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U.S. NAVY SHIP SALVAGE MANUAL

VOLUME II

SUBMARINE SALVAGE

OFFICE OF THE SUPERVISOR OF SALVAGE, U. S. NAVY
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PREFACE

Submarine salvage is a rare evolution in the U.S. Navy. For training purposes, submarine ex-HAKE (AGSS 256) was sunk and recovered in 1969; thirty years had passed between this operation and the previous sunk submarine recovery in 1939. Because of this wide time span, and the fortunate infrequency of submarine salvage operations, the U.S. Navy does not maintain specially designated submarine salvage teams; personnel likely to be assigned to submarine salvage operations are those employed in salvage ships and possessing general marine salvage experience.

This manual is compiled to offer a ready guide and reference for personnel assigned to submarine salvage. It compiles information gained by the U.S. Navy, listing techniques, experiences good and bad, and includes nine submarine salvage reports offering articulation of theory and guidelines into practice. Equipment and methods used by salvors in the past are ready for use again. New techniques and salvage tools are developed.

Herein is a presentation of the State-of-the-Art 1970; while new methods in development are briefly presented, no direct guideline for their use is given. The Submarine Salvage Manual must remain an active reference, updated and corrected with each new development, tool, and salvage operation; it shall remain the duty of salvors to make this a living guideline.

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Record of Changes

Change Number	Date of Change	Date Entered	Entered By

Information Regarding the Manual and its Use

Scope

The Submarine Salvage Manual presents techniques used in salving sunken submarines. Comprehensive references are included on allied subjects. Reports on past submarine salvage operations are included.

Section Numbers

This manual is divided into eight major sections with sub-sections; the division is made along subject lines; the material is contained, by subject, in the appropriate section or sub-section. Nine letter-designated appendix sections supplement the text with case studies.

The Table of Contents lists, by subject, all material in the manual by section.

Page Numbers

The pages are numbered consecutively, starting with page number 1 at the beginning of each major section.

The section title and number appear at the top of the page. The section and page number appear at the bottom of the page.

In the Appendices, the section title and letter appear at the top of the page. The section letter and page number appear at the bottom.

List of Plates and Photographs

All plates and photographs are included in the applicable subject section.

How to Locate Information

Information regarding a general subject can be located by the use of the Table of Contents.

Information regarding a specific subject, or item, can be located by the use of the Alphabetical Subject Index.

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1. Introduction

The Salvage Officer confronted with the task of retrieving a sunken or stranded submarine will need to draw heavily upon previous submarine salvage operations. Most likely he will not have had personal experience in this field, and will therefore need background information which will prepare him for his particular salvage problem and provide a basis for a modus operandi.

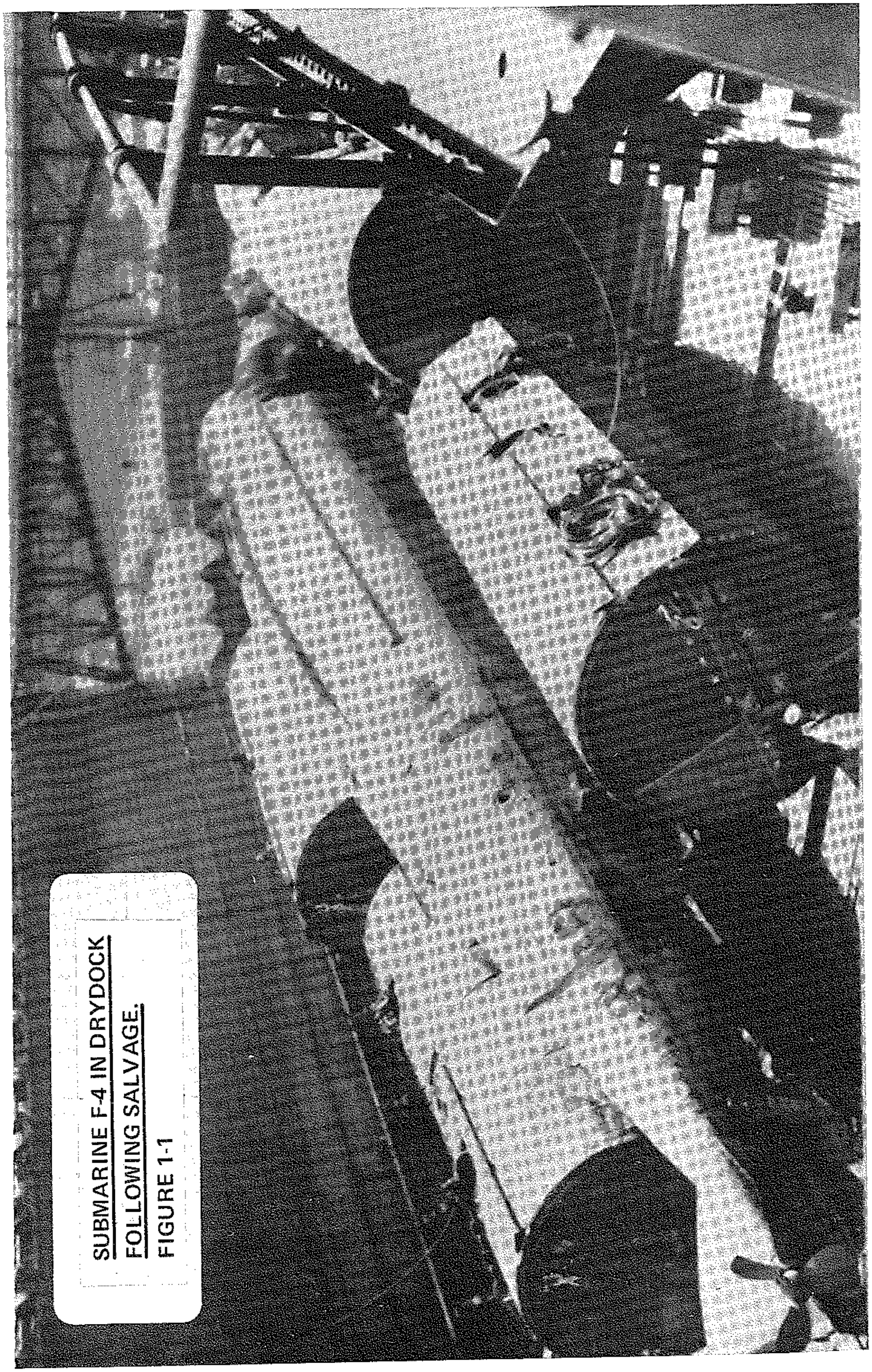
Every submarine salvage operation has different circumstances, depending upon the size of the submarine, its position, flooded condition and depth, and the type of bottom on which it rests. The review of past submarine salvage operations given in the Appendices to this manual, may assist the Salvage Officer in estimating the requirements for his job and in anticipating some of the problems that may arise.

There have been approximately twenty three submarine losses of non-combatant nature in the US NAVY. Of these, ten occurred in such deep water that salvage could not be attempted. Out of the remaining eleven, six were in shallow water or under conditions that made salvage relatively simple; however, of the other five submarine salvage attempts in deep water, four were successful.

The first operation was the raising of USS F-4 off Honolulu harbor in 1915. The submarine had to be brought up from a depth of 306 feet; to date, the deepest salvage ever completed. Divers had to work at depths far exceeding the limits which had been reached in that day. However, in comparison with later salvage operations, it must be remembered that F-4 was small, displacing only 400 tons, and considerably easier to handle than S-51 at 876 tons and SQUALUS at 1450 tons.

The submarine service was not prepared for such disasters as F-4. The deepest a diver had gone was 274 feet and little was known about the effects of decompression sickness or other physiological aspects of diving. There were no rescue or salvage vessels fitted out for recovering crews or submarines.

F-4's salvage force consisted of chartered tugs, two decked-over scows with improvised windlasses for lifting, and a diving lighter with a recompression chamber. The method of bringing the submarine into shallower water was by sweeping wire cables and chain slings under the hull, lifting with the scows, and then towing until the submarine grounded. A second purchase would then be taken on the hoisting cables and the process repeated.



SUBMARINE F-4 IN DRYDOCK FOLLOWING SALVAGE.
FIGURE 1-1

S-4 UNDER TOW ARRIVING AT THE BOSTON NAVY YARD.
FIGURE 1-2

The operation was attended by all of the adverse elements normally associated with underwater salvage; failure of equipment, accidents, and bad weather conditions slowed the job considerably. After weeks of lifting and towing, the wreck was finally hauled into shallow water, at which time a sudden onset of heavy swells carried away all of the lifting slings and severely damaged the submarine. The action of the sea had sawed the cables and chain slings nearly through the hull, making further lift by the scows impracticable. It was feared that the hull would be cut entirely in two, or that the bow section would sag out of the slings and ground in the harbor. The first submersible pontoons were designed and built to suit the condition of F-4, and to bring her to the surface without further damage.

