OTC 3564

# THE FIRST YOKE MOORING FOR A VLCC IN THE OPEN OCEAN

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This paper was presented at the 11th Annual OTC in Houston, Tex., April 30-May 3, 1979. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

## ABSTRACT

A permanently moored storage vessel for crude oil was installed in March, 1978 in the South China Sea approximately 115 naut mi (213 km) off the coast of Malaysia in 214 ft (65 m) of water. The system constitutes the first yoke mooring for a VLCC (Very Large Crude Carrier) in the open ocean. The mooring is a SALS (Single Anchor Leg Storage) system which employs a slender riser and depends on buoyancy in the rigid mooring yoke to provide the necessary restoring moment.

This paper broadly describes the technical aspects of the mooring system such as the design philosophy, model testing performed and engineering criteria. It specifically addresses many novel aspects of the installation of the mooring system; the horizontal tow of the combined mooring base and riser, the free upending of the system, the vertical tow of the system to the mooring site, and the hookup of the VLCC with the rigid yoke to the installed riser. In addition, the paper describes the experience gained with the operations of the storage vessel and the alongside mooring procedures which are utilized to offtake crude oil from the storage vessel to shuttle vessels.

Information contained in this paper is directly applicable to the design and installation of any single point mooring system for the open ocean.

## INTRODUCTION

In 1974 an SALM (Single Anchor Leg Mooring) system was ordered by EPMI (Esso Production Malaysia, Inc.) for use in the Pulai Field offshore Malaysia in the South China Sea. The system, consisting of a mooring base, slender riser, and mooring buoy, was to soft moor a storage vessel in approximately 245 ft (75 m) of water (Fig. 1). The contract for the SALM was awarded to SBM (Single Buoy Moorings, Inc.) and the system was designed, model tested, and built during 1974 and 1975. However, due to renegotiation of operating agreements with the Malaysian government at the time construction was in progress, the system was not installed. Instead, the SALM was kept in storage by EPMI in Singapore.

References and illustrations at end of paper.

In late 1976 an agreement was reached with the Malaysian government national oil company, PETRONAS, and development of the contract area was resumed. However, instead of using a bow hawser to soft moor the storage vessel it was decided for various technical and economic reasons to moor the vessel permanently by means of a rigid-yoke. The rigid-yoke mooring would eliminate the problems and costs associated with the necessity in the mild weather environment of maintaining constant power astern on the storage vessel in order to hold position, and replacement and maintenance costs associated with the bow hawser and crude oil hose systems. In addition, a rigid-yoke system would include piping to allow gas from the production field to be used as fuel on the storage vessel.

An engineering design study was undertaken to determine if the existing SALM system could be modified to accept a rigid-yoke. Essentially three engineering options were available:

- Increase the buoyancy of the existing buoy and install a yoke similar to the SALM rigid yoke system for Santa Barbara,[1]
- Increase the length of the existing riser to above the waterline and provide a buoyant yoke similar to the SALS system for Castellon,[2]
- Or, a hybrid solution of option 1 and 2.

Following the engineering review of the options, and considering the need for a timely solution, increasing the length of the riser and providing a buoyant yoke was selected as the most viable alternative and SBM's contract was extended to modify the existing SALM to accept a buoyant rigid yoke (Fig. 2). A preliminary design study was then initiated and model tests were conducted to determine the behavior and the loads in the modified mooring system. The results of the model tests showed that the existing pile and gravity base could be used essentially unmodified, and that the existing riser could be extended. In addition, a yoke similar to the Castellon design could also be used. However, due to the much larger tanker size the yoke structure would have to be of much heavier construction. From a timing standpoint this alternative meant that the base and extended riser could still be installed in late 1977 before the northeast monsoon season. This in turn would allow for a hookup of the tanker plus yoke in early 1978 directly after the monsoon season.

## MOORING SYSTEM PARAMETERS AND ENVIRONMENTAL CONDITIONS

The mooring system was installed in the Tapis Field which is located in the South China Sea approximately 115 naut mi (213 km) off the East coast of West Malaysia in 214 ft (65 m) of water. The system is designed to moor a 167,000 dwt storage vessel in the 100-year storm condition. This environmental condition is as follows:

### 100-Year Storm Condition

| | |
|---|---|
| Spectrum | Pierson-Moskowitz |
| Significant Wave Height | 17.5 ft (5.3 m) |
| Maximum Wave Height | 34.0 ft (10.4 m) |
| Wind Velocity | 43.2 kn (22.2 m/s) |
| Surface Current | 1.8 kn (0.93 m/s) |
| Bottom Current | 0.5 kn (0.25 m/s) |

In addition to the 100-year storm condition, the mooring system is also designed to withstand those forces associated with permanently mooring the storage vessel when shuttle vessels, in the range of 28,000 to 120,000 dwt, moor alongside the storage vessel under the maximum operational condition. This environmental condition is as follows:

### Maximum Operational Condition

| | |
|---|---|
| Spectrum | Pierson-Moskowitz |
| Significant Wave Height | 10.0 ft (3.0 m) |
| Wind Velocity | 30.0 kn (15.4 m/s) |
| Surface Current | 1.0 kn (0.52 m/s) |
| Bottom Current | 0.5 kn (0.15 m/s) |

## DESCRIPTION OF THE MOORING SYSTEM

The SALS mooring principle is based on the removing of the buoyancy function from the riser and as such it differs from other rigid yoke systems. The buoyancy to provide the mooring force restoring moment is provided in the rigid-yoke instead of the mooring buoy or riser. In the SALS system the only functions of the riser are to provide a link from the rigid-yoke to the mooring base for the transfer of the mooring forces, and to provide a conduit for the transfer of product. The following is a description of the main components of the as-built mooring system.

