once set, this seal will allow the swivel to continue to operate as usual until maintenance can be scheduled thus preventing panic shutdowns of the system without the necessity of maintaining external hydraulic pressure once the seal is set. This emergency seal is incorporated in all the rotary swivels utilized in the fluid swivel assembly.

One of the key problems solved during the development of the Ju' Aymah fluid swivels was the achievement of a large reduction in the torque required to rotate the swivel. Reduced torque means longer bearing and seal life and longer life for the submarine hoses.

Previous data indicated that the majority of the swivel turning resistance was a result of seal friction. Misalignment of the swivel bearings in stacked assemblies also contributes to torque build-up but to a lesser degree than seal friction.

Several possible avenues for torque reduction were investigated including reduction of seal contact area, impregnation of the seals with a low friction substance, special coatings for surfaces on which seals bear, special lubricants and mechanical modifications to prevent torque build-up due to bearing misalignment. After preliminary studies, two of the above solutions were chosen for application: surface coatings and mechanical modifications.

What was needed in way of a surface coating was a low friction, long wearing material that could be readily applied to a finished, dimensionally correct part and that would achieve a mechanical bond with the surface to which it was applied. Several "low friction" components were tested on both steel and overlaid surfaces. A fixture was constructed which allowed continuous rotation of test discs which were coated with the various materials under study. This fixture allowed the effect of the force exerted by the seals when under pressure to be simulated. Test discs were periodically removed from the fixture and examined under a high-power microscope for damage or deterioration. A combination of low friction coating and surface overlay was selected after extensive testing during which the surfaces experienced the equivalent of more than five (5) years of actual use. This coating has excellent low friction and wear characteristics, is very impervious to damage by chipping or gouging and tends to be "self-healing" when physically damaged.

Mechanical modifications involved the development of a floating, adjustable packing gland which would allow the bearings to "run-out" freely while still maintaining a pressure tight seal.

The application of the low friction coating to the seal surfaces of the Ju' Aymah swivels in conjunction with the floating packing gland resulted in swivel torques over 50% lower than originally expected.

The Ju' Aymah SALM hose systems consist of twin 24-inch diameter crude oil hoses and a single 12-inch diameter bunker fuel oil hose. Twin 16-inch diameter tail hoses are attached to each 24-inch hose string for attachment to the tanker manifold. The systems are designed to ultimately accept 30-inch diameter crude oil hoses which will boost throughput to the maximum design rate of 210,000 BPH.

The SOFEC-SALM design utilizes the loading hose to transmit torque to the hose arm and thus rotate the fluid swivel. Thus, as previously mentioned, it is necessary to consider the fluid swivel, hose arm and loading hose as a complete system. The basic design problem is to determine the flexural rigidity required for the submarine portion of the hose system and insure that this rigidity (generally defined as EI) is sufficient to cause this portion of the hose string to assume a configuration that provides a moment arm (in conjunction with the hose arm) adequate to rotate the fluid swivel when the hose string is acted on by nominal surface currents.

Model tests were conducted on nine (9) different hose systems to determine the "optimum" submarine hose system with respect to profile, length and flexural rigidity both of the individual hoses and of the combined 24-inch-12-inch-24-inch system whose rigidity depends largely on the method used to link the individual hose strings together i.e., the hose spreader bar design. Models were constructed at scales of 1:53, 1:38 and 1:20 for these tests. The test results clearly indicated the best underwater hose profile and demonstrated the difference in the torque producing capabilities of a hose system linked via rigid spreader bars and one linked via articulated spreader bars. The tests also verified the flexural rigidity requirements which had been previously calculated. Bending moments in two planes and axial forces were measured in each hose string during the model tests and the effect of hose system design on torque input to the swivel was studied as a function of both hose system orientation with respect to current direction and current velocity. It was found with the "optimum" hose system that a current velocity of 0.3 - 0.5 knots with hose arm at 90° and 180° respectively to current direction was sufficient to rotate the fluid swivel.