Perhaps the most significant salvage of a submarine was that of S-51. Prior to this achievement by the NAVY, an unsuccessful attempt had been made to salve S-5.

The salvage problems in these two cases were quite similar as to depth of water, size of the submarine, character of the bottom, availability of qualified divers, and the availability of a suitable salvage vessel and other salvage equipment. S-51 was completely flooded, whereas S-5 had only one main compartment flooded with little if any water in the other compartments. S-5 was rigged for dive, all compartments were intact, and all bulkheads secured. S-51 was rigged for surface, the hull had been opened by collision, and none of the bulkheads was watertight. Both sites were exposed to the open sea, and although S-51 had somewhat better protection from winds than S-5, this difference in exposure was not great insofar as its effect on salvage operations was concerned.

The salvage of S-5 was undertaken with a preconceived notion that the submersible pontoons, which were available in sufficient quantity, could not be used in the open sea. This assumption apparently extended to any form of external lifting force and led to a salvage plan which included only self-lift and required removal of the water from all compartments and large tanks. There were no air salvage connections, so it was necessary to provide spill pipes and air connections for the compartments that were to be dewatered. In preparing the compartments for blowing down, explosives, which were used for cutting and for removal of hatches, caused damage that eventually led to abandonment of the salvage attempt. Utilizing hindsight, it seems clear that the decision to attempt the salvage without any external lift was responsible for failure to recover the submarine. When the salvage began, S-5 was in the most favorable condition of any of the five deepwater salvages that the US NAVY has undertaken. In the other four cases, external

S-51 SUPPORTED BY PONTOONS UNDER TOW AFTER SUCCESSFUL SALVAGE.

FIGURE 1-3

lift was included in the salvage plan and greatly reduced the amount of work required. External lift may have been the factor that made the difference between success and failure in these attempts.

The S-51 salvage operation is of great interest because:

1. There was a well-conceived salvage plan.
2. Problems encountered were diagnosed and overcome as they occurred.
3. The salvage plan was adjusted as better information became available, and as difficulties were encountered.
4. An excellent technical report was prepared covering all features of the operation, with particular emphasis on the difficulties.
5. The salvage force was at all times confident of success even though many things seemed to be going wrong. This confidence is present in all successful salvage operations, and even the most discouraging catastrophies do not affect it. This confidence or determination to succeed is the essential part of any salvage plan.

By contrast, the raising of S-51 proved to be a valuable experience to the US NAVY. Tunneling under the submarine, using water jets supplied by a 2-1/2-inch firehose, created problems for the divers. These centered about the handling of the hose and nozzle when subjected to pressure sufficient to cut and wash away the soil on the bottom. This brought about the development of a balanced washing nozzle that speeded the tunneling required for rigging of slings. During the winter, when salvage was suspended, a new underwater cutting torch was developed, as well as a more efficient underwater light.

For the first time, actual experience was gained in calculating the suction effect of the bottom, and determining breakout force needed to overcome it. The big 80-ton pontoons were found to be extremely difficult to control when placed alongside S-51, and again, when they were on the surface knocking about in rough seas. This experience, described in the S-51 salvage report, proved valuable later when S-4 salvors prepared for their job. The pontoons were modified to make them easier to handle, based primarily on the S-51 report.

A little more than eighteen months after S-51 was salved, on 17 December 1927, another submarine disaster struck the US NAVY.

S-4 sank off Provincetown, Cape Cod, after colliding with a Coast Guard destroyer. The NAVY decided to salve the submarine even though the salvors were faced with the prospect of conducting diving operations in midwinter. The rescue vessel FALCON and many of the divers who had worked on S-51 were on hand for the job, and, consequently, the salvage work proceeded at a good rate. In the beginning, the divers had problems with air lines freezing, which caused particles of ice and snow to fly about in their helmets. This was corrected by the invention and installation of an air conditioning plant that heated the divers's air.

In many respects the raising of S-4 was similar to that of S-51. Both submarines had been sunk through collision which opened the pressure hull and flooded compartments that could not be sealed. In both cases tunneling was required to permit reeving chain slings, and the raising was done by dewatering compartments and using submersible pontoons. However, aside from the weather, the S-4 operation was easier. The excellent salvage report of S-51 and the availability of the same salvage ships, officers, crew, and divers speeded the work. The water was shallower and protected from the open sea; the new washing nozzle cut tunneling time from days to hours; the sea floor was soft and porous, and, consequently, the suction effect was negligible when breaking the wreck free of the bottom. The submersible pontoons were modified to the condition described in Chapter 5. This is the only salvage of a US submarine which was so meticulously planned that nothing serious seems to have gone wrong. It is an excellent example of the value of detailed knowledge of previous salvage operations.

The S-4 disaster occasioned a serious review by the NAVY of problems concerning submarine safety and personnel rescue. There resulted many innovations, mostly in the field of rescue devices. The tragedy of not being able to rescue trapped men at the shallow depth of 102 feet spurred the development of the Momsen escape lung and the McCann rescue chamber. This latter device was to save thirty three men of USS SQUALUS, trapped in 240 feet of water. Also, salvage air connections were installed on all compartments, main ballast tanks, and fuel oil tanks.

Other maritime nations were not without their submarine accidents as is illustrated in Table 1-1. At the time of the S-4 sinking, Britain listed fourteen submarines sunk, while France had suffered eight losses. The worst attrition rate for submarines occurred during a 24-day period in 1939. First, USS SQUALUS sank on 23 May; eight days later, HMS THETIS went down followed by the French submarine PHENIX.

Unlike S-51 and S-4, SQUALUS was raised in three stages, the first two of which were accomplished without any attempt to remove water from the flooded compartments. All lifting forces were supplied by pontoons, and ballast tanks were blown through salvage air fittings. For the third and final lift, water was removed from the main compartments and the number of pontoons reduced.

The interesting features of this operation were:

1. The salvage was accomplished in three stages.

2. Control pontoons were used to limit the distance the ship was lifted.

3. No water was removed from the main compartments while the submarine was in deep water.

4. When SQUALUS was brought to shallow water (90 feet), and the main air induction valve closed by external gagging, the compartments were pumped down. To assist the pumps against a 90-foot head of water, air pressure equal to the sea pressure was applied to the compartments. In this way, much work which had been done on the previous salvage operations to make the compartments tight against internal pressure was avoided.

5. The salvage plan adopted for SQUALUS was to minimize divers's time on the bottom in the initial deep site. Of particular interest is the fact that the submarine was rigged with pontoons and actually raised off the bottom after only 31 man-hours of diving. Although this attempt failed because of lack of control, the additional time that would have obviated this deficiency would not have exceeded one man-hour.

6. Only two locations were used for pontoon slings while the submarine was in deep water. Since the hull of SQUALUS was clear of the bottom at one of these locations, it was necessary to provide only one passage for slings through the mud. For this passage a lance was devised which was safer and required much less work by the diver than the previous tunneling method.

In the Appendices are two reports of British submarine salvage operations which reflect a different approach for recovering a wreck. These reports describe the techniques for lifting by a specially designed "lift ship" which literally hauls the submarine up from the bottom by cables at the surface.