### Mooring Base

The mooring base, as shown in Fig. 3, is a gravity and piled base. It is designed to transmit the mooring loads induced by the permanently moored storage vessel during 100-year storm conditions from the bottom universal joint to the ocean floor. The piles have been designed to withstand the design lateral loading, and all vertical loading is resisted by the weight of the base, piles and ballast. To reduce the weight of the base during its tow to the mooring site and during upending, the base was designed for onsite gravity ballasting. The base is a hexagonal steel structure approximately 59 ft (18 m) on the diagonal and 10 ft (3 m) high. Each of the six anchor piles is 95 ft (29 m) long, including driving head, with a diameter of 48 in. (1219 mm) and a wall thickness of 1-1/4 in. (32 mm).

### The Riser

The riser, shown in Fig. 4, is a tubular structure 213 ft (65 m) long. It is a pressure resistant vessel with ring stiffeners and is divided into a lower and an upper section. The lower section has two compartments, and the upper section has four compartments. One of the upper compartments contains a hydraulic jack used for the hookup of the riser to the rigid-yoke. The bottom section of the riser has a length of 98 ft (30 m) and a diameter of 6.6 ft (2.0 m). The upper section of the riser is 115 ft (35 m) and has a diameter of 8.2 ft (2.5 m). The riser is designed to transfer the axial loads from the rigid-yoke to the mooring base and to withstand the bending moments induced by the relative motion of the riser with respect to the surrounding seawater. After installation at the site the bottom section of the riser was flooded in order to reduce the vertical load on the lower universal joint and the mooring base. To allow for the effect of the external product and ballasting piping, a higher than normal drag coefficient was used during analysis. An additional allowance was made in the riser diameter to allow for marine growth.

### The Rigid Mooring Yoke

The rigid mooring yoke, pictured in Fig. 5, forms the connection between the riser and the storage vessel and provides the necessary buoyancy for the mooring system. The total length of the rigid-yoke between hinges and the turntable center is approximately 171 ft (52 m). The buoyancy tank has a diameter of 26 ft (8 m) and is 59 ft (18 m) long. The structural pipes have diameters ranging from 24 in. (610 mm) to 86 in. (2184 mm) and wall thicknesses from 3/4 in. (19 mm) to 2-1/2 in. (64 mm).

### Universal Joints

The two universal joints designed and built for the original Pulai SALM were used to provide the necessary articulations at the top and bottom of the mooring riser. Each universal joint has two self-lubricating bearings with axes at right angles but not in the same horizontal plane. The overall design and layout of the universal joints is standard and similar to the ones used for the Thistle SALM[3] and the Castellon SALS.

### The Fluid Transfer Systems

Two fluid paths are provided from the seabed to the permanently moored storage vessel; a crude oil line, 12 in. (305 mm) in diameter, and a fuel gas line, 6 in. (152 mm) in diameter. Both conduits are piggable, with pigs launched from the nearby production platform. The gas is supplied to the storage vessel to fuel its power system. The bottom universal joint has been bridged by two jumper hose systems connecting the pipeline manifolds to the riser. The crude oil and fuel gas lines are extended up the outside of the riser by steel piping.

The overall layout of fluid swivels, mooring swivel and jumper hoses between the top of the riser and the yoke is rather unconventional. The design was dictated by the desire to retain the crude oil swivel and top universal joint of the original SALM system as well as the necessity to add a flow path for fuel gas for the storage tanker. The crude oil swivel which was originally designed for underwater use in the SALM system now sits on top of the extended riser and consists of a cylindrical volute built around a load-carrying shaft. A jumper hose bridges the top universal joint and forms the connection to the crude oil piping on the yoke. A single 12 in. (305 mm) swivel is provided between the top of the riser and the jumper hose to reduce bending of this hose due to the relative pitch motion between yoke and riser.

For the fuel gas conduit, a 6 in. (152 mm) line was installed inside the load-carrying shaft of the crude oil swivel. The fuel gas swivel sits on top of the load-carrying shaft inside, and concentric with, the mooring-load bearing in the mooring swivel. Finally, the top universal joint is mounted above the fuel gas and mooring swivel arrangement and forms the articulating connection between yoke and riser. The articulation between the rigid-yoke and storage vessel is bridged by a 12 in. (305 mm) hose for the crude oil, a 6 in. (152 mm) hose for the fuel gas transfer and a 3 in. (76 mm) line for service compressed air.