The effect of current reversals was studied with both loaded and ballasted tankers and the resulting tanker motions were observed as the tanker swung around the buoy. In one series of tests, a 274,000 DWT tanker in both loaded and ballasted condition was deliberately pushed between the buoy and the floating hose. An interesting conclusion from the Model Test Report regarding the events of these tests: "During the turning of the tanker, the bow of the tanker will push the underwater hose, inducing the turning of the fluid swivel. . . . . No obstruction was observed in hose behavior and relatively low values were measured in the hose bending moments and axial forces."

The hose arm (see Figure 1) provides a flexible transition point for attachment of the subarine hoses and also constitutes an important part of the overall "moment arm" available to rotate the fluid swivel. The Ju' Aymah SALM hose arms are a self-stabilizing design. With this feature, the hose arm is stabilized at a pre-determined angle with the horizontal, typically 20° - 30°. When it is upset by external forces and moves either upward or downward, the "self-stabilizing" effect takes place and a positive righting moment is exerted which tends to return the arm to its equilibrium position. This function was clearly demonstrated during the Ju' Aymah model tests which also demonstrated the stability of the overall hose configuration . . . "Once the correct buoyancy has been added, the submarine hose configuration is stable and will, after deformation due to external forces, resume its static configuration again when the external forces are removed." The model tests also demonstrated conclusively that heeling angles i.e., changes in vertical orientation, of the hose arm under all current conditions tested (.5 - 1.75 knot) are moderate as are the motions under the influence of waves.

The Ju' Aymah SALM's mooring buoys (Figure 5) are each cylindrical structures 20 feet in diameter by 40 feet deep providing a fully submerged net buoyancy of 250 tons. Buoy net buoyancy is a key design factor for the SALM. Selected net buoyancy was determined by engineering study as that which provided the optimum resistance for adequate control over the motions of the maximum design tanker in the maximum design environment at an acceptable bow hawser load.

The length of the buoy is another key design factor. The selected length, 40 feet, was determined by consideration of the trough associated with the maximum (survival) wave. Buoy length must be sufficient to provide buoyancy well in excess of that required to maintain the system in tension even when in the trough of the maximum wave.

The buoy is anchored to the mooring base by a "Single Anchor Leg" which consists of 20 links of 6-inch oil rig quality stud-link chain. Integral with this chain are two (2) universal joints at either end and a rotary chain swivel at one end. The heavy chain constantly in tension and isolated between the two universal joints behaves essentially as a solid link. The universal joints accommodate angular motions and the chain swivel allows rotational motion. Thus, relative motion between the links is avoided and chain wear is nil.

The structural design of the SALM buoy treats it as an externally loaded cylindrical pressure vessel with ring stiffeners. The Ju' Aymah buoys are designed for 70 foot safe submergence. The buoy interior is divided into eight (8) watertight compartments via one horizontal bulkhead and two vertical bulkheads 90° apart. The buoy structure is assembled around a 48-inch diameter center shaft having a 2-inch wall thickness in the lower quarter of the buoy. This center shaft provides the attachment point for the buoy universal joint and is designed with extra length to allow adjustment for actual water depths at the installation site and thus assure proper buoy freeboard and buoyancy (when the buoy is in its neutral position).

It is appropriate at this point to note that since the SALM buoy may not be considered a "Floating Structure", it must be treated under Section 5.15 "Buoyancy Tanks" of the ABS "Rules for Building and Classing Single Point Moorings" instead of Section 5.9 "Floating Structures."

The Ju' Aymah buoys are equipped with large V-type butyl rubber fenders which are mounted around the circumference of the buoy at both the upper and lower ends to protect it from damage in the event the tanker overruns the buoy. Experience with other SALM systems has proven in cases where a tanker rides into the SALM mooring buoy, the buoy will simply be pushed under the tanker's keel and will resurface without damaging the tanker or any critical components.[3,4]

The Ju' Aymah SALM buoys are equipped with specially designed mooring brackets which feature a pin mounted adapter that will allow the system to be readily modified to accept a 7-inch grommet-type hawser which is anticipated for future use when tanker sizes increase. The present SALM systems utilize 5-inch grommet-type hawsers consistent with other type SPMs at the Ju' Aymah facilities which were not specified for tankers as large as 750,000 DWT. Connection of the hawser to the buoy is achieved via a reusable thimble which eliminates chafing chain at the buoy end of the hawser assembly.