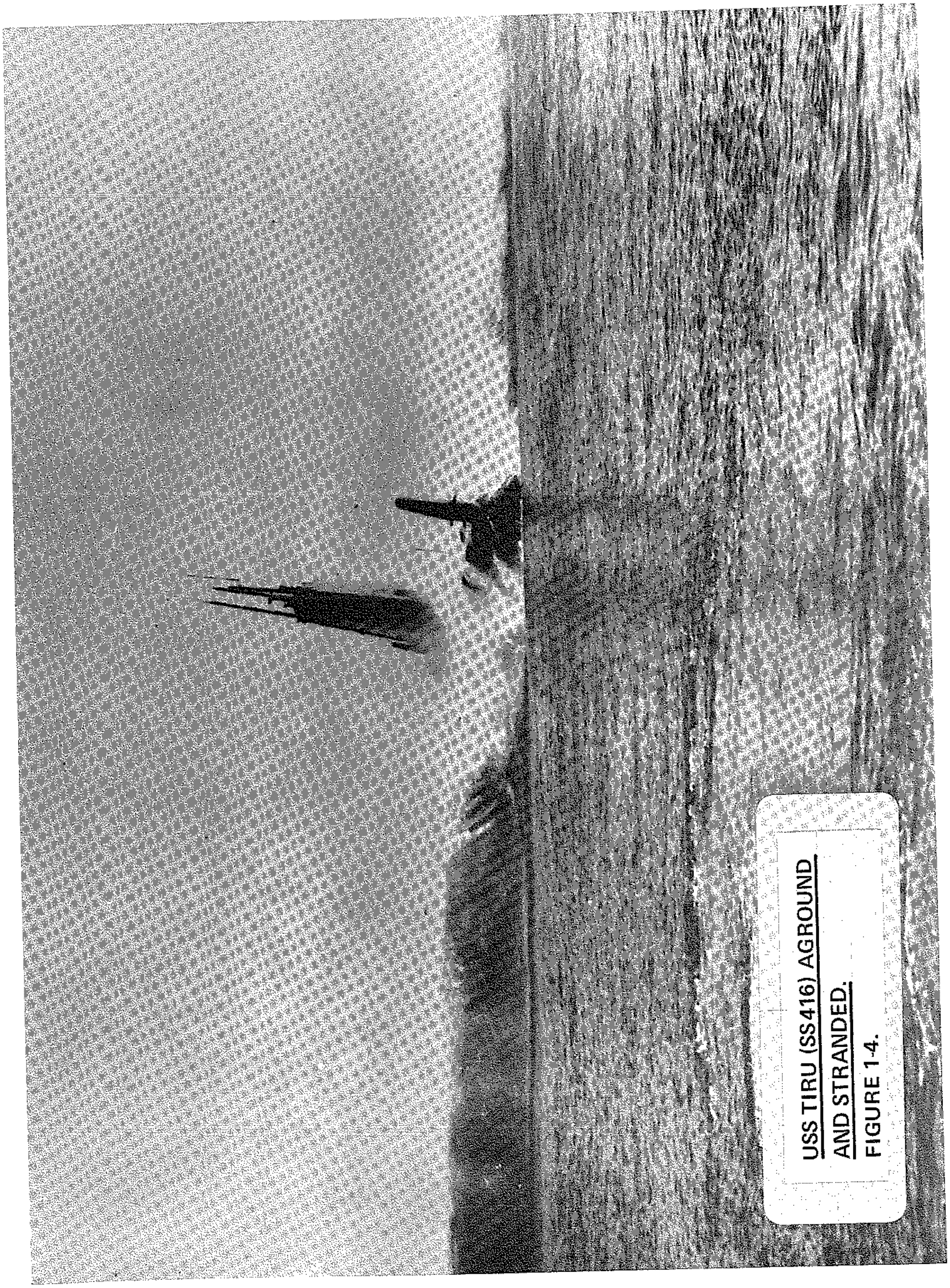
HMS THETIS was salved employing a lift method not previously used and it required finding a suitable vessel to accomplish the task.

In almost all cases of submarine salvage, specialized equipment and material were designed specifically for the job A notable exception was the work on S-4 which was undertaken very shortly after the salvage of S-51. Generally, after each major undertaking, the salvage force was disbanded and the specialized equipment put in storage. It has been found to be too costly to maintain a large manned force in anticipation of a submarine salvage job. In salvage, time is rarely of the utmost importance; the rescue aspects in such an event have normally been concluded before the salvage force moves in.

It is difficult to forecast submarine accidents, as it is with any other disaster. The time between the sinking of S-4 and SQUALUS was twelve years. During World War II, some fifty two submarines failed to return from patrols; possibly some small portion of these were due to accidents and not through enemy action. However, if such wartime accidents did occur, they must be few in number judging from the evidence available since the war. Of the four US NAVY submarine losses following World War II, it is interesting to note that all went down in water too deep for salvage. USS COCHINO sank in 840 feet of water, USS STICKLEBACK was sunk in 9000 feet of water. USS THRESHER was lost in 8400 feet of water, and USS SCORPION in 10,000 feet of water.

What can be anticipated in water depths for a submarine salvage operation? The majority of submarine accidents occur in or near congested water routes to ports. If failure of equipment is involved, the casualty will usually occur during the first few hours underway or during the initial trim dive. These conditions tend to make the locale of a submarine casualty coincide with the shallower ocean areas.

The limiting depth from which a submarine can be salved can only be expressed in terms of the latest operational techniques in diving by men, or submersibles, and the operational availability of a lifting force to be applied to the submarine. Pontoons, lifting slings, or a water-blowing system must be attached or applied to the submarine in some manner or combination, if it is to be raised. As the depth of the sunken submarine increases, the feasibility of surface-supported diving or lifting with cables decreases. At the present time, divers still must be used to seal up compartments and to cut tunnels for necessary pontoon slings. Deep sea diving, supported from a surface salvage vessel, is the only method there is at this time for performing underwater work in salvage operations.



USS TIRU (SS416) AGROUND AND STRANDED.
FIGURE 1-4.

The current experimentation and research in advanced diving systems employing pressurized habitats, lock-out saturated diving techniques, submersibles with diver lock-out capabilities, and the various combinations possible for deep diving will initiate some radical changes in future operations. The Salvage Officer will, of course, employ the latest operational techniques available to him.

The deep sea diver today depends directly on the surface ship to supply his breathing gas, communications and underwater tools. He is limited in depth to about 250 feet if breathing air, or 380 feet if he is on a helium-oxygen mixture. The new technique of saturation diving using the Personnel Transfer Capsule is extending diver depths to 600 feet and more. There are other limitations in diving, other than the physiological ones. Currents, even moderate ones, can drag a diver off his feet if he is in deep water, with the long scope of his life line and air hose being affected by this force. The weather conditions on the surface may prohibit diving because of the danger of the tending ship dragging anchor, or the surging of the vessel causing lines to become fouled. Divers working in deep water will have their time on the bottom shortened and will have to undergo extended decompression periods. This will necessitate a large manning requirement in order to rotate divers safely so as to keep the operation going and take advantage of good weather.

A Salvage Officer can begin to appreciate the involvement of personnel and time in performing an underwater salvage job by reviewing the operations discussed in the Appendices. Apply these experiences to a different salvage problem, such as one in 350 feet of water with a hard clay and rock bottom. How long would a diver be able to work with a lance in washing a tunnel? What are the risks involved when divers enter compartments to seal them? What is available to commence such a salvage job under these conditions? The purpose of this submarine salvage manual is to provide answers to some of these questions and to help the Salvage Officer in estimating his job and planning for the successful recovery of a submarine.

