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An Offshore Petroleum Discharge System (OPDS) Application of Commercial Technology to Military Operational Requirements

by M.D. Brightwell, SOFEC Inc.; J.R. Exell, U.S. Dept. of the Navy, Naval Sea Systems Command; and R.L. Furness, Uniroyal Manuli Rubber (USA) Inc.

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ABSTRACT

This paper describes the operational requirements, equipment design and application for an OFFSHORE PETROLEUM DISCHARGE SYSTEM (OPDS) capable of mooring tankers to 70,000 DWT four miles offshore in water depths to 200 feet and delivering 1.2 million gallons of fuel to the beach each day. Deployment of the system and start of pumping operations can be accomplished in minimal time with minimal support equipment.

INTRODUCTION

The operational requirement to provide supplies to forces ashore from ships offshore is not new. It has existed as long as there have been amphibious operations. Of special interest to this paper is the provision, over the beach, of large amounts of petroleum products required by today's "fighting machines".

This problem was faced by the Allied Forces in World War II during the Normandy Invasion. Their answer was to develop a petroleum delivery system called Pipeline Under the Ocean, known as PLUTO. PLUTO consisted of up to twenty, 3 inch pipelines laid on the ocean floor from Great Britain to France. It delivered over 120 million gallons of fuel to the forces in Europe during the ten months following the invasion. The maximum daily delivery rate achieved was one million gallons.

Today the requirement is much larger. One million gallons a day is now required for a force one tenth the size of that supported by PLUTO. Fuel consumption rates have skyrocketed with the use of helicopters, jets and vehicles with high performance engines. The modernization from the M-60 to the M-1 tank alone increased fuel requirements 73 percent per tank. In addition, today's system cannot be site specific, but must be installable nearly anywhere in the world.

References and illustrations at end of paper

THE OPDS SYSTEM

OVERVIEW

A Government-owned tanker with the OPDS installed on-board travels over open ocean to the Amphibious Operations Area. With the support of four Side Loadable Warping Tug's (SLWT's) the tanker temporarily sets a four point moor, deploys up to four miles of conduit and commences delivery of fuel to the beach within two days of arrival in the Area. The Single Anchor Leg Mooring (SALM) is then unloaded, deployed and the conduit connected to it. SALM deployment has been accomplished in less than five hours in actual field demonstrations. Tankers are moored directly to the SALM and product is discharged through the hose string and product piping. (Figure 1). All equipment (SALM and conduit) is retrievable by the SLWT's following use and reutilized at other locations. Existing commercial technology was applied to fill a Military requirement by utilizing a gravity base SALM. It can either be towed by or carried on board the tanker to the Operations Area and rapidly deployed to provide a mooring and fuel delivery system. Flexible conduit is carried on board the tanker in eight one-half mile lengths on storage reels. The conduit is an application of commercial hydraulic and marine hose technology and is the "pipeline" from the SALM to the beach. The tanker is manned by Merchant Marine personnel while the SLWT, diving and shore based support is provided by Military personnel.

The contract for OPDS 1 was awarded in 1984. The SALM and other system components were installed on board the tanker SS Potomac and a full demonstration conducted in the Fall of 1985 off Cape Charles, Virginia. OPDS 2, 3 and 4 are currently under construction, the first three of six production units to be built over the next four years. Prime contractor to the U.S. Navy for these follow-on systems is SOFEC, Inc. SOFEC provides the SALM system and Uniroyal Manuli Rubber (USA) Inc. is the subcontractor providing the flexible conduit and related equipment.

OPERATIONAL PARAMETERS

Operational requirements demand that the system be easily transportable anywhere in the world, quickly installable, operatable in sea state 5, and be recoverable when it is no longer needed. Of course, it must also be able to provide adequate quantities of fuel for consumption and stockpile build-up. These general requirements translate into the following specifics.

The entire system must be transported and installed by one tanker modified for this work. The system includes the SALM, four miles of conduit, moorings and all associated equipment. The only equipment the tanker would not be required to carry to the operating area is the side loadable warping tugs (SLWT's).

The system must commence pumping the required 1.2 million gallons per day (GPD) from the tanker located up to four miles offshore, within 48 hours of arriving in the objective area. A permanent, all weather, single point moor must be established within 7 days after arrival. This mooring system must accommodate a 70,000 DWT tanker.

The site conditions in which the system must operate are:

Water depths from 35 to 200 feet
Sea floor gradient of 1:2 to 1:500
Wave heights of 12 feet
Currents of 4.0 knots
Maximum winds of 40 knots
Mud, sand or coral bottom

TANKER

The host tanker for OPDS 1 is the SS Potomac. SS American Osprey as shown in Figure 2 is currently receiving the first of six production systems and will be designated OPDS 2. These and future tankers will be part of the Ready Reserve Fleet managed by the Maritime Administration and on a 5 day activation schedule.

Pumps

The combination of using 6 in. ID conduit for handling ease and the 4 mile offshore requirement rendered the regular 125 psi cargo pumps ineffective in reaching the 1.2 million GPD requirement. Two 500 GPM booster pumps are installed in parallel downstream of the cargo pumps. Each booster pump is a motor driven, positive displacement pump with a discharge pressure of 700 psi. Pumps and pump controls are located in a house installed on the tanker main deck, with emergency shutdown capability provided on the bridge.

When the tanker is located two miles or less from shore, the system can pump two different products simultaneously using one pump for each product.

Spread Mooring System

The removal of the SALM from the tanker and its deployment to the bottom takes sufficient time that pumping operations would not be able to commence within the 48 hours stipulated. The use of a spread or four point moor as a temporary step shown in Figure 3 permits the ship to be fixed in relation to the beach, conduit deployed and pumping commenced expeditiously. The tanker can then be heeled over, SALM removed and deployed at a safer pace without impacting fuel delivery to the troops ashore.