FABRICATION

SALM components basically involve three categories of fabrication: Medium shipyard fabrication, heavy section shop oriented fabrication and heavy machine shop fabrication. Most components involve a combination of these three types with mooring base and buoy requiring a majority of medium shipyard fabrication plus some heavy section welding and fluid swivel/ universal joints requiring heavy machine shop plus heavy section welding.

The base and the buoy are of a size that makes long distance transportation costly and thus they are best fabricated as near to the installation site as possible. Other components, while often very large, are adaptable to shipping by available cargo carriers and therefore may usually be fabricated in a centralized area in the vicinity of project headquarters.

For the Ju' Aymah project located off the coast of Saudi Arabia, it was desirable from a logistics standpoint to fabricate the base and the buoy in the Arabian Gulf area. This decision prompted several changes in the design and in the preliminary fabrication plans for the base and buoy as available fabrication capabilities were somewhat limited in this area.

For example, heavy sections associated with the base and buoy were designed and welding procedures developed to preclude the necessity for stress relieving. T-stiffeners for mooring base torus shells and buoy bulkheads and decks were standardized and designed to be fabricated from plate. Rolled sections were designed to enable the use of available plate rolling equipment. Heavy rolled sections, the pile sleeves in the mooring base and the lower section of the buoy center shaft were farmed out to fabrication yards in Singapore and shipped to the Arabian Gulf site for assembly. The buoy mooring brackets which involved fabrication with 4-inch and 6-inch T-1 plate were fabricated in the U. S.

The hull work of the base and buoy was fabricated in accordance with ABS "Rules for Building and Classing Steel Vessels", heavy section fabrication followed AWS D1.1 and pressure piping, API 1104. Fabrication materials were generally ASTM A-36. Fabricated weight of the base plus piping was 192 tons and the buoy (not including fenders and universal joint) weighed 113 tons.

The fluid swivel assembly, universal joints and chain swivel required a large amount of heavy plate fabrication and heavy, precision machine work and were in this instance fabricated in the U. S.

Each fluid swivel assembly (Figure 2) for the Ju' Aymah SALMs weighed 75-1/2 tons and employed rolled plate sections with thicknesses up to 4-1/2-inches as well as heavy section castings and forgings.

The construction of these giant swivels required detailed planning, engineering and quality control for weld procedures, stress relieving, machining operations and assembly and testing. Materials were principally ASTM A-516 Gr. 70 (plate), ASTM A216 Gr. WCC (castings) and AISI 4130 (forgings). All structural welding was per AWS D1.1.

The lower universal joints (Figure 3) each weighed 23 tons and employed plate thicknesses up to 6 inches. Materials were chiefly ASTM A-516 and welding was per AWS D1.1. All of the SALM universal joints employ life-lubricated aluminum-bronze bushings and overlaid pins. The pins are 16-inch diameter x 5-feet long. Again, detailed planning, engineering and quality control were required during all phases of welding, stress relieving, machining and assembly and testing. The universal joints were trial fitted to the fluid swivels prior to shipment.

All components were pre-assembled at the fabrication site in the Arabian Gulf Shaikhdom of BAHRAIN.

The assembly procedure prior to loadout was as follows:

a. The fluid swivel was attached to the mooring base with 16 - 3-1/2-inch diameter high strength bolts. Bolt tightening was achieved via BIACH tensioner, a device which "stretches" the bolt thereby providing accurate pre-tensioning even under Field conditions. Each bolt was pre-loaded with a force of 600,000 lbs. Base piping spools were then assembled with the inlet header.

b. The hose arm was bolted to the 30-inch swivels on the main cargo housing. The 12-inch bunker fuel oil hose was then connected and attached to the hose arm.

c. The entire fluid system was hydrostatically tested to 425 psig. Crude oil and bunker fuel circuits were tested individually. The swivel was then rotationally tested and torque measurements taken at 30° increments. The hose arm was rotated in the vertical plane to check smoothness of operation.

