THE LOUISIANA OFFSHORE OIL PORT (LOOP)

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ABSTRACT

The Louisiane Offshore Oil Port, commonly referred to as (LOOP), is the first mooring facility capable of accommodating deep draft tankers in United States waters. The facility, consisting of mooring buoys, platforms, pipelines and underground salt dome storage, was originally conceived more than ten years ago. It became operational in May of 1981.

Located aprroximately 35 km (19 nautical miles) south of Grand Isle, Louisiana in 34 m (110 feet) of water, the LOOP terminal is designed to accommodate deep draft vessels of up to 700,000 DWT. Mooring these vessels and crude oil transfer is accomplished by the use of three Single Point Moorings of the SALM (Single Anchor Leg Mooring) type. Crude oil is transferred from the vessels via twin 610 mm (24 inch) hose systems to the SALM fluid swivel assemblies. A 1422 mm (56 inch) diameter pipeline connects each SALM to the pumping and metering platform. There, pumps boost the pressure in the line to allow for transfer of the crude to the Clovelly Salt Dome Storage Facility. Through additional pipeline networks, oil from the storage area is tied into thirty percent of the nation's refining capacity.

It is the intention of this paper to provide a complete overview of the LOOP project, with specific emphasis placed on the Single Point Moorings. As such, it will discuss the early planning of LOOP, including deepwater port philosophy and alternative solutions. The design, fabrication, construction and installation of the facility are presented. Startup procedures are discussed and, one year of operational experience is presented.

INTRODUCTION

The Louisiana Offshore Oil Port (LOOP) is the nation's first deep water port capable of offloading crude oil from Very Large Crude Carriers (VLCC) and Ultra Large Crude Carriers (ULCC). With its various facilities located in coastal Louisiana and the adjacent Gulf of Mexico, the port can unload crude oil at extremely high discharge rates from the largest existing ships. The port, which opened late last year, can handle up to 1.4 million barrels (220,000 m^3) per day, nearly one third of present imports, and serves 30% of the total refinery capacity of the continental United States through connecting pipelines. Cost for the completed project is around $ 700,000,000.

EARLY PLANNING

LOOP started with a feasibility study in 1972 by 10 oil companies, to determine if it would be economically and technically feasible to build a deepwater port in the Gulf to deport crude oil. These 10 companies determined that it was feasible and shortly thereafter LOOP was formed as a corporation to start construction on the port.

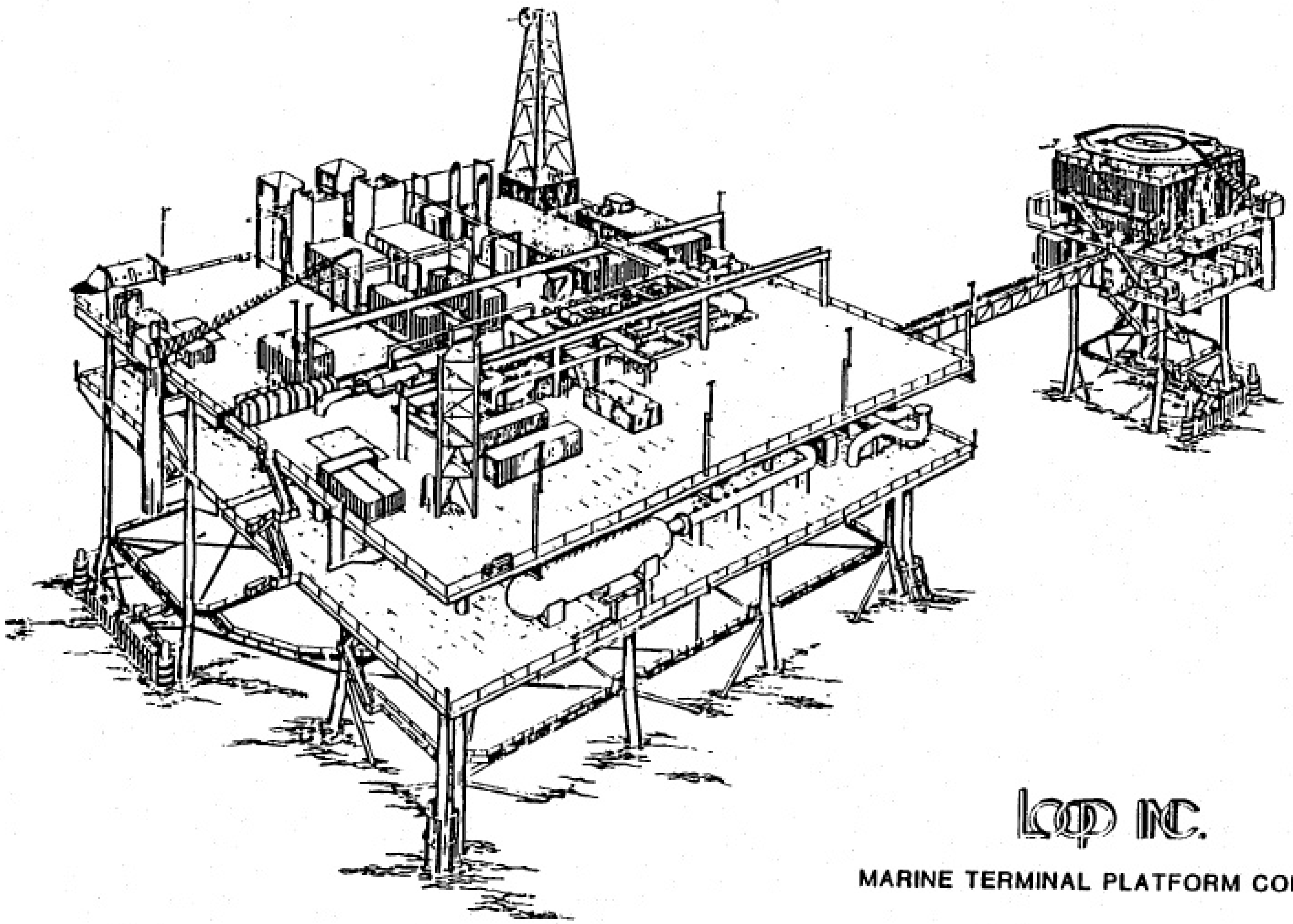
Construction started in the early part of 1978. The reason for the delay until 1978 was because there was not a legal regime that would permit building these facilities since the port is located outside the territorial limits of the U.S.
The U.S. Congress had to pass a law authorizing the Federal Government to issue the necessary permits required to build the terminal. LOOP had to push the law through Congress and once that law was passed, set up the procedures for applying for and issuing licenses. The license was issued in January of 1977 and accepted in August 1977. The license permitted building the project in stages, as necessary, to supply the needs of the country. Actually, there were two or three superport projects considered

back in 1973 or 1974: an application for a license was put in by Seadock in Texas as well as LOOP in Louisiana.

LOOP is a corporation owned by five oil companies. The shareholders and their percentage of stock ownership are Ashland Oil , Inc., 18.6 percent; Marathon Pipe Line Company, 32.1 percent; Murphy Oil Corporation, 3.2 percent; Shell Oil Company, 19.5 percent; and Texaco Inc., 26.6 percent.

LOOP's purpose is to permit large deep draft tankers, presently unable to use any natural U.S. port, to unload crude petroleum directly into the U.S. network of crude petroleum pipelines.
Although most large, crude-importing countries have ports like Rotterdam capable of handling supertankers, the United States has not, until LOOP, had this capacity. The mouth of the Mississippi River, for example, can only accommodate ships with a draft of 40 feet, whereas the largest supertankers draw at least 90 feet. LOOP is able to accommodate up to a 700,000 DWT tanker which would include any supertanker afloat today and, in addition, can handle smaller tankers to the extent they have the capability to physically hook-up at the SPMs.

LOOP is not only unique in purpose, but also in its design, construction and operation. LOOP is able to offload crude petroleum and transport it 47 miles at rates up to 100,000 barrels per hour to underground salt cavities with a storage capacity of over 32 million barrels from whence it can be delivered by connecting pipelines to points in the Gulf Coast and the Midwest.



LOOP INC.