### The Mooring Swivel

The mooring swivel, a three race 5.2 ft (1.6 m) diameter rollerbearing is situated on top of the riser above the fluid swivel. This mooring swivel allows the permanently moored storage vessel to weathervane under the influence of the environment. The bearing is similar to the ones used on many other single point moorings and is easily accessible for maintenance.

### The Hinges and the Tanker Beam

Hinges between the rigid yoke and storage vessel provide the articulation for the tanker pitch and heave motions. The load transfer is provided by two different types of bearings. Radial bearings on both the port and starboard side of the rigid-yoke extremes transfer the radial loads, and a thrust bearing is provided for the axial load component. Mountings for auxiliary bearings are installed next to the main radial bearings to be used in case of a major on-site overhaul.

The tanker beam constitutes the structural interface between the tanker framing and the hinge flanges. This approach allowed for an easy trial fit of the hinge connections, prior to the incorporation of the beam in the tanker framing. To facilitate the installation of this beam into the bow of the vessel, the tanker modification design called for a permanent cutout at the top section of the forecastle. This cutout was closed off with the installation of the beam.

## THE ONSITE INSTALLATION OF THE STORAGE SYSTEM

The installation of the complete mooring system was executed in two phases. The first phase, in the fall of 1977, consisted of installation of the base and riser, driving of the anchor piles, ballasting of the base and installation of jumper hoses between the pipeline end manifolds and the mooring riser. The second phase in early 1978 consisted of the hookup of the storage vessel to the rigid-yoke in the shipyard and the onsite connection of the rigid-yoke and storage vessel assembly to the riser onsite.

### Phase 1 - The Installation of the Mooring Base and Riser

The installation of the mooring base and riser took place during September and October of 1977, just before the northeast monsoon season. The major events of the installation were as follows. Each will be discussed separately.

- Connection of the mooring base to the riser.
- Horizontal tow of the mooring base and riser.
- Free upending of the mooring base and riser.
- Vertical tow of the mooring system.
- Positioning and placement of the system.
- Piling of the mooring base.
- Ballasting of the mooring base.
- Grouting the piles to the mooring base.

### Connection of the Mooring Base to the Riser

The connection between the mooring base and riser was made in the sheltered harbor waters of Singapore (Fig. 6). First, the base was lowered into the water and placed on the seabed. The water depth at the connection site was approximately 40 ft (12 m). The riser was then placed horizontally in the water and floated over to the mooring base. After the riser's lower universal joint and mating flange were positioned over the center of the mooring base, guide wires were attached to the mooring base through positioning holes in the mating flange of the riser. Once the positioning wires were in place, the base was raised from the seabed until the clearance between the mating flanges was reduced to approximately 6 in. (152 mm). Draw bolts were then inserted between the flanges and the mating surfaces were drawn together. Forty-two, 1-7/8 in. (48 mm) diameter, bolts were then inserted and stressed to the required load by Pilgrim jacking tools.

### Horizontal Tow of the Mooring Base and Riser

After completion of the hookup between the mooring base and the riser the system was prepared for the horizontal tow to the upending site. This tow had previously been model tested and the results of the tests indicated that the system should be towed by the base with the riser trailing and that the angle of inclination of the mooring base should be approximately 35 degrees. To prepare for the tow, a towing bracket was attached to the mooring base. Two tanks were attached along the lower section of the riser to provide additional buoyancy, for damage control, in case one of the riser compartments flooded. The assembled unit was then towed by a single 4500 HP tug 350 naut mi (648 km) from Singapore to the upending site. During the tow the system behaved well. The angular pitch motion between the base and the riser was small.

### Free Upending of the Mooring Base and Riser

The design of the original SALM mooring base and riser was such that by controlled flooding of the central tank in the mooring base the system could be brought to a vertical position. The installation of the modified mooring system utilized this same ballasting system. However, the tank in the base was free flooded instead of being flooded in stages. The buoyancy and ballasting system in the mooring base consisted of a central buoyancy chamber, hexagonal in shape, and six radial buoyancy chambers. For the free upending of the system, only the central buoyancy chamber was flooded. An air manifold system, consisting of valving and flexible hose, was connected to the top of the mooring base. This manifold system was in turn connected to a 4 in. (100 mm) air vent hose which was run partially up the side of the riser.

The location of the upending site was approximately 14 naut mi (26 km) from the actual mooring installation site. The reason for the different site locations was the necessity for deeper water during the upending. The water depth at the mooring site was 214 ft (65.2 m) and the maximum instantaneous calculated draft of the riser and base during upending was 219 ft (66.8 m). The water depth at the upending site was 230 ft (70.2 m), which allowed for a 11 ft (3.4 m) clearance for overshooting during the upending maneuver.

After the horizontal tow arrived at the upending site, the auxiliary buoyancy tanks were removed and the towing bridle disconnected. A safety line was attached to the riser and the system was ready to be upended. To initiate upending, water intake valves were opened in the central buoyancy chamber of the mooring base and the air vent valve was opened on the riser. In a time span of 12 minutes, the upending was completed without any problems (Fig. 7).

