OTC 5253

A Rapid Deployment Tanker Loading System

by W.L. Kiely, R.H. Gruy, C.O. Etheridge, and K.I. Pedersen, *SOFEC Inc.*

ABSTRACT

This paper describes the design, construction, deployment and retrieval of a unique Rapid Deployment Single Anchor Leg Mooring system (hereinafter designated RA-DE SAIM™). The RA-DE SAIM™ (patent pending) is an adaptation of commercial SAIMs for military use which offers significant advantages for commercial oil field applications especially for extended well testing in water depths up to 500 feet (152 m).

The system is totally self-contained, can be towed at high speed and deployed and recovered with minimal personnel and equipment.

INTRODUCTION

The fast and efficient transfer of POL products (petroleum, oil, lubrication) from a tanker to the shore has been a continuing problem for the armed forces. Petroleum products have been delivered by floating 55 gallon drums ashore, by towing large rubber bladders and by conventional multiple buoy mooring systems. A CAIM buoy has also been tried but was not suitable for rapid deployment due to the manpower, equipment and time required for installation.

The RA-DE SAIM™ (Fig. 1), in conjunction with a flexible pipeline, provides a means to deliver large quantities of fuel to shore-based operations. It can be towed into the deployment area or transported and launched from the deck of a tanker and be installed and ready for operations in less than 24 hours using only Navy warping tugs (SWLT's) or small floating work vessels.

In a similar manner, a RA-DE SAIM™ can be utilized to moor and load a floating production vessel for short to medium well testing or 1-2 well production in remote areas.

During the RA-DE SAIM operational demonstration, the RA-DE SAIM™ was towed at speeds in excess of 10 knots using a single 1600 H.P. tug boat and was installed in the Gulf of Mexico in 150 feet (46 m) water depth in five (5) hours using only a supply boat with four point spread mooring, a small tug boat and two divers. Subsequently, the system was fully recovered in twenty-four hours using the same floating equipment.

The RA-DE SAIM™ is designed to moor tankers up to 70,000 DWT in water depths from 35 feet (11 m) to 200 feet (61 m) and includes piping, swivels and hose systems for transfer of petroleum products between the sea bed and the tanker's manifold. Alternate designs, as described elsewhere in this paper, can service the needs of the petroleum industry.

The technology involved has been developed by SOFEC through numerous SAIM installations since 1973. The basic SAIM concept, developed by Exxon Research and Engineering during the late 1960's, provides a constantly tensioned cylindrical buoy which is connected to a mooring base on the sea floor by means of a single anchor leg. The buoy provides a mooring point for the tanker which, moored by its bow lines only, may swing freely (weathervane) about the buoy. Thus, the vessel may orient itself "head-on" into the prevailing seas and remain safely moored in very rough weather conditions.

The key differences between most commercial Single Point Mooring (SPM) systems and the RA-DE SAIM™ are that the RA-DE SAIM™ utilizes prepositioned ballast and can be installed very quickly by using controlled flooding of the buoyancy tanks, with a minimum of other equipment. The RA-DE SAIM™ can be recovered readily without the use of auxiliary floating hoist equipment and it can be towed at high speeds to alternate locations for redeployment, as applicable.

---

1 References and illustrations at end of paper.

SYSTEM PARAMETERS

The following are overall performance specifications and capabilities of the RA-DE SALM™ as built for the U.S. Navy.

Water Depth	35 ft - 200 ft (11 m-61 m)
Tanker Size (max.)	70,000 DWT
Hs (operating)	12 ft (3.7 m)
Wind (operating)	40 kt (21 m/s)
Current (operating)	4 kt (2 m/s)
Hmax (survival)	37 ft (11.3 m)
Wind (survival)	55 kt (28 m/s)
Sea Bed Soils	Soft mud - hard sand
Max. Flow Rate	60,000 GPH (228 cu.m/hr)
Operating Pressure	600 psi (4140 KPa)
Hose Size	Dual 6 in. (152 mm)

Installability

The RA-DE SALM™ can be installed and operational under a wide range of conditions (sea floor, environment, water depth). Installation can be accomplished in 24 - 48 hours utilizing three tug boats and one to two divers, depending upon water depth. The SALM is anchored to the sea floor by means of a gravity base which uses preplaced high density solid ballast material. Installation is accomplished by selective flooding of the base flotation tanks (Fig. 7, 8) which are compartmented to negate free surface effects and insure stability during descent and ascent through the water column.

The system is entirely self contained, i.e., chain leg segments and loading hoses for any water depth from 35 ft - 200 ft are carried on the SALM as is the mooring hawser. Chain leg segments and submarine hose sections are coded for assembly in the proper sequence for the expected water depth at the site (plus/minus 5 ft). All items are handled and assembled on the SALM base (Fig. 2) using only manpower (2 men) and "come alongs." The floating hose is stored coiled around the SALM buoy and is pulled free by a small tug after base installation is completed. The SALM to pipeline connection is made in the dry after a flexible hose stored on the SALM base is brought to the surface by means of an acoustic recall buoy.