Two anchor/towing winches with 9,000 lb high holding power Stato anchors are installed on the tanker stern. Once the tanker has anchored in the assigned anchorage using one bow anchor, SLWT's assist in running out the other three anchors. The stern winches can also be used to tow the SALM as an alternate or emergency transport. Each winch carries 3,000 ft of 1 3/4 in. eips wire rope. Rated line pull is 60,000 lbs with 100,000 lb braking capacity. The winch structure has been tested to 336,000 lb static pull, first layer on the drum against the dog. This demonstrates the capability of the winch to withstand loads in excess of the wire rope breaking strength.

SALM Launch and Recovery Equipment (SL&RE)

The SALM for OPDS 1 onboard the SS POTOMAC is stowed aft resting on the skid beams that are used for launch and recovery, as shown in Figure 4. To launch the SALM, the POTOMAC is listed 13 degrees to port, the skid beams hydraulically extended over the side and the SALM lowered using sets of hydraulic grippers. When the hooks holding the SALM to the skid beams are just below the surface of the water, the inboard end of the skid beams are elevated causing the hook to pivot down and release the SALM. The SALM is back loaded by reversing this process.

OPDS 2 onboard the American Osprey will utilize a fixed beam with a hinged extension. Osprey will be heeled 12 degrees and the SALM lowered using hydraulic linear winches.

SALM

The SALM consists of a tensioned cylindrical buoy connected to a mooring base by means of a single chain anchor leg (Figure 1).

The tanker is moored to the buoy with a mooring hawser from its bow and may swing freely (weathervane) about the mooring base. This allows the vessel to orient itself into the prevailing weather.

Base

The OPDS SALM Base is a gravity base configured as a towable barge designed to carry the buoy, chain leg assembly, product swivel and submarine hose as a compact self-contained unit (Figure 5). The SALM may be towed or carried on the tanker SL&RE system.

The SALM Base is approximately 57 ft wide x 150 ft long x 12 ft deep and has a weight in air of 875 st. A combination of permanent ballast and flooded buoyancy tanks provide the on-bottom weight to develop the required holding power. Sequential flooding of the buoyancy tanks allows a controlled sinking of the base to the sea floor with minimal marine support.

Retrieval of the base is accomplished by deballasting the buoyancy tanks with air in a sequence that provides a controlled, stable rise to the surface. A built-in "jetting system" can be used to break any suction pressure between the base bottom and seabed.

Mooring Buoy(s)

The main mooring buoy is a cylinder 17 ft in diameter, 30 ft long, weighs 110 st in air and is used in water depths of 60 to 200 ft. It is of reinforced steel construction with four watertight compartments to protect against sinking in case of collision. Mooring loads from the tanker are carried by the mooring hawser through the buoy to the chain leg. The buoyancy of the buoy provides the righting moment or restoring force to hold the tanker on the moor in the specified operating environment. The chain leg is attached to a universal joint on the buoy bottom. This universal joint provides the required freedom of motion for the chain, thereby preventing significant chain wear.

A smaller auxiliary buoy is used in water depths of 35 to 60 ft. It is also of reinforced steel construction, 7 ft in diameter, 15 ft long and weighs 6.5 st in air. This buoy is divided into two water tight compartments and functions as support for the chain leg while transferring mooring loads.

An instrumented shackle is provided on the tanker end of the mooring hawser to indicate the safe range of mooring loads.

Chain Leg Assembly

Standard Oil Rig Quality (ORQ) 3 1/2 in. diameter stud-link chain is used to transmit mooring loads from the buoy to the base. It is connected to the buoy universal joint and to a similar universal joint on the base mooring post. Within the assembly is a chain swivel, with fully sealed bearings, that allows the buoy to rotate as the tanker weathervanes. The chain leg is adjustable for the entire 35-200 ft water depth range through addition or removal of links joined by Kenter shackles.

Product Swivel

The product swivel is a 740 psi working pressure, dual 6 in. diameter flow path assembly (Figure 6). The toroidal configuration makes co-mingling of the two fluid paths impossible and facilitates the pigging of the product transfer system through the swivel. A different product may be pumped through each flow path simultaneously. A swivel orientation system is provided with a display at the tanker bridge to indicate the swivel positions where pigging may be performed. Orientation is detected by dual magnetic proximity switches on the swivel circumference. A signal is sent to the surface by acoustic beacon, received by a hydrophone, processed and displayed on a unit that indicates go/no-go for each fluid path.

The product swivel flow paths are isolated from the sea by dual seals with annular leak detection ports. The bearings are also protected from seawater intrusion by dual seals and a third seal is provided for testing.

Although the product swivel encloses the mooring post attachment to the base, no mooring forces are transmitted by the swivel. The product swivel is bolted to the base and allows the submarine loading hoses to rotate freely as the tanker weathervanes about the chain anchor leg.

Hoses

The SALM Hose System is a dual path 6 in. ID, 740 psi working pressure system. The system is comprised of submarine hoses from the product swivel to the surface and floating hoses to the tanker rail. Cover material provides resistance to ozone and weather aging in order to meet the twenty year storage requirement. A fuel resistant liner will carry the variety of specified products.

Submarine Hoses

The Submarine hoses are designed to provide the flexural stiffness and buoyancy required to maintain a smooth suspended profile in the specified range of water depths (35-200 ft) with varied product densities. They also drive the product swivel in response to changes in position of the moored tanker. There are three types of submarine hoses, each with a different stiffness. The most rigid is near the swivel with the least rigid at the transition to the floating hose.

Eight 40 ft sections are required for the 200 ft water depth case. As water depths become more shallow, sections of hoses are deleted to adjust the overall length.

Each hose is constructed similar to a flowline bundle utilizing two 6 in. ID conduit carcasses contained in a 24 in. ID reinforced submarine hose carcass (Figure 7). Specified buoyancy is established by placing solid ballast within the 24 in. carcass. The 24 in. carcass is resistant to crush and the resulting changes in buoyancy to depths greater than the maximum 200 ft. The special flange terminations, weight and quality controls and critical buoyancy adjustments were significant challenges presented in the design and production of the submarine hoses.