TABLE 1-1

ACCIDENTAL SUBMARINE SINKINGS SINCE 1904

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
March 18, 1904	U.K.	A-1	42	11	yes	Collision; rammed at periscope depth by the SS BERWICK CASTLE off Nab Lightship, Spithead, England.
June 20, 1904	Russia	DELFIN	*	26	yes	Flooded via open hatch while trimming on the surface off Kronstadt, Russia, by wash from passing steamer.
1905	France	ANGUILLE	*	none	yes	Gasoline explosion.
June 8, 1905	U.K.	A-8	180	14	yes	Flooded via open hatch while making high speed on surface; off Plymouth, England.
July 6, 1905	France	FARFADET	100	all	yes	Flooded via open hatch while diving off Bizerte, Tunisia.
Oct. 16, 1905	U.K.	A-4	*	*	no	Rammed off Plymouth, England.
Aug. 13, 1906	France	ESTURGEON	*	none	yes	Sunk at dock at Saigon.
Oct. 16, 1906	France	LUTIN	110	13	yes	Flooded via leaky hull plates, after end; lost off Bizerte, Tunisia.
Jan. 11, 1907	France	ALGERIEN	40	none	yes	Sunk during absence of crew because of carelessness in mooring.
April 26, 1909	Italy	FOCA	*	13	yes	Flooded after internal explosion.
June 12, 1909	Russia	KAMBALA	*	20	no	Rammed by battleship RESTISLAV while running on surface; cut in half and sunk.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
July 14, 1909	U.K.	C-11	*	13	no	Sunk in collision with SS EDDISTONE off Dover, England.
April 15, 1910	Japan	No. 6	*	14	no	Flooded via open ventilation valve during deep dive.
May 26, 1910	France	PLUVIOSE	*	26	*	Collided with mail steamer PAS DE CALAIS in English Channel.
June 1, 1910	Russia	FOREL	*	*	yes	Sunk while being towed.
Jan. 17, 1911	Germany	U-3	30	3	yes	Flooded while at mooring in Kiel docks. Men escaped via torpedo tubes. Lifted by crane.
Feb. 2, 1912	U.K.	A-3	66	14	yes	Rammed by gun boat HAZARD off Isle of Wight while running submerged.
June 8, 1912	France	VENDEMI-AIRE	350	24	no	Broke surface ahead of battleship ST. LOUIS during maneuvers off Cape de la Hague, France.
Oct. 4, 1912	U.K.	B-2	*	15	no	While running on surface at night off Dover; was rammed and sunk by liner AMERIKA; probably cut in two.
1913	Russia	MINOGA	*	none	yes	123-ton. Sunk near Libau in the Baltic Sea. Cause unknown-pulled to surface 12 hours after sinking.
June 8, 1913	U.K.	E-5	*	3	*	Flooded following internal explosion; sunk.
Dec. 10, 1913	U.K.	C-14	*	none	yes	Running on surface in Squadron. Rammed by lighter and sunk.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
1914	Netherlands	O-5	*	1	yes	Sunk at Scheldt Quay, Netherlands
Jan.16, 1914	U.K.	A-7	150	11	no	Failed to come to the surface after submerged run in Whitesand Bay off Plymouth, England.
July 8, 1914	France	CALYPSO	500	3	no	Collision with submarine CIRCE while cruising on the surface; due to jammed rudder.
Sept.14, 1914	Australia	AE-1	*	all	no	Failed to return from training dive.
March 25, 1915	U.S.	F-4	306	22	yes	Flooded; failure of hull plates during dive off Honolulu.
Aug.8, 1916	U.K.	E-4	66	all	no	Collision with the E-41 off Harwich, England.
Aug.8, 1916	U.K.	E-41	60	none	yes	Collision with the E-4.
Oct.10, 1916	Denmark	DYKKEREN	28	1	yes	Sunk off Copenhagen after collision with a Norwegian merchantman abaft conning tower.
Jan.29, 1917	U.K.	K-13	55	49	yes-and recommissioned as K-22	Flooded; boiler room ventilators open during test dive in the Gareloch, Scotland.
March 19, 1917	Germany	UB-25	*	16	yes	Rammed and sunk with DDV-26.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
Sept.14, 1917	U.S.	D-2	30	none	yes	Flooded at dockside via "slow leaks" into machinery compartment; New London, Conn.
Sept.17, 1917	Germany	UC-45	*	*	yes- and re-commis-sioned	Foundered in North Sea as result of material failure.
Nov.18, 1917	U.K.	K-1	*	none	*	Sank in North Sea after collision with H.M. sub K-4.
Dec.6, 1917	Germany	UC-69	*	11	*	Sank in English Channel after collision with U-96.
Dec.7, 1917	Germany	UB-84	*	19	yes- and re-commis-sioned as training boat	Sunk in Baltic Sea following collision.
Dec.17, 1917	U.S.	F-1	600	19	no	Collision; port side abaft the main hatch; off Point Loma,Calif. Collided with F-3.
1917	U.K.	H-5	*	all	no	Collision; rammed by British merchant vessel, mistaken for a German submarine.
Jan.31, 1918	U.K.	K-17	*	42	no	Sunk by collision with British cruiser FEARLESS off Firth of Forth, Scotland.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
Jan.31, 1918	U.K.	K-4	*	50	no	Sunk by collision with British SS K-6 off Firth of Forth, Scotland.
Feb.18, 1918	Russia	IGOR	*	*	*	Foundered in the ice off Revel, Estonia.
March 15, 1918	Germany	UB-106	*	35	yes- and re-commis-sioned	Sunk in Baltic Sea through mate-rial casualty.
April 29, 1918	France	PRAIRIAL	*	*	*	Sunk by collision with merchant-man off Le Havre, France.
Aug.2, 1918	France	FLOREAL	*	*	*	Sunk by collision off Saloniki, Greece.
Sept.5, 1918	Germany	UC-91	*	*	yes- and re-commis-sioned	Sunk by collision with German steamer ALEXANDER WOERMANN.
Oct.21, 1918	Germany	UB-89	*	7	yes- surren-dered after armistice	Sunk by collision with German cruiser FRANKFURT.
July 30, 1919	U.S.	G-2	80	3	yes	Flooded via leaky hatch cover in heavy seas; Long Island Sound. Salved by blowing apart, 1962.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
March 12, 1920	U.S.	H-1	50	4	no	Grounded during storm near Point Redondo, Magdalena Bay, Columbia. Later sank during salvage operations.
Sept.1, 1920	U.S.	S-5	194	none	no	During dive, flooded via open main induction; off the Delaware Capes. Stern was raised and crew escaped through hole cut in stern. Later attempts to salve were a failure.
Jan.20, 1921	U.K.	K-5	*	57	no	Cause unknown; 120 miles S.W. of Scilly Islands while practicing an attack on the Atlantic Fleet.
Sept.26, 1921	U.S.	R-6	32	2	yes	Flooded via tube; failure of interlocking mach.; alongside her tender, CAMDEN, San Pedro Harbor, Calif. Raised in 17 days.
Oct. 1921	Nether-lands	O-8	*	none	yes	After section filled with water and sank during her fitting-out period in the basin at Den Helder, Netherlands.
Dec.7, 1921	U.S.	S-48	67	none	yes	Flooded via manhole cover from MBT #5, during trials, Long Island Sound off Bridgeport, Conn.; escape was made via torpedo tube.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
March 23, 1922	U.K.	H-42	3000	26	no	Collision with destroyer; was rammed and sunk after it broke surface ahead of VERSATILE off Gibraltar.
July 17, 1923	U.S.	S-38	102	none	yes	In Anchorage Bay, Alaska; sank due to accidental flooding of the motor room; S-38 settled by the stern until water came up to conn. tower plat. aft; further sinking prevented by air pressure. Towed into shoal water and pumped out.
Aug.21, 1923	Japan	RO-31	*	all	yes	Flooded; premature opening of hatch before securely surfaced off Kariga, Hyogoken.
Oct.29, 1923	U.S.	O-5	42	3	yes	Collided with United Fruit steamer ABANGARES; approx. amidships; Limon Bay near entrance to Panama Canal Zone.
Jan.10, 1924	U.K.	L-24	180	41	no	During mimic attack on the Atlantic Fleet battleships, surfaced almost under bow of the battleship, RESOLUTION, and was rammed.
March 19, 1924	Japan	RO-25 (ex-#43)	156	all	no	Collision with cruiser TATSUTA off Sasebo Harbor, Japan.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
Aug.26, 1925	Italy	SEBASTIANO VENIERO	300	all	no	Collision off Cape Passero, Sicily, with SS CAPEA while running submerged.
Sept.25, 1925	U.S.	S-51	132	33	yes	Collision with SS CITY OF ROME off Block Island. Hit fwd. of the conn. tower, port side.
Oct.29, 1925	Japan	RO-52 (ex-#26)	48	none	yes	Flooded via tube during repairs, Kure Harbor, Japan, alongside cruiser YAHAGI.
Nov.12, 1925	U.K.	M-1	*	all	no	Collision with Swedish steamer, VIDAR, while running submerged in the North Atlantic.
Aug.9, 1926	U.K.	H-29	32	6	yes	Flooded at dockside while trimming on the surface with open hatches.
Dec.17, 1927	U.S.	S-4	102	all	yes	Collision with USCG destroyer PAULDING just fwd, amidships, while off Provincetown, Mass.
Aug.6, 1928	Italy	F-14	*	31	yes	Collision off Pela in Adriatic Sea with Italian destroyer MISSORI.
Oct.3, 1928	France	ONDINE	*	43	no	Collision off Vigo, Spain, with a Greek steamer.
July 8, 1929	U.K.	H-47	*	20	no	Collision with the British submarine L-12 in St. George's Channel off Pembroke, Wales. Two men on L-12 lost.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
May 26, 1931	Russia	B-9 (ex-RABOCHY)	*	"heavy"	*	Cause unknown; lost during maneuvers in the Gulf of Finland.
June 9, 1931	U.K.	POSEIDIN	130	21	no	Collision with steamer TUTA off Wei Har Wei, China.
Oct.24, 1931	Russia	L-55 (ex-British L-55)	*	all (50)	no	Sunk by unknown causes in the Gulf of Finland.
Jan.26, 1932	U.K.	M-2	106	all	no	Flooded during plane launching operations off Portland Bill, England.
Feb.25, 1932	U.K.	H-42	*	all	no	Sunk by unknown causes off Gibraltar.
July 7, 1932	France	PROMETHEE	150	63	no	Flooded via failure of hydraulic MBT vents off Cherbourg, France.
July 25, 1935	Russia	B-3	*	55	yes	Collision with battleship MARAT while surfacing in the Baltic Sea.
Nov.20, 1936	Germany	U-18	*	8	yes-and re-commissioned	Sunk by collision with German torpedo-retriever T-156 off Luebeck, Germany.
Dec.12, 1936	Spain	unidentified	*	45	no	Sunk by internal explosion off Malaga, Spain.
Feb.2, 1939	Japan	I-63	*	all	no	Collision; lost in Bungo Channel.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
May 23, 1939	U.S.	SQUALUS	240	26	yes	Flooded, mechanical failure of main engine induction valve during test dive off Portsmouth, N.H.
June 1, 1939	U.K.	THETIS	120	99	yes	Flooded via torpedo tube off Mersey, Liverpool Bay.
June 16, 1939	France	PHENIX	390	all	no	Cause unknown; lost off Point Cam Ranh Bay, South Vietnam.
July 24, 1939	Russia	SHCH-424	*	*	no	Sunk by collision with a fishing trawler in Kola Inlet, Barents Sea.
Jan.30, 1940	Germany	U-15	*	*	*	Sunk by collision with German destroyer IL TIS off Helgoland, North Sea.
March 6, 1940	Nether-lands	O-11	30	3	yes	Collision; rammed by Naval tug while on the surface off Helder Navy Yard, Netherlands.
April 29, 1940	U.K.	UNITY	*	4	*	Sunk by collision with steamer ATLE JARL off South English coast.
Aug.29, 1940	Japan	I-67	*	*	*	Sunk during maneuvers in Japanese waters.
Nov. 1940	Russia	D-1	*	*	no	Sunk by diving accident in Motovsky Bay, Arctic Coast.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
June 20, 1941	U.S.	O-9	440	all (33)	no	Flooded; crushed hull while exceeding test depth of 212 ft. off Isle of Shoals, New England Coast.
July 19, 1941	U.K.	UMPIRE	65	15	no	Collision; rammed forward by A/S trawler P. HENDRICKS.
Oct. 1941	Germany	U-579	*	*	yes-recommissioned	Sunk by collision in Baltic Sea.
Oct.3, 1941	Japan	I-61	*	all	yes	Cause unknown; lost off Kyushu, Japan.
Nov.11, 1941	Germany	U-580	*	12	*	Sunk by collision off Memel, E. Prussia.
Nov.15, 1941	Germany	U-583	*	45	*	Sunk by collision in Danzig Bay, Baltic Sea.
Jan.24, 1942	U.S.	S-26	300	46	no	Collision with PC 460 while on surface; stbd., amidships; 14 miles off Balboa, Canal Zone.
May 2, 1942	Poland	JASTRZAB (ex-Brit-P551) (ex-US S-25)	*	*	*	Sunk by collision with British Battleship KING GEORGE V in the Norwegian Sea.
May 1942	Russia	SHCH-212	*	*	no	Lost near Sevastopol on the Black Sea due to explosion of gasoline fumes.
June 21, 1942	U.K.	P-514	*	all	no	Cause unknown; reported as rammed and sunk by HMCS GEORGIAN in West Atlantic Ocean.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
July 14, 1942	Turkey	ATILAY	*	*	*	Lost by accident while on trials off Kanakkale, Turkey.
Aug.6, 1942	Germany	U-612	*	*	yes-recommissioned as a training boat	Sunk off Warnemuende, Baltic Sea Coast by material casualty.
Sept.2, 1942	Germany	U-222	*	42	*	Sunk by collision off Pillau, East Prussia.
Sept.4, 1942	Sweden	SJOEBORREN	*	*	yes-recommissioned	Lost by collision in the Baltic Sea.
Sept.27, 1942	Japan	I-33	*	*	yes-recommissioned	Accidentally foundered at TRUK Island.
Nov.4, 1942	U.K.	X-3	114	3	yes	Flooded via leaky sea valve in Loch Striven.
Nov.12, 1942	Germany	U-272	*	28	*	Lost by collision off Hela Peninsula, Baltic Sea.
Feb.24, 1943	Germany	U-649	*	35	*	Lost by collision in the Baltic Sea.
Feb.24, 1943	U.K.	VANDAL	*	*	*	Sank in the Firth of Forth due to diving failure.
March 19 1943	Germany	U-5	*	21	*	Lost in Danzig Bay due to diving failure