MARINE TERMINAL PLATFORM COMPLEX

FIGURE 1

LOOP FACILITIES

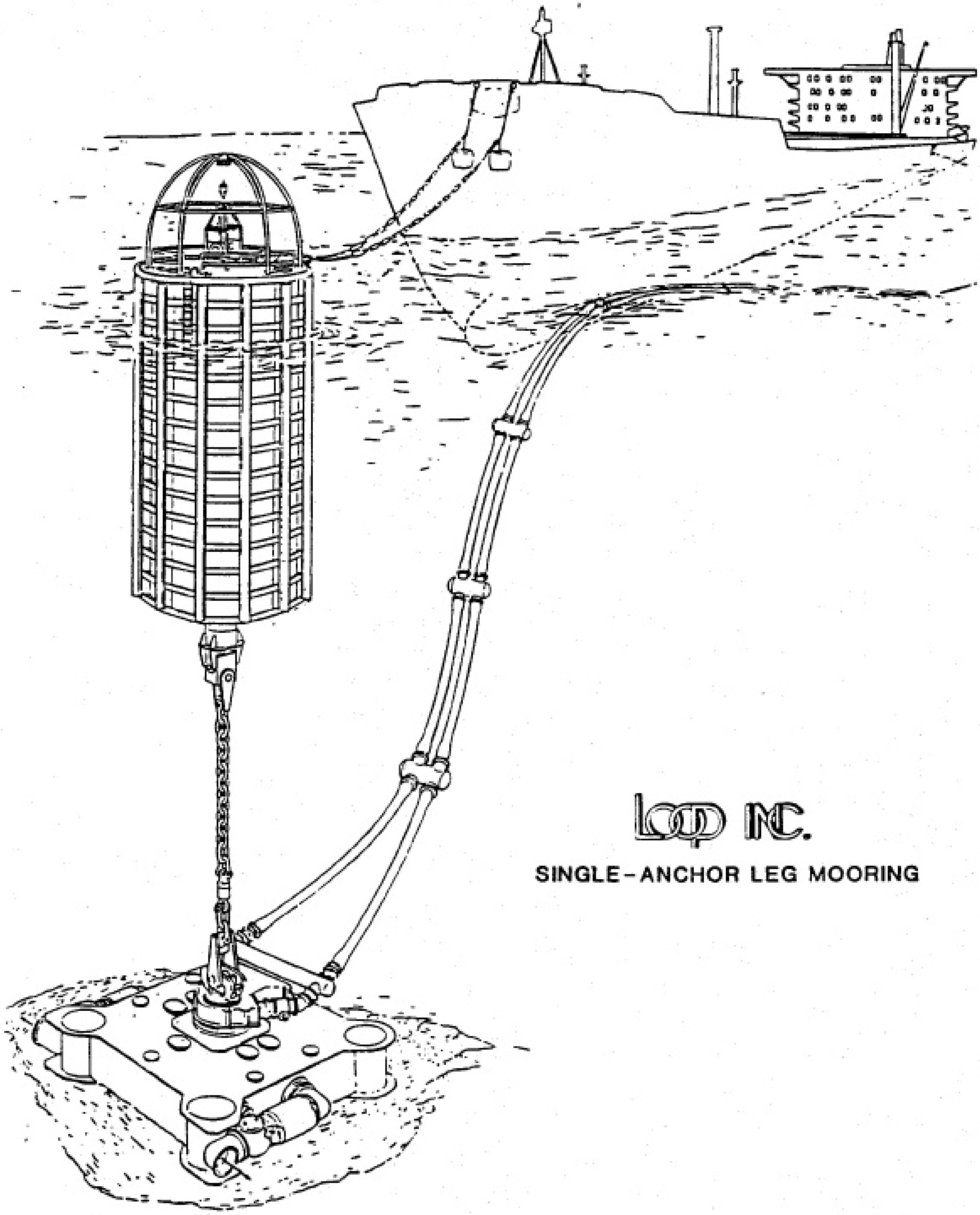
Pumping Platform

The principal structure of the oil port complex is a marine pumping platform located some 18 miles off the Louisiana shoreline (Figure 1). In response to environmental and safety concerns, the LOOP facility was constructed to withstand forces equivalent to a 100-year storm. Because there are approximately 18 miles between the mooring buoy and shore, the ship's pumps alone do not have sufficient pressure to move the crude oil to the onshore storage terminal at economical rates without assistance. Consequently, pumping equipment is installed on the pumping platform to "boost" pressure. This equipment matches each ship's offloading rate up to a maximum of approximately 100,000 barrels per hour.
The pumping platform has two decks each measuring 215 feet by 204 feet. The lower deck contains crude oil pumps and motors while the upper deck houses gas turbine generators which furnish electric power. The upper deck contains turbine meters which will be used for crude oil measurement.

The control platform measured 70 feet by 70 feet and contains ships, storage areas, and emergency equipment on its lower deck; a control room and offices on its second deck; and living quarters and recreational facilities on its third deck. The roof of the third deck serves as a heliport.

Single Point Mooring Buoys

Approximately a mile and a half from the platform are three, single point mooring buoys. The principal components of the SPM system are: a) the buoy, anchored to the seabed with an anchor chain; b) mooring lines, connecting the tanker with the buoy; and c) flexible, floating hoses used for transporting crude oil from the tanker's cargo manifold to the submarine pipeline buried in the seabed.



LOOP INC.

SINGLE-ANCHOR LEG MOORING

FIGURE 2

The floating buoy is 21 feet in diameter and 46 feet high. It consists of a cylindrical hull divided into two individual chambers and is attached to the base with a chain and swivel assembly. The base is anchored to the seabed with ballast and pilings.

Two parallel strings of flexible, floating and submarine hoses, each approximately 1,050 feet long, are used to connect the tanker's cargo manifold with the fluid swivel unit on the single point mooring base assembly (Figure 2). The oil is pumped from the cargo manifold through the hoses to the fluid swivel base assembly and into a 56-inch diameter submarine pipeline, the largest ever laid in the United States. This pipeline extends 8,000 feet from the buoy's base to the LOOP pumping platform complex. There the oil is metered and boosted to shore by the three pumps, capable of pumping the oil at a rate of over 1,000 gallons per second. These pumps are powered by two gas turbine generators, each of which produces 22 megawatts of electricity. (Twenty-five megawatts would light all the street lights in the City of Houston).

Pipelines

Oil is moved from the platform to shore through an 18-mile, 48-inch pipeline. When the oil reaches the shore, LOOP's pumps at the Fourchon Booster Station may boost the pumping rate of the crude to 100,000 barrels per hour. From there it is moved another 28-mile through a 48-inch pipeline through the marshlands east of Bayou Lafourche to the Clovelly Salt Dome Storage Terminal.

The Clovelly Salt Dome Storage Terminal, when complete, will consist of eigh underground cavities 190 feet in diameter and 1,000 feet deep, almost as deep as New York's Empire State Building is high. Currently two cavities are in service, with another scheduled to begin service by the end of this month. The remaining five cavities will be put in service during the remainder of 1982 and the first part of 1983. The tops of the cavities are approximately 1,600 feet below the surface level. Each cavity will have a storage capacity of approximately four million barrels and will contain crude oil of specific ranges of quality characteristics to prevent undue commingling from the mixing of the widely different quality crudes which LOOP handles.