This final hydrostatic and rotational test was the third series of tests to which the swivels had been subjected. The rotary swivels were tested individually prior to their incorporation into the fluid swivel assembly, then the entire assembly was tested prior to shipment to BAHRAIN.

d. The lower universal joint was attached to the fluid swivel via the lug-type connector. This connection involves setting sixteen (16) wedge shaped lugs which are driven into place with set screws.

Both mooring base assemblies and the anchor piles were loaded onto a barge for transportation to the installation site at Ju' Aymah, approximately 60 miles to the Northwest.

INSTALLATION

Phase I of the installation of the Ju' Aymah SALM Terminals took place during early summer, 1976. Construction activities were divided as follows:

Phase I - Install PLEM and tie-in main pipelines (2 - 48-inch and 1 - 18-inch). Install mooring base and pilings.

Phase II - Install buoys.

Phase III - Install loading hoses.

These activities were spread over a five month period to accommodate hardware deliveries and to optimize the use of floating construction equipment.

The mooring base assemblies were set on the sea floor into 4-foot deep recesses which were air-lifted prior to the arrival of the bases at the installation site. The bases were set into the water by means of a 500 ton stiffleg crane mounted on a 90 foot x 300 foot barge. Maximum required lift was 325 tons which was reduced to 80 tons (static) when the entire base plus hose arm was fully submerged. The bases were transported from BAHRAIN to Ju' Aymah, a distance of approximately 60 miles, on a barge rather than floated to the location under their own buoyancy. This procedure was utilized due to the loadout facilities which were better adapted for skidding the bases onto a barge than for launching directly into the water.

The base was aligned with the Pipeline End Manifold (PLEM) by means of a special bi-planar alignment "Protractor" built by SOFEC to assist the SALM installations. The base was then leveled so that adjacent corners were within ± 1 foot of grade (approximately 1:50 slope). This was done to insure uniform, adequate clearances for the piling installation. The mooring base slope was checked via underwater level indicator built especially for this job. Once leveled, the main flotation tanks were flooded prior to piling installation.

The mooring bases were each anchored to the sea floor with 4 - 60-inch diameter piling, design penetration 80 feet. The decision was made to install the anchor pilings using a "drill and drive" technique whereby 48-inch pilot holes were drilled to 70 feet penetration. The pilot holes were drilled through the piles after the piles had been driven to approximately 20 feet penetration. Drilling operations were carried out using the same barge that set the bases in the water.

The adoption of the drill and drive technique posed potential problems that did not exist with the alternate drill and grout plan. Thus, contingency plans were developed in the event the pile drove too easily or did not reach design penetration. Insert piles were designed to provide the required axial capacity in the event the pile reached grade but did not achieve design "refusal" of 200 blows/foot. If the pile(s) could not reach design penetration, the problem was complicated due to the varying wall thickness of the pilings i.e., lateral load capacities could not be satisfied if the pile stopped in a position which left the light wall section of the pile inside the pile sleeve in the mooring base. In this event, a short heavy wall insert would be required to provide adequate lateral load carrying capability. Several assumptions were made regarding the various possibilities. Axial and lateral inserts and combinations of inserts were designed, shop fabrication drawings were prepared, materials were located and remedial installation procedures were prepared in the event problems were encountered during piling installation. NOTE: The final analysis provides valuable insight for future projects in this area: Of eight pilings installed, six required 36-inch inserts for axial capacity. While these inserts insured that the piles fully achieved design requirements and no "lateral load" inserts were required, hindsight positively indicates the desirability of the drill and grout procedure rather than the drill and drive method employed for this project.

Once the pilings were successfully installed, each pile - pile sleeve annulus was grouted and the torus legs of the mooring base were filled with cement for ballast. The PLEM-base hoses were installed and preparations were made to install the buoys.

Prior to installing the buoys, it was necessary to accurately determine the water depth at the attachment point between the mooring base and the buoy. The water depth was then corrected to low, low water condition and the buoy center shaft was trimmed to the proper length to provide the correct mooring buoy freeboard. The buoy universal joint was then attached to the center shaft.

During installation, the buoy's lower compartments were flooded to ballast the buoy and thus provide slack in the anchor leg. The attachment to the mooring base was made between the shackle at the lower end of the anchor chain and the bracket on the lower universal joint attached to the fluid swivel on the base. This hook-up was facilitated by a specially designed landing box and a hydraulically actuated mechanism which located the shackle in place and then pulled the pin into place. Once the connection was secure, the buoy was deballasted completely which placed the anchor leg permanently in tension.