Floating Hoses

There are two 6 in. ID x 560 ft long floating hose strings. Each contains thirteen - 40 ft self-floating hoses and one-40 ft self-floating dumbbell tanker rail hose. The floating hose system is based on a helix-free design utilizing the conduit carcass to meet the requirement for a higher working pressure of 740 psi. The basic carcass of wire reinforced elastomer materials with flotation medium built-in (instead of separately layered material) affords a constant bend modulus. This helix-free integral design provides for recovery from kinking and rigorous installation demands. The conventional marine hose design was improved based on experience gained during conduit development and testing. Improvements included the ability to meet the higher working pressures and increased ozone and abrasion resistance of the hose cover.

CONDUIT

The design goals of the OPDS conduit were to provide a rugged, flexible, float/sink pipeline that met deployment and in-service requirements. Survivability under the given environmental conditions, as well as rapid deployment in 48 hours with limited equipment were major considerations in the design of the conduit and support equipment. The conduit and marine hose operating pressure of 740 psig is easily four times greater than the normal pumping pressures associated with commercial Single Point Mooring terminals. The long storage and service life of the conduit affords a cost-effective pipeline system within Navy budget requirements for total procurement. The major development accomplishment was the manufacture of continuous long lengths of elastomeric product to the close tolerances demanded by the float/sink criteria. Those tolerances are far stricter than normal Rubber Manufacturer's Association (R.M.A) standards. Quality Assurance procedures were revised to guarantee that the weight control requirements of the design envelope were met.

The conduit carcass (Figure 8) is a complex elastomeric bonded construction comprised of fuel-resistant tube liner, multiple spiral reinforcement plies of counter-wound steel cables, a bonded layer of high-density material, and abrasive-resistant cover. The continuous conduit length was established at approximately 1,000 ft with each tanker storage reel containing three sections or 1/2 mile. The 1,000 ft lengths may be transported on a smaller diameter shipping reel within a commercial container. This eases handling and increases shipping options. The 1,000 ft lengths also enhance the ability to repair and/or replace damaged segments within the 1/2 mile storage lengths.

Special properties of the conduit include adhesive bonding that is three times stronger than that found in traditional military specifications dealing with elastomeric hose products for fuel delivery. The conduit follows the commercial criteria of OCIMF hose specifications governing offshore marine hose which, typically, require in excess of 40 lb/in. width adhesion for all bonded layers. The conduit design was required to be durable and able to recover from temporary collapse, kinking/twisting or excessive tension loads.

A layer of high-density material is utilized to add weight to the conduit in order to meet bottom stability criteria. A strict tolerance is imposed on all layers by the design weight vs buoyancy envelope. The high density layer allows the control of weight and buoyancy to meet the specifications (Figure 9).

The conduit structure of wire cable reinforcement allows for field repairs to be performed on the conduit by Merchant Marine or Military personnel within several hours. Conduit repairs can be accomplished by cutting the carcass and re-coupling with special repair fittings, using a hydraulic power pack. Sophisticated splicing of composite materials and epoxy bonding is not required.

High Pressure Couplings

A number of connector designs were examined using commercially accepted fasteners and found to be unsuitable due to the need to provide a high pressure, 6 in. ID fitting that had a positive lock and a low profile for reeling and transition through the conduit deployment/retrieval system. From a number of conceptual designs a bayonet-type fitting with a barrel seal and floating flange was selected. The coupling was subjected to extensive testing as part of the conduit test samples as well as individual testing under combined loads of hydrostatic (740 psig), tension loads (90,000 lb), and bending moment (70,000 ft-lb).

Conduit Handling Equipment

The eight 1/2 mile lengths of conduit are each stored on a reel whose drum has a core diameter of 8 ft and inside length of 24 ft. These reels are mounted forward on the tanker in two rows of four (Figure 10).

The reels are powered by low-speed, high-torque motors with integral band brakes and a dual-pinion single bull-gear drive. The reels are variable speed with an overhauling tension control which allows the reels to pay out conduit at up to three nautical miles per hour under tension. The speed will be automatically reduced so that the reel's speed mirrors the speed with which the conduit is being deployed by the warping tugs.

A level wind with remote actuator is provided for each bank of reels. The operator can move among the reels and control the level wind from various positions. A ninth auxiliary reel is used for repair of the conduit and re-reeling onto the main storage reels. A tenth reel with its own level wind and overboarding chute has been added to the system for storage of the pigtail and floating marine hose.

The eight main storage reels and the tenth reel are designed to allow the hydrostatic testing of the conduit and/or marine hose while coiled on the drum. They will support both the added weight of the test water and the crushing action of the conduit/hoses during periodic testing.

Turning quadrants, conduit coupling clamps, overboarding chutes and a hydraulic capstan are provided to move the conduit from each reel across the tanker deck and overboard to the SLWT's. Half mile lengths are joined at the conduit clamps that grip and align the couplings bringing them together so the flange bolts may be tightened (Figure 11).

All of the conduit contact surfaces on the level winds, turning quadrants, hose supports, and overboarding chutes are coated with an ultra-high molecular weight (UMHW) plastic to minimize friction. UMHW plastic rollers are also used on the sides of the turning quadrants.

SIDE LOADABLE WARPING TUG (SLWT) EQUIPMENT

Installation of the OPDS requires the assistance of four specially outfitted Navy SLWTs. Three of these tugs are outfitted with equipment which enable them to perform towing operations. Such equipment includes towing bitts, cap rails and norman pins (Figure 12).

The two main tasks that tugs perform are in-water conduit handling and anchor handling operations. The fourth SLWT is outfitted with equipment which enables it to connect, repair and deploy the conduit. A conduit clamp identical to those on the tanker with an assembly to guide and overboard the conduit allows conduit sections to be joined and handled by the SLWT.