### Vertical Tow of the Mooring System

After the upending, the system was positioned alongside the barge to remove a ballast chain in the mooring base which had been placed there to obtain the proper angle of the base during the horizontal tow. Once this was completed, and the compartments of the riser sounded to determine if any water had entered then, the system was ready to be vertically towed to the mooring site location (Fig. 8). Results of model tests indicated that the system could be towed at up to 2.0 kn (1.0 m/s) which would give a riser heel angle of approximately 20 degrees. During the tow no problems were encountered.

### Positioning and Placement of the System

When the system arrived at the mooring site it was positioned between the ends of the previously installed crude oil and fuel gas pipelines. The positioning and orientation of the system was accomplished through the use of transponders placed on the pipeline manifolds and the mooring base, by diver measurement, and by visual sighting to the production platform. After the mooring base and riser were positioned with respect to distance and orientation, compartments in the riser were flooded to lower the unit to the seabed. The radial buoyancy tanks in the base were flooded after final position checks were made.

### Piling the Mooring Base

Piling of the base was accomplished through the use of a conventional underwater hammer. The installation barge was moored alongside of the riser and positioned so that the pile guide platform attached to the side of the barge was directly over each respective piling position. Piles were picked up horizontally, by a crawler crane on the barge, and then transferred to a vertical position over the side of the barge and placed on the pile guide platform. Guide wires were attached from the pile cones on the mooring base through a frame assembly attached to the bottom of the pile to two constant tension winches on the barge.

After the pile was in position on the platform and the guide wires attached, the pile hammer was secured to the top of the pile. The whole system was then lowered down the guide wires until the bottom of the pile entered the pile guide cones on the mooring base. Once the piles were in this position the actual pile driving operations took about 45 minutes for each pile.

### Ballasting the Mooring Base

To achieve the required dead weight in the mooring base approximately 7,100 $ft^3$ (200 $m^3$) of iron ore was placed in the open areas of its interior. For this operation a separate barge was mobilized in Singapore. The ballast was an iron ore with a high proportion of fully converted ferric oxide. This avoided a potential problem with the sacrificial corrosion cathodic protection system on the base. The ore had a grading of 3/8 in. (9.5 mm) down, a Specific Gravity of 4.95 and a soaked bulk density of 211 lbs/$ft^3$ (3.38 kg/$dm^3$). Method of placement of the ballast in the base was by gravity feed, fed through two 6 in. (150 mm) hoses attached at several points to the riser and fed from hoppers on the barge containing the iron ore. The hoppers were loaded by a wheeled front-end loader and the ore slurried by jetting sea water into the bottom of the hoppers. On the base structure the ore slurry was fed into the compartments by divers using Tirfor winches to adjust the outlets of the slurry hoses. By the end of the ballasting an estimated 450 t of ballast had been placed.

### Grouting the Piles to the Mooring Base

After completion of the ballasting, two days were spent testing hoses and preparing the grouting equipment, which was also installed on the ballasting barge, for operation. This time lapse allowed measurements to be taken to check that all measurable settlement of the base had stopped.

The grout was batched and pumped using pressure grouting equipment. Cement was fed from a hopper mounted on the barge and sea water was used. Initially it had been intended to fill the anulus between pile and guide in one operation, but when the first attempt was made to grout a pile, it was discovered that the base had not settled sufficiently into the sea bed to prevent grout loss when the full anulus height was filled. Accordingly thereafter, a grout plug was spotted in the bottom of each annulus which was then left for a minimum of four hours before grouting the remainder of the pile. Additionally, circulation problems during the first operation led to a decision to half the $CaCl_2$ accelerator quantity in the grout to 1 percent. Thereafter, no problems were encountered with premature set up.

The grout was pumped at virtually zero pressure through standard fire hoses to a manifold mounted on the outside of each pile guide. These hoses worked well despite initial reservations as to their use. Valves on each pile annulus manifold allowed flushing of the line after each operation on each pile. In order to ensure maximum bond between each pile and the pile guide, each guide was filled until the diver reported that the grout had reached the top of the pile guide cone, some 4.0 ft (1.2 m) above its design level.

### Final Operations

The last operation to be performed in the installation of the base and riser was the connection of the crude oil and fuel gas lines between the riser and the pipeline manifolds. These connections were achieved through the use of jumper hoses. This completed the first phase of the installation. The riser was provided with a navigational aid package consisting of a fog horn, light and radar reflector and left alone during the upcoming monsoon.

### Phase 2 - The Installation of the Mooring Yoke and Storage Vessel

The hookup of the rigid mooring yoke and storage vessel to the previously installed base and riser took place in early March of 1978, just after the monsoon. In order to assure a good fit of the mating flanges of the riser and the mooring yoke at the installation site, a trial fit of the ultimate flange makeup had been made in Singapore prior to the installation of the mooring base and riser. The actual interface section was then sent to Japan and incorporated into the rigid-yoke structure.

