# A MOBILE SINGLE POINT MOORING FOR EXTENDED WELL TESTING


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THIS PAPER describes a unique *Rapid Deployment Single Anchor Leg Mooring* system (hereinafter designated RA-DE SALM$^{TM}$). The RA-DE SALM$^{TM}$ (patent pending) was developed for military use but offers significant advantages for commercial oilfield 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.

During the operational demonstration, the RA-DE SALM$^{TM}$ 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 24 hours using the same floating equipment.

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

The RA-DE SALM$^{TM}$ (Fig. 1), in conjunction with a flexible pipeline, provides a means to deliver large quantities of fuel to shore-based operations.

In a similar manner, a RA-DE SALM$^{TM}$ 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.

The key differences between most commercial *Single Point Mooring* (SPM) systems and the RA-DE SALM$^{TM}$ are that the RA-DE SALM$^{TM}$ utilizes pre-positioned ballast and can be installed very quickly by using controlled flooding of the buoyancy tanks, with a minimum of other equipment. The RA-DE SALM$^{TM}$ 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.

The technology involved has been developed by SOFEC through numerous SALM installations since 1973. The basic SALM concept, developed by EXXON Research and Engineering during the late 1960s, 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.

## DESIGN PARAMETERS

| Item | | Military (Actual) | Commercial (Typical) |
|---|---|---|---|
| Water Depth | : | 35 ft – 200 ft (11 m – 61 m) | 100 ft – 500 ft (30 m – 152 m) |
| Tanker Size (max.) | : | 70 000 DWT | 100 000 DWT |
| Hs (operating) | : | 12 ft (3.7 m) | 20 ft (6 m) |
| Wind (operating) | : | 40 kt (21 m/s) | 70 kt (137 m/s) |
| Current (operating) | : | 4 kt (2 m/s) | 2 kt (1 m/s) |
| Hmax (survival) | : | 37 ft (11.3 m) | 90 ft (27.4 m) |
| Wind (survival) | : | 55 kt (28 m/s) | 130 kt (66.1 kt) |
| Seabed Soils | : | Soft mud – hard sand | Soft mud – hard sand |
| Max. Flow Rate | : | 60 000 GPH (228 cu. m/hr) | 10 000 BPH (1590 cu. m/hr) |
| Operating Pressure | : | 600 psi (4140 KPa) | 5000 psi (34 450 KPa) |
| Hose Size | : | Dual 6 in. (152 mm) | Dual 10 in. (254 mm) |

From the above specifications, it is apparent that the RA-DE SALM$^{TM}$ 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 programme, the RA-DE SALM$^{TM}$ should offer an attractive solution for such requirements. The ability to install, recover, relocate and re-install the system utilizing only tug boats and minimal diver assistance should offer attractive economics as compared to more standard solutions.

The SALM (Fig. 2) 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).*

## SYSTEM COMPONENTS

The following brief descriptions are for RA-DE SALM$^{TM}$ components which have been designed, constructed and tested:—

### Mooring Base

The mooring base (Fig. 3) supplied with the RA-DE SALM$^{TM}$ is 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. The base is configured to provide the necessary buoyancy, freeboard, stability and seaworthy features to assure safe transportation at high towing speeds.

### Fluid Swivel Assembly

The fluid swivel (Fig. 4) for the RA-DE SALM$^{TM}$ 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 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 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$^{TM}$ during storage and transport. 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.

### 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. 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 of 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 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.

## MAINTENANCE REQUIREMENTS

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, maiantenance-free life in submerged service will also result in minimal maintenance when the system is stored between service deployments.

## INSTALLATION AND RECOVERY

Installation and recovery 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 ft (9 m – 46 m). Each installation/retrieval has been successfully completed utilizing the minimal personnel and equipment referred to herein.

Typical of the demonstrations performed to date is a 100 ft (30 m) demonstration which was performed off Cape Charles, Virginia, and included tie-in to the flexible submarine pipeline, tanker hook-up and pumping product to a beach manifold and storage facility. During this test 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 tests 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$^{TM}$ 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.

## CONCLUSIONS

1. A *Rapid Deployment Single Point Mooring* known as the RA-DE SALM$^{TM}$ 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 installed (24 – 48 hours with minimal equipment and personnel) and recoverable (again with minimal equipment and personnel).

2. The RA-DE SALM$^{TM}$ and the system on which it is based are proven concepts having been constructed and successfully installed/retrieved on numerous occasions.

3. The RA-DE SALM$^{TM}$ offers an attractive solution for the production or long term testing and reservoir analysis of commercial oil wells. The adaptability of the system to long distance transport, installation, retrieval and re-installation without the use of floating construction equipment (tug boats only, no lifting capacity) offers significant cost savings over methods employed to-date.