The submarine hose string (six lengths) was attached to the hose arm utilizing a specially designed guideframe to facilitate line up and to assist the diver with connection of the flanges.

The floating hoses were attached to the submarine string via variably reinforced transition hoses and the submarine hose profile was then adjusted to the design shape by means of flotation beads. Attachment of buoy safety cage and hawser completed the installation.

The SALMs were hydrostatically tested for a 24-hour period immediately prior to the first tankers actually mooring to the buoys. The tankers took on the water used for testing the SALMs, along with the first "dirty oil" (oil mixed with water) which the tankers then pumped back through the buoy to the shoreside terminal. Ju' Aymah is one of the few shipping ports in the World that permits tankers to discharge cargo to shore in case of accident.

OPERATION

The Ju' Aymah SALM Terminals were commissioned in late November, 1976. A visit was made to Ju' Aymah during early February, 1977, to observe the terminals in operation and to meet with operations and maintenance personnel. Several important items were confirmed:

1. The "self-stabilizing" hose arm functions as designed and as predicted by the model tests. The arm absorbs the highly damped motions of the hose string through small vertical excursions and returns to its "stabilized" design position.

2. Submarine hose profile is very stable and requires no maintenance or adjustment once set.

3. The fluid swivel rotates readily under the influence of torque produced by currents acting on the hoses.

Since the Ju' Aymah SALMs have been in operation, they have almost continuously been occupied by VLCC's of the World fleet. During the first three months of operation, approximately 100,000,000 barrels of oil were transferred through these SALM terminals. Thus far their performance capabilities and minimum maintenance attributes have lived up to all design expectations.

CONCLUSIONS

1. These Single Anchor Leg Mooring (SALM) terminals are designed to safely moor and load -- in the open ocean -- the largest tankers ever considered (750,000 DWT). This application demonstrates the viability of the SALM concept, previously considered primarily applicable for deep water mooring, in relatively shallow water.

2. The research conducted for this project resulted in improved hardware which minimizes operating stresses, maintenance requirements and the risk of pollution, and eliminates the necessity for emergency shutdown should swivel leakage occur.

3. The design parameters, construction techniques and unique maintenance features employed in these SALMs will provide useful guidance for future projects which involve open ocean tanker terminals.