Transportability

The RA-DE SALM™ may be loaded onto a tanker fitted with a transport/launch ramp, delivered to site and launched directly into the sea in a fully self-contained mode. The SALM may also be re-loaded onto the tanker using this ramp (Fig. 6). Alternatively, the RA-DE SALM™ may be towed at speeds up to 10 knots in the fully self-contained mode using a single towing vessel.

A commercial RA-DE SALM™ can be transported by convenient method to the general vicinity of the installation site, off-loaded and towed the remaining distance. Tow distances of several thousand miles may be accommodated in order to maximize economics.

Product Deliverability

The RA-DE SALM™ is designed for simultaneous delivery of two different products. It is equipped with a dual product, high pressure, piggable fluid swivel. The design is such that the products in the two independent flow paths cannot commingle and result in the delivery of a contaminated product. Each circuit will accommodate flow rates of 60,000 gallons per hour (228 cu. meters per hour).

Maintainability

The key SALM components, i.e., fluid swivel, product piping, buoy swivel and universal joints are all located below the sea surface. The fluid swivel is pre-assembled and tested and does not require periodic lubrication or maintenance. Likewise, no lubrication or periodic maintenance is required on universal joints, buoy swivel or anchor chain leg. The design of these components for long, maintenance-free life in submerged service will also result in minimal maintenance when the system is stored between test deployments or actual service deployments.

Recoverability

The RA-DE SALM™ is fully recoverable by a simple deballasting operation. It is equipped with a jetting system to facilitate removal. The pre-placed solid ballast is an integral part of the system and is recovered intact. The entire unit is recovered using the same floating equipment employed during installation. Recovery may be accomplished with tug boat assistance only, i.e., no lifting equipment is required.

Survivability

The RA-DE SALM™ terminal is not readily susceptible to damage from tanker overrun or hostile attack from the air or sea because the key critical components are located within the perimeter of the mooring base near the sea floor. The buoy is a pressure vessel which houses no product piping, swivels, valves or other critical components. Its small diameter does not present a highly visible target and its multiple internal compartments make it very difficult to sink. In the event the buoy is lost the SALM is still operational and vessels can moor directly to the base universal joint via the shallow water auxiliary buoy. With respect to storm survival, SOFEC SALM's have been designed and constructed to survive 70 ft (21 m) hurricane waves and to moor tankers in 40 ft (12 m) typhoon waves. SOFEC SALM systems have experienced these conditions without mishap.

SYSTEM COMPONENTS

Mooring Base

The mooring base supplied with the RA-DE SALM™ designed to fulfill several purposes. This fabricated steel structure provides the means of developing the "holding power" at the base soil

interface as a result of its inherent weight and configuration. In addition, the base provides the compartmented flotation necessary to transport the total SALM system by towing the base with its preplaced ballast and then allowing its controlled flooding to position the base on the ocean floor in the required water depth. Compartmentation is provided in the ballast control tanks at the forward and aft ends of the base to assure that no detrimental free surface effects exist during the critical phase of moving through the water column. Piping is fabricated into the base to allow the connection of "jetting lines" from the surface to assure that suction pressures developed between the bottom of the base and a cohesive soil can be broken during retrieval of the base or to assist in selectively levelling the base if necessary. The base is configured to provide the necessary buoyancy, freeboard, stability and seaworthy features to assure safe transportation at high towing speeds. During transoceanic transportation onboard the tanker or other vessel, the base interfaces the deck mounted structure on the vessel and distributes loads to the transverse frames or bulkheads. The base is designed to withstand the forces incurred when side launching the SALM system from the deck of a transport vessel.

Universal Joints

A universal joint is used at both the base/anchor chain interface and the mooring buoy/anchor chain interface. Such U-joints are required to prevent chain wear which could otherwise completely destroy a large chain in only a few days of service. Permanently self-lubricated bearings are used at each articulation point in these joints in order to provide the freedom of motion. The bearing surfaces of the connecting pins are overlaid with corrosion resistant material.

Anchor Chain

Standard Oil Rig Quality (ORQ) stud link chain is used to transmit the mooring forces from the buoy to the foundation of the SALM. This chain is connected from the lower universal joint atop the base to the swivel beneath the mooring buoy. Kenter links as necessary are included in the anchor leg to provide a means of adjusting the chain length to achieve the proper tension for the water depth at the installation site.

Anchor Chain Swivel

A chain swivel is incorporated in the anchor leg at the buoy universal joint to allow the buoy to rotate as the tanker swings about the system. The swivel is a fully sealed, bearing mounted unit of the design which has been employed successfully on all SOFEC SALM systems.

Mooring Buoy

The mooring buoy of the RA-DE SALM™ is a stiffened steel cylinder that serves as mooring point for the tankers and transfers the mooring load from the hawser to the anchor chain. This buoy is equipped with external fendering to protect against impact by marine vessels and the necessary navigational aids. The buoy is divided into several watertight compartments to provide the required damaged stability and protect against accidental sinking. The length of the buoy allows it to function satisfactorily in regions which experience substantial tidal variations. The buoy will continue to perform its full function even if it is completely submerged at high tide conditions.