## REFERENCES

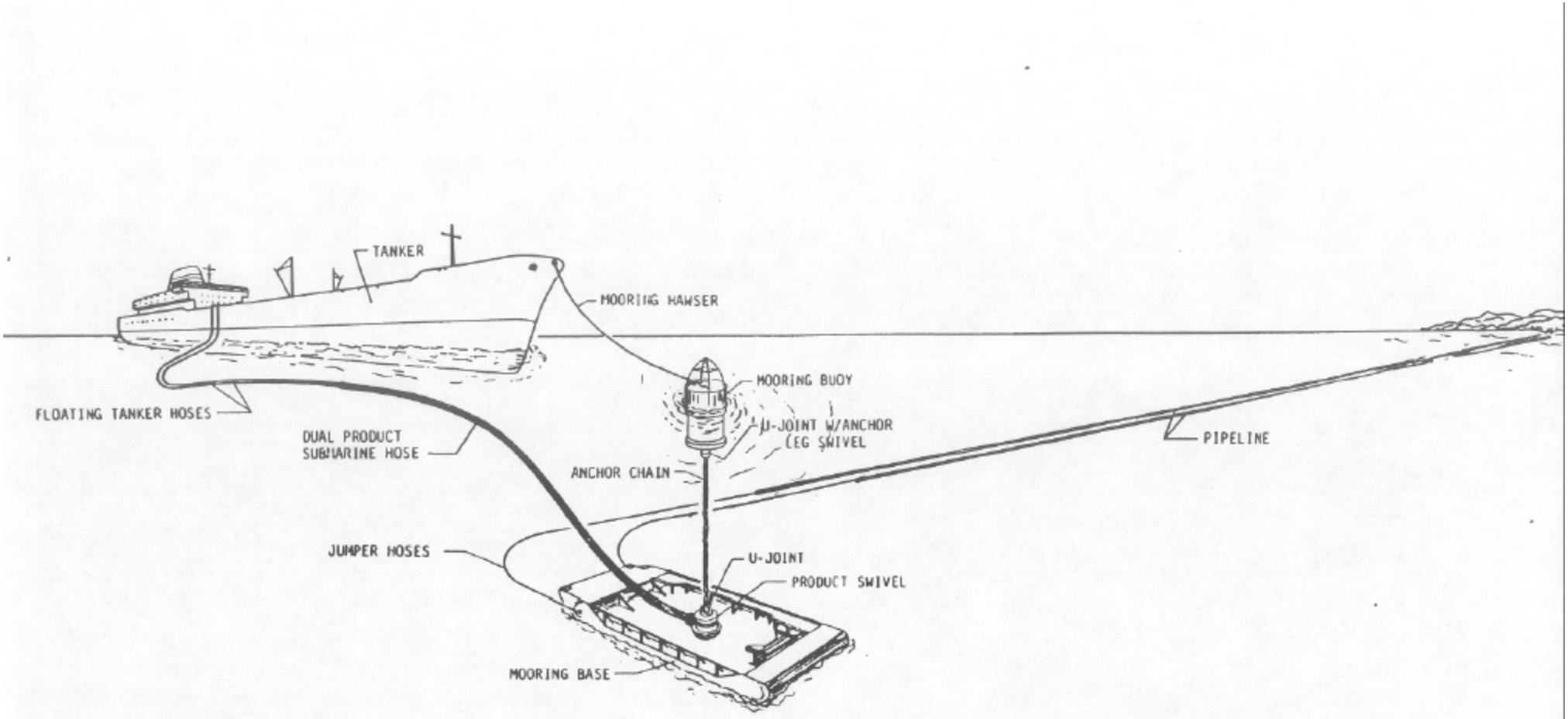

1. Gruy, R.H., Kiely, W.L.: **"Single Point Moorings: Options for Offshore Loading, Storage and Process"**, 5th Offshore Southeast Asia, Singapore (Feb. 21 – 24, 1984).

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.