Deployment of the conduit is accomplished by connecting, positioning, and submerging half-mile lengths along a predetermined path towards the beach. In normal operations, two towing SLWT's receive a half-mile length of conduit from the tanker and pass the near tanker end to the lay/repair SLWT for connection to the previously deployed length.

All outfitting equipment is provided in kits and the SLWT's are adapted on location before commencing their support tasks.

Beach Termination Unit (BTU)

The BTU performs the function of a valve station at the OPDS and Beach Interface Unit (US Marine Corps) or the Inland Petroleum Distribution System (US Army) interface (Figure 13). The BTU is used to control the pressure and flow rate of product supplied to the IPDS. The BTU also provides a means to take product samples for purity tests. The BTU is equipped with a pigtrap which enables the OPDS pipeline to be pigged for cleaning or product batching. An SLWT carries the BTU close to the beach where it is floated and pulled ashore by available construction equipment. The 1,500 lb anchor is attached and buried, providing a minimum 30,000 lb holding capacity and the BTU is ready to receive the conduit from the tanker. The BTU is located above the high water mark at the beach and has two 40 ft sections of conduit that cross the beach.

TESTS AND DEMONSTRATIONS

The OPDS concept was validated by extensive testing and a final full scale demonstration of OPDS 1 in October of 1985. The SALM had been successfully deployed and recovered in water depths to 150 ft on four occasions and had been towed in open ocean from Houston to Mobile to Norfolk and back to Mobile. The October 1985 exercise included mooring a tanker, pumping to the beach and pigging operations. This exercise was interrupted by Hurricane Gloria whose eye passed within 30 miles of the installation. The SALM and conduit remained in place without damage or movement.

The current procurement requires extensive testing of all components. The product swivel will be subjected to rotational torque and hydrostatic tests as well as flow, piggability and flushing tests.

The SALM system, including submarine and pigtail hoses, will be deployed and recovered in 120 ft of water during which time all systems required to ballast the base to the sea floor and deballast for recovery will be exercised.

The Spread Mooring System is subject to a 336,000 lb static pull to prove the structural design. A complex testing program to confirm line pull and speeds, braking capacity and function of controls, sensors and safety interlocks with be performed.

The qualification of the conduit, conduit coupling and marine hose required building samples and performing the following tests. Testing was conducted and evaluated by an independent testing organization with considerable experience in testing of marine hose.

Visual
Break-in torsion, tension, bending
Flexibility, kinking, bending stiffness
Hydrostatic, burst
Kerosene, vacuum, collapse
Axial strength
Flow performance
Weather resistance and low temperature creep
Extreme cold flexibility
Adhesion, fuel resistance
Abrasion resistance
Compound heat aging, ozone resistance, xeno

Two long-length samples have been provided for additional testing and trials to evaluate surf zone survival conditions and bottom stability against higher sea states and cross currents under a worst-case military scenario.

The SS American Osprey will be returned to the Ready Reserve Fleet in Beaumont, Texas in June, 1988 after installation of OPDS 2.

CONCLUSIONS

1. The OPDS concept based on commercial technology has been demonstrated through procurement and testing.

2. The OPDS concept is viable and effective and is now embodied in hardware ready to support Amphibious and Logistics over the Shore (LOTS) Operations by delivering fuel to the beach within the critical two day period after arrival in the Operations Area.

ACKNOWLEDGEMENTS

SOFEC Inc. as the prime contractor of the NAVSEA OPDS procurement wishes to express appreciation for the support of the major subcontractors: Orange Shipbuilding, Inc., fabrication of SALM base and buoy; Appleton Marine, Inc., spread mooring systems and the Uniroyal Manuli Rubber (USA) Inc. group comprised of Uniroyal Manuli S.P.A., conduit and marine hose; Almon A. Johnson, Inc., conduit reels and deck handling equipment; Hydrosearch Co, Inc., conduit coupling and repair fitting; Diversified Technologies, warping tug outfitting and beach termination units.

Independent testing of conduit, conduit coupling and marine hose testing and analyses was performed by Southwest Research Institute.

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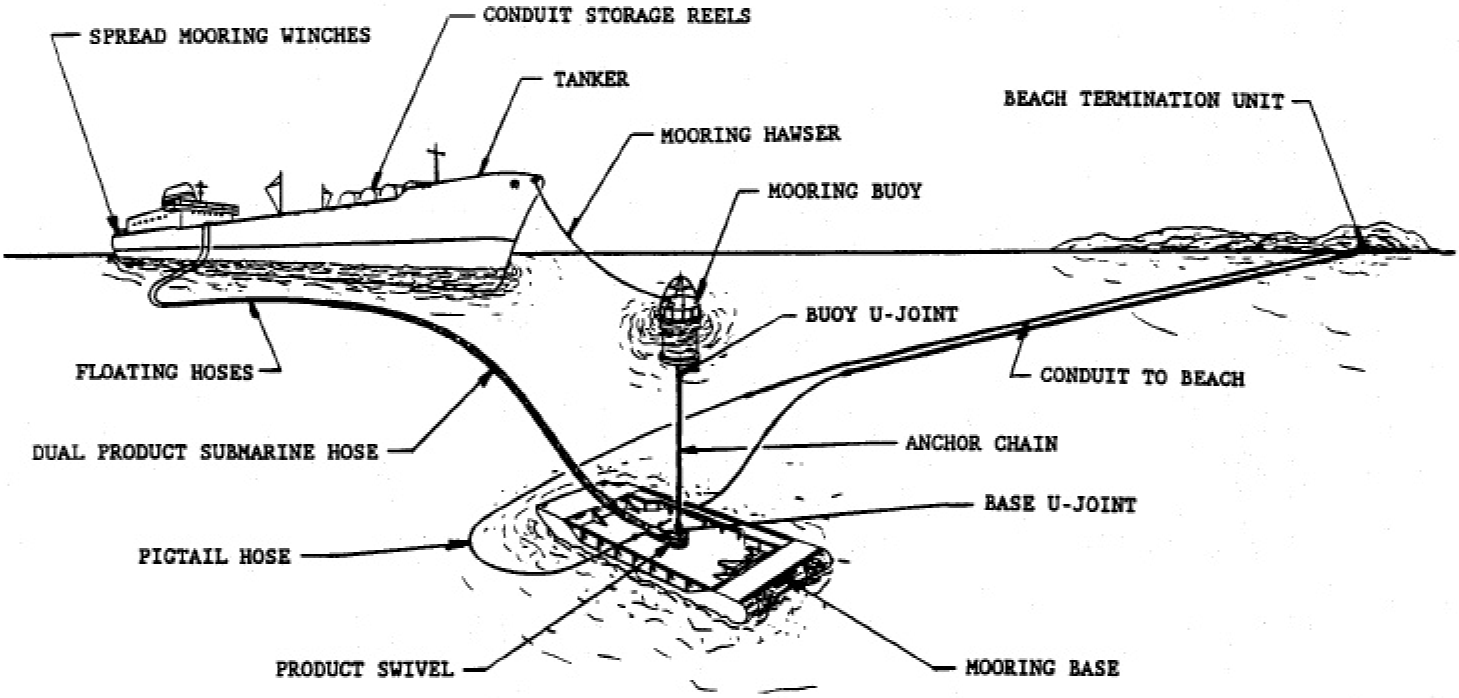