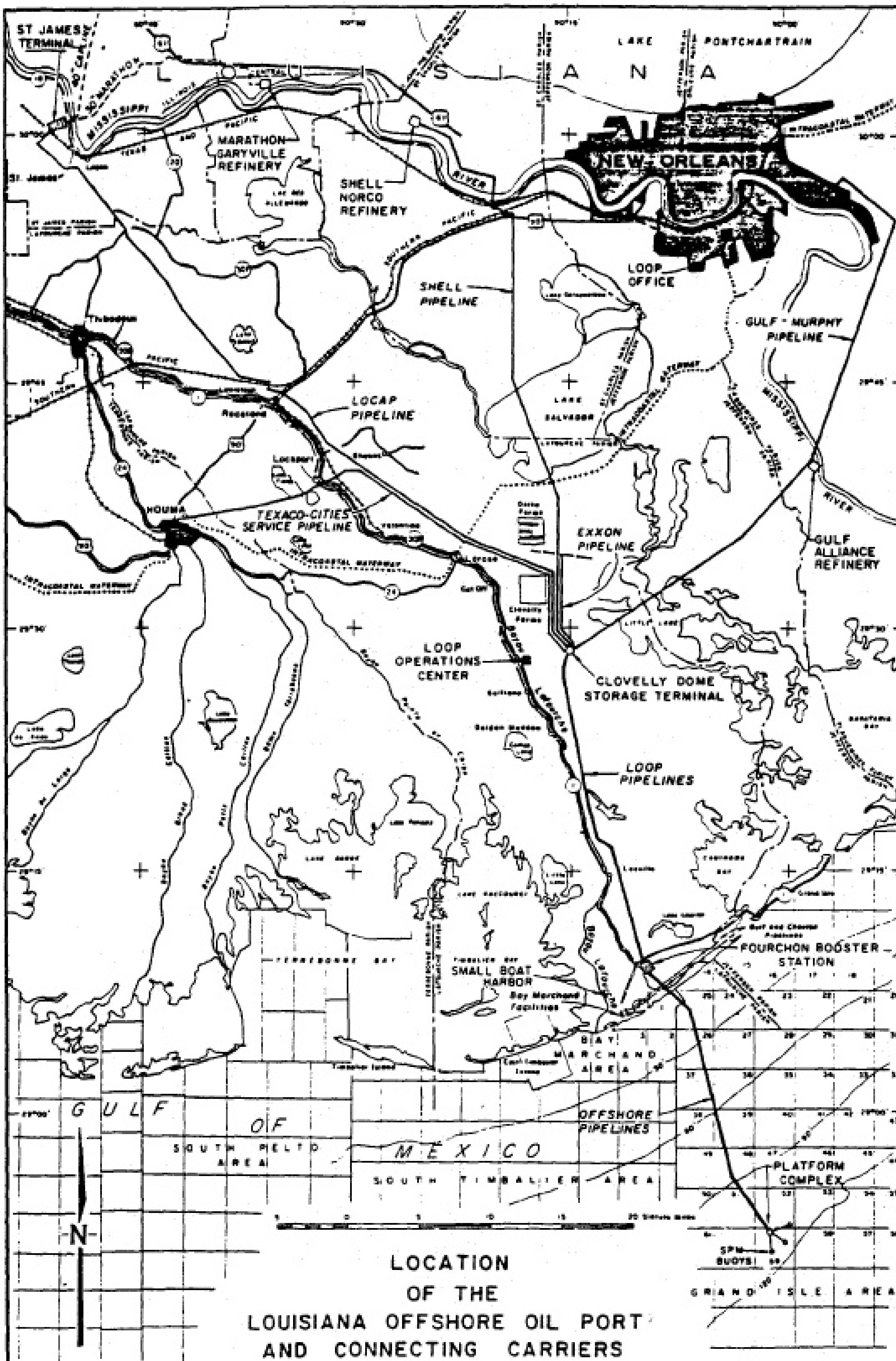


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FIGURE 3

Oil is discharged from the cavities to connecting pipelines by pumping salt-saturated brine into the cavities from a brine storage reservoir adjacent to the area, thereby forcing out the crude. The brine reservoir is a mile and-a-third long, half a mile wide, and 18 feet deep, and is capable of holding 25 million barrels of brine.

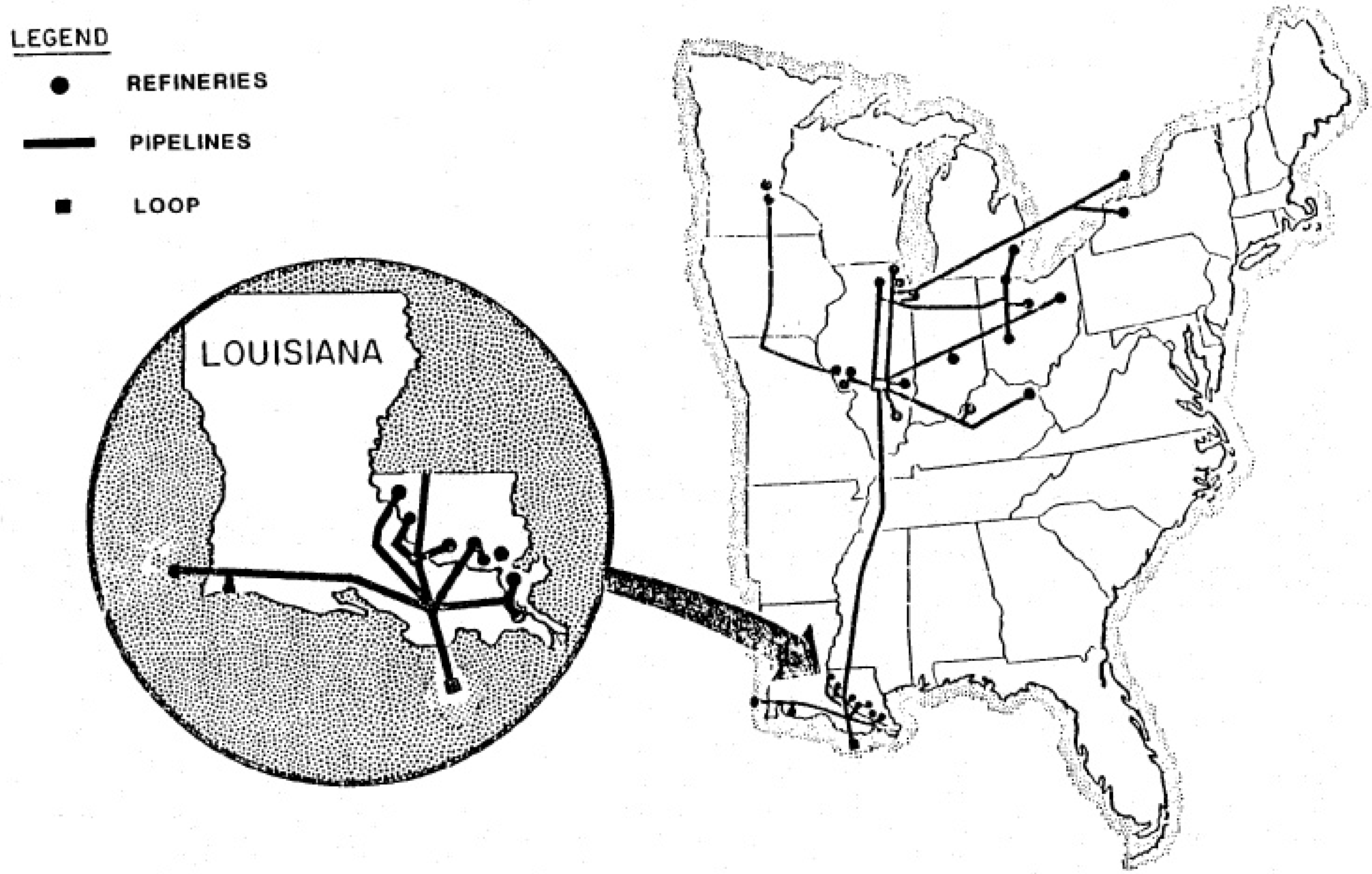
The Clovelly Salt Dome Storage Terminal is an essential and integral part of the successfull operation of LOOP as an oil port. This is so for several reasons. The average-size VLCC of 250,000 deadweight tons discharges approximately 1,850,000 barrels of crude oil. None of the pipelines which connect to LOOP is able to handle such a quantity of crude as a single batch at the speed at which the oil is delivered by LOOP.
Thus, the efficiency of the oil port would be enormously reduced and, indeed, would be rendered uneconomic, without the "working storage" at Clovelly. In addition, even if it were possible for connecting pipelines to receive such quantities of crude at such speeds, no shipper or refinery could, except under extraordinary circumstances, use such huge quantities of crude in single batches at one time. Normally, these large quantities of crude are stored temporarily and delivered out to shippers in smaller "working" batches.

There are five connecting carriers, or distributing pipelines, tied into the LOOP storage area (Figure 3).

Although difficult to estimate, LOOP anticipates that when fully operational, about half of the crude received by the oil port will be transported to Gulf Coast refineries, with the remainder destined for refineries in the Midwest (Figure 4). Through various pipeline connections, LOOP will provide an alternate means of delivering crude petroleum to 30 percent of the nation's refining capacity.

DEEPWATER PORT PHILOSOPHY

Two factors triggered interest in alternate means of importing crude oil into the United States: the increasing dependence on foreign



EXISTING REFINERIES
AND CONNECTING PIPELINES

FIGURE 4

nations for our energy supplies and technology in the form of large tankers.

High levels of crude petroleum imports into the United States are a recent phenomenom. From 1955 to 1970 the United States' crude imports only increased from approximately 782,000 B/D to 1,324,000 B/D, a growth rate of only 3.5 percent per year.

However, from 1970 to 1977, crude imports shot up to 6,533,000 B/D, reflecting a growth rate of over 25 percent per year.

Forecasters, at that time, anticipated the level of imports would continue to increase although perhaps not at that rate.