**RA-DE SALM™ Isometric**

**FIGURE 1 – RAPID DEPLOYMENT SALM SYSTEM**

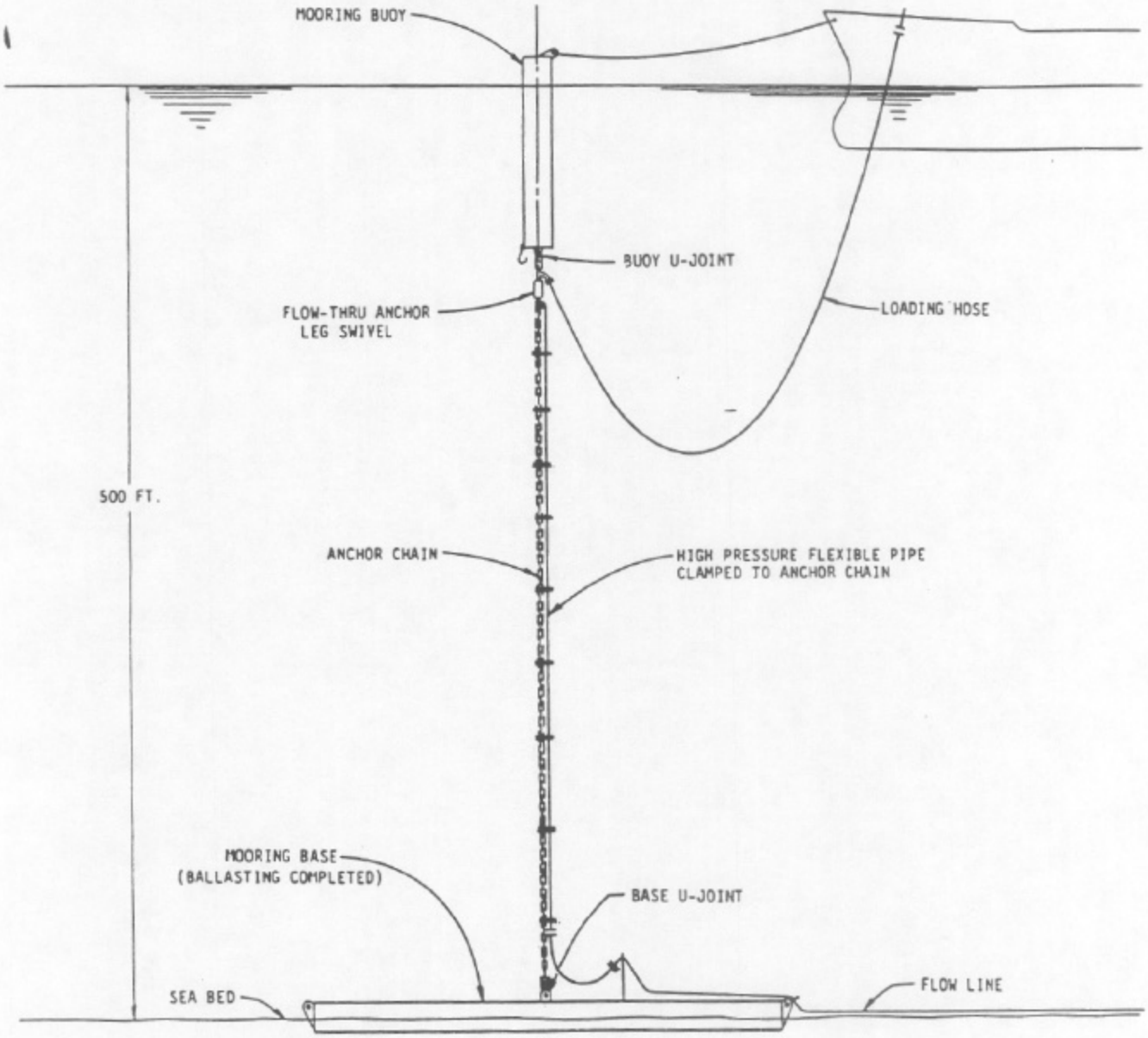



FIGURE 2 – RA-DE SALM COMMERCIAL INSTALLATION


FIGURE 3 – BASE (PHOTO)