Following the completion of the rigid-yoke construction and tanker bow modifications, the yoke was connected to the storage vessel at the shipyard in Japan. The completed assembly was then towed by two tugs from Japan to the installation site. The vessel was towed by its stern, in a ballasted condition, with the rigid mooring yoke trailing. The tow arrived on site on March 3, 1978.

Prior to the arrival of the tow the riser was prepared for the hookup. These procedures entailed unlocking, preparing and testing the hydraulic jack located in the compartment in the top of the riser, and laying out of a 200 m long, 3.5 in. (89 mm) wire cable and chain pennant from the riser top along the sea bed. The wire cable and chain pennant would be used as a hauling in cable between the rigid mooring yoke and the riser, and the hydraulic jack would bring both the yoke and riser mating flanges together during the final hookup.

The actual hookup of the rigid-yoke and storage vessel to the riser was split into two stages; an initial stage in which the storage vessel and rigid-yoke approached the riser from approximately 1,000 ft (300 m) to about 10 ft (3 m), and the final stage in which the flanges were mated. Both stages were fully studied in simulation model tests at NSMB to determine line tensions and limiting seas. The results of these model tests showed that the hookup could be made in up to 3 ft (1 m) significant seas.

Prior to executing the first stage of the hookup the two tugs reversed their towing positions from the stern of the vessel to just aft of the bow of the vessel. A third tug was hooked up to the stern of the vessel in order to control the speed of approach and yaw motion of the storage vessel. As the tugs began their approach a messenger line was brought over from the vessel and attached to the previously prepared wire cable and chain pendant (Fig. 9). Using a winch aboard the tanker the messenger and main cable were reeled in over a pulley arrangement on the rigid-yoke. Tension control during this stage of the operation was provided by a tension meter installed in the main pulling line. When the tension in the hauling in cable approached the maximum traction of the winch, 10 t, a hydraulic pulling machine with a capacity of 150 t took over. Using this device, the two interfacing flanges were brought to a distance of approximately 10 ft (3 m). Because of very mild environmental conditions during the hookup, two 7/8 in. (22 mm) stabilizing cables, which would have been attached between the riser and air tuggers mounted on the port and starboard sides of the rigid-yoke to control riser pitch motion, were not used.

The second stage or final approach was completed in two phases. The first phase consisted of transferring the load from the hauling in cable to a connecting chain between the center lines of the two flanges (Fig. 10). After this was accomplished, the hydraulic jack located in the top section of the riser was activated (Fig. 11). The jack, with a stroke of 16.4 ft (5.0 m) allowed for a very closely controlled mating of the two flanges. Guiding cones and pins, and hydraulic orientation winches of the fluid swivel, assured the final alignment of the flange bolt holes. After alignment, forty-two 1-7/8 in. (48 mm) diameter bolts were inserted and stressed to the required load by Pilgrim jacking tools.

## TERMINAL OPERATION

Since installation was completed in March 1978, the terminal has been in constant use. Up to mid-January 1979, forty-five liftings have been made by shuttle tankers varying from 35,000 to 102,000 deadweight tons, lifting parcels varying from 100,000 to 740,000 barrels. Thus far only one vessel has had to stand off for an appreciable time due to bad weather. This occurred over a two day period with 30 kn (15.4 m/s) winds and 12 ft (3.6 m) seas running. Some alongside berthings have been hampered by bad weather and have taken several hours longer than the normal one hour achieved in reasonable conditions.

During steady northeast and southwest monsoon conditions the storage tanker lines up with the wind. During slack periods the current tends to dominate the vessel's heading, but under these calm conditions mooring is not generally a problem. On one occasion when the storage tanker was lined up with the current, although a fresh wind had sprung up, the berthing tug was used to pull the tanker's sterm round to a head-to-wind position. The tanker then stayed in that position. The only problem associated with the constant head-to-wind attitude of the tanker is that of providing a lee for supply boats in heavy weather.

The normal mode of berthing is for the shuttle tanker to approach on the storage tanker's starboard beam with a tug holding the shuttle tanker's bow. As the shuttle tanker comes alongside the storage tanker with the vessels approximately a beam width apart, messenger lines are passed using inflatable dinghys. The shuttle tanker is then brought up to the storage tanker using the shuttle tanker's winches. Berthing in moderate seas has been complicated by the heavy swell which runs between the two vessels as they are brought together. This swell has given rise to such substantial relative motion between the two vessels that only shuttle tankers with self tensioning winch drums are scheduled for crude liftings in order to avoid the line breakages that happened in the early months of operation.

Chafing problems with the soft lines supplied by the shuttle tankers have resulted in a decision that the storage tanker provide lines made up from 1.7 in. (42 mm) wire with a 35 ft (10 m) centre section of nylon, 12 in. (305 mm) in circumference, to act as a spring. This nylon is replaced for every second berthing. The berthing lines are run from bollards on the shuttle tankers to winches on the storage tanker. These winches have to be manned continuously to allow adjustment as required to accomodate vessel draft changes while cargo is being transferred.

