Offshore South East Asia 82 Conference
9 - 12 February, Singapore

Tembungo Salm — Seven Years Operating Experience

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This paper describes the performance of the Tembungo Single Anchor Leg Mooring (SALM) tanker loading terminal during its first seven years of operation. This facility, located in 300 ft. (91 m) of water, 50 miles (93 km) offshore Sabah, East Malaysia, has been in continuous service since October 1974. It was designed to permanently moor a 94,000 DWT storage tanker in maximum wave heights of 39 ft. (12 m), winds of 65 mph (29 m/s) and 2 kt (1 m/s) currents.

The Tembungo SALM has performed very effectively since start-up. Operational efficiency rates of up to 99.4 percent on an annual basis have been achieved, with an average of 95%. A major factor in the high utilization of this terminal has been the very low level of maintenance required on the SALM components. Pre-planning the annual inspection and maintenance program with the diving contractor and developing detailed procedures for tanker change-out and for hose and hawser replacement were also important contributors towards maximizing operational efficiency.

INTRODUCTION

In recent years the petroleum industry has accepted the concept of employing a Single Point Mooring (SPM) as an integral part of an offshore production facility. The SPM, which provides direct tanker loading, may allow a field to be brought on-stream earlier than with a pipeline to shore and it may allow the development of those fields which have insufficient recoverable reserves to justify a pipeline. The Tembungo SALM, described herein, is a good example of an early production application (**Fig. 1**)[2,3].

OTC Paper No. 3804, copyrighted and presented at the 1980 Offshore Technology Conference, described the performance of the Tembungo Single Anchor Leg Mooring (SALM) during its first five years of service[4]. With permission from the OTC, portions of that paper will be incorporated herein.

The SALM is located 7,000 ft (2,134 m) from a fixed separation platform and is connected to the platform via a single 10 in. (9254 mm) pipeline. While the SALM was designed to permanently moor a storage tanker, which would be periodically offloaded by shuttle tankers moored alongside, it has only been used for shuttle service to date in an operation which employs two dedicated tankers[5]. While one tanker is loading, the other tanker departs to discharge its cargo. In this service, with prolonged periods of berth occupancy, the two shuttle tankers effectively become temporary storage facilities. This type of operation requires periodic production shut-in while the loaded tanker departs the SALM and the empty tanker comes on. These operational procedures have proven to be very effective for producing this field and should be equally as effective in the production of other similar fields.

SYSTEM DESIGN CRITERIA

The Tembungo SALM has been designed to permanently moor a 94,000 DWT vessel in the 100-year design environment. This environment and other pertinent design criteria are presented in the following tables:

Design Criteria for the Tembungo SALM

Water Depth	296 ft (90 m)
Tanker Size	94,000 DWT
Significant Wave Height	21.0 ft (6.4 m)
Maximum Wave Height	39.0 ft (11.9 m)
Maximum Wind Velocity	65 mi/hr (29.5 m/s)
Max. Current Velocity (perpendicular to waves)	2.0 kt (1.0 m/s)
Product Transfer Piping	10 in. (254 mm)
Max. Operating Pressure	200 psig (1.38 MPa)
Max. Surge Pressure	400 psig (2.76 MPa)

Peaking mooring forces for the Tembungo SALM facility were determined by means of an empirical technique which has been developed over the past fifteen years by Exxon Research and Engineering and Exxon Production Research Company. The procedures used have been discussed in the literature by Flory, Poranski[6] and Maddox[7]. Based on the given environmental conditions, the predicted Maximum Bow Hawser Load was 840 kip (3,736 kN), the Maximum Anchor Leg (axial) Load was 1,200 kip (5,338 kN), and the Maximum Anchor Leg Deflection was 37½° from vertical.

SYSTEM COMPONENT DESCRIPTION[1,7]

The SALM mooring buoy is anchored through a single pretensioned anchor leg to a gravity-type mooring base at the sea-floor (**Fig. 2**). To minimize diver time and underwater work, the universal joint attachments between riser and base (**Fig. 3**) and buoy and riser (**Fig. 4**) were designed to be hydraulically latched (or unlatched) from the surface.

Basic components of the SALM are the Mooring Base (**Fig. 5**), the Riser Shaft (**Fig. 2**), the Anchor Leg Assembly, (**Fig. 4**), the Hose Arm and Loading Hose System (**Fig. 6**), the Mooring Buoy (**Fig. 7**), the Mooring Hawsers, and the Pipeline End Manifold (PLEM).

OPERATIONAL DOWNTIME EXPERIENCE

The Tembungo Field has produced continuously since October 1974 at quarterly average rates which have varied from 2,000 BOPD to 16,000 BOPD. For this seven-year period, the average overall operational efficiency, i.e. total days minus total downtime days divided by total days, has been 95%. Operational efficiency is categorized below and is shown graphically in Fig. 8.

1974 — Last quarter of 1974 (operation started October 14) 18 days total system downtime which consisted of 1 day for tanker change-outs (2 tankers), 4 days for maintenance and 13 days waiting for tankers to arrive (77% efficiency).

1975 — 26 days total system downtime which consisted of 2 days for tanker change-outs (4 tankers), 15 days for maintenance, 4 days waiting on tankers to arrive and 5 days with tanker standing by due to rough seas (92.8% efficiency).

1976 — 45 days total system downtime which consisted of 1 day for tanker change-outs (4 tankers), 4 days for maintenance, 20 days waiting on weather to do maintenance and 20 days waiting on tankers to arrive (87.7% efficiency).

1977 — 32 days total system downtime which consisted of 6 days for tanker change-outs (13 tankers), 8 days for maintenance and 18 days waiting on weather or equipment to do maintenance (91.2% efficiency).

1978 — 5 days total system downtime which consisted of 4 days for tanker change-outs (12 tankers) and 1 day for maintenance 98.6% efficiency).

1979 — 14 days total system downtime which consisted of 4 days for tanker change-outs (11 tankers), 6 days for maintenance and 4 days waiting on weather for maintenance (96.2% efficiency).

1980 — 19 days total downtime which consisted of 2 days for tanker change-out (8 tankers), and 17 days for maintenance (94.8% efficiency).

1981 — 2 days total downtime which consisted of 1½ days for tanker change-outs (6 tankers) and ½ day for maintenance (99.5% efficiency).

Total downtime October 14, 1974, thru October 14, 1981, was 161 days, which included 37 days "waiting for tanker to arrive". Actual overall efficiency (discounting early logistics problems) is then 95%.

Downtime Summary (days)	1978	1979	1980	1981
Tanker Change-outs	4	4	2	1.5
Maintenance Activities	1	6	17	0.5
Waiting on Weather	0	4	0	0
TOTAL days down	5	14	19	2
% Downtime	1.4	3.8	5.2	0.6

INSPECTION & MAINTENANCE

1975 — The first annual maintenance and inspection was conducted April 14 — 24. Maintenance consisted of changing out the submarine and floating hoses and the buoyancy tanks. Two underbuoy hoses and all but one of the floating hoses were retained for future use.

No scour was evident around mooring base and PLEM, the universal joints and the chain swivel were in good condition, the fluid swivel showed no leaks and the protective coating system on the swivel and hose arm was in good condition.