Fluid Swivel Assembly

The fluid swivel for the RA-DE SALM™ is designed to withstand a working pressure of 600 psi and allow the loading hose to rotate freely during tide changes or as the tanker weathervanes around the buoy. The fluid swivel assembly and bearings are completely independent of the mooring post and do not transmit any of the mooring load. Each of the two swivels of the swivel assembly is an independent unit. Each of these units is arranged to allow the pigging of the lines as required and maintain the purity of the products being transferred. The assembly allows the passage of one product or two products simultaneously without imposing any penalty on the flow rate of either unit. The bearings of these swivels are completely protected against intrusion by foreign particles by redundant seals that are arranged to run on machined corrosion resistant surfaces. Lip seals are provided to protect the system against intrusion by sand or scale. The seals are totally compatible with the products being offloaded. All of the seals are self-energizing and utilize the internal pressure to increase the sealing force provided by the seals. The product swivel can be quickly removed and brought to the surface independently of the mooring base.

The Fluid Swivel assembly was subjected to extensive pressure testing (with Kerosene at 1000 psi) as well as flow testing to confirm piggability.

Loading Hoses

The loading hoses are dual 6 in. (152 mm), 600 psi (4140 KPa) working pressure hoses. All hoses are contained on the RA-DE SALM™ during storage and transport. The surface floating hose system consist of two separate strings made up from 40 ft (12 m) sections with integral flotation built into the hose carcass. This provides effective buoyancy for surface flotation with an ample safety margin. In its stored position, the surface floating hose strings are coiled around the mooring buoy. The submarine hoses are stored on the base structure and are supplied in 40 ft (12 m) sections which are made up to accommodate six (6) distinct ranges of water depths from 35 ft - 200 ft. The dual 6 in. (152 mm) flow paths are contained in one integral hose bundle which includes internal flotation material. This highly specialized type of hose construction provides smooth, easy to handle hose units which will provide the proper submerged profile without the use of external flotation beads.

The performance requirements for the submarine hoses dictate that it is designed and built to very exacting standards. It is of prime importance that the submarine hoses have adequate flexural stiffness to maintain a smooth suspended profile

from the surface to the product swivel. The density of the products contained in the hoses will vary from seawater (during installation) to light gasoline and the submerged weight of the filled hoses will vary accordingly. The flexural stiffness of the hose carcass must be adequate to prevent excessive sagging or sharp bends regardless of the density of product contained. The bulk rigidity of the hose body must be adequate to withstand external pressures ranging from zero at the surface to close to 90 psi at the maximum design depth without significant volume change in order to assure buoyancy stability and to maintain the profile within acceptable tolerance limits.

The submarine hoses must also perform the function of turning the product swivel in response to changes in current directions and to weathervaning motions of the moored ship. This requirement provides a second criteria for flexural stiffness and also for adequate torsional stiffness of the submarine hoses. If the flexural and torsional stiffness is not adequate the hose will not rotate the swivel, but will tend to wrap itself around the SALM buoy.

Specialized Equipment

The RA-DE SALM™ incorporates three distinct electronic/acoustic systems.

1. Product Swivel Orientation Indicator:

   This system permits the remote monitoring of the relative position between the rotating and fixed components of the product swivel. This is required since the SALM swivel has a "dead sector" of about 60 degrees in which a pig cannot pass. An automatic, visual surface display informs the user when it is permissible to pig through either of the two swivel chambers.

2. Mooring Load Monitoring System:

   This system measures the tension in the mooring hawser and transmits this information to the tanker's bridge where it is visually displayed and recorded. The system will operate in the most severe environment and requires few adjustments, little operator training and almost no maintenance.

3. Jumper Hose Deployment System:

   This system provides for remote retrieval of the flexible jumper hoses which allow the installed SALM to be connected to the submarine pipeline(s) at the surface. It permits an operator on a surface vessel (installation tug) to activate the subsurface release mechanisms to retrieve the port or starboard jumper hoses. A flotation device is remotely released from the SALM base via acoustic signal and rises to the surface with a retrieval line which is used to bring the jumper hose to the surface for connection to the flexible sea floor pipeline whose end is also lifted to the surface.

These special systems were provided to assure the highest level of safety and reliability during operation and to reduce diving requirements.

Deployment and Retrieval

Deployment and retrieval of the RA-DE SALM™ is accomplished through a series of ballasting (deballasting) operations which cause the Mooring Base to transit the water column from the surface to the sea floor (or reverse). The RA-DE SALM™ is engineered in a manner which assures positive stability of the system during this transit phase and ensures a safe, controlled transit of the structure from surface to sea floor and back.

The system has been installed a total of seven (7) times to date in water depths from 30 to 150 feet. Each installation/retrieval has been successfully completed utilizing the minimal personnel and equipment referred to herein.