The world tanker fleet responded during the 1970s to the increased energy consumption in the United States as well as the rest of the world. Although the number of tankers in the world fleet stayed relatively the same, the average tanker size increased from 46,897 DWT to 93,287 DWT between 1970 and 1977. Viewed another way, tankers over 125,000 DWT increased their share of the world fleet from 26 percent to 65 percent in the same period. The UNIVERSE PORTUGAL at 327,089 DWT was the largest tanker ever built in 1970. By 1977 that distinction had been passed to many other "superships" and the PIERRE GUILLAUMAT of 546,265 DWT then was the largest. It was largely those two factors that precipitated the decision to construct LOOP, and thereby enable the United States to more fully realize the economies of scale of VLCCs.

Today, there exists a huge surplus in the VLCC/ULCC fleet. That surplus keeps their rates low and makes delivering crude oil long distances very economical. The current situation for crude imports is not so fortuitous. Crude imports in 1981 were down 19 percent from 1980 and 35 percent from 1977. Some of that decline is because of the recession in the U.S. economy and therefore is temporary. However a large portion of that decline is because of conservation efforts and fuel substitution and likely represents a permanent shift in demand. Nevertheless based on the present level of imports we estimate that LOOP, when fully operational, should handle between 0.8 and 1.0 million barrels per day.

Before LOOP began operations last year, the three transportation alternatives for landing foreign crude supplies were direct shipment, transhipment and lightering.

Direct Shipment - Foreign crude oil is shipped from various oil producing areas direct to refinery and pipeline terminals along the United States' Gulf coast in tankers typically in the LR-1 class (45,000 to 80,000 DWT capacity). This class tanker, fully laden, can directly access existing Gulf Coast ports.

Transhipment - Several deepwater ports and storage terminals have been developed at Caribbean Islands (Bonaire, Curacao, Aruba, Bahamas and Trinidad) that can accommodate receipts of crude oil via VLCCs of the 160,000 tot 320,000 DWT size and larger. The oil is reloaded to LR-1 tankers for shipment to United States' draft limited ports.

Ship-to-ship Lightering - Lightering involves shipment of crude oil to the nearby offshore United States' Gulf area, or other weather protected areas in the Caribbean, in VLCCs. The cargo is then transferred at sea into the smaller LR-1 tankers for movement into the United States' Gulf ports. Lightening is a variation of lightering, where a smaller VLCC transfers part of its cargo to a shuttle and both vessels proceed to an inland port. Tanker size involved in this activity usually ranges from 80,000 to 125,000 DWT.

An analysis of imports into New Orleans area ports during 1980 indicates that of the crude oil imports, about 28 percent was lightered, about 21 percent was transhipped, and the balance of 51 percent arrived by direct shipment. The high levels of direct shipments result partly from the short haul movements from the Carribbean Basin which are not sufficiently long voyages to realize the scale economies of VLCCs.

Certain other movements will continue to come via direct shipments for various reasons. Loading port restrictions such as dock depth, length, and strength limitations; shoreside storage limitations; and crude lifting contractual arrangements can preclude the use of VLCCs. Where those restrictions occur, direct shipment on smaller tankers is the only mode of transportation available. The flexibility of shallow draft tankers, which can proceed directly to any port in the U.S. or Europe, also makes them desirable at current tanker rates.

Therefore, LOOP is in principal competitive with transhipment and lightering. In setting LOOP's tariff, the Company looked hard at the costs of those alternatives. LOOP estimated the costs of demurrage time, crude oil losses, transhipment terminal fees and voyage costs for lightering or transhipment movements, and set its tariff to break even with those alternatives. LOOP's tariff is $ 2.65 per cubic metre ($.42 per barrel) plus $ 1000 per hour of discharge time. This expressed as one unit is nearly equivalent to $.44 per barrel.

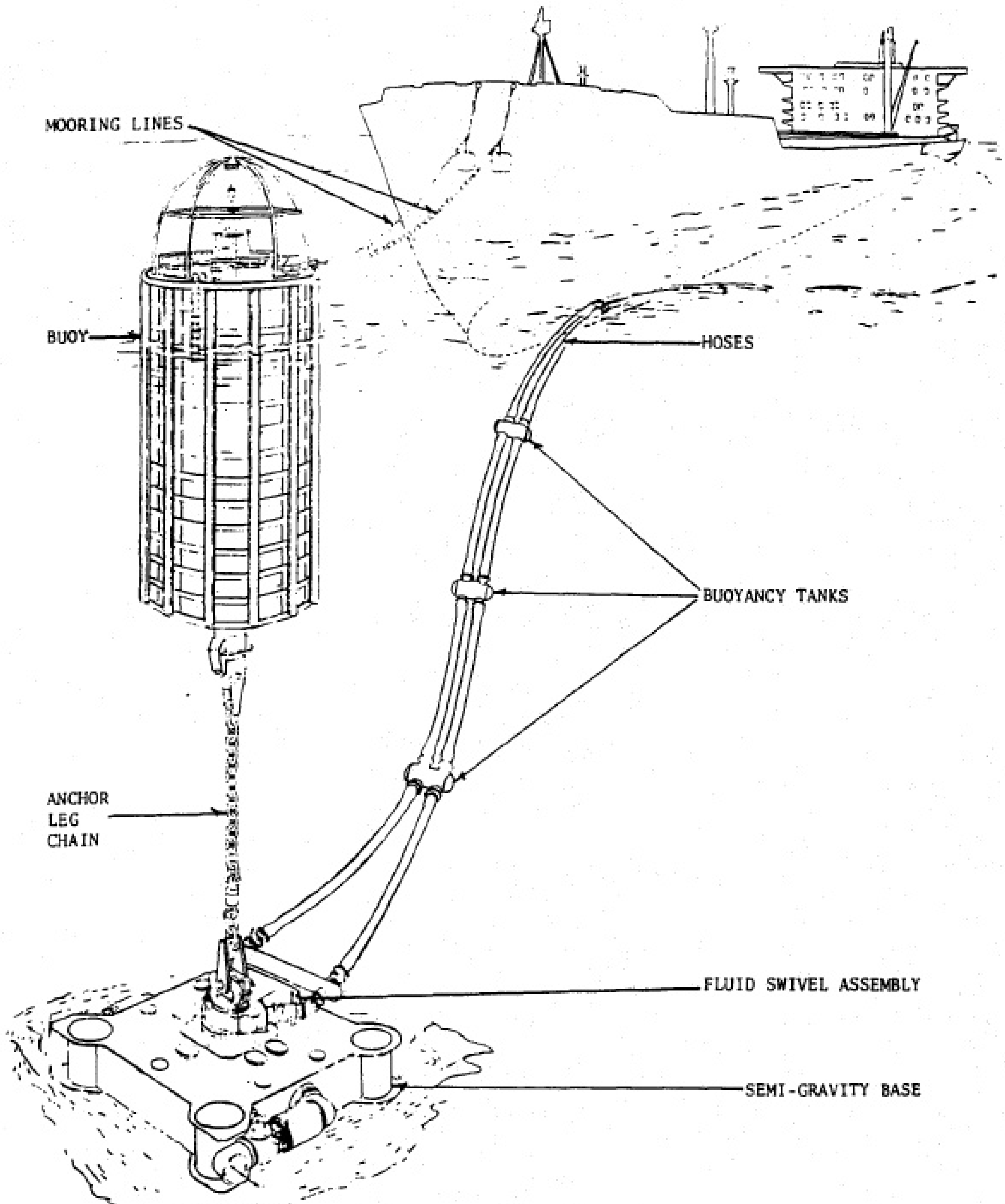
MODEL TESTS

Introduction

Two different types of Single Point Mooring (SPM) systems were under consideration for the LOOP project; the SALM (Single Anchor Leg Mooring), and the CALM (Catenary Anchor Leg Mooring). In order to evaluate the differences and similarities between these two systems a very extensive set of model tests was conducted at the Netherlands Ship Model Basin (NSMB) during July through October, 1974. It should be noted that this model test series is still considered to be the most comprehensive set of model tests ever conducted on SPM systems.

The general objective of the test series was to first develop optimum designs for both the SALM and the CALM and then compare these optimum system on a direct basis under operational and survival conditions. To achieve the stated objective the model test program was divided into the following three separate studies:

Test Study I	:	System Optimization
Part - 1	:	Hawser Systems
Part - 2	:	Hose Systems
Test Study II	:	Hurricane Survival
Test Study III	:	Operational Study



LOOP'S SINGLE-ANCHOR LEG MOORING SYSTEM

FIGURE 5

SALM System Description

The SALM system is characterized by its single, constantly in tension, anchor leg which attaches the mooring buoy to the mooring base (Figure 5). The SALM's elasticity is derived from the increase in restoring moment as the buoy excursion increases with tension. The stiffness of the SALM mooring system is determined by the dimensions of the mooring buoy and the tension in the anchor chain. The tanker moors to the buoy by means of a bow hawser and is free to weathervane about the buoy, minimizing the forces on the system. The cargo transfer system is completely segregated from the mooring system. The tanker discharges its cargo through a hose system which extends from the tankers manifold to the fluid swivel assembly located at the sea floor on the mooring base. The majority of the hose system, extending from the vessel, is floating. A short section of submerged hose connects the floating hose to the fluid swivel assembly.