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
May 30, 1943	U.K.	UNTAMED	160	all	yes-recom-missioned as VITALITY	Flooded off Campbeltown, Scotland.
June 12, 1943	U.S.	R-12	600	42	no	Flooded via forward torpedo tube during training cruise south of Florida.
1943	Norway	WELLMAN X	186	none	no	Cause - accident.
July 14, 1943	Japan	I-179	*	*	*	Accidental sinking, Inland Sea.
Aug.5, 1943	Germany	U-34	*	4	*	Sunk by collision off Memel, East Prussia.
Aug.12, 1943	Sweden	ILLERN	*	*	yes	Sunk by collision with a steamer in the Baltic Sea.
Aug.20, 1943	Germany	U-670	*	21	*	Sunk by collision with target ship BOLKOBURG in Bay of Danzig, Baltic Sea.
Sept. 1943	Russia	M-60	*	*	no	Failed to surface after diving in the Black Sea.
Sept.20, 1943	Germany	U-346	*	37	*	Accidental sinking in the Baltic Sea.
Nov.18, 1943	Germany	U-718 q	*	43	*	Sunk by collision with U-476 off Bornholm, Is., Baltic Sea.
Nov.20, 1943	Germany	U-768	*	*	*	Lost by collision, Baltic Sea.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Dept (Ft)	Men Lost	Salved	Geographical Location and Cause
Feb.14, 1944	Germany	U-738	*	9	*	Lost by collision with steamer off Gdynia, Baltic Sea.
Feb.18, 1944	Germany	U-7	*	26	*	Diving failure in Danzig Bay, Baltic Sea.
1944	Germany	U-1013	*	25	*	Lost by collision with U-286 east of Ruegen Is., Baltic Sea.
April 8, 1944	Germany	U-2	*	27	yes	Lost by collision with fishing trawler H. FROESE off Pillau, Baltic Sea.
May 14, 1944	Germany	U-1234	*	13	yes-recom-missioned	Lost by collision with a tug off Gdynia, Baltic Sea.
May 19, 1944	Germany	U-1015	*	36	*	Sunk by collision with U-1014 in Danzig Bay, Baltic Sea.
June 13, 1944	Japan	I-33	*	*	*	Lost in Inland Sea by material casualty.
July 4, 1944	U.S.	S-28	8400	50	no	Cause unknown; material casualty; lost off Hawaii.
July 22, 1944	Germany	U-1166	*	*	raised-scrapped	Sunk in Eckern Fjord, Baltic Sea, by torpedo explosion.
July 27, 1944	Russia	V-1 (ex Brit SUNFISH)	*	*	no	Sunk by mistake by British air-craft in the North Sea.
Sept.21, 1944	Russia	SHCH-402	*	*	no	Sunk by mistake by Soviet air-craft near Fish Harbor, Norwegian Coast.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
Sept. 1944	Germany	U-703	*	54	*	Foundered east of Greenland while attempting recovery of a weather buoy.
Oct.10, 1944	Germany	U-2331	*	15	*	Sunk off Hela Peninsula, Baltic Sea, due to material casualty.
Nov.28, 1944	Germany	U-80	*	*	*	Material casualty, Baltic Sea.
Dec.12, 1944	Germany	U-416	*	36	*	Rammed and sunk by German mine-sweeper while approaching Pillau, E. Prussia.
Dec.30, 1944	Germany	U-382	*	*	*	Sunk by collision in Danzig Bay, Baltic Sea.
Feb.18, 1945	Germany	U-2344	*	7	*	Sunk by collision off Heligendamm, Baltic Coast.
March 6, 1945	U.K.	XE-11	204	2	no	Collision while running sub-merged; Loch Striven.
May 12, 1946	France	U-2326 (ex German)	*	*	*	Lost by material casualty off Toulon, France.
June 1946	Spain	C-4	*	*	*	Sunk by collision with the Spanish Destroyer LEPANTO in exercises off the Bolearic, Is.
Nov.21, 1947	U.K.	P-511	*	all	yes-raised-scrapped	Cause unknown; reported as lost as the result of "perils of the sea."