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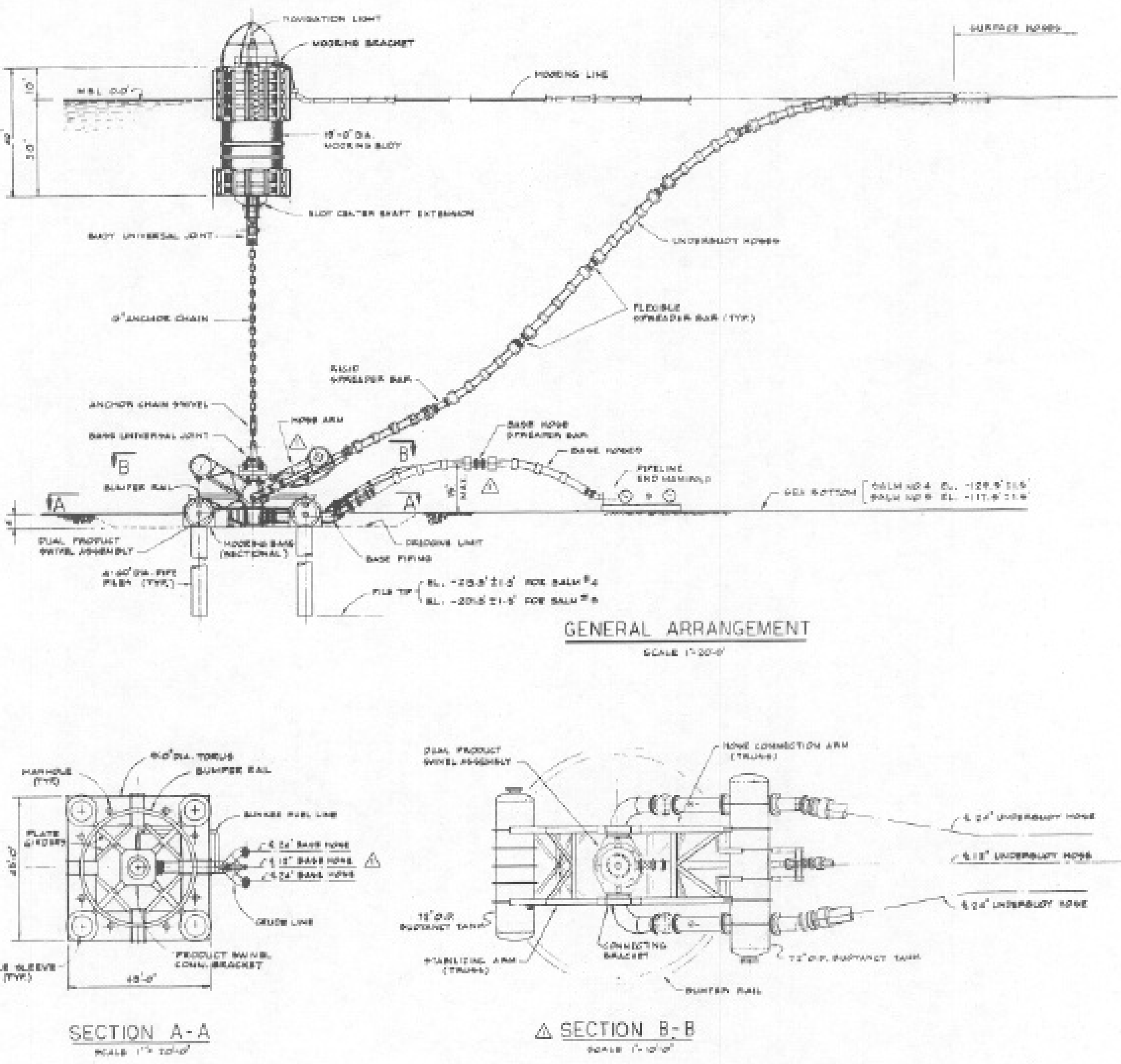

Fig. 1 - Ju' Aymah SALM plan and elevation.

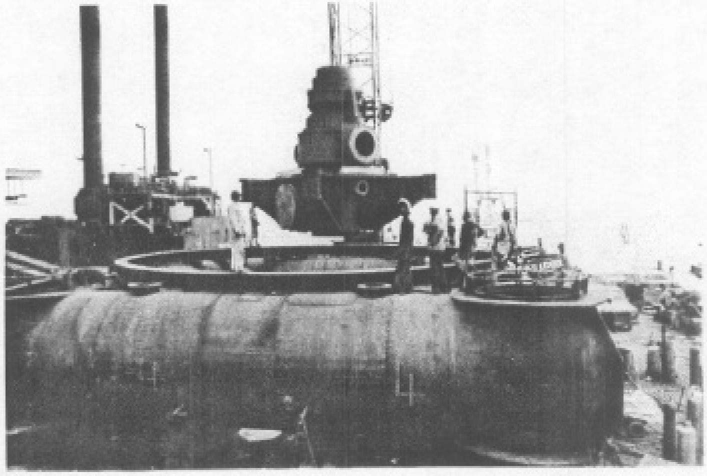

Fig. 2 - Fluid swivel assembly being installed in mooring base.

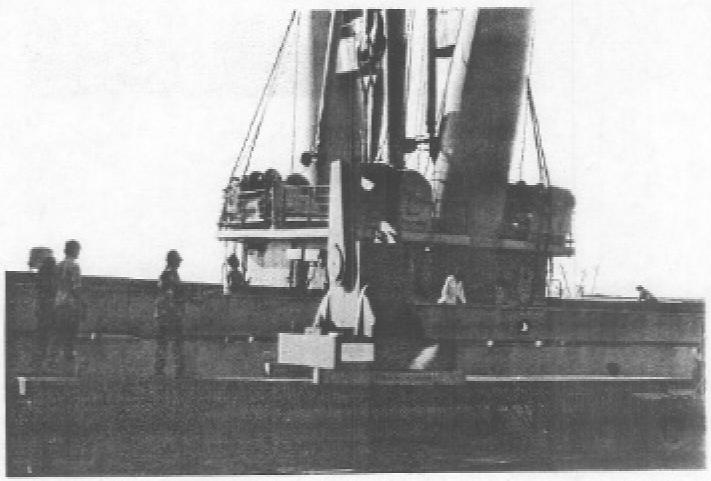

Fig. 3 - Base u-joint being loaded onto transport vessel.