The mooring itself has been trouble free. Maintenance inspections carried out both above and below water have confirmed that no problems exist on the mooring. Underwater, the base hoses are in good condition although they have some marine growth on the flanges. The riser which is coated with coal tar epoxy and antifouling is still almost completely free of marine growth. Above water, maintenance has been limited to visual checks on the crude oil line, greasing of the mooring and fluid swivels, and checking the buoyancy tank for water-tightness.

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3. Foolen, J., Pincemin, M., and Smulders, L. J., "A Single Anchor Leg Mooring System for the North Sea," OTC 3041, Houston, Texas, May 2-5, 1977.

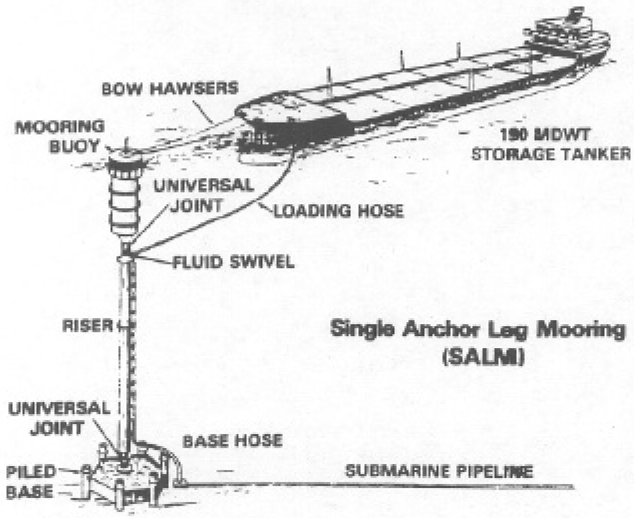


Fig. 1 - Original SALM configuration.

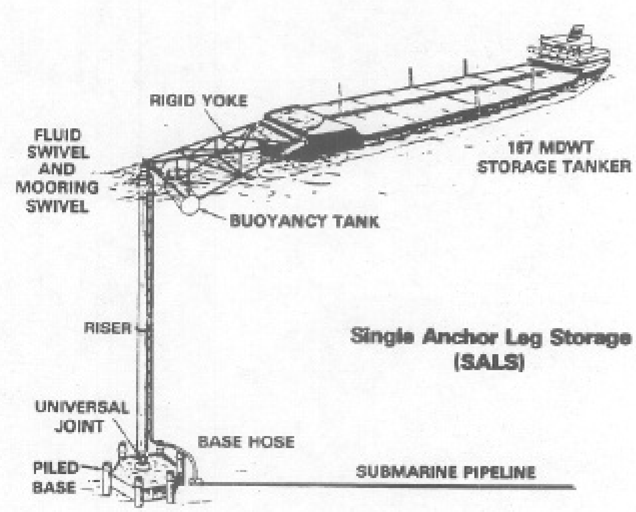


Fig. 2 - Modified SALS configuration.

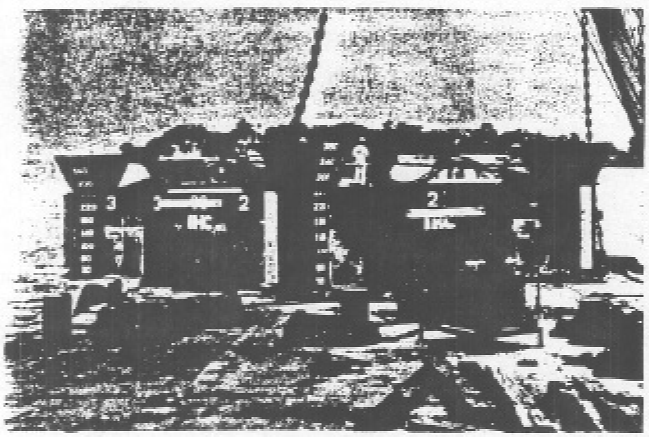

Fig. 3 - Mooring base.

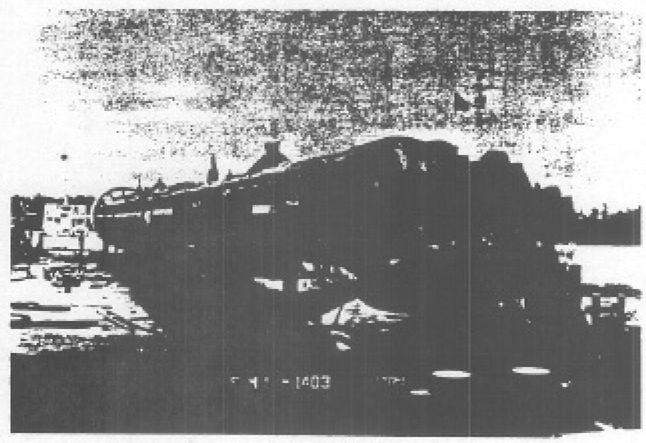

Fig. 4 - Mooring riser.