CALM System Description

The CALM system is characterized by its catenary anchor legs, normally six in number. These moor a cylindrical buoy which contains the main bearing and fluid swivel assembly (Figure 6). The CALM derives its elasticity from the increasing weight of its chains as they are lifted off the sea floor. Its stiffness is determined by the number and unit weight of the chains and their pretension. Similar to the SALM, the tanker moors to the buoy by means of a bow hawser and is allowed to weathervane. Unlike the SALM, the CALM does not completely segregate the cargo transfer system from the mooring system. The tanker discharges its cargo through a floating hose system which is attached through piping to the fluid swivel assembly located on the mooring buoy. The cargo then passes through the fluid swivel assembly and, by means of under buoy hoses, is transferred to the pipeline end manifold (PLEM).

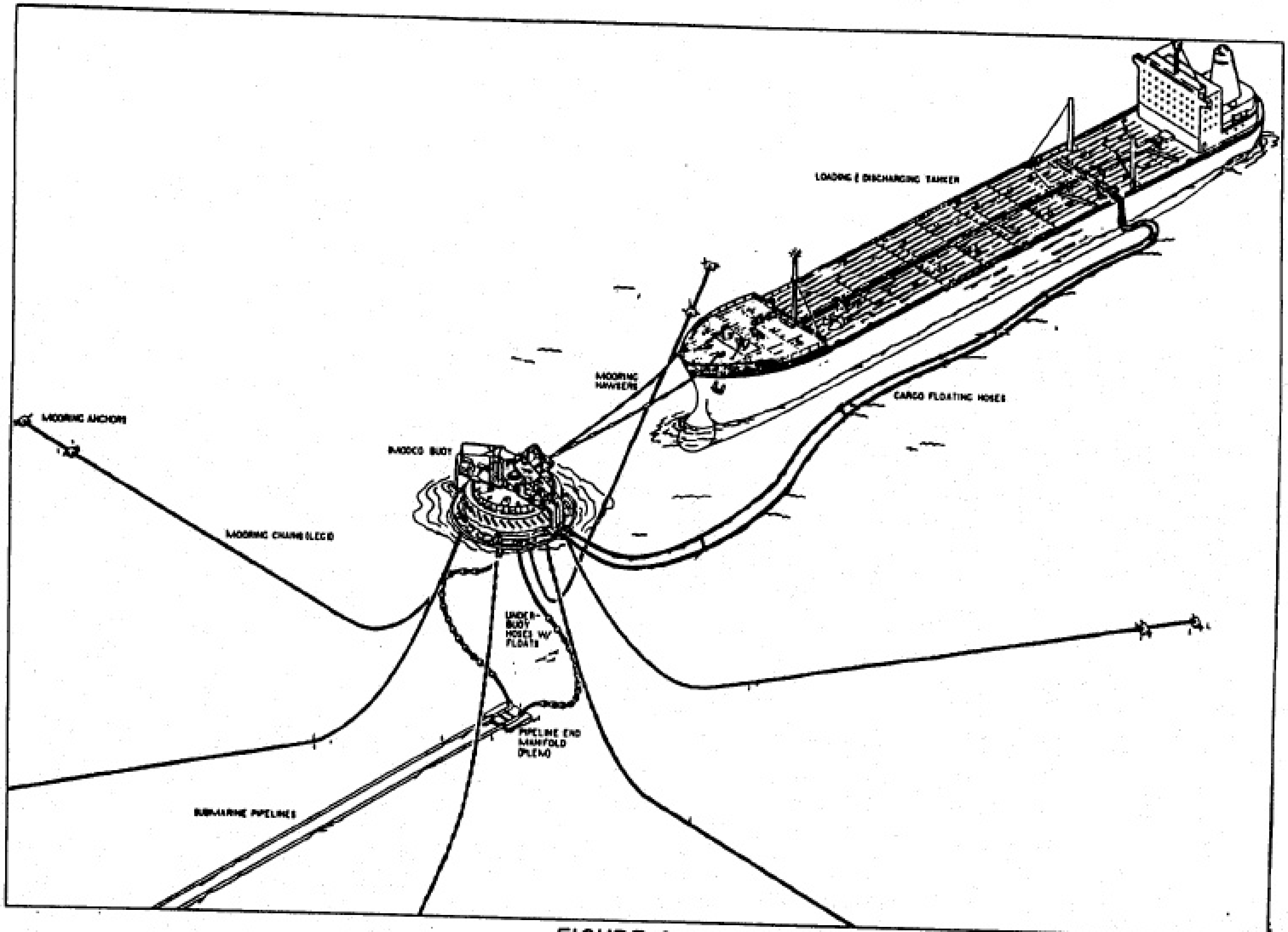

LOADING & DISCHARGING TANKER
CARGO FLOATING HOSES
MOORING HAWSERS
MOORING ANCHORS
IMODCO BUOY
MOORING CHAINS (LEGS)
UNDER-BUOY HOSES W/ FLOATS
PIPELINE END MANIFOLD (PLEM)
SUBMARINE PIPELINES

FIGURE 6

Model Test Setup

The model tests were conducted in NSMB's wave and current basin at a scale of 1 to 53. The basin is rectangular in shape with a length of 60 m (197 ft) and a width of 40 m (131 ft). The water depth was 0.7 (2.3 ft). Current can be generated parallel to the short sides of the basin. Waves can be generated from two adjoining sides of the basin by means of snake type wave generators, enabling the generation of waves with an arbitrary direction of propagation with respect to the current direction. Wind is generated by means of a battery of portable wind fans.

The model tests were based on Froude's law of similitude since the hydrodynamic phenomena involved in the behavior of a buoy system with or without a ship are dominated by inertia related forces. Measurements taken during the model tests included some or all of the following during each phase of testing.

- Wave Height

- Current Velocity

- Wind Velocity

- Anchor Chain Forces
  - CALM (6 axial force measurements)
  - SALM (1 axial force measurement)

- Bow Hawser Forces (port and starboard)

- Buoy Motions
  - CALM (surge, sway, heave, roll and pitch)
  - SALM (none)

- Hose Forces
  - Underwater (3 axial forces)
  - Floating (1 axial force)

- Hose Bending Moments
  - Underwater (6 bending moments)
  - Floating (2 bending moments)

- Tanker Motions (surge, sway, heave, yaw and pitch)

All of the measurements taken were recorded on magnetic tape so that the data could be reprocessed at a later date if necessary. In addition, all tests were recorded on video tape through the use of two underwater cameras and one overhead camera.

Test Study I - Part 1 : Hawser Optimization

The objective of Test Study I - Part 1 was to optimize mooring hawser elasticities and lengths for the best performance of the systems. In addition, some data was obtained to determine design operating loads. Bow hawser systems selected from these tests were used in Test Study III: Operational Study.
Bow hawsers ranging in length between 40.0 meter (131.2 ft) and 90.0 meter (295.3 ft) and with breaking strengths between 554 metric-ton (1219 kips) and 1208 metric-ton (2658 kips) were used in this test study in an effort to optimize the various buoy systems. Three different size tankers were used; 165,000 DWT, 300,000 DWT, and 700,000 DWT. Each of the tankers were used in ballast conditions of 30, 43, and 100 percent of their loaded draft. A one percent trim, bow to stern, was added to the tankers when they were in the 43 percent ballasted condition.

The environmental conditions and water depth for these tests were as follows:

Significant Wave Height	4.6 m (15.0 ft)
Wind Velocity	87.5 m/s (45.0 kt)
Wind Direction	45.0 deg from wave
Current Velocity	1.9 m/s (1.0 kt)
Current Direction	90.0 deg from wave
Water Depth	35.1 m (115.0 ft)

During this phase of the model tests, a total of 50 tests were conducted; 24 with the CALM system, 26 with the SALM systems.

Test Study I Part 2 : Hose Optimization

The objective of Test Study I - Part 2 was to optimize the hose configuration for the SALM system and the under buoy hose configuration for the "Lazy S" and "Chinese Lantern" for the CALM. Both oil filled and sea water filled hose configurations were studied. Hose configurations selected from these tests were used in Test Study II: Hurricane Survival.