The safety and stability of the RA-DE SALM™ has been well demonstrated without the requirement for specialized and expensive floating equipment. Five (5) of the demostrations conducted to date were performed in 30 ft - 40 ft (9 m - 12 m) water depth to demonstrate the ballast system and acquaint the Navy Crew with the system operation. One (1) demonstration was conducted in 150 ft (46 m) to demonstrate the deep water deployment (Fig. 8), and one (1) demonstration was conducted in 100 ft (30 m) water depth to demonstrate the intermediate depth deployment (Fig. 7).

The 100 ft (30 m) demonstration was performed off Cape Charles, Virginia and was a complete demonstration which included tie-in to the flexible submarine pipeline, tanker hook-up and pumping product to a beach manifold and storage facility. During this demonstration the SALM and submarine hoses were deployed in four (4) hours. During deployment, currents up to 1.5 knots (2.9 m/s) were measured. The demonstrations were delayed during the passage of hurricane "Gloria" during which the SALM was subjected to the maximum design environment which it survived with no damage. Following the storm, the tanker was connected to the RA-DE SALM™ and one million gallons (3800 cu.m) of product was delivered to beach storage in 20 hours. During deliverability test, the swivel operated at 600 psi (and was static tested at 650 psi), and a pig was pumped from the tanker through the SALM swivel to a pig receiver on the beach.

COMMERCIAL APPLICATIONS

The RA-DE SALM™ offers significant commercial potential especially for extended well testing and development of one or two well marginal fields. It is adaptable for a wide range of water depths, readily transportable by direct tow and may be installed and recovered without the use of an expensive floating equipment spread. As these costs are often among the most significant in a 90 - 180 day extended well test program, the RA-DE SALM™ should offer an attractive solution for such

requirements. The ability to install, recover, relocate and reinstall the system utilizing only tug boats and minimal diver assistance should offer attractive economics as compared to more standard solutions.

The following specifications are typical for oil field applications.

Water Depth	100 ft-500 ft (30 m-152 m)
Tanker Size	100,000 DWT
Hs (operating)	20 ft (6 m)
Wind (operating)	70 kt (137 m/s)
Current	2 kt (3.9 m/s)

The SALM (Fig. 9) utilizes a gravity-type base which may be fabricated steel construction with pre-placed high density solid ballast (as in the military version) or alternatively, concrete construction with steel tension members. The base is designed to function in sea floor conditions ranging from soft mud (50 psf) to hard sand and coral. The SALM buoy attaches to the base through a single, heavy stud-link anchor chain. Universal joints at each end of the chain absorb system deflections and hence, prevent chain wear. For a production/testing unit situated in 200 ft - 500 ft (61 m - 152 m) water, production is transferred from the sea floor to the moored tanker via flexible high pressure riser which is clamped to the anchor leg and terminates in an in-line swivel located below the buoy. High pressure hoses connect from the swivel to the tanker manifold.

Like the military version, installation is accomplished by selective flooding of the ballast tanks. Lowering is accomplished in a series of steps depending on water depth, whereby complete stability is continually maintained. Anchor chain and riser length are pre-adjusted for water depth at the site. When the base is on the sea floor all tanks are fully flooded. It is not required to install additional ballast material. The SALM design provides a reliable, maintenance free Single Point Mooring which has been previously extensively proven in field applications. (Ref. 1-5).

CONCLUSIONS

1. A Rapid Deployment Single Point Mooring known as the RA-DE SALM™ has been developed to meet specific U.S. military requirements. The system conforms to the military goals of being rapidly transportable (on vessel or towed), rapidly and easily installable (24-48 hours with minimal equipment and personnel) and recoverable (again with minimal equipment and personnel).

2. The RA-DE SALM™ and the systems on which it is based are proven concepts, having been constructed and successfully installed/retrieved on numerous occasions.

3. The RA-DE SALM™ offers an attractive solution for the production or long term testing and reservoir analaysis of commercial oil wells.

The adaptability of the system to long distance transport, installation, retrieval and reinstallation without the use of floating construction equipment (tug boats only, no lifting capacity) offers significant cost savings over methods employed to date.

REFERENCES

1. Gruy, R. H., Kiely, W. L.: "Single Point Moorings: Options for Offshore Loading, Storage and Process", 5th Offshore Southeast Asia, Singapore (Feb. 21-24, 1984).

2. Gruy, R. H., Kiely, W. L.: "Marginal Field (Early Production): Options for Offshore Loading", Proceedings of the Second International Offshore Mechanics and Arctic Engineering Symposium (ASME), Houston, Texas (Jan. 30-Feb. 3, 1983).