1976 — The annual survey was conducted June 28 — July 4. It is noted that 20 days waiting on weather to do maintenance was incurred waiting to re-connect the submarine hoses which had been removed to conduct a fluid swivel rotational torque test. The test showed that hose kinking was not due to swivel torque but to the excessive length of the hose string. The tankers were modified later in the year to allow bow loading in lieu of mid-ship loading, which had been employed since start-up.

Maintenance consisted of installing a new loading hose string, replacing mooring hawser assemblies and sandblasting and painting the mooring buoy above the water line. Additionally, the navigation lantern and batteries were replaced. A "Y" piece was installed on the hose arm to facilitate future hose replacements by allowing the old hose to be used as support while installing the new hose.

Inspection revealed the SALM to be generally in good condition, although the anodes had disintegrated more rapidly than anticipated. Steel construction debris left on the bottom and uncoated ballast bars in the hose arm counterweight were suspected of contributing to the rapid anode consumption.

1977 — The SALM was shut-in for 23 days for annual inspection and maintenance. During this time 9½ days were lost waiting on weather and 6 days due to breakdowns on the maintenance vessel. Much of the weather and equipment downtime could have been avoided by better pre-planning and the establishment of definitive maintenance procedures. The major task was the replacement of 42 cathodic protection anodes. Additionally, the buoy was sandblasted and coated above the water line and navigation lantern and battery pack were replaced. The loading hoses were replaced during this shut-down. Inspection of the U-joints, anchor chain and chain swivel was not performed due to bad weather and excessive downtime replacing anodes.

Three days were lost during a shut-down in February in an attempt to replace the #5 floating hose which was chafing against the tanker's bulbous bow. Replacement was prevented because of bad weather. A total of six shut-down days were spent during tanker turnarounds in 1977.

1978 — The annual inspection program was carried out April 20 — 24, during which time the SALM was inspected by divers utilizing an underwater video camera. The Cam-Lok clamps, which connect the base hoses at PLEM and SALM riser piping, appeared to be deteriorated as a result of cathodic action. Bracelet anodes were installed and one of the two clamps was later replaced in 1980.

1979 — The annual SALM inspection and maintenance program was conducted August 13 — 20th. As a result of careful pre-planning, production was only shut-in for 13 hours while a new submarine hose string was connected. Except for that time, the tanker was loading continuously during the entire inspection and maintenance program.

The hose inspection showed that liners and covers were in good condition. There was no evidence of scouring around mooring base or PLEM. Bracelet anodes at ends of PLEM-SALM hose were approximately 30 to 50% consumed. The universal joints and all other components were in good condition.

1980 — The annual inspection was conducted March 25 — April 6, during which time the usual visual inspections were conducted, measurements were taken on the fluid swivel and chain assembly, and the 10" ball valve on the hose arm was replaced.

The most significant operation planned for this period was the replacement of the base hoses. While there had been no evidence of malfunction of these hoses after 5½ years of continuous operation, they were covered with a layer of marine growth and replacement was done as a precautionary measure.

The work was done by a two-man saturation diving system working from a 150-foot barge with a four-point mooring system. The replacement operation went very smoothly, and bracelet anodes were installed on the spool pieces between riser, hoses, and PLEM.

Later inspection showed both the original hoses and the Cam-Lok connections to be in good condition. Twelve days downtime was required for this work, however it should be noted that during 70% of this period there were 6'-7' seas and 20-25 knot winds.

On May 11 during a routine inspection dive, divers noticed that the gap between the two moving parts of the chain swivel had opened up quite considerably. The gap was measured to be 2⅞", as compared to the original as-built gap of ⅛". At this time the decision was made to install a spare chain swivel located at the warehouse in Kota Kinabalu. (Later detailed investigation by the manufacturer revealed that swivel failure was due to failure of the oil seal between the shank and the barrel. Loss of lubricant and subsequent deterioration of the bearing in seawater caused bearing failure and total lock-up of the swivel. Since then a new seal arrangement has been designed, consisting of a TURCITE element energized by a BUNA-N insert, plus a guide spacer to prevent 'cocking' of the shaft during shipping and handling).

As the only support vessel available at the time was a 130-foot supply boat with a four-point mooring system, it was necessary to wait for calm weather. By May 27 the gap was 4¼" (**Fig. 9**). During this period, detailed preparatory work was carried out, including fabrication and installation of a support frame for the upper universal joint (**Fig. 10**), and a support cradle for the main shackle pin.

The vessel was anchored and ballasting of the buoy commenced on June 1st. After the chain assembly was slack (**Fig. 11**), a 15-ton hydraulic jack was used to remove the pin from the shackle connecting the chain assembly and universal joint (**Fig. 12**). The buoy was then de-ballasted, the anchor chain assembly winched over the stern roller and onto the deck of the supply boat, and the buoy secured to the stern of the vessel. The chain swivel and connecting shackles (**Fig. 13**) were replaced and lowered into the water, and the buoy re-ballasted. The four-point mooring system was then manipulated to precisely position the shackle over the universal joint, and the pin installed using the hydraulic jack and pre-installed pin cradle (**Fig. 14**). Total downtime amounted to only 69 hours from shutdown of production to restart of production through the SALM, thus illustrating the value of thorough preparation (total preparatory dive time was 9.5 hours vs. 8.9 hours diving during the actual replacement operation).

1981 — The annual inspection was divided into two phases, with the first phase to cover the shallow components (from the hose arm up to the buoy) and the second phase covering the deeper components (from the top universal joint down to the base).

Phase I was conducted from April 8-23, and except for the "U" joint thrust washer the system was in good order. On April 14, during Phase I, the routine inspection of the upper universal joint revealed that one washer had disintegrated. Several pieces of the broken thrust washer were recovered at the bottom of the "U" joint housing. (Later investigation revealed that failure occurred because of dezincification of the Dorcolube self-lubricating bronze thrust washer (ASTM B-22-Alloy E). Use of this alloy was discontinued by the fabricator several years ago in favor of a nickel aluminium bronze (ASTM B148-Alloy 955).

After discussions with local maintenance personnel it was decided to manufacture a mild steel washer on location. The washer was made in two halves from ¾" plate. The tanker was unmoored, the buoy ballasted down, and the two halves of the washer fitted in and wet-welded (**Fig. 15**). Total production downtime amounted to 13 hours.

As of October 1981 no swivel torque test had been carried out. Careful monitoring by divers and tanker crew gave no indication of any torque build-up and the fluid swivel hose arm was moving relative to the tanker. No major operational problems are immediately foreseen, and regular monitoring will continue.

Phase II of the annual inspection was conducted in August, 1981, and all of the deep components were found to be in good condition.

EARLY OPERATING PROBLEMS/SOLUTIONS

Initially, there were certain operational problems which resulted in some system/production downtime. These initial operating problems were two-fold:

1) The tanker had a tendency to ride-up on the buoy in calm weather causing kinking of the cargo hose directly off the hose arm.
2) The chafing chain at the tanker fairlead experienced accelerated wear.

The tankers ESSO CHILE and ESSO CRISTOBAL, which were used for most of the operating period covered by this paper, were unable to run their engines astern for extended periods without overheating their condensers, which made it difficult for them to maintain the necessary hose tension in calm weather.