The initial hose system optimizations, design static configurations, were carried out in a small observation tank. The system would then be installed in the model basin and preliminary "look see" runs would be made. Adjustments would be made if necessary and then the actual data gathering tests would be made.

Three separate hose systems were evaluated for the SALM system. Variations were made in the hose buoyancy tanks, hose floatation bead combinations, and the angle and vertical excursion capability of the hose arm. For the CALM system one "Lazy S" hose and three "Chinese Lantern" hose systems were evaluated. They varied in length, hose buoyancy tank arrangement and floatation bead combinations.

During this phase of the model tests, a total of 55 tests were conducted; 38 with the CALM system, 17 with the SALM system.

Test Study II : Hurricane Survival

The objective of Test Study II was to establish the response of the selected SALM and CALM systems to the environmental conditions approximating those expected to occur during a Gulf of Mexico hurricane. Of primary interest were the hose motions, forces and moments, and the anchor chain forces.

Based on the results of Test Study I - Part 2, three different hose configurations were tested with CALM system, one "Lazy S" and two "Chinese Lanterns"; two hose configurations were tested with the SALM systems. The tests were conducted with sea water in the hose systems and at ambient pressure. No tankers were moored to the buoys. PLEM-buoy direction relative to the current ("Lazy S system), hose orientation relative to the current ("Chinese Lantarn" systems), and capability for rotation of the flotation hoses in the vertical plane were variables for the CALM. For the SALM, the hose system was left floating or placed on the sea floor.

The environmental conditions and water depths for these tests were as follows:

Sea State 1:	
Maximum Wave Height	12.2 m (40.0 ft)
Current Velocity	4.9 m/s (2.5 kt)
Current Direction	0.0 deg from waves
Sea State 2:	
Maximum Wave Height	16.8 m (55.0 ft)
Current Velocity	9.7 m/s (5.0 kt)
Current Direction	90.0 deg from waves
Sea State 3:	
Maximum Wave Height	21.3 m (78.0 ft)
Current Velocity	9.7 m/s (5.0 kt)
Current Direction	90.0 deg from waves
Water Depth	36.9 m (121.0 ft)

During this phase of the testing, a total of 39 tests were conducted; 29 with the CALM system, 19 with the SALM systems.

Test Study III : Operational Study

The objective of Test Study III was to establish and compare all aspects of the behaviour and response of the selected, or optimized, CALM and SALM systems from Test Study I and Test Study II in wind and sea conditions approximating expected operating conditions. In additions, a vast amount of data was obtained to aid in the development of the final design loads.

The environmental conditions and water depth for these test were as follows. Two different combinations of wave, wind and current direction were used with each environmental condition.

Condition 1:	
Significant Wave Height	4.6 m (15.0 ft)
Current Velocity	1.9 m/s (1.0 kt)
Wind Velocity	87.3 m/s (45.0 kt)
Condition 2:	
Significant Wave Height	3.7 m (12.0 ft)
Current Velocity	1.9 m/s (1.0 kt)
Wind Velocity	67.9 m/s (35.0 kt)
Condition 3:	
Significant Wave Height	1.2 m (4.0 ft)
Current Velocity	1.0 m/s (0.5 ft)
Wind Velocity	19.4 m/s (10.0 kt)
Water Depth	35.1 (115.0 ft)

During this phase of testing, a total of 67 tests were conducted; 38 with CALM systems and 29 with the SALM systems.

<u>Additional Tests</u>

At the conclusion of testing with each individual single point mooring system additional tests were conducted to evaluate the following:

1. The behavior of vessels at the moorings under the influence of various combinations of wind and current only;

2. The behavior of the hose strings when the buoy was unoccupied during a reversal of current direction, with specific emphasis on the required force to rotate the CALM turntable and the SALM fluid assembly;

3. The response of the moorings when the vessels were allowed to overrun the systems, a simulation of a manoeuvring failure during berthing.

SINGLE POINT MOORING SELECTION PROCESS

Model Test Results

The model test series just described was extensive and comprehensive. A total of 211 tests were conducted; 129 tests with CALM systems, 82 with SALM systems. More tests were required with the CALM systems because two dinstinctly different hose systems were tested. The analysis of the model test data was equally as extensive. NSMB produced a five volume set of reports which documented every aspect of the study. Participating companies produced their own reports and analysis.

1. Operational Test Results - Mooring Forces

   Both the CALM and the SALM systems performed equally as well with regards to mooring the various vessels while under the influence of the operational environments. This is to be expected. Assuming that the systems are designed properly, their force deflection characteristics would be approximately the same over the range of interest.

   The general behavior of a vessel moored to an SPM is a slow oscillation of the vessel in the horizontal plane. The oscillations are induced by the second order wave and wind forces. Although the amplitudes of the slowly varying forces are small, their effect can be large since the frequency of the variations may correspond with the natural frequency of the vessel and buoy spring mass system. The amplitudes of motion, and thus the mooring forces, were considerably larger for the ballasted vessels. The principle means of controlling the horizontal motions of the moored vessel was to shorten up on the bow hawser.

2. Operational Test Results - Hose Systems

One of the primary purposes of the model tests was to investigate hose behavior for both SPM systems under similar conditions. The absolute values of the measured forces were at times difficult to interpret. However, relative trends were observed in the analysis of the data and these form the basis for comparing the two systems.

The results of the analysis indicate that for the CALM system the motions of the buoy appear to have a significant effect on both the floating and under buoy hose strings. The SALM buoy, because of its inherent design separation of the mooring and cargo transfer functions, has no effect on the hose system. Bending moments were typically higher for the CALM system; the "Chinese Lantarn" under buoy hose system generally had lower moments than the "Lazy S" system. Axial forces were, on the average, slightly higher for the SALM system. This is due to current drag forces on the longer length of hose and ancillary equipment.

3. Hurricane Survival - Mooring Forces

The measured mooring forces during hurricane survival were less than those recorded during the maximum operational conditions for both the CALM and the SALM systems. From a stress standpoint, the SALM system performed better than the CALM system. The maximum load in the chains of the CALM system were slightly greater than 50 percent of their rated breaking strength. The SALM system exhibited a maximum load of approximately 35 percent of its breaking strength. The minimum SALM anchor chain force was approximately 20 percent of the systems net submerged buoyancy; the chain does not go slack.

4. Hurricane Survival - Hose Systems

The highest bending moments and axial forces recorded in the hose systems, for both the CALM and SALM systems, occurred during the hurricane survival tests. However, the behavior of the SALM underwater hose system seemed to be superior to both the finally selected "Chinese Lantern" and "Lazy S" under buoy hose systems of the CALM system. The bending moments were considerably lower. The axial forces were higher than those in the "Chinese Lantern" hose system, but smaller than those in the "Lazy S" system. It should be noted that no significant differences were observed whether the SALM hose system was in its normal configuration or submerged on the seal floor during the hurricane conditions.

Design Process

Either the CALM or the SALM systems could have been utilized by LOOP; however, a few major considerations favored the SALM.

Based on the results of the model tests, and at the time supported by some early SALM experience, it was believed that the maintenance and replacement requirements of the SALM underwater hose system would be less than the CALM system.
Another major factor in the decision process was the opinion the SALM system was superior in survivability if a collision occurred between the system and a vessel during the mooring procedures. The fluid swivel and piping in a CALM buoy have a much larger probability of damage during a collision than a SALM buoy. The SALM buoy can be pushed aside by an approaching vessel while the CALM buoy, anchored with multiple chains, cannot and is liable to incur greater damage. If major damage does occur, the replacement cost for the SALM buoy would be less than for the CALM.

The survivability of the mooring systems in the event of a hurricane was discounted because of the low probability of occurrence of hurricanes and the possibility of taking remedial action. However the inherent characteristics of the SALM hose system during hurricane conditions support the SALM recommendation.

There are many additional factors that could be considered in the SPM selection process; however, there do not appear to be any major items other than those discussed above that would strongly favor one system over another. As previously stated, the model tests showed that both systems could be designed to accommodate the mooring requirements.

Operating experience of the numerous CALM systems was also discounted in the selection process because of the limited number of SALM berths in operation at the time of the analysis.
Total installed costs developed by LOOP, based on preliminary quotes, did not indicate a consistent significant difference between the two systems.

The SALM System

A. Design

The LOOP SALM terminals are designed to provide reliable import facilities which will be available for continuous use with a minimum of outage time. The following design basis describes the environment and vessel size utilized for the prediction of the maximum mooring loads, the required anchoring capacity and the structural component strength.

