SOFEC INC.
2000 WEST LOOP SOUTH
HOUSTON, TEXAS 77027
TEL. 713-626-5400
TWX. 910-881-5026

SOFEC INSTALLS LARGEST SPM TERMINALS IN THE ARABIAN GULF

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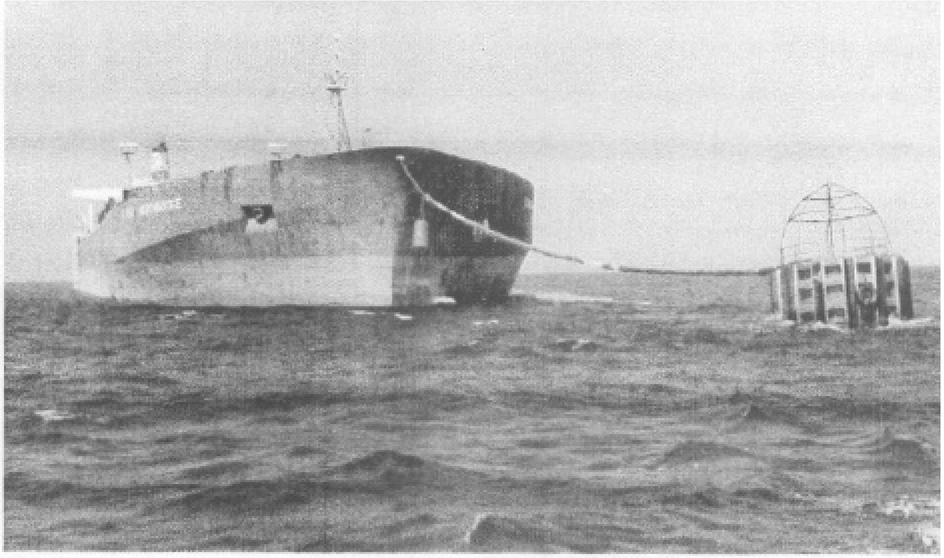
TANKER LOADS OFF JU' AYMAH. The two SALM terminals are designed to handle 750,000-dwt tankers—none of which have yet been built.



SOFEC constructs the largest SPM terminals in the Arabian Gulf

Robert H. Gruy, Vice President, SOFEC, Houston, Texas

The largest export SPMs in the world, two SALM (Single Anchor Leg Mooring) terminals, have recently been completed by SOFEC, Inc., of Houston in 125 ft of water in the Arabian Gulf. The two terminals are part of the latest expansion of the offshore loading capabilities at Ras al Ju' Aymah, Saudi Arabia.

Design capabilities. Each SALM is designed to moor and load tankers up to 750,000 dwt* in seas up to 15 ft (significant wave height), winds up to 50 mph and currents of three ft/second.

The basic design philosophy for a SALM terminal is to provide a mooring system having sufficient elasticity to minimize mooring forces while retaining adequate stiffness to control tanker excursions. Mooring forces are predicted via an empirical method developed through several years of model testing and prototype design, installation and operation.

For the Ju' Aymah Project, two separate series of model tests were carried out at the Netherlands Ship Model Basin: The purpose of the first series was to assess the performance of the SALM system in general, select an optimum hose system design and to verify mooring forces. The second series was conducted to study on a large scale the performance of the SALM hose system in waves and currents. Nine different hose systems were tested to determine the optimum system with respect to profile, length and flexural rigidity. Models were constructed for these tests at scales of 1:53, 1:38 and 1:20.

Swivel assembly. The heart of the SALM system is the fluid swivel assembly. Because this unit must be located underwater, SOFEC designed it for long life and maintenance-free operation. Actual field histories indicate that periodic lubrication is not necessary and seal replacements are infrequently required—on the order of seven or more years.