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
Aug.26, 1949	U.S.	COCHINO	840	one civilian technician	no	Flooded following hydrogen explosions; in the Barents Sea, 100 miles north of Hammerfest, Norway. USS TUSK assisted in rescue and lost six of her crew.
Jan.12, 1950	U.K.	TRUCULENT	66	61	yes	Collision with Swedish tanker DIVINA; 55 miles east of London, Thames Estuary.
April 17, 1951	U.K.	AFFRAY	198	75	no	Flooded due to failure of snorkel mast weldment; English Channel.
Sept.24, 1952	France	LA SIBYLLE	3000	70	no	Flooded in unknown manner, near Toulon, France.
April 4, 1953	Turkey	DUMLUPINAR (ex-USS BLOWER-SS 325)	228	all	no	Collided with Swedish NABOLAND, struck near the bow; in Dardanelles.
June 16, 1955	U.K.	SIDON	36	13	yes	Flooded, internal casualty in Portland Harbor, England.
May 30, 1958	U.S.	STICKLE-BACK	9000	none	no	Collision during maneuvers with destroyer, 19 miles S.W. of Pearl Harbor.
1959	Chile	O'BRIEN	30	none	no	Slow flooding overnight while moored; near Naval Base, Talcahuano, Chile.

* Unknown

TABLE 1-1 (Cont)

Date	Country	Submarine	Depth (Ft)	Men Lost	Salved	Geographical Location and Cause
April 10, 1963	U.S.	THRESHER	8400	129	no	Cause unknown; off New England Coast.
Oct. 1963	Russia	PUCHINA	*	*	yes	Sunk in collision with merchant-ship Kola Gulf, Barents Sea.
Sept.15, 1966	West Germany	HAI	145	19	yes	Flooded during North Sea Gale.
Jan. 26 1968	Israel	DAKAR	*	69	no	East Mediterranean
Jan. 27 1968	France	MINERVE	*	52	no	Western Mediterranean
May 27 1968	U.S.	SCORPION	12000	99	no	Atlantic, South-West of the Azores
May 15 1969	U.S.	GUITARRO	35	0	yes	Mare Island Naval Shipyard, Vallejo, California; flooded.
March 2 1970	France	EURYDICE	*	45	no	Mediterranean

2. Diving Systems

2.1. Introduction

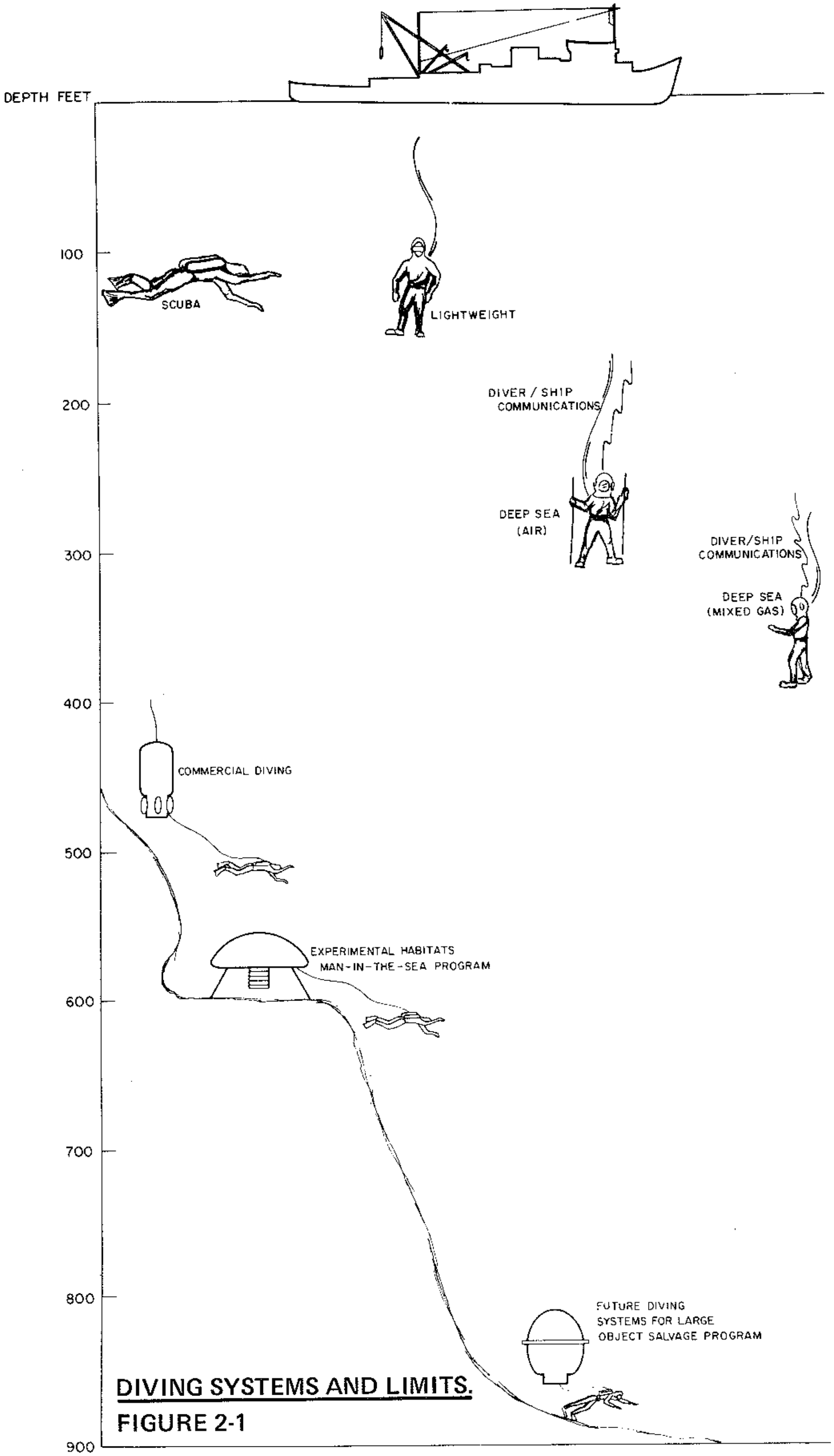
One of the important components in the salvage of sunken submarines is the diving system. Through the diving system, the Salvage Officer has access to the wreck site for observation and actual work to be performed (see Figure 2-1). The diving system includes the vessel from which the diver operates, and the diver support devices such as diving stages, lifting booms, underwater tools, tunneling equipment and any underwater observation equipment such as television, photography or observation chambers. In almost all cases, the pivotal role in this system is that of the diver; his performance capability may be the limiting factor in the operations.

2.2. Diving Physiology

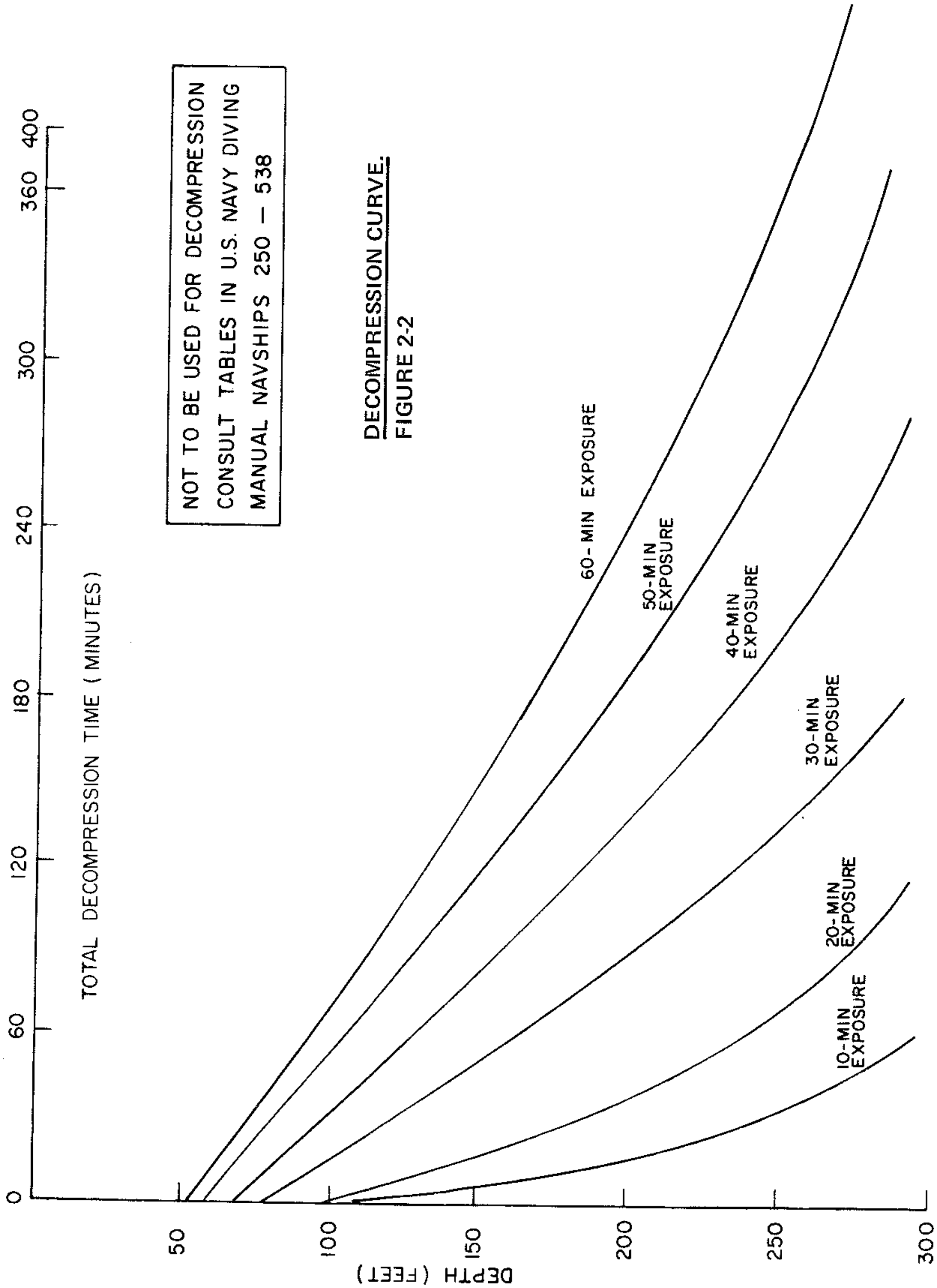
While the diver may be seriously handicapped in the performance of his work by the physical aspects of the sea, because of extreme cold or being buffeted about by wave action, the effect of the inhaled gases imposes certain subtle and less obvious limitations. These latter effects are related to the depth of the dive and the length of time the diver is exposed to elevated pressure. As the diver descends, the gas mixture he breathes must be in pressure equilibrium with the pressure surrounding his body.