Water Depth	34.7 m (114.0 ft)
Vessel Size	
Dead Weight Tonnage	700,000 DWT
Overall Length	427 m (1,400 ft)
Beam Width	76 m (250 ft)
Maximum Draft	29 m (95 ft)

Maximum Operational Environment

Significant Wave Height	4.6 m	(15.0 ft)
Mean Wave Period	9.0 s	
Current Velocity	1.0 m/s	(1.8 kt)
Current Direction	parallel to waves	
Wind Velocity	23.2 m/s	(45.9 kt)

Survival Conditions

Maximum Wave Height	21.3 m	(70.0 ft)
Current Velocity	1.3 m/s	(2.5 kt)

Based on the above requirements, the SALM systems have been designed for a maximum hawser force of 373 metric tons (820 kips) and a corresponding axial anchor leg force of 591 metric tons (1,300 kips). The structural components of the SALM system are designed to assure that an applied load of 1.75 times the maximum operating hawser load, or 652 metric tons (1,435 kips), will not cause yielding in any component which might effect the integrity of the product swivel or any other critical member. An additional measure of safety was designed into the system through the use of overload stress control links in the chafing chain assemblies. The design of all welded joints and structural components subject to significant stress variations were based on considerations for a fatigue life in excess of 20 years.

B. Description of Major SALM Components

Mooring Buoy

The SALM mooring buoy provides the systems necessary restoring force. The LOOP buoys have a net submerged buoyancy of 318 metric tons (700 kips) and are designed to maintain positive tension in their anchor legs at all times. Each buoy has an outside diameter of 6.4 meter (21.0 feet) and is 14.0 meter (46.0 feet) in height. They are designed as externally loaded ring stiffened pressure vessels with a minimum design factor against buckling of 2.5 to 1 at a design submergence of 21.3 meter (70.0 feet). The structural framework is on the exterior of the buoys serving as external ring type hull stiffeners to which elastomeric fenders are attached. This type of arrangement provides excellent structural protection for the buoy hull and in addition assures full utilization of the energy absorbing capabilities of the fenders. The interior of the buoy is divided into eight watertight compartments.

Anchor Leg Assembly

The SALM anchor leg assembly connects the mooring buoy to the mooring base. The assembly incorporates a universal joint at both ends and an anchor chain swivel at the base end. With this arrangement, the universal joints accommodate lateral displacement of the buoy and the chain swivel allows for rotational motion. The LOOP SALM's utilize 165.1 millimeter (6.5 inch) Oil Rig Quality (ORQ) stud link anchor chain with a rated breaking strength of 1,805 metric tons (3,970 kips). The anchor chain is stressed to less than one third of its breaking strength at the maximum predicted design load.

All universal joints utilize full monel overlay on the load carrying pins and their respective facing surfaces. In addition, permanently lubricated aluminum bronze thrust washers and bushings are utilized. The chain swivels employ five rows of angular ball bearings and are grease filled and sealed against sea water intrusion.

Mooring base

The mooring base anchors the SALM system to the sea floor. It may either be a gravity base or pile anchored. For LOOP the bases are open square steel structures. Their inside diameter is 9.1 meter (30.0 feet), and their outside diameter is 12.2 meter (40.0 feet). They have an overall height of 4.0 meter (13.0 feet). Four piles, one at each corner of the mooring base, anchor it to the sea floor. Each pile is 27.4 meter (90.0 feet) long with an outside diameter of

1.5 meter (5.0 feet). The connection of the base to the piles was achieved through pressure grouting. In order to achieve maximum under keel clearance for the design 700,000 dwt vessel, the bases were recessed into the sea floor 2.1 meter (7.0 feet).

Fluid Swivel Assembly

The fluid swivel assembly is the heart of any SPM system. It allows for the flow of cargo to be achieved as the vessel weathervanes about the mooring system. For LOOP, the fluid swivel assemblies are designed to accommodate crude oil flow rates of 100,000 barrels per hour at operating pressures of up to 1,896 Pa (275 psi). They are designed as complete separate modular units which set into the mooring base and are connected to it with high strength bolts.

Each fluid swivel assembly is designed around a heavy walled tubular center shaft. The fluid distribution chamber is mounted concentric with the center shaft in a manner that prevents mooring forces from being transferred into the rotary fluid swivels. The lower end of the center shaft is integral with the stationary crude oil outlet chamber. This allows the connection between the mooring base and the fluid swivel assembly to be strictly structural. The rotating crude oil inlet chamber is mounted on two rotary fluid swivels. Each swivel incorporates five large volume seals; two on the seawater side and three of the crude oil side. The primary oil seal is a large cross section, multiple contact, self energized seal. In addition, an emergency seal is incorporated on the oil side which may be brought into service in the event of a primary and secondary seal failure.

The fluid swivel assemblies are designed for minimum torque resistance and are able to rotate under the influence of the torque created by currents acting on the hose string only. In order to allow for on site maintenance checks, a series of test ports are designed into the system.

Hawser Assemblies

A dual hawser assembly system is utilized on the LOOP SALM systems. Each assembly consists of a 54.9 meter (180.0 feet) long, 381 millimeter (15 inch) circumference nylon grommet and is completely autonomous. Each attaches to its own mooring bracket on the mooring buoy deck with a quick change hawser coupler and strain gauged load pin. A 76 meter (25.0 feet) long chafting chain is attached at the tanker end by means of a quicke change thimble. Each hawser has a rated breaking strength, new, of 545 metric tons (1,200 kips) for a combined strength of about three times the maximum predicted load.

Hose System

The hose system provides the path for cargo transfer between the vessel and the SPM. For the LOOP SALMs the hose system consists of twin 610 millimeter (24 inch) inside diameter hose systems. Each is approximately 335 meter (1,100 feet) long and consists of a long floating section, a short transition section, and a submerged section which connects to the fluid swivel assembly through specially designed elastomeric joints. The joints were designed to provide a transition between the hose system and the rigid piping on the fluid swivel assembly.

The floating hose is made up of 12.2 meter (40.0 feet) long integral float type hoses. The submerged section utilizes specially reinforced submarine hose whose rigidity is sufficient to provide an adequate moment arm to rotate the fluid swivel. The transition hose connects the floating hose section and the submerged hose section and provides for the necessary transition of stiffness between them.
Integral in line buoyancy tanks, mounted between the hose flanges on the submarine hoses, and hose flotation collars provide the necessary positive uplift to achieve and maintain the under water hose profile.

Load Monitoring System

The LOOP SALM's are equipped with a system for monitoring forces in the bow hawsers when vessels are on the mooring. The system was designed to measure, compare and automatically transmit to the control platform the peak loads which occur in each of the two hawsers in a system during a pre-selected time frame. The load monitoring system design was selected to provide maximum integrity and minimum maintenance.

INSTALLATION AND START-UP

As many as nine construction vessels were at work during the summer of 1980 to ready the facility for start-up at the end of the first quarter in 1981.

The offshore segment of the first U.S. deepwater unloading terminal consisted of two platforms making up the pumping and control complex, three single-anchor leg mooring systems, three 56 inch pipelines routing crude from the SALM systems to the pumping complex and a single 48-inch pipeline to transport the crude ashore.

All three SALM systems were installed minus the hoses, which were installed early in 1981. The two platforms were installed and hooked up. All of the pipelines with risers were installed next.
Two derrick barges lifted the deck section in five pieces. Lift loads ranged from 1,200 tons to 2,000 tons.

Three synchronized two-barge "double lifts" were necessary to place the heaviest deck sections of LOOP's pumping platform jackets. Brown & Root's derrick barges Ocean Builder and Atlas, each capable of lifting 1,600 tons, were used to set the sections. LOOP's offshore pumping platform has two 215 x 204 foot decks.

The lower deck contains three booster pumps, connected in parallel and each driven by a 7,000 horsepower electric motor to move the crude to shore through a buried 48 inch diameter pipeline at rates to 100,000 bph.

The upper deck houses gasturbine generators used to furnish electric power and turbine meters to measure crude troughput.
A triple-deck 70 x 70 foot control platform is joined to the pumping platform is joined to the pumping platform by a personnel bridge.

The large pipelines from the complex to each of the SALM systems required a four foot bottom cover, which in turn required a trench 10 feet deep and 15 feet wide. Jetting barges pulling a sled had to make three passes to obtain the necessary depth for the pipelines.

Start-up at the end of the first quarter of 1981 was at the rate of 40-50,000 bbl per hour until leaching of the three storage caverns onshore was completed. Full operational capacity for Phase 1 of the project is 100,000 bph.