FIG. 1 OPDS SYSTEM

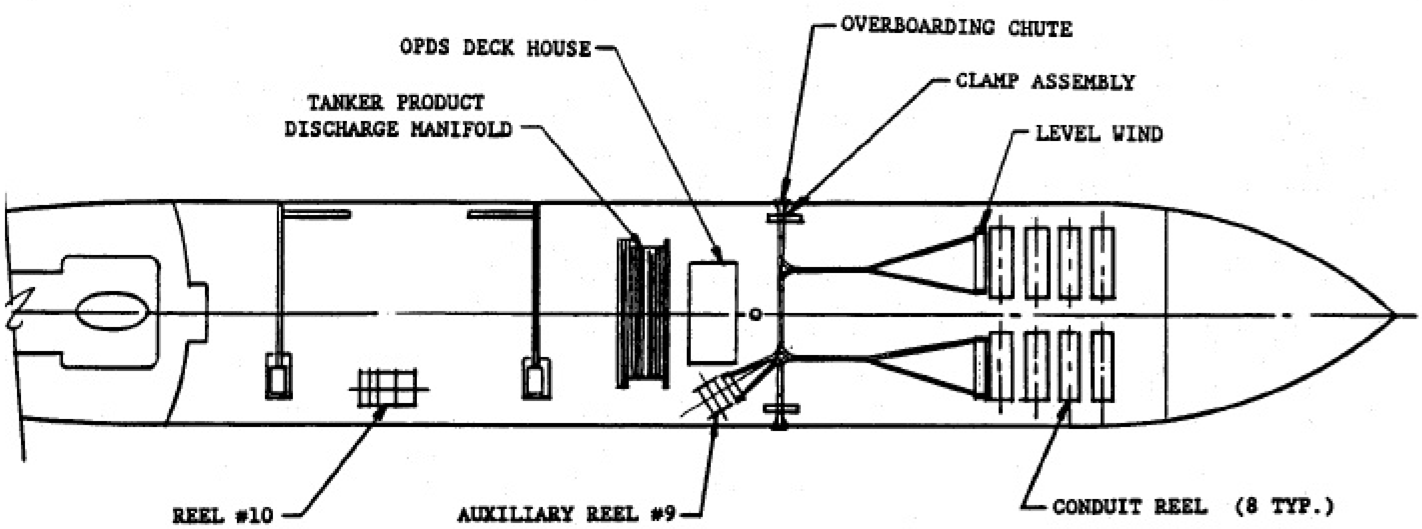


FIG. 2 "SS AMERICAN OSPREY"