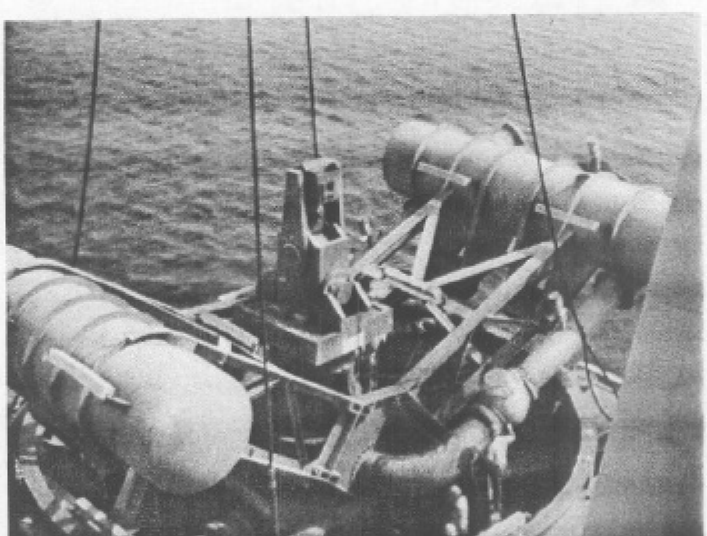

Fig. 4 - Mooring base with fluid swivel; hose arm and base u-joint being lowered to seafloor.