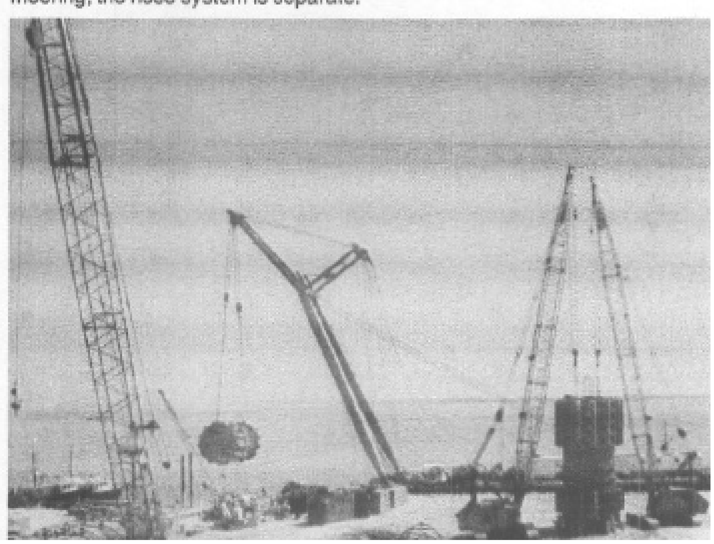
Thus, the underwater location provides a positive advantage as the swivel is removed from the harsh surface environment to a quiet zone near the sea floor well below tanker draft and safe from damage by collision should the tanker override the buoy. Additionally, the underwater swivel allows separation of the mooring function and the cargo transfer function i.e., the SALM buoy is strictly a mooring device and is not involved in cargo transfer. No hoses are attached to it. Thus, the hose system is not subjected to forces (and potential damage) caused by motions of the buoy.

The Ju' Aymah SALM fluid swivels are designed for simultaneous transfer of two fluids: crude oil and bunker fuel oil. Design flow rates are 210,000 and 20,000 barrels per hour, respectively. Present operations which utilize twin 24-in. hose strings with 16-in. tail hoses for crude oil and a single 12-in. for bunker fuel limit transfer rates to about 110,000 barrels per hour for crude oil and 5,000 barrels per hour for bunker fuel oil.

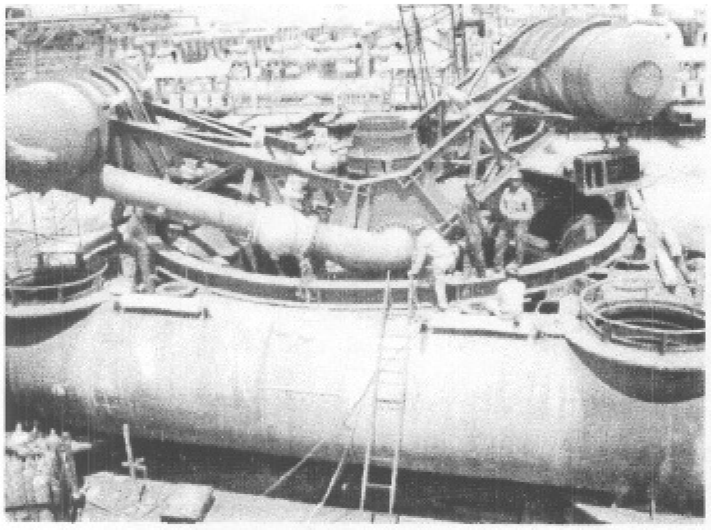
The fluid swivels for the Ju' Aymah Project incorporate several unique features which insure their operational viability:

1. It is impossible to commingle the crude and bunker fuel oil. The two products are segregated via structural separation i.e., no elastomer or other type seals are utilized.
2. The swivel assemblies are completely modular and all pressure sealing connections may be readily brought to the surface either as a unit or individually.
3. Each of the rotary swivels which mount the fluid distribution chambers incorporate 5 large volume seals: 3 on the oil side and 2 on the side exposed to seawater. The primary seal on the oil side is a multiple contact, self-energized seal and the secondary seal is a large, pressure-energized type. Additionally, there is an emergency seal which is normally in a passive or retracted position. It can be energized and set with externally applied hydraulic pressure. Once set, this seal will allow the swivel to continue to operate as usual until maintenance can be scheduled. This prevents panic shut-downs of the system.
4. Swivel torque requirements were reduced significantly through research and development efforts. Low torque means longer

BUOYS UNDER CONSTRUCTION. The buoys are used strictly for mooring; the hose system is separate.



*750,000 dwt tankers have not been constructed to date. Typical dimensions for a vessel of this size are: length = 1,480 ft, beam = 250 ft, draft = 100 ft. The largest tankers in the world at this time are about 550,000 dwt.