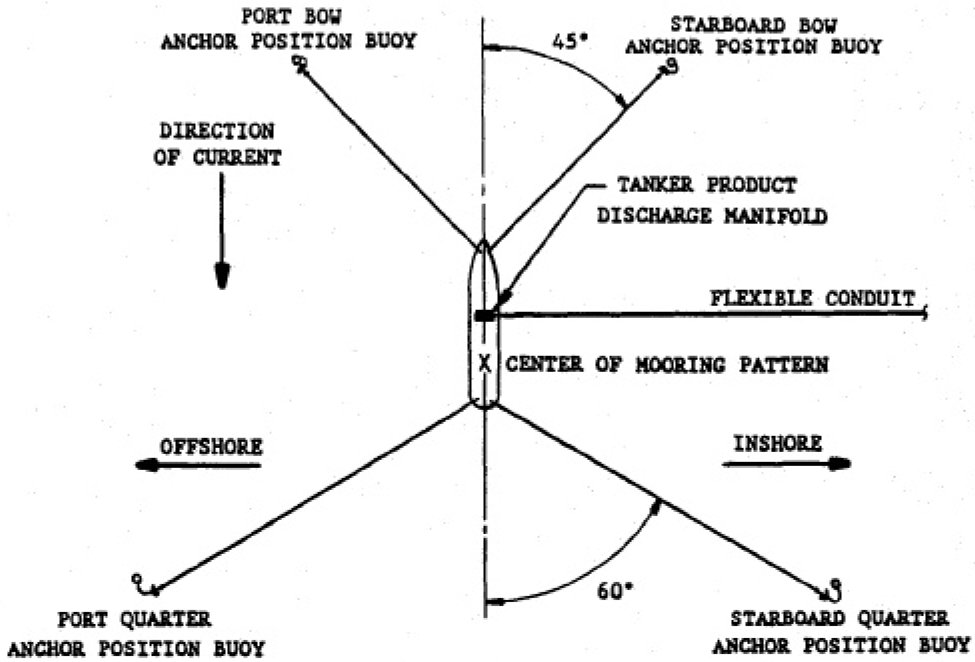


FIG. 3 FOUR-POINT MOORING ARRANGEMENT

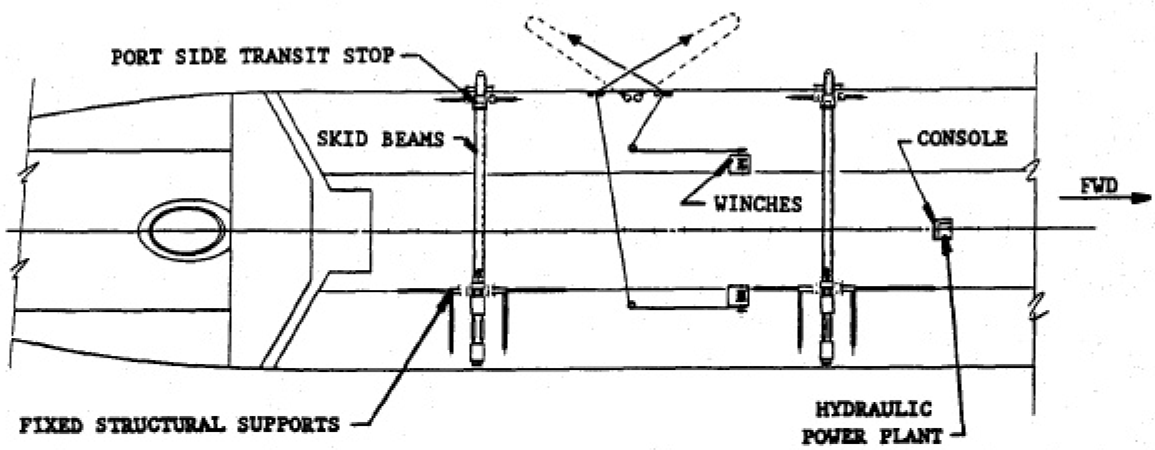


FIG. 4 SALM LAUNCHING AND RETRIEVAL EQUIPMENT

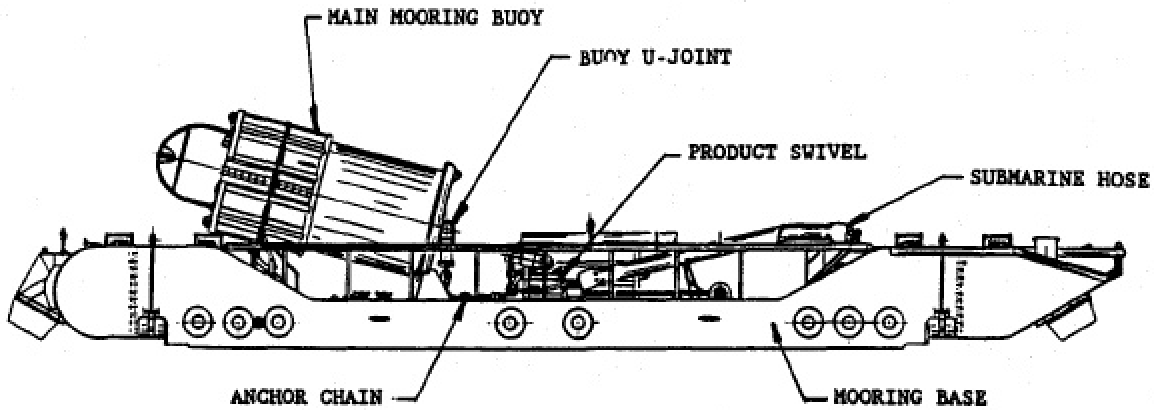


FIG. 5 RAPID DEPLOYMENT SALM

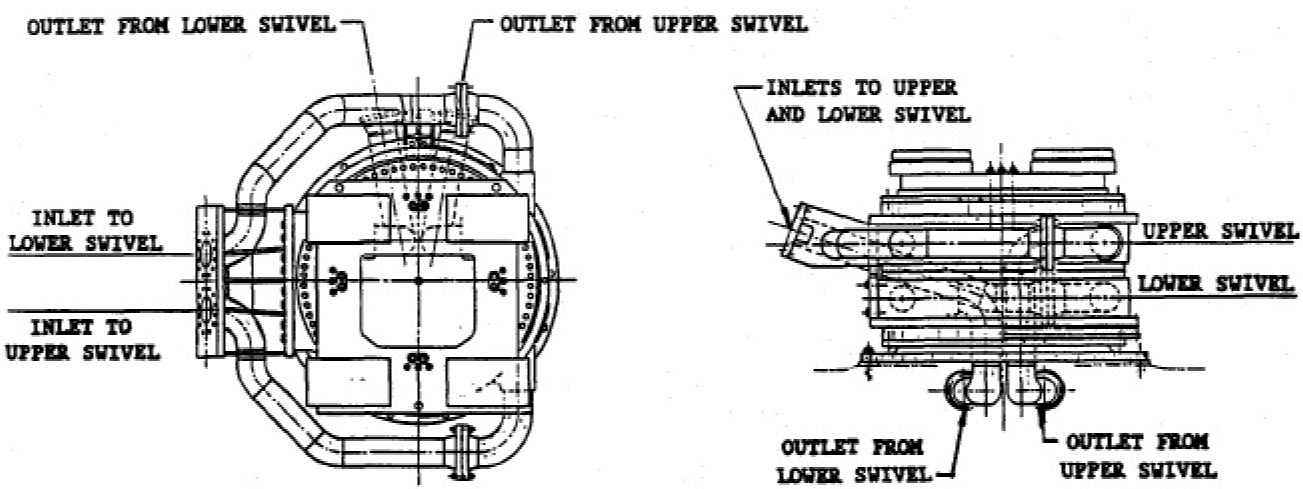


FIG. 6 DUAL PATH PRODUCT SWIVEL ASSEMBLY

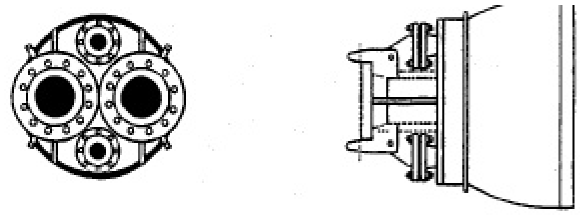
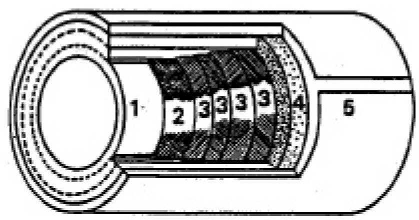


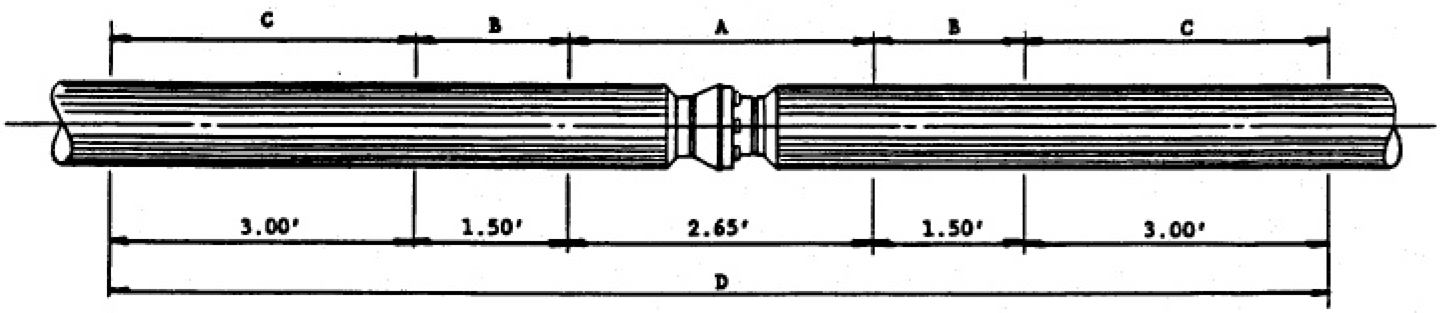
FIG. 7 SUBMARINE HOSE



CONSTRUCTION

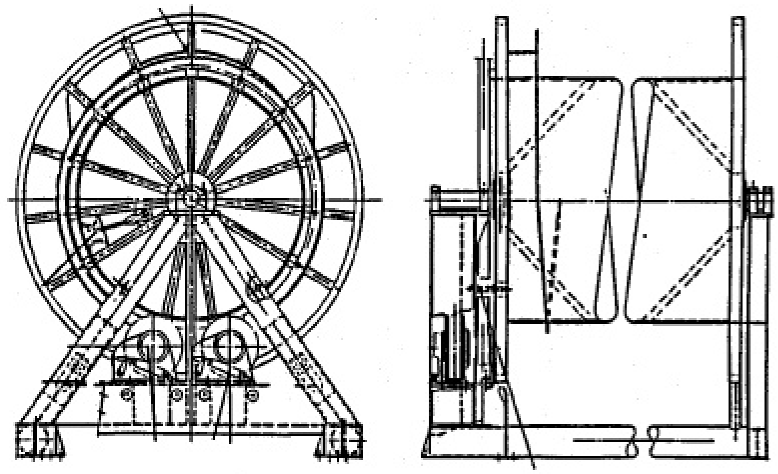
1. LINING — SMOOTH HIGH GRADE SYNTHETIC RUBBER FOR UP TO 60% AROMATIC AND OPTIMUM FLOW RATE
2. BREAKER — INNER BREAKER PLY IMPREGNATED WITH FUEL RESISTANT SYNTHETIC RUBBER.
3. REINFORCED MEMBERS — FOUR PLIES OF HIGH TENSILE STEEL WIRE CORDS APPLIED AT OPTIMUM ANGLE TO MAXIMUM REINFORCEMENT AND MINIMUM ELONGATION UNDER PRESSURE.