The vast majority of diving performed in the past century and a half has been done with the diver breathing air. Air is a mixture of gases, chiefly nitrogen (approximately 79 percent), and oxygen (approximately 21 percent). The first and inescapable limitation is imposed on the diver as a result of the absorption of nitrogen in his body in solution in the tissues. The rate at which nitrogen enters his body is related to the depth, while the amount is related in a particular way to the amount of time he is exposed to elevated nitrogen pressure. The amount of gas entering the body is greatest at first, and gradually tapers off as time passes in the manner of a hyperbolic curve. (Figure 2-2 is an illustrative example of such curves.)

It must be kept clearly in mind that the nitrogen in the body in this circumstance is in solution and not in the form of gas pockets. After a sufficient time has elapsed, the diver's body will have taken up gas until very little more is entering.



DIVING SYSTEMS AND LIMITS.
FIGURE 2-1



DECOMPRESSION CURVE.
FIGURE 2-2

The diver's body is then approaching a state of equilibrium with the air he is breathing. For practical purposes in diving operations, it is considered that 12 hours are required for the diver's body to reach approximate equilibrium. It could then be said that his body is saturated with nitrogen for that depth. While this situation does not occur when diving is conducted from a surface vessel, because of time limitations, it does occur when operations are conducted from a submerged habitat or pressurized chamber. It makes no difference, however, as long as the pressure on the diver is unchanging. If pressure is increased, more nitrogen will enter the diver's body. If the diver is placed in a chamber which is maintained at the bottom pressure, the amount of nitrogen will be unchanged. But when the pressure is reduced, the additional gas which has entered the diver's body must leave, and this imposes the limitations of decompression. The pressure can be reduced only at a speed which will ensure that the nitrogen has ample opportunity to leave the diver's body without forming bubbles.

Decompression is accomplished according to a definitely developed plan which can be varied only at the risk of increased danger to the diver. The rate of reducing the pressure (ascent) is faster in the first stage of decompression than it is in the later stages (as the diver approaches the pressure at the surface). If the decompression process is not observed correctly, or "shortcuts" are taken, it must be understood that it is at the diver's peril. The most obvious and common casualty is that accompanying too little decompression time, encouraging the formation of bubbles in the diver's blood stream since the gas is not being adequately eliminated. This manifests itself as decompression sickness which is essentially an interference of blood flow due to the obstruction of a vessel by the bubble or bubbles that have been formed.

There is another problem of diving related to the narcotic effect of nitrogen under elevated pressures which can make the diver intoxicated and render him ineffective. Under certain conditions, pure oxygen can cause convulsions, and if breathed too long, can cause irritation of the lungs and a condition that resembles pneumonia. Diving below 200 feet involves a decision as to whether it should be undertaken using air as a breathing medium, or should be made using helium-oxygen as the breathing gas.

2.3. Diving Equipment

There are several kinds of diving equipment in use by the US NAVY; these are discussed in detail in the US NAVY Diving Manual (NAVSHIPS 250-538). The techniques of diving can be broken-down into two general classifications:

1. Surface-supplied diving which includes the use of deep-sea diving outfits and lightweight rig.
2. Self-contained underwater breathing apparatus (SCUBA).

The deep-sea diving outfit consists of a watertight canvas suit, helmet, weighted shoes, and weight belt (Figure 2-3). The diver breathes compressed air or a mixed gas supplied by the salvage or diving ship through an air hose. This has, for many years, been the primary diving method for performing heavy work underwater. The diver is in communication with the Salvage Officer, on the surface, and can thus report observations or receive instructions.

The lightweight, surface-supplied diving apparatus is also made up in a heavy canvas suit (Figure 2-4). The air is breathed through a full-face mask strapped to the head of the diver. In the lightweight rig, the diver is freer in his movements, but seldom has voice telephone communications with the surface; a definite handicap in salvage operations. A surface-supplied diver, whether in deep-sea dress, or in a lightweight rig, is especially vulnerable to fouling his air hose and lifeline on projections of the wreck. The diver must constantly be aware of his position, and where his air-line might become entangled.

Supervisory personnel must keep in mind that loss of communications with a diver may, but not necessarily so, mean he is having difficulties. Efforts must be made immediately to reestablish communications by auxiliary means, including sending down the stand-by diver to assist if needed.

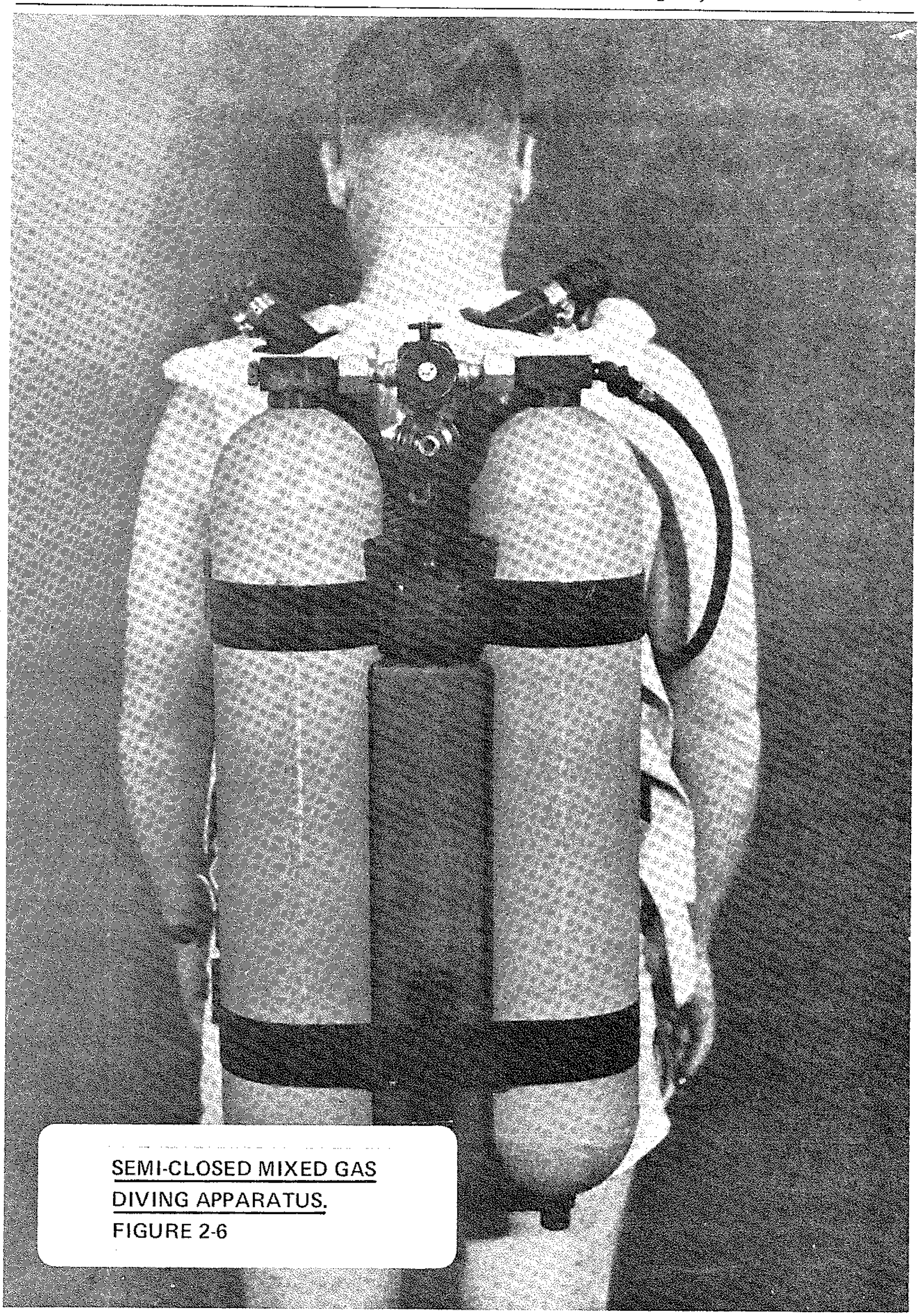
In self-contained diving, there are three types of equipment which have been developed primarily for military, tactical missions. However, the special characteristics of these systems might find an application in salvage work.