Remedial actions which were considered included:

- Rotation of the hose by a workboat
- Periodic reversal of tanker engines to tension hawser and hose string
- Provision of a tug boat to keep tension on the stern of the tanker
- Installation of stern thrusters
- Installation of 24 in. (610 mm) surplus marine hoses over 10 in. (254 mm) cargo hoses #1 and #2 to increase hose rigidity
- Installation of a "backstop" on the hose arm to limit vertical excursion.
- Modification of the tankers to accept bow loading, thereby reducing the length of hose in the water
- Modification of the tankers to run continuously astern

After discarding all other solutions as either impractical or too expensive, and after consultation with the manufacturers of the ship's turbines, a simple, inexpensive modification was effected which allowed low speed (10 — 24 rpm) astern power to be maintained over an extended period. This modification featured installation of a 5 in. (127 mm) line from the de-superheated (saturated) steam line, which powers the cargo pumps, to the steam inlet on the low pressure astern turbine.

The operating philosophy for engine reverse running was to run continuously at 10 rpm whenever windspeeds fell below 10 — 15 mph (4 — 7 m/s). For the 50,000 DWT class tankers, ESSO CHILE and ESSO CRISTOBAL, this procedure resulted in incremental fuel (diesel) consumption of 2 long tons per full day of continuous astern running.

Additionally, the tankers were modified to allow the cargo hose to come over the forecastle rail at a point about 20 ft (6 m) abaft the stem. This modification reduced hose maintenance by helping to prevent kinking of the long hose string and by eliminating chafing against the ship's bow.

The use of astern power substantially eliminated operating problems at the Tembungo SALM, as evidenced by the average seven year terminal efficiency of 95% and the last four years of 97.2%:

1978	1979	1980	1981
98.6%	96.2%	94.8%	99.4%

The problem of excessive chafing chain wear was greatly reduced by the application of astern power and frequent lubrication of the chain where it enters the tanker bow chock. The average frequency of chain replacement has been approximately every 3 — 4 months and is generally coincident with tanker change-outs.

COSTS

Of particular interest to potential operators of offshore loading systems are the overall costs involved. For the Tembungo SALM in 1982 dollars, typical costs are:

Complete SALM hardware and hose system for bow loading	$5,500,000 U.S.
Transportation, Installation and Commissioning	$2,000,000 U.S.
Total Cost (without pipeline)	$7,500,000 U.S.
Modifications to allow continuous slow astern power	$20,000 U.S.
Bow loading modifications	$25,000 U.S.
Incremental diesel fuel cost @ $1.00 per gallon assuming 80% astern running annually	$270,000/year
Maintenance Vessel and crew charged to SALM	$600,000/year
SALM Maintenance Costs	$250,000/year
Replacement costs of hoses, hawsers and chafing chain	$100,000/year

CONCLUSIONS

The Tembungo SALM has proven to be a mechanically sound system which allowed bringing a small field onto production earlier and cheaper than would have been possible by other means. The design criteria of 95% operational efficiency has been met, as indicated by the operating history described in this paper.

Pertinent conclusions offered by this history are:

1. The importance of prudent tanker selection to optimize performance and minimize modifications.
2. The importance of pre-planning maintenance and inspection activities and of developing practical offshore procedures for the replacement of hoses and hawsers.
3. The necessity of having capability to apply slow astern power for extended periods.
4. The inherent low maintenance features of the mooring system.

It is important to re-emphasize that only two major components of the Tembungo SALM have required maintenance of any significance since start-up in 1974. This low requirement for maintenance on SALM components may be attributed to the inherent advantages of the SALM system and to novel design features which completely eliminate the necessity for periodic lubrication of the fluid swivel, chain swivel and universal joints.

With a properly modified tanker and careful attention to planning and training functions, a competently designed hawser-type SALM mooring system can provide an efficient, low-cost offshore storage/loading facility.

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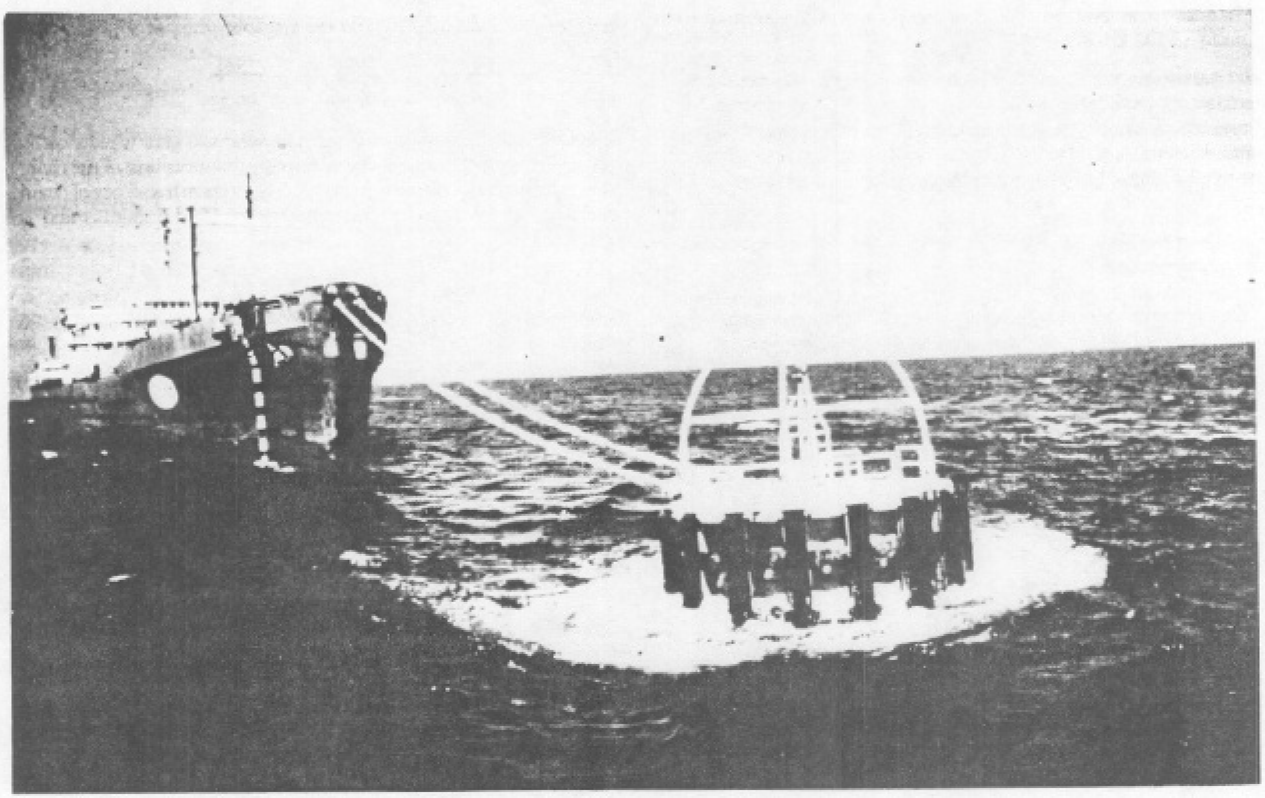