Phase II of the project, not anticipated at this time unless crude importation increases substantially, consists of the addition of more SALM systems and increased pumping capability.

To meet stringent environmental protection guidelines incorporated in its operating regulations, LOOP demanded a method of rapidly and reliably shutting-in all or any portion of its offshore crude transporting system. The engineering design and construction contractor of the pollution control system devised a means for day-to-day operational opening/closing of the platform's entrance/exit valves, and of immediately shutting-in the entire system in an emergency.

The system incorporates eight 48 inch valves placed around the periphery of the platform in the lines connecting the SALM units to the platform and the lines moving crude from the platform to shore. Provisions also were made to expand the system by adding seven additional valves to the network at a later date.

Valve actuators were used to supply the hydraulic system necessary to actuate both the eigth installed valves, and the seven which might be added later.

Primary hydraulic power for valve operation is provided by two 25-gpm, 5,000-psi axial piston pumps operating at 12 gpm and 3,000-psi pressure for extended pump service lift. The pumps are driven by 30-hp explosion-proof electric motors connected to the platform's electric power supply.

A 660-gallon hydraulic oil reservoir and back-up accumulators are located in the power unit skid. Another 75 total gallons of piston-type nitrogen-oil integral accumulators are manifolded together on the power unit skid to provide emergency back-up for the five skid-mounted satellite accumulator banks, containing a total 218 gallons of deliverable hydraulic oil, located in the vicinity of the valves.

Since LOOP will handle six different designations of crude imports, use of the specific caverns for segregation was important. In its layout and functions, the Clovelly facility is essentially an underground tank farm.

Some difficulty was encountered during early drilling on the three caverns nearing completion.

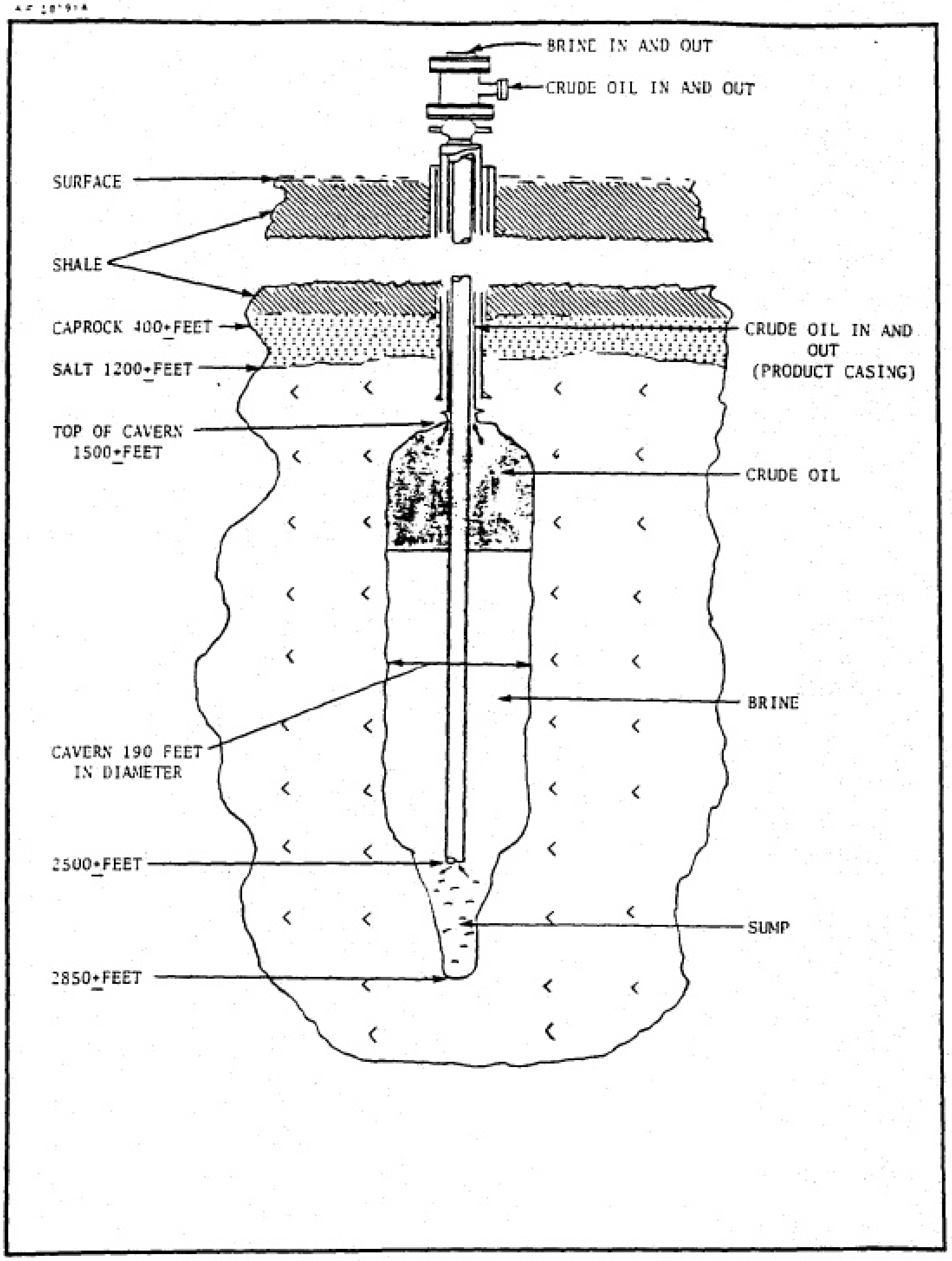

BRINE IN AND OUT
CRUDE OIL IN AND OUT
SURFACE
SHALE
CAPROCK 400+FEET
SALT 1200+FEET
CRUDE OIL IN AND OUT (PRODUCT CASING)
TOP OF CAVERN 1500+FEET
CRUDE OIL
BRINE
CAVERN 190 FEET IN DIAMETER
2500+FEET
SUMP
2850+FEET

FIGURE 7

Big-hole drilling was necessary in the high-porosity 1,200 feet-thick shale caprock, where 60-inch diameter conductor pipe was set. The conductor was followed by 48, 36 and 30-inch casing strings. Each 1,000 x 190 foot cavern leached in the salt dome extends vertically from 1,500 feet to a depth of 2,500 feet below the surface. A pump beneath each cavern extends 350 feet beneath the cavern to a total depth of 2,850 feet below the surface (Figure 7).
It takes a total of 10 months from the time water is injected into the salt dome to leach a cavity of the desired dimensions.

Crude will move in and out of the caverns via brine displacement. Brine water is stored in a 25-million-bbl surface storage reservoir. Crude pumped into a cavity will displace brine to the surface storage reservoir. Conversely, brine from the reservoir will be piped into the bottom of the cavity to displace crude and send it out to other pipeline systems.

By mid-1981, LOOP engineers had the system completely "debugged" and capable of expanding up to its design capability of handling a maximum of 330 supertankers annually.

Early throughput capacity at LOOP will be limited by the unavailability of underground storage caverns to be used in the system. When fully operational (by the close of 1982), LOOP will have eight 4-million-bbl capacity storage cavities in operation and a throughput capacity of 1.4 million bopd. The first three salt dome storage cavities should be completed this fall.

SUMMARY

LOOP is attractive to shippers for the following reasons:
Three single-point mooring buoys; the United States' only deep draft (90 feet) accommodations; working storage capacity, when complete, of 32 million barrels, and five connecting pipelines

enabling delivery to approximately 30 percent of the nation's refining capacity.

The cargo capability is safe, assured and accurate. LOOP's metering system is state-of-the-art, and the Company provides shippers an independent inspection service for tankers offloaded. Cargo can be offloaded at up to 100,000 barrels per hour and two tankers, if discharging a like crude, may offload at the same time. Crude quality changes are minimized by eight specially-designed segregations (each maintained in a separate cavity) for the various types of crudes which LOOP will handle. For any variations in quality between what a shipper delivers into a crude segregation and what is received from that segregation, LOOP administers a Quality Bank to make monetary adjustments among shippers for those quality changes.

Other advantages of LOOP include fewer delays from weather, less port congestion, simplified scheduling of crude shipments to refineries because of the large availability of working storage, and highly experienced and professional personnel.

The project, first conceived in the early 1970s was brought to fruition in only nine years, a remarkably short period of time considering that both state and federal legislation was required before license could be issued or construction initiated.

In recognition of the efforts of the LOOP design and construction team, the project has been awarded the Outstanding Civil Engineering Achievement of 1982 by the American Society of Civil Engineering.