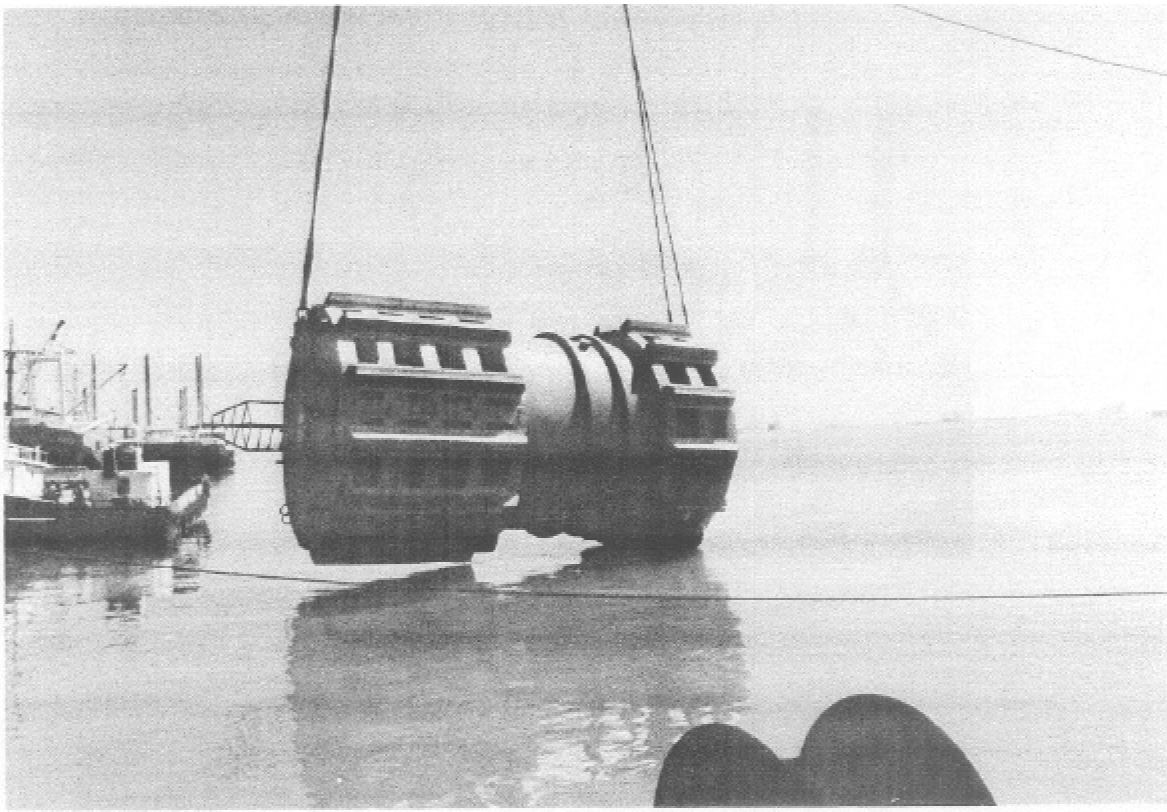

Fig. 5 - Mooring buoy during load out.

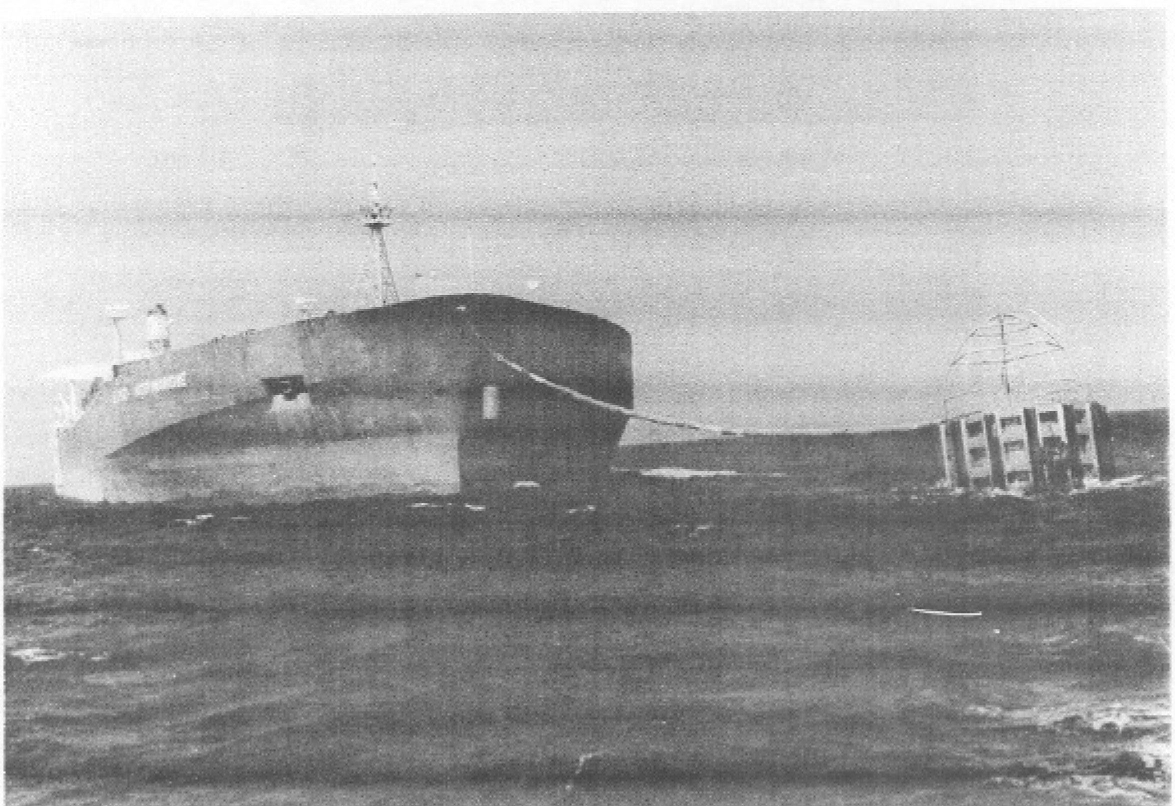

Fig. 6 - SALM buoy with 280,000 DWT tanker moored.