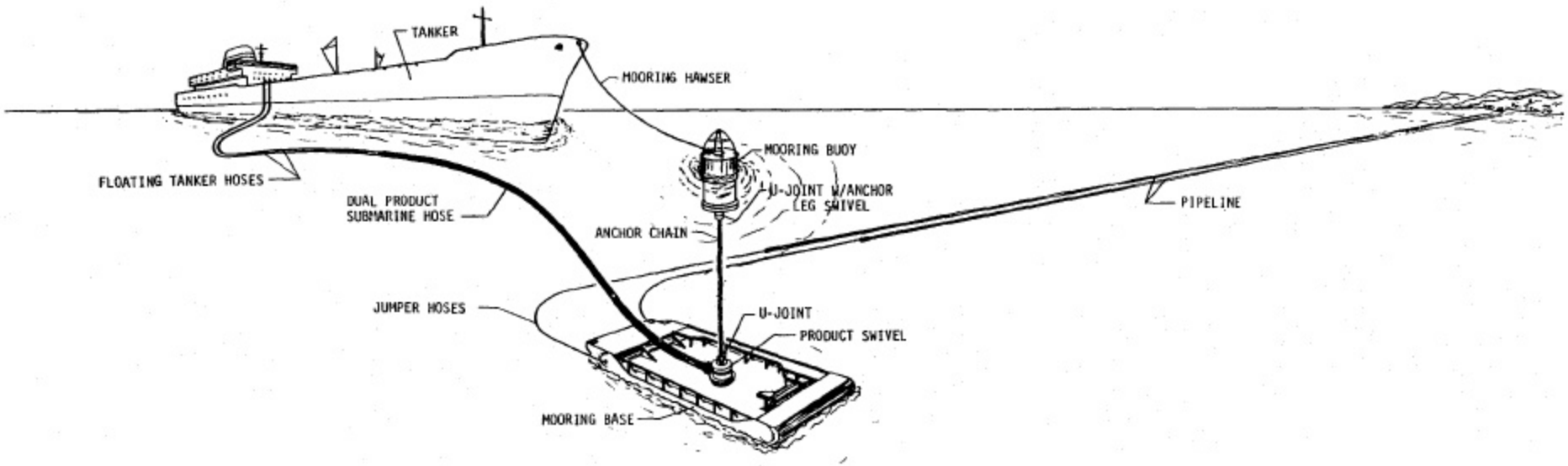
3. Gruy, R. H., Kiely, W. L., Pedersen, K. I., Wolfram, W. R., Swan, R. D.: "Seven Years Experience With the First Deepwater SALM", Journal of Petroleum Technology, June, 1983, pp 1219-1225.

4. Gruy, R. H., Kiely, W. L., Pedersen, K. I., Wolfram, W. R., Swan, R. D.: "Five Years Experience with the First Deepwater SALM" OTC 3804, 12th Annual OTC, Houston, Texas (May 5-9, 1980).

5. Gruy, R. H., Kiely, W. L.: "Float System Helps Develop Marginal Field", OCEAN RESOURCES ENGINEERING, Oct. 1978, pp 4-7.

TRADEMARK

RA-DE SALM™ is a trademark of SOFEC, Inc.



RAPID DEPLOYMENT
SALM SYSTEM

Fig. 1—Isometric drawing: RA-DE SALM with tanker moored.

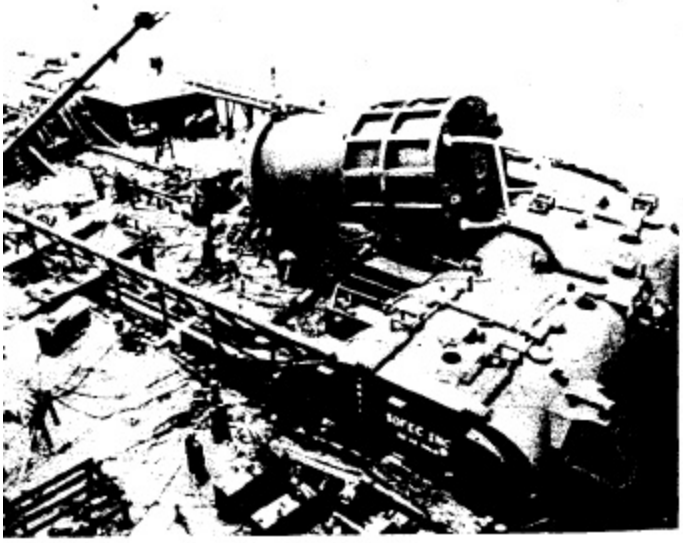


Fig. 2—Deck view during assembly.

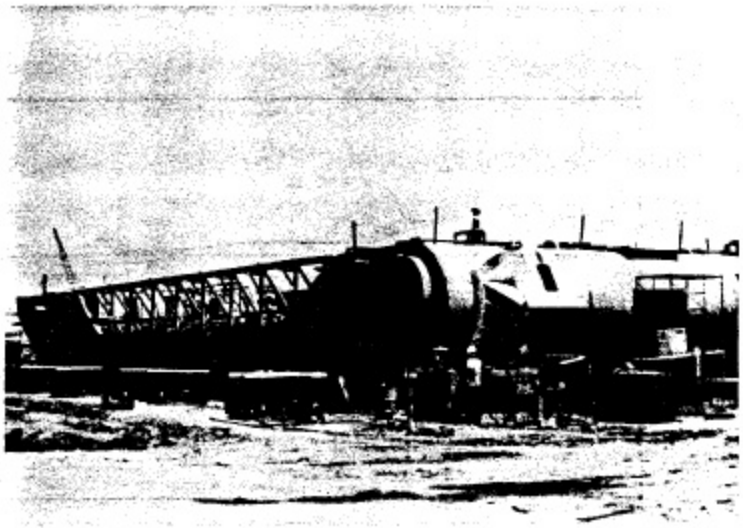


Fig. 3—RA-DE SALM hull during fabrication.