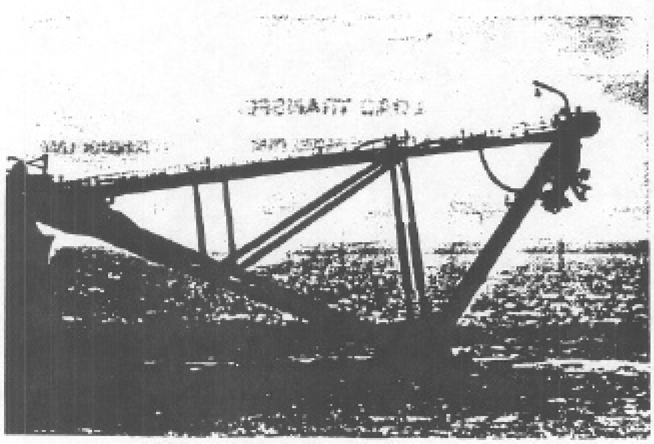

Fig. 5 - Rigid mooring yoke.

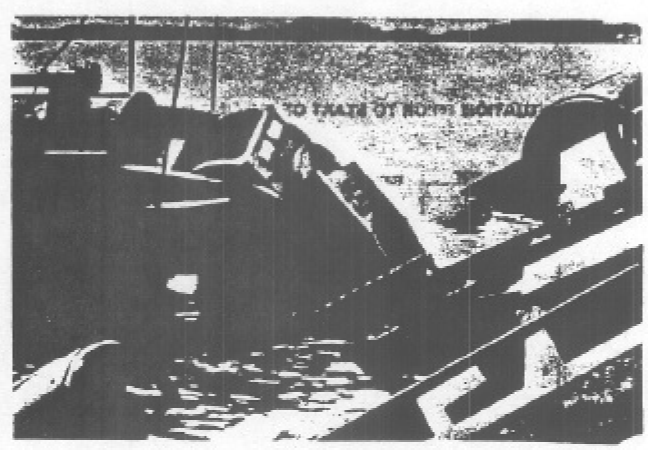

Fig. 6 - Riser-base connection.

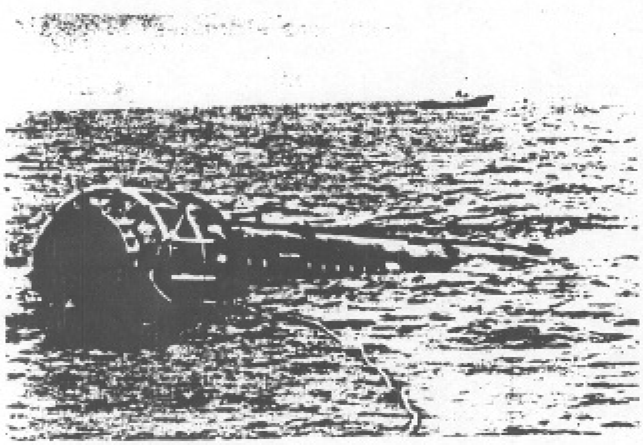

Fig. 7a Fig. 7 - (A,B and C) - Free upending of base and riser.