4. LAYER — HIGH DENSITY SYNTHETIC LEAD/RUBBER COMPOUND.
5. COVER — ABRASION, MARINE, AND WEATHER RESISTANT SYNTHETIC RUBBER.

FIG. 8 FLEXIBLE CONDUIT



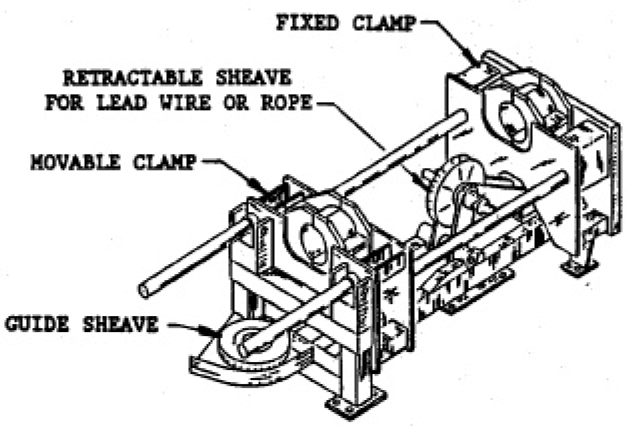
ITEMS	INSIDE DIAMETER (INCH)	OUTSIDE DIAMETER (INCH)	WEIGHT PER FOOT (LBS)	SEA WATER DISPLACED PER FOOT (LBS)	AVERAGE BUOYANCY PER FOOT (LBS)
A	6	9	53	28.3	-24.7
B	6	8.4	15.5	24.6	+9.1
C	6	7.8	13.6	21.2	+7.6
D	6	------	23.05	23.69	+0.64

FIG. 9 BUOYANCY AT COUPLING INTERFACE



SERIES "622" CONDUIT REEL FOR STORAGE OF 3,040 FT. OF UNIROYAL MANULI OPDS CONDUIT. THIS CAN BE HYDROSTATICALLY TESTED AND PIGGED WHILE ON THE REEL. A SEPARATE HYDRAULIC POWER UNIT (HPU) FOR BELOW DECK MOUNTING IS FURNISHED TO POWER THE REELS AND OTHER DECK EQUIPMENT.