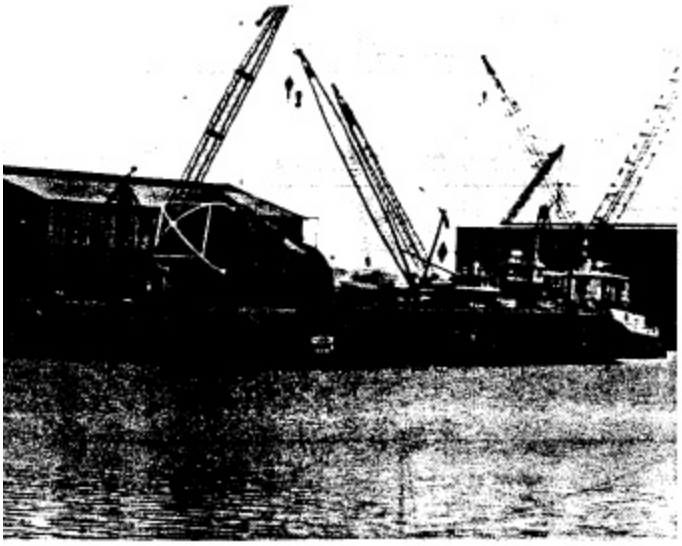


Fig. 4—RA-DE SALM during final assembly.

Fig. 5—RA-DE SALM High Pressure, dual product, piggable fluid swivel.