Figure 1 — Photo-Buoy & Tanker

Figure 2 — Perspective Drawing of SALM

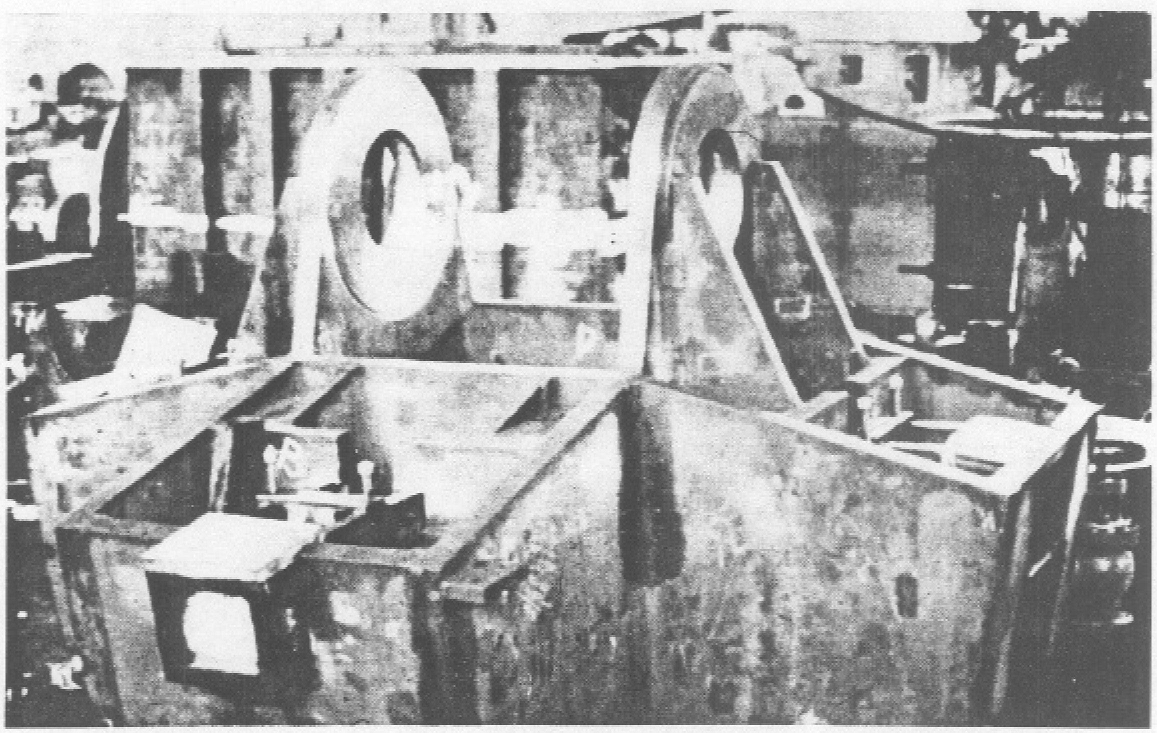

Figure 3 — Photo-Universal Joint Between Riser & Base

Figure 4 — Photo-Top U-jnt & Anchor Leg Ass'y