FIG. 10 CONDUIT REEL



CLAMPING ASSEMBLY. TWO ASSEMBLIES ARE MOUNTED ON THE DECK OF THE TANKER AND A THIRD ON THE LAY/REPAIR SLWT. THE TANKER CLAMPS ARE HYDRAULICALLY POWERED BY THE CENTRAL HPU.

FIG. 11 CLAMPING ASSEMBLY

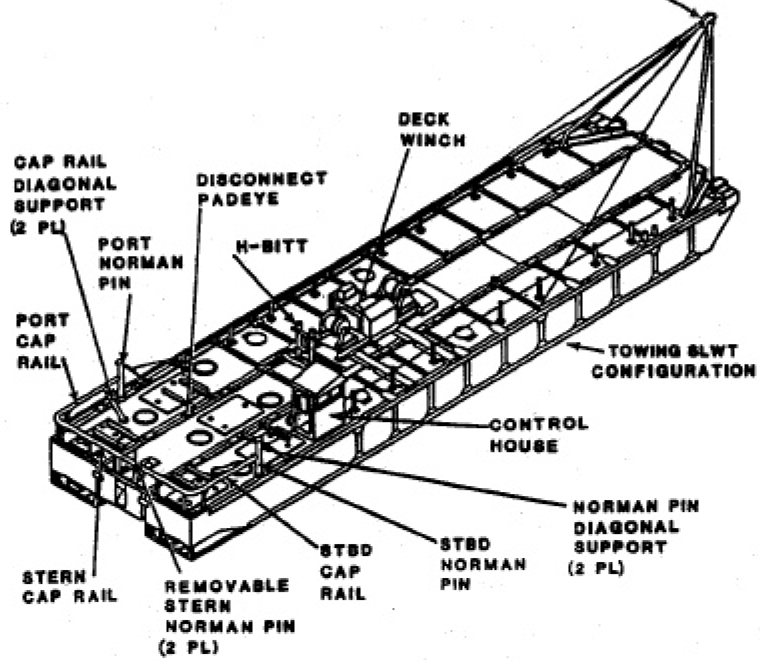


FIG. 12 TOWING SLWT

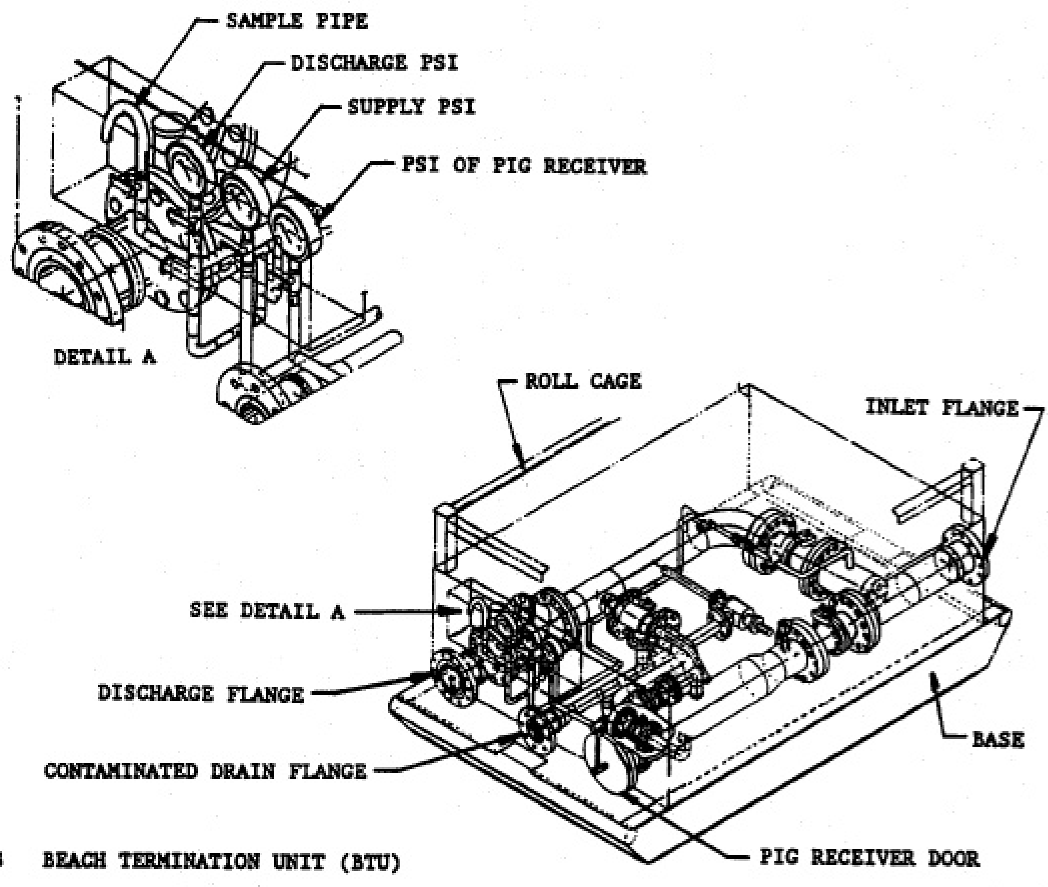


FIG. 13 BEACH TERMINATION UNIT (BTU)