BASES UNDER CONSTRUCTION AT BAHRAIN. Once on the sea floor, the 9-ft diameter sections of the 45-ft square base are filled with cement and pinned to the floor with piling. One of the unusual features of the installation are the hose arms, which usually stabilize at 20 to 30° during loading. After vertical excursions due to waves, the arms return to the original configuration.

bearing and seal life and longer life for the submarine hoses. Torque reduction was achieved *without* reducing bearing or seal contact areas through the use of a special low friction overlay material on the sealing surfaces in combination with mechanical modifications to avoid torque build-up due to bearing misalignment.

The SALM design utilizes the loading hose to transmit torque to rotate the fluid swivel. The connection between the hose system and the swivel is achieved through a hose arm which provides a flexible transition point for the attachment of the submarine hoses and also constitutes an important part of the over-all moment arm available to rotate the fluid swivel.

Another important feature of the Ju' Aymah SALM hose arms is the self-stabilizing capability. With this feature, the hose arm is stabilized at a predetermined angle with the horizontal, typically 20° to 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 also demonstrated that heeling angles i.e., changes in vertical orientation, of the hose arm under all current conditions tested (.5 to 1.75 knots) are moderate as are the motions under the influence of waves.

One other important design parameter that was verified during model testing was the ability of the fluid swivel/hose arm/loading hose system to rotate under the influence of nominal surface currents. It was found that the optimum hose system would rotate the fluid swivel with current velocities of 0.3 to 0.5 knots at directions of 90° and 180° to the hose arm. Proper attention to this important parameter during the design phase insures that the loading hoses will not wrap around the buoy should the terminal remain unoccupied during a tide change or other shifts in weather directions.

Mooring buoys

The Ju' Aymah SALM mooring buoys are each cylindrical structures 20 ft in diameter by 40 ft deep providing a fully submerged net buoyancy of 250 tons. This 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 buoy is anchored to the mooring base by a single anchor leg which consists of 20 links of 6-in. oil rig quality stud-link chain. Integral with this chain are two 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.

Mooring base

The sea floor foundation or mooring base is a hollow square measuring 45-ft O.D. and 27-ft I.D. Each leg of the square is a 9-ft diameter, internally stiffened cylinder. Bulkheads at each corner separate the base into four watertight compartments so the entire structure is self-floating. During installation, two of the compartments are designed to be flooded for submergence while the other two remain dry. This reduces hook loads during the lowering of the base from the surface to the sea floor.

Once on the sea floor the legs are flooded and then filled with cement ballast. This 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.

Fabrication of the mooring bases and buoys took place in the Arabian Gulf on the island of Bahrain. Fluid swivels and universal joints came from the U.S.; the hose arms were fabricated in Singapore and pilings were fabricated in Japan.

Installation

Installation of the Ju' Aymah SALM terminals took place during summer, 1976. Prime contractor for SALM installations was Brown & Root—Wimpey M.E.S.A.

The mooring base assemblies were transported from Bahrain to Ju' Aymah—a distance of about 60 miles—where they were lifted off the barge and set by a 500-ton stiff leg crane. The maximum lift required was 325 tons. The bases were lowered into four-ft deep recesses which had been air-lifted from the sea floor prior to their arrival.

Once the bases and pilings were installed, the buoys were attached via single connections as shown in the accompanying drawing.

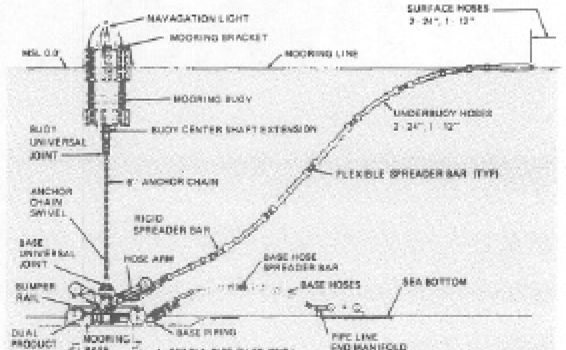
The Ju' Aymah SALM terminals were commissioned in late November, 1976. Since start-up, several important items have been confirmed:

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

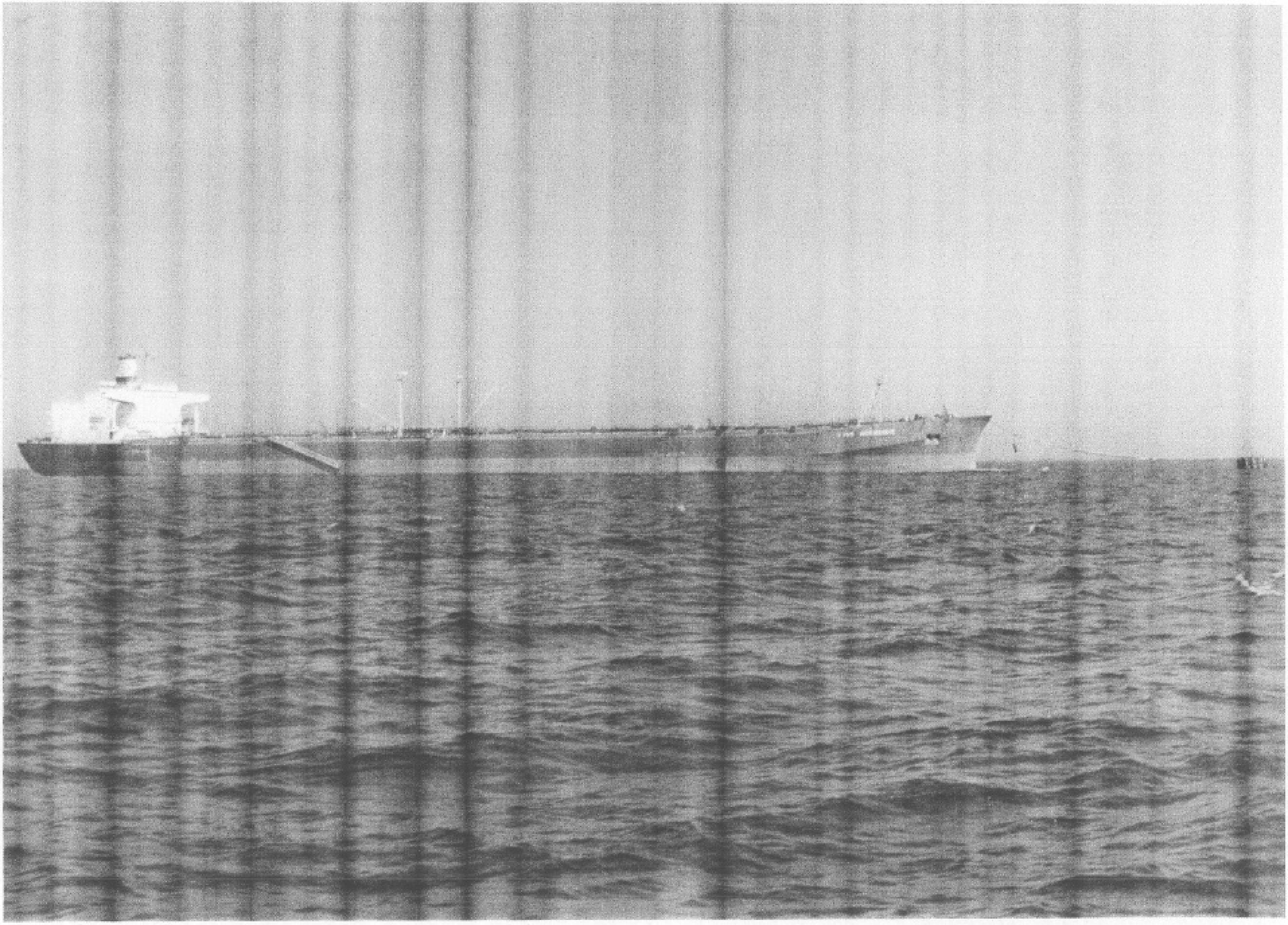
2. Submarine hose profile is very stable and requires no maintenance or adjustment once set.

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 been continually occupied by VLCC s of the world fleet. During the first three months' operation, approximately 100 million barrels of oil were transferred through the terminals. Thus far their performance capabilities and minimum maintenance attributes have lived up to all design expectations.



SCHEMATIC OF THE SALM



SOFEC SALM RAS AL JU'AYMAH SAUDI ARABIA