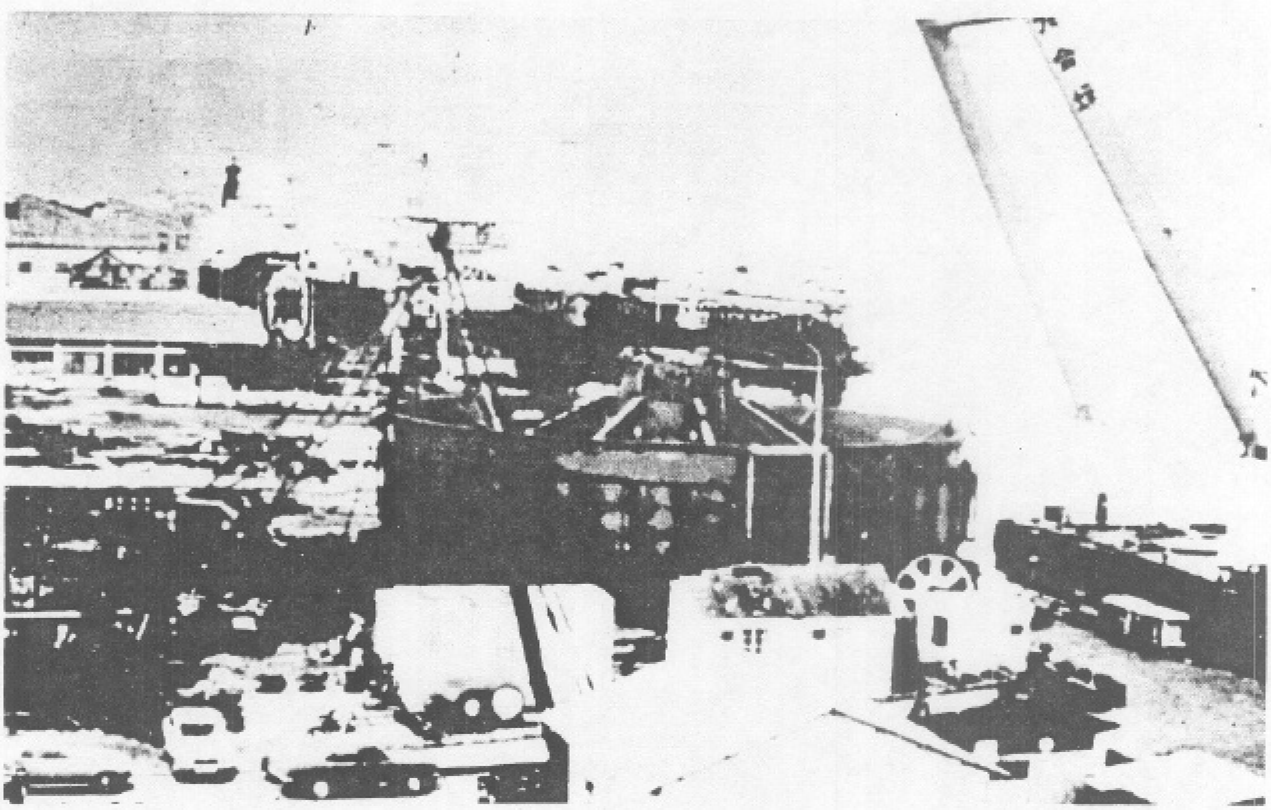

Figure 5 — Photo-Mooring Base

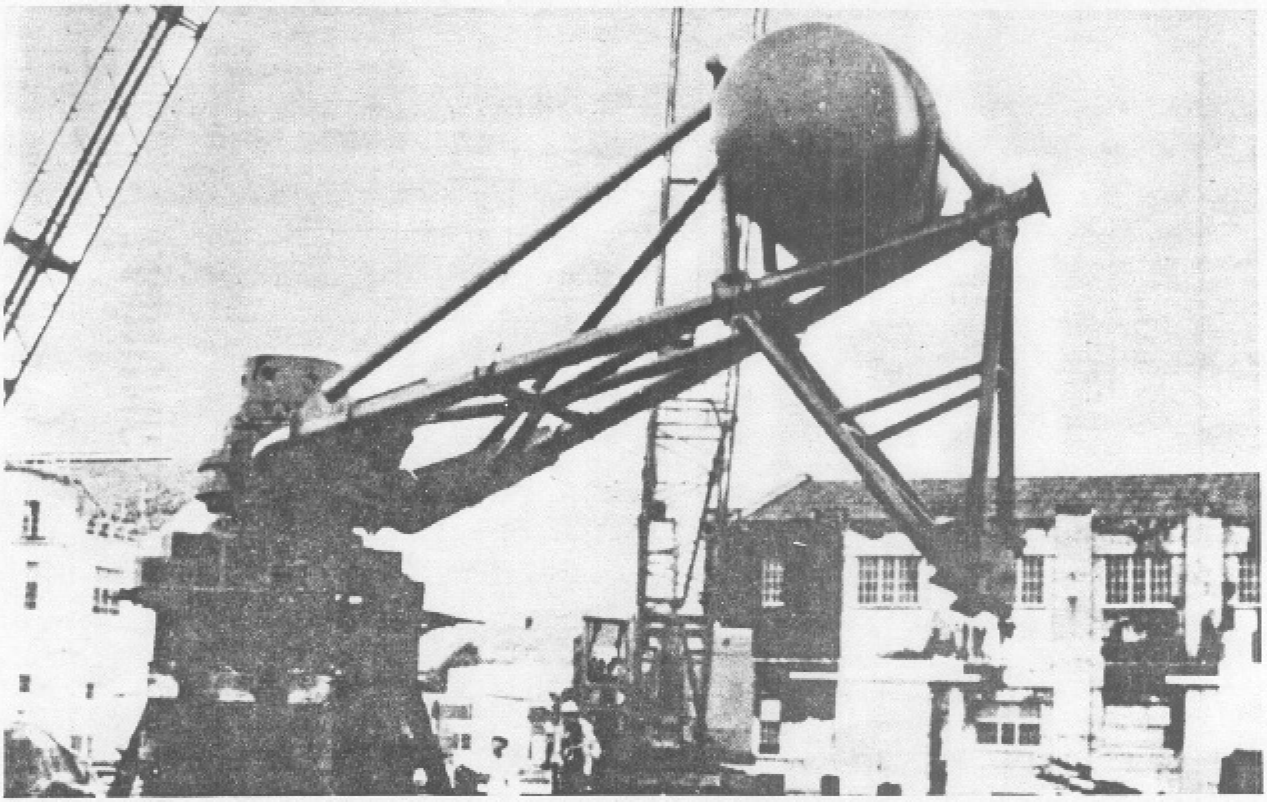

Figure 6 — Photo-Hose Arm

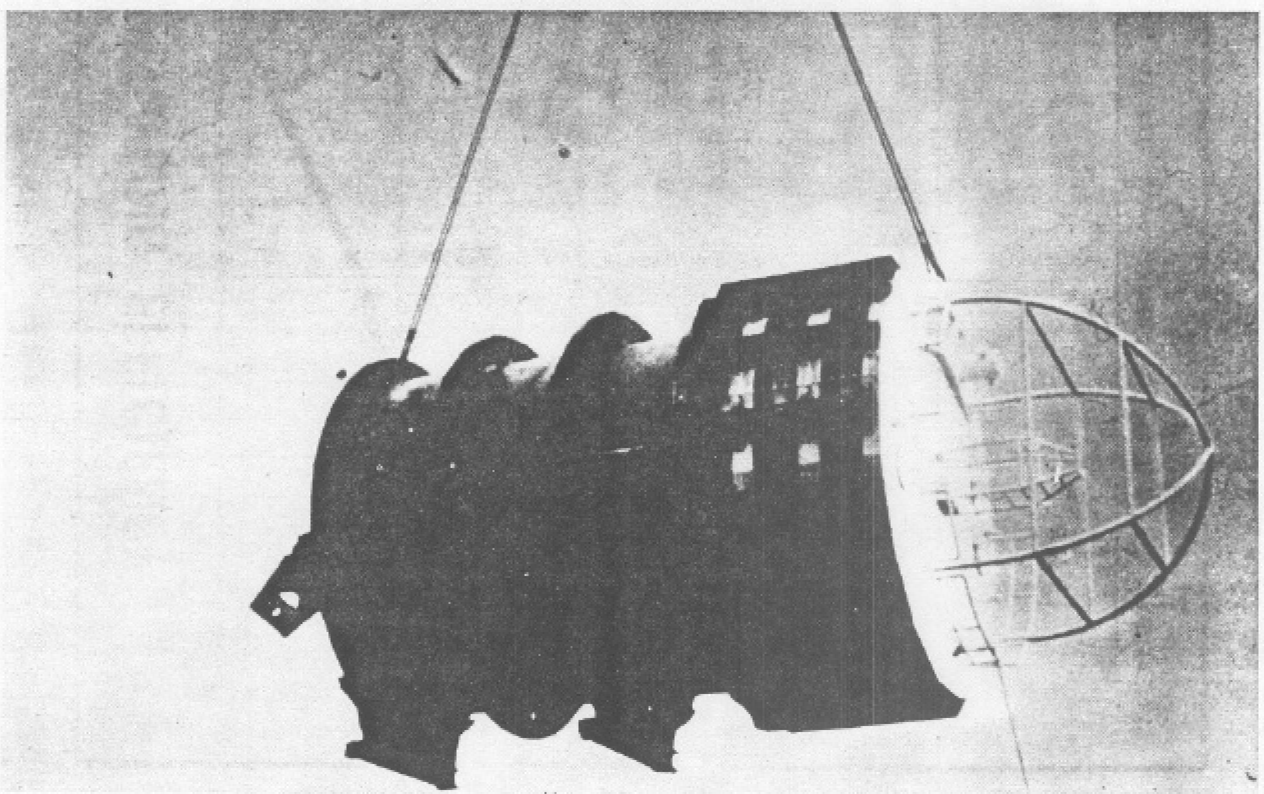

Figure 7 — Photo-Mooring Buoy