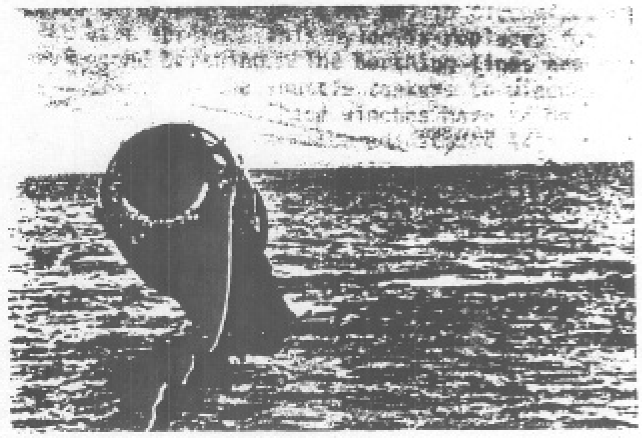

Fig. 7b

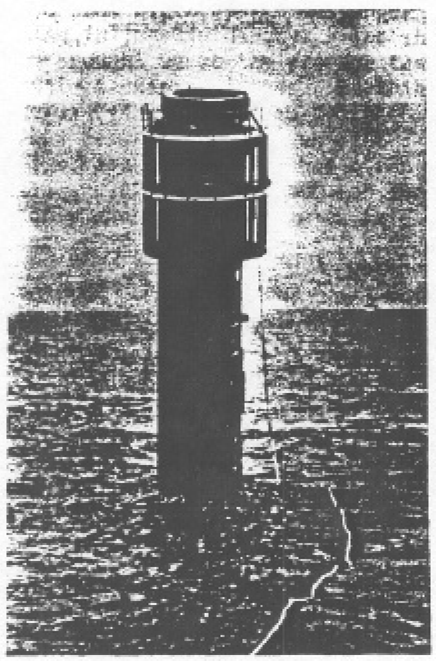

Fig. 7c

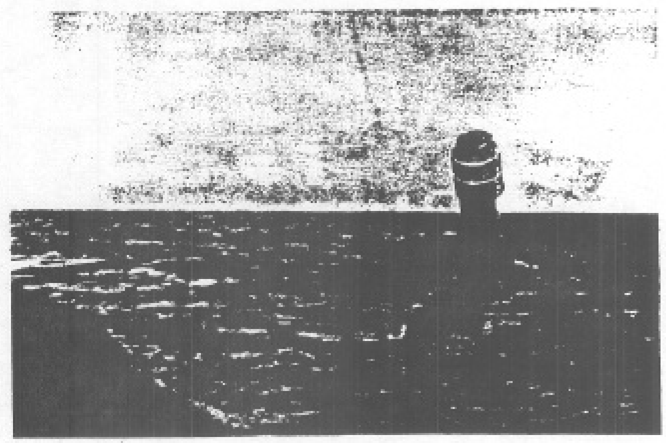

Fig. 8 - Vertical tow of base and riser.

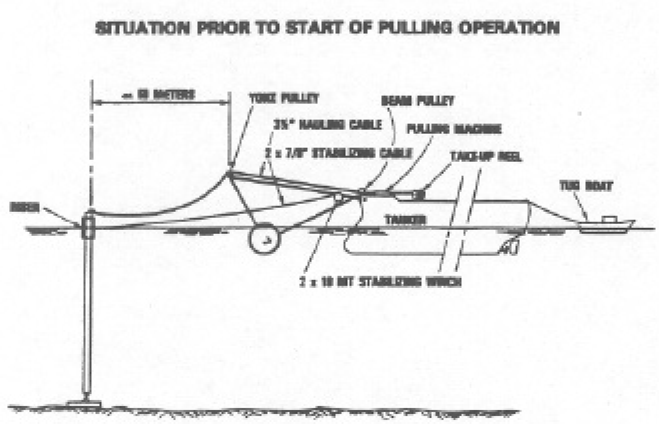


Fig. 9 - Schematic of rigid arm - riser connection procedure.

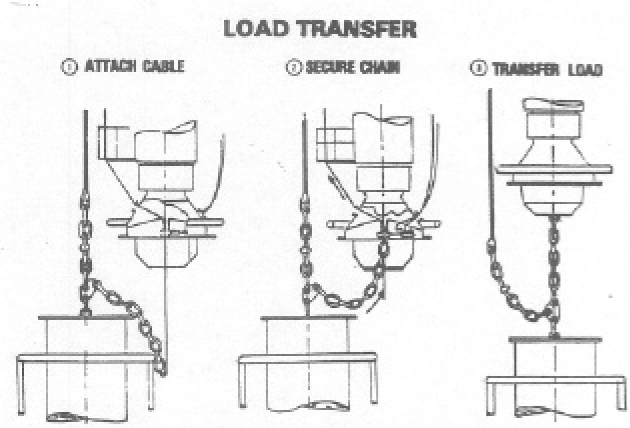


Fig. 10 - Final stage of rigid arm - riser connection.

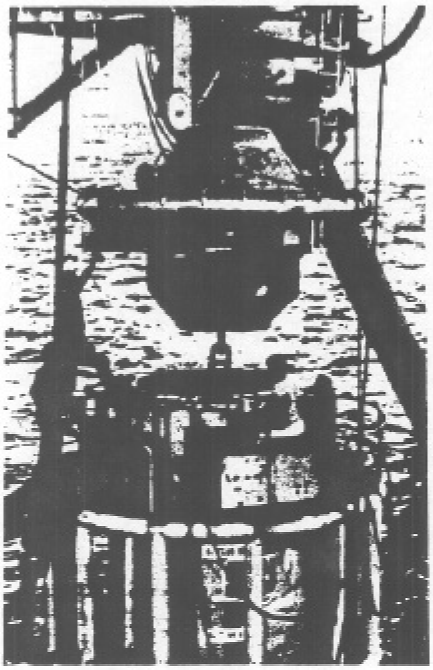

Fig. 11 - Final mating.

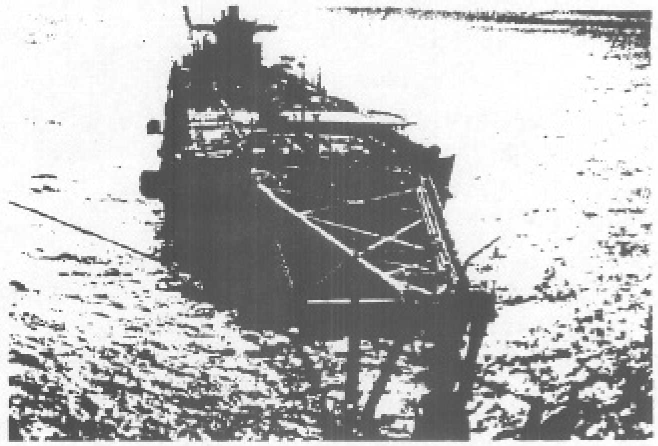

Fig. 12 - The installed offshore terminal.