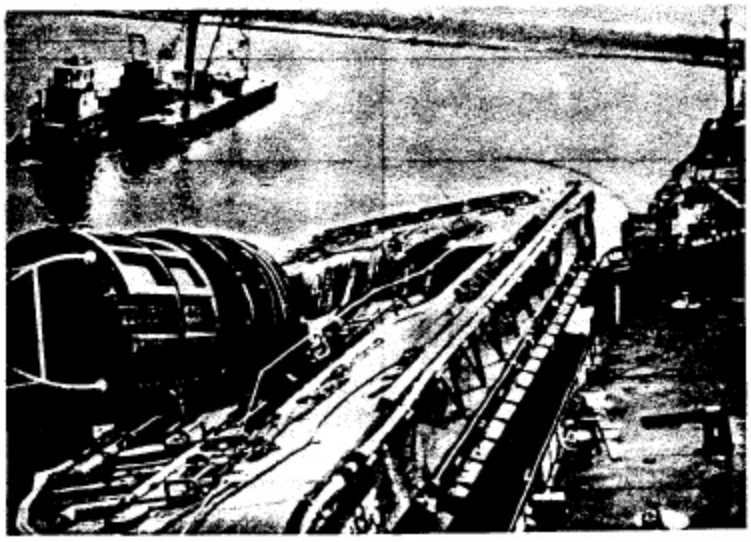


Fig. 6—RA-DE SALM fully assembled being loaded aboard tanker by hydraulic ramp

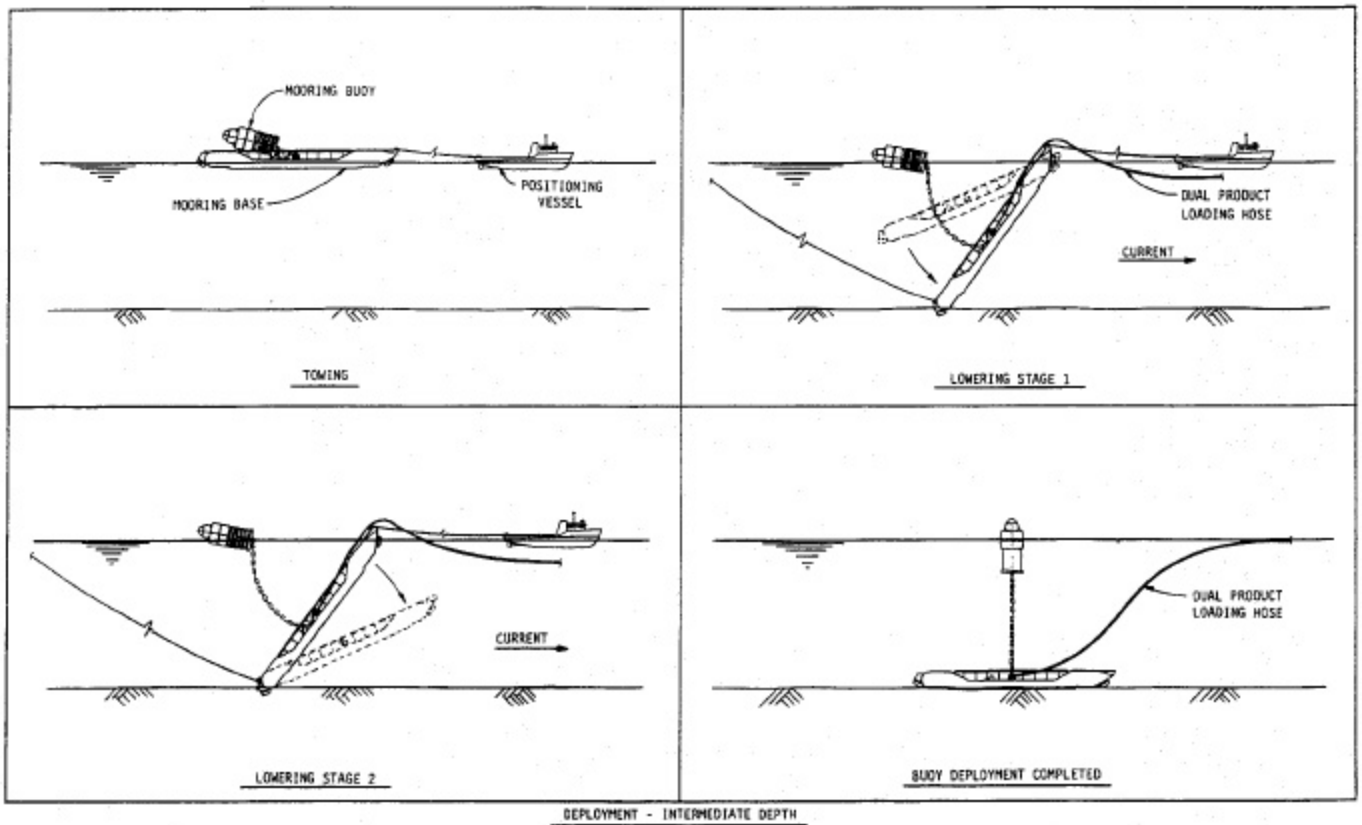


Fig. 7—Deployment procedure for water depths up to 120 ft (37 m).