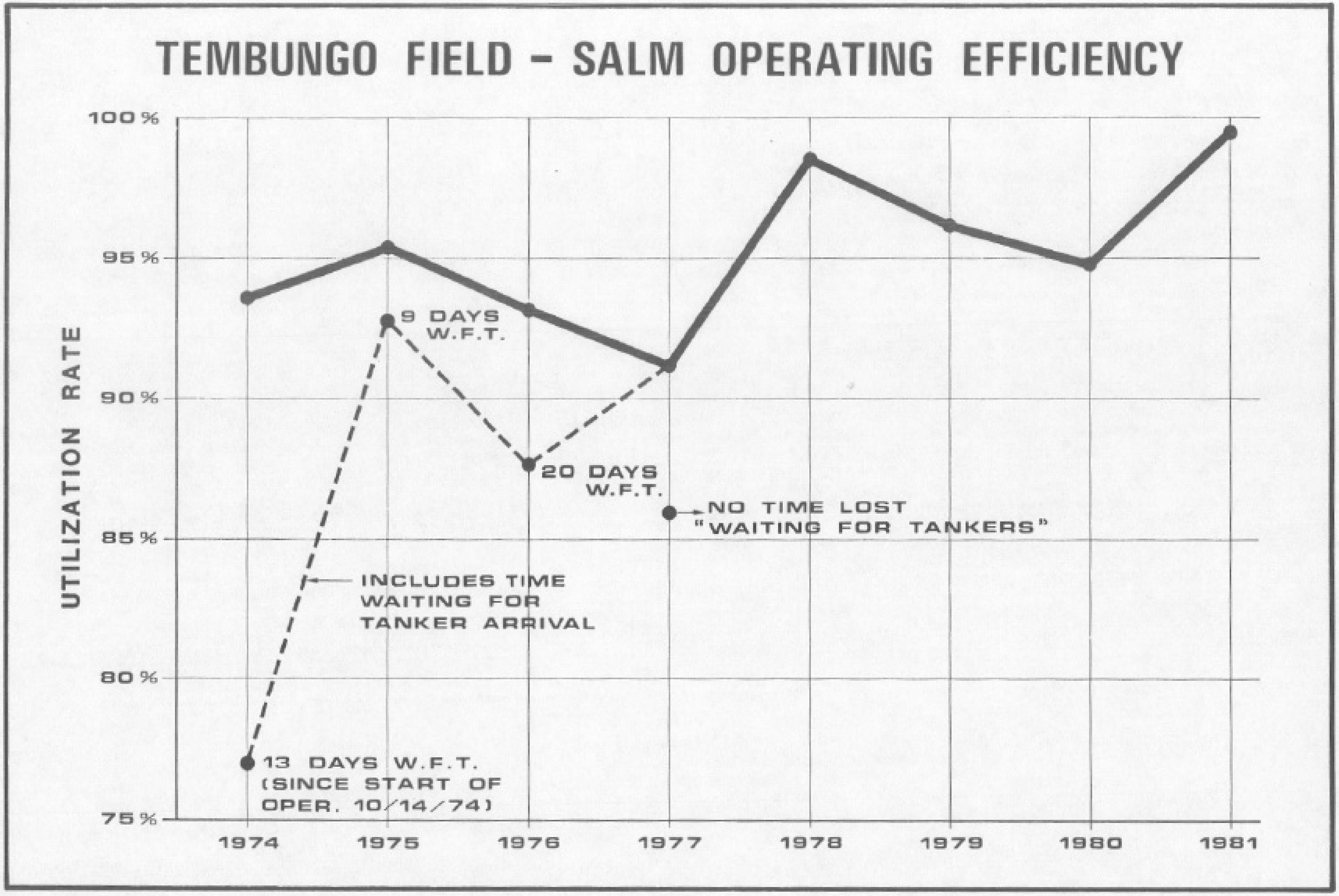

Figure 8 — Operating Efficiency Plot

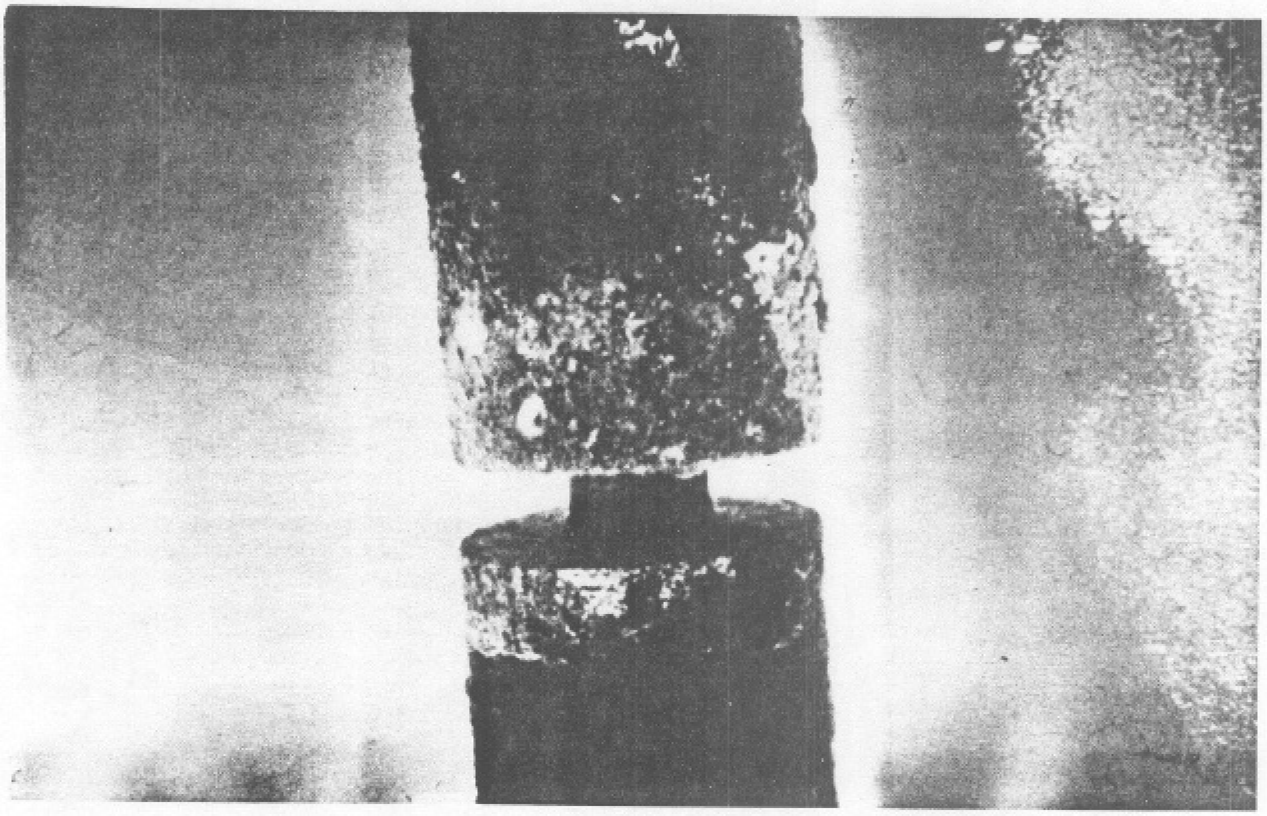

Figure 9 — Photo-Chain Swivel

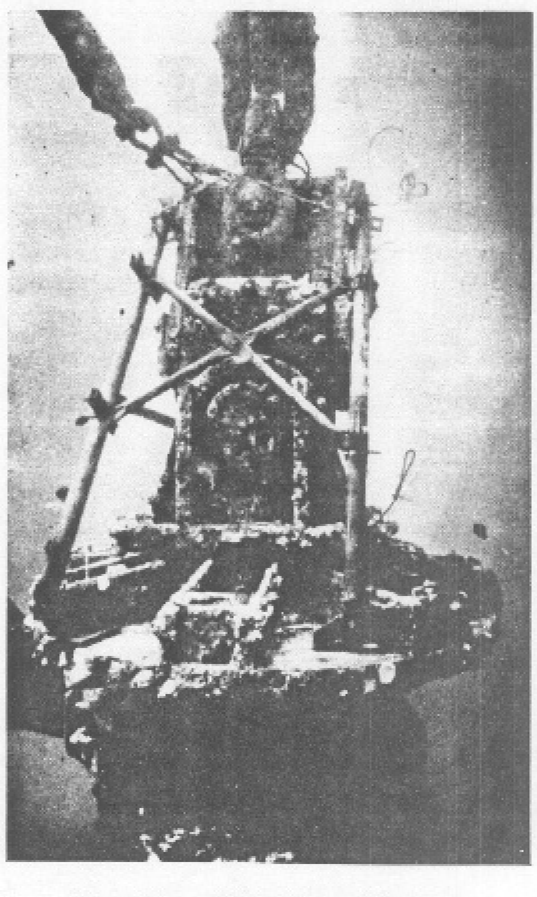

Figure 10 — Photo-Support Frame