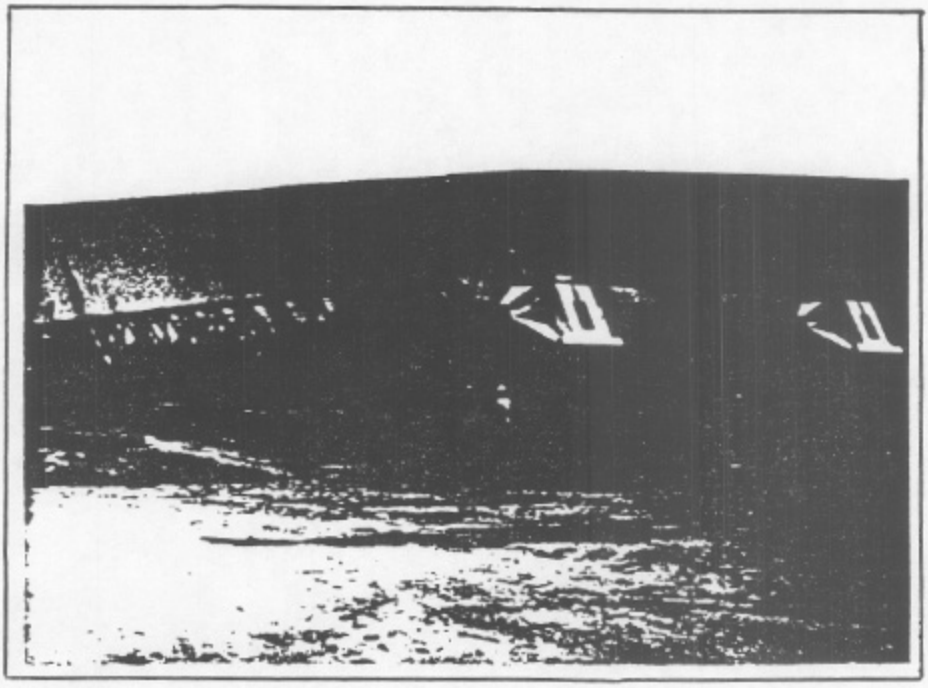


FIGURE 4 – FLUID SWIVEL (PHOTO)

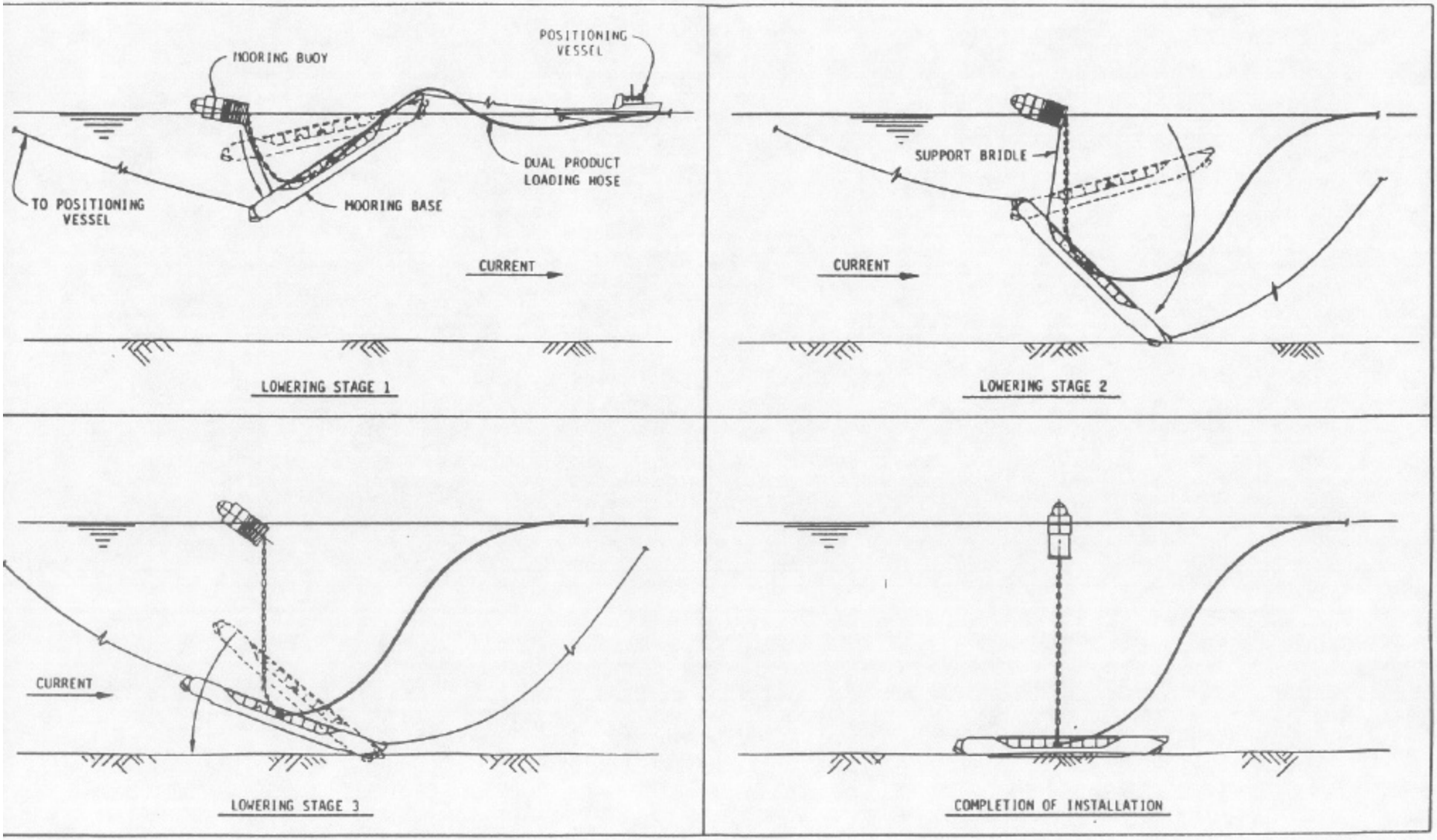



**FIGURE 5 — DEEPWATER DEPLOYMENT**