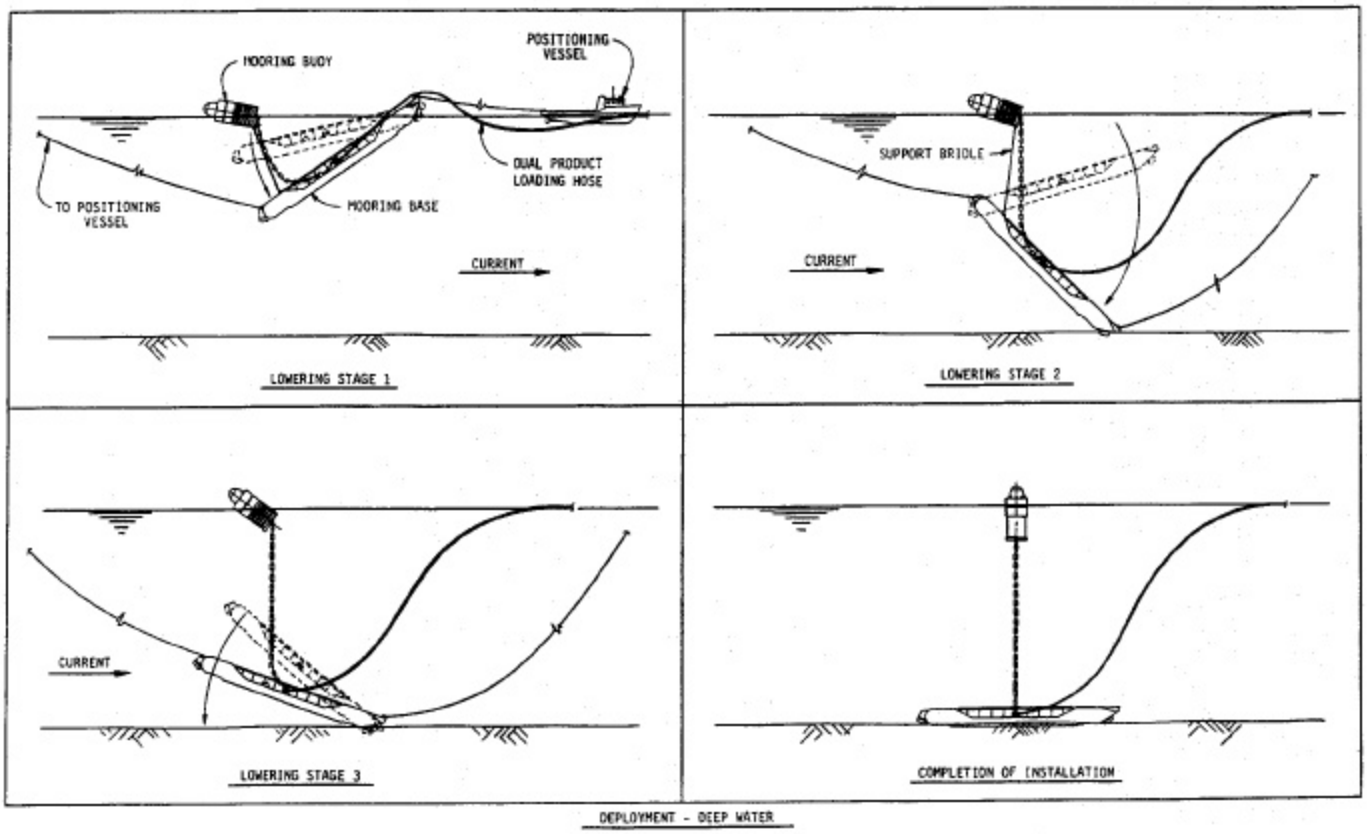


Fig. 8—Deployment procedure for water depths beyond 120 ft (37 m).

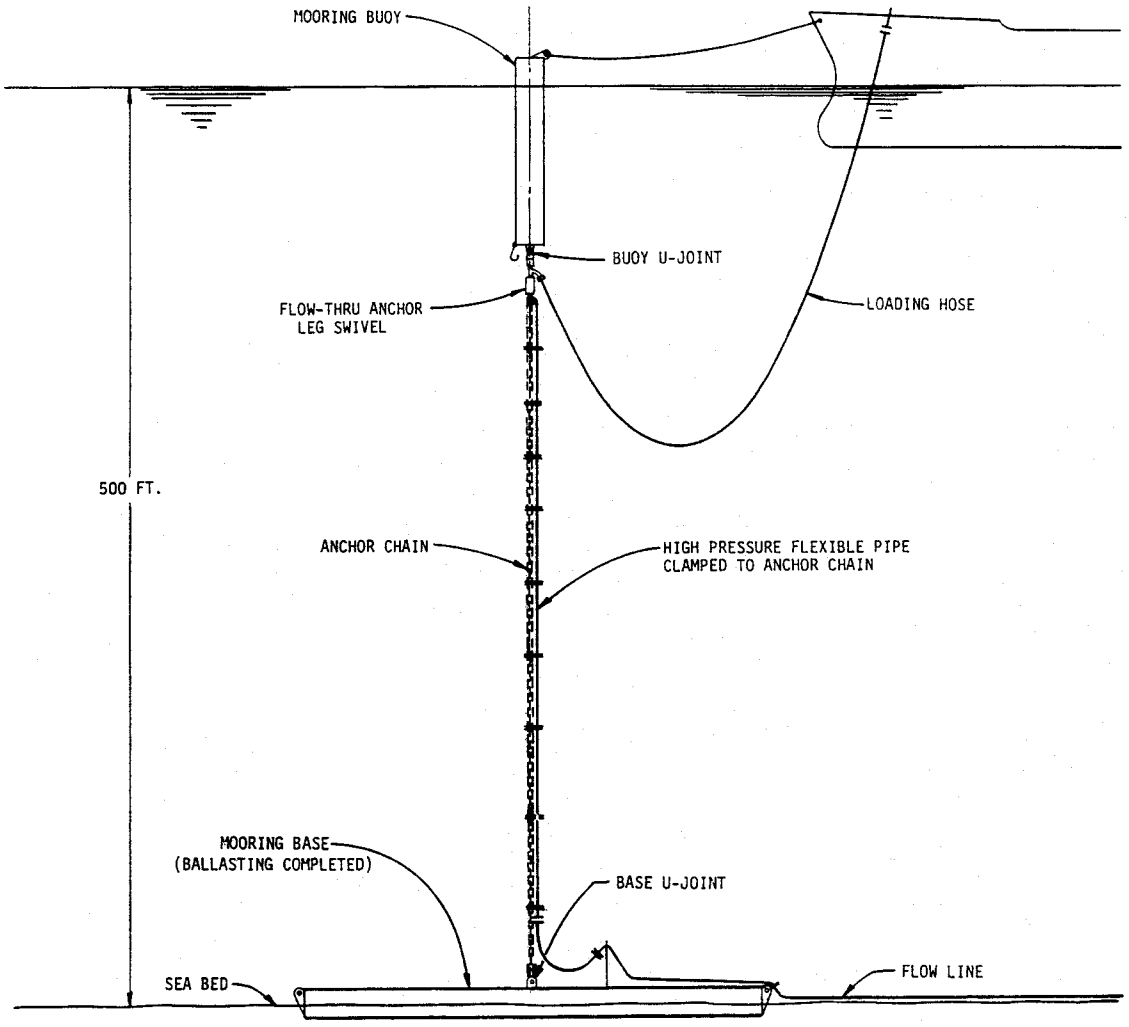


Fig. 9—Commercial rapid deployment SALM.