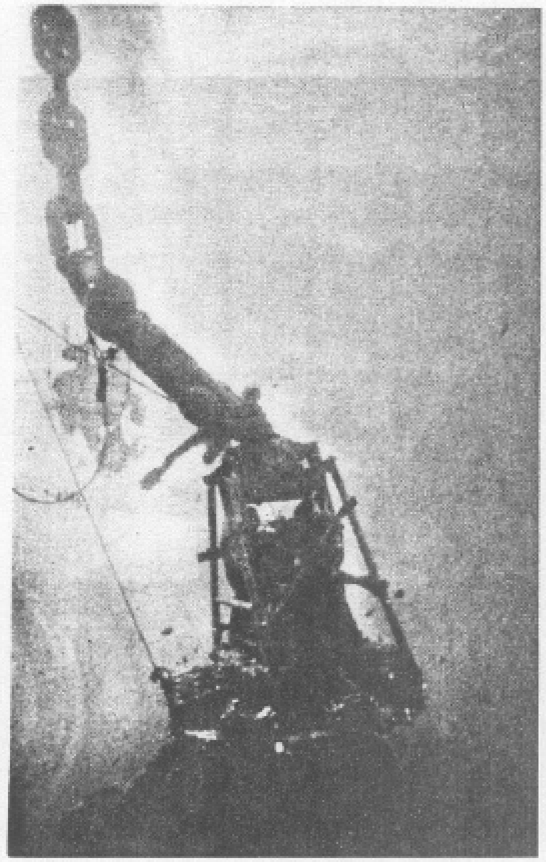

Figure 11 — Photo-Chain Assembly Slack

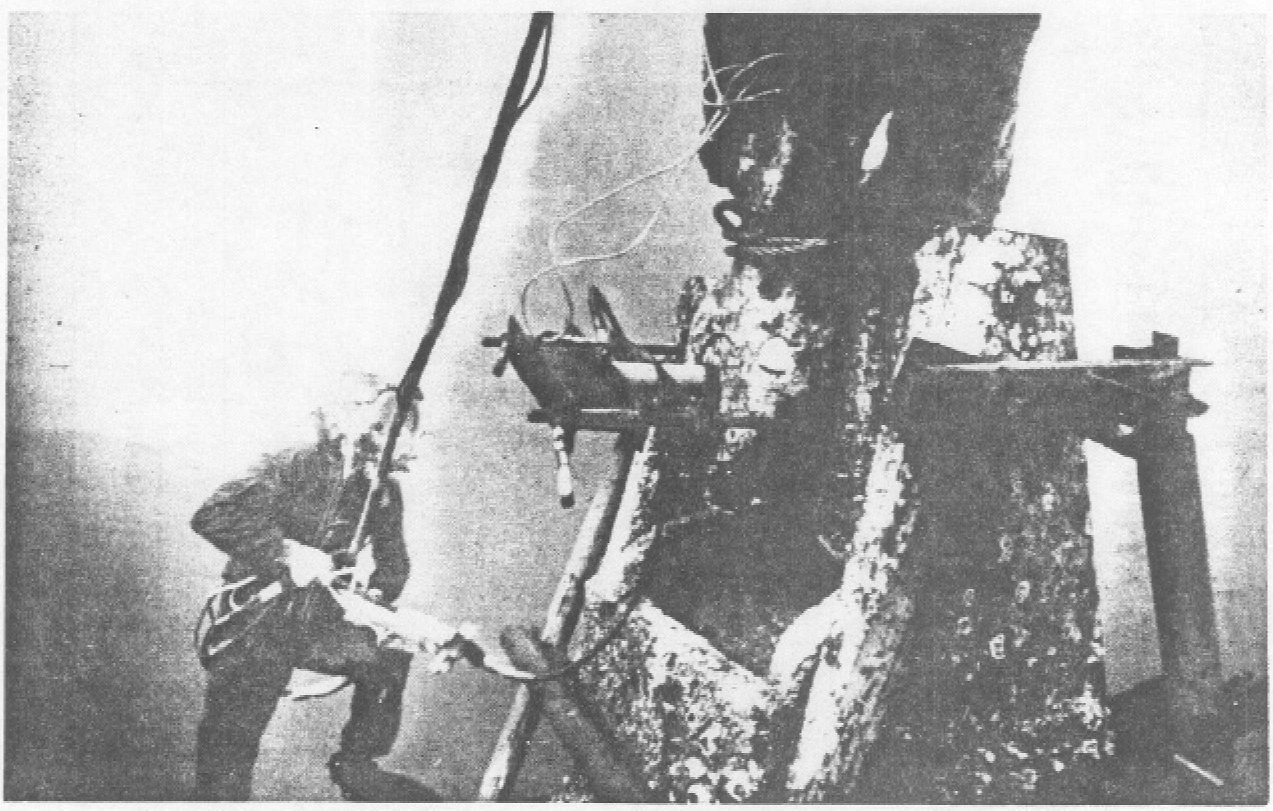

Figure 12 — Photo-Jacking Out The Pin

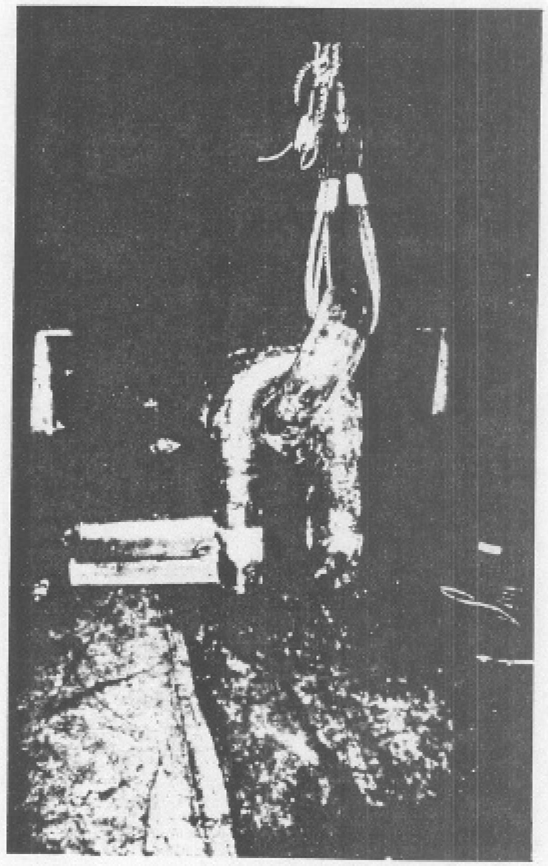

Figure 13 — Photo-Connecting Shackle & Pin

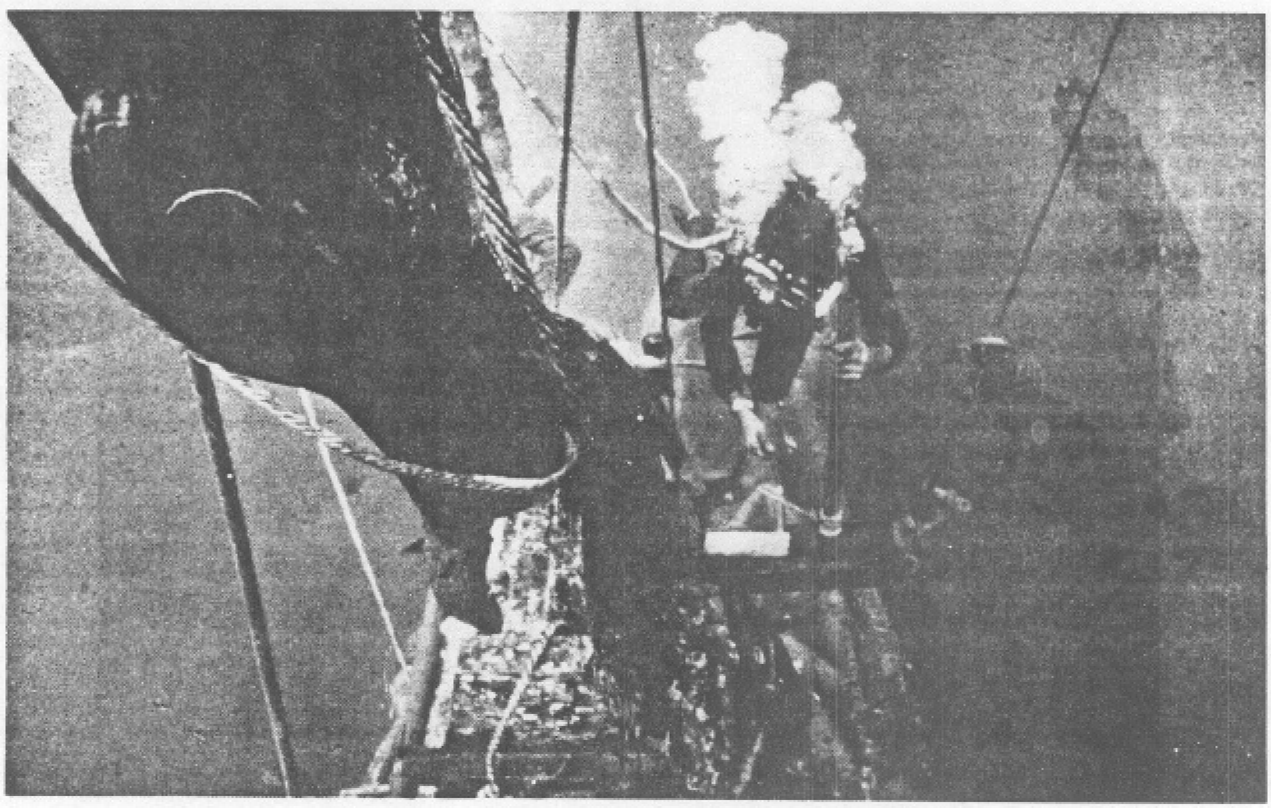

Figure 14 — Photo-Jacking in the Pin

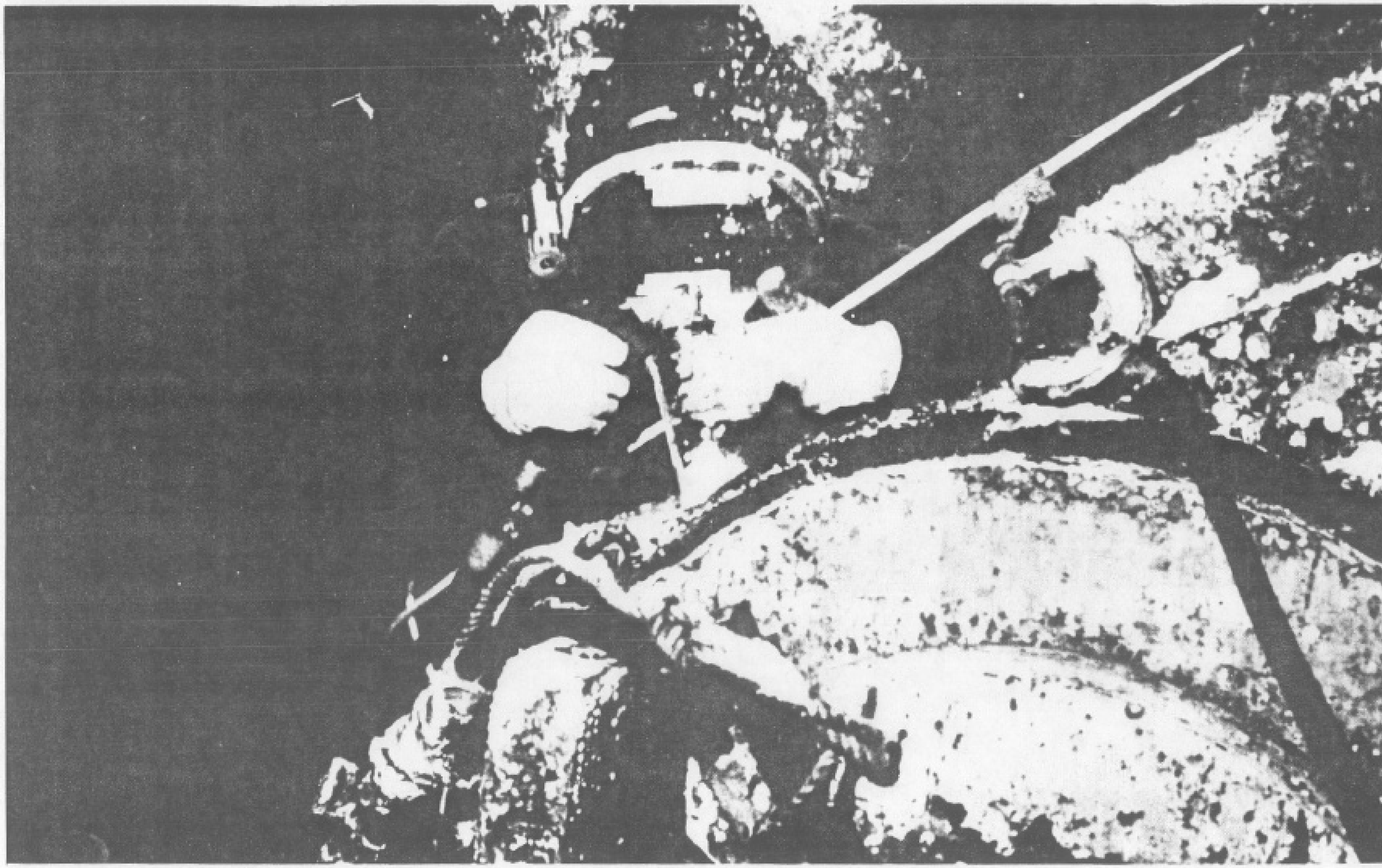

Figure 15 — Photo-Field Built Thrust Washer