The demand type (open circuit) breathing apparatus is the simplest type and the one most frequently used. The diver carries large cylinders of compressed air on his back and breathes through a mouthpiece (Figures 2-5 and 2-6).

DEEP SEA AIR DIVING RIG.
FIGURE 2-3

LIGHTWEIGHT AIR DIVING RIG.
FIGURE 2-4

SCUBA DIVER.
FIGURE 2-5



SEMI-CLOSED MIXED GAS DIVING APPARATUS.
FIGURE 2-6

The high pressure air is reduced at the demand regulator and the diver receives his air supply automatically.

The closed circuit units use pure oxygen as the breathing medium. The diver breathes and exhales the oxygen into a bag that has a canister containing a carbon dioxide absorbent. The advantage of this unit is in freedom from bubbles and noise, and the lightweight compactness of the apparatus. The big disadvantage is the severe limitation of safe depth of use imposed by the possibility of oxygen poisoning.

The closed circuit equipment has other disadvantages which indicate that only personnel who have been thoroughly indoctrinated in their use should be permitted to employ them.

The semi-closed circuit apparatus was developed to conserve gas by rebreathing a gas mixture (nitrogen-oxygen or helium-oxygen) that is proportional to the depth. The system is similar to the closed circuit SCUBA, but a continuous flow of gas ensures that excessive, as well as a lack of, oxygen in the inert gas is not breathed. The diver rebreathes the major part of the gas, but a certain amount is continually exhausted from the system. Considerably longer dives can be made at greater depths with the semi-closed circuit equipment than with the demand type unit.

A new concept of diving has evolved in which gas saturation of the diver is maintained at the pressure at which work is to be accomplished. This technique involves the use of a helium-oxygen gas mixture as a breathing medium to permit deeper penetrations without the debilitating effects of nitrogen narcosis. Instead of terminating the diver's work for the purpose of decompression, he is allowed to become gas-saturated for continued bottom time. Normally, This would require many hours of decompression if the diver is to be brought back to atmospheric pressure for sustenance and rest. Saturation diving removes the rotational decompression cycle of divers by furnishing hyperbaric living quarters where they are provided with sleeping, eating and hygienic facilities.

Several commercial diving companies are actively providing equipment and diver services, utilizing the saturated diving concept; two of them are: Ocean Systems, Inc. (Advanced Diving System IV), and the Westinghouse Corporation (Cachelot Diving System). Since most of the systems now commonly in use are fundamentally alike, the Advanced Diving Systems (ADS IV) is described for familiarization.

The ADS IV consists of two basic components: the living quarters, referred to as the Deck Decompression Chamber (DDC), and the Personnel Transfer Capsule (PTC). The PTC is a spherical chamber that mates with the DDC and can be pressurized for transferring the divers to the work site on the bottom.

The personnel transfer capsule is a single, 6000-pound, pressure-proof, helium-tight, spherical compartment constructed of carbon steel on a support frame. The support frame is designed to provide easy entry to and exit from the PTC for the divers when it rests on the bottom. The internal diameter of the sphere is 64 inches and the shell thickness is one-half inch.

The PTC contains life support and atmosphere monitoring equipment. Life support equipment consists of carbon dioxide scrubbers and a metabolic oxygen makeup system; modified analyzers comprise the monitoring system.

There is a single bottom access trunk, 27 inches long and 24.5 inches wide, with a double hatch arrangement. The outer hatch seats with external pressure and is designed to swing clear of the flange yoke during mating. The inner hatch seats with internal pressure and allows the divers to pressurize the chamber upon reaching the work site, exit, and then return to the surface under pressure.

Viewports and external lighting provide 360-degree visibility from the PTC. The PTC is ballasted to 1000 pounds negative buoyancy in operation. Because it is essential to diver safety that the unballasted PTC have inherent positive buoyancy, the ballast is releasable by the divers to ensure their ability to surface in emergencies.

Electric power, communication, and television control are supplied to the PTC through a composite cable. Gas is surface supplied by a separate hose to the PTC. All lifting is accomplished through use of a separate strength cable. The communications system incorporates a three-wire design to allow the diver, the PTC occupant, and topside control to be on the same circuit concurrently. The PTC is also equipped with two neutrally buoyant helmets which are made of fiberglass and have a special wide viewing port and a diver's communication system incorporated into their basic design.

The outer lock of the larger DDC chamber is primarily used as an entrance lock providing pressured entry to or egress from the mated PTC or deck.

The lock is large enough to permit decompression after medical personnel have entered if the diver needs decompression treatment. It is approximately 88 inches long and has a diameter of 60 inches.

The inner lock is a living chamber providing life support for two divers during decompression from dives up to 600 feet in depth. The inner lock, approximately 104 inches long and 60 inches in diameter, is identical in size to the second single lock living chamber. Interior arrangements of the living chambers are based on human engineering studies previously conducted during the design of chambers for commercial and US NAVY use. Each DDC living chamber is provided with heating and air conditioning, a communications system, and life support equipment.

The arrangement of the DDC provides for eight hatches. There is the PTC to outer lock hatch for diver access to the DDC; this hatch seats with outer lock pressure to permit needed personnel entrance to the inner lock in emergencies. Three hatches form the outer lock: one to the inner lock living chamber and two auxiliary hatches for an additional living chamber and for the occasions when the PTC is mated horizontally. All hatches seat with outer lock pressure to permit transfer under pressure of PTC occupants to living chambers while the other is at a lower absolute pressure. In each of the two living chambers there are two hatches that seat with chamber pressure to provide pressure-tight containment throughout decompression of the DDC occupants.

A weather-proof control console permits centralized topside control of both diving and decompression phases. Gas control, communications, power, and television monitoring are included.

The gas supply for both PTC and DDC consists of 10 gas supply modules consisting of six "T" cylinders each. Gas is fed to the control console and then to the DDC and PTC through flexible high pressure hoses equipped with quick-disconnect fittings.

Current diving practices in the US NAVY limit diving depth according to the following schedule (from: US NAVY Diving Manual):

Depth in Feet	Type of Diving System
25	Oxygen rebreathing SCUBA.
60	Normal working limit for open-circuit compressed air SCUBA.
130	Lightweight diving equipment (air) and maximum limit for open-circuit SCUBA.
150	All divers below qualification of First Class and Master.
250	Surface-supplied deep-sea rig (air).
380	Helium-oxygen deep-sea outfit.
450	PTC/DDC advanced diving systems.

New diving techniques are being developed that will greatly extend these limits and may be operational when the Salvage Officer is preparing for a specific job. To date, various excursion dives have been performed to great depths; the advanced diving system, utilizing a personnel transfer capsule (PTC) and a deck decompression chamber (DDC), has supported working divers to nearly 500 feet.

2.4. Operations

There are other factors that will have a bearing on how deep divers should be employed. Weather and sea state conditions could be such that deep diving would be nearly impossible. If the salvage site is in an unprotected, open sea area with strong currents, divers may only be used for observation. Entering a wreck or working around loose wreckage could prove extremely dangerous. In rough seas or large ground swells, the tending ship for a diver will be rolling and surging about at her moorings. This could cause the air hose and lifeline to draw taut at one moment and at the next allow slack that could become looped on an obstruction of the wreck. If there is a bottom current in the work area of two knots or more, the diver will only be particularly effective since his energies will be directed toward staying in position and preventing his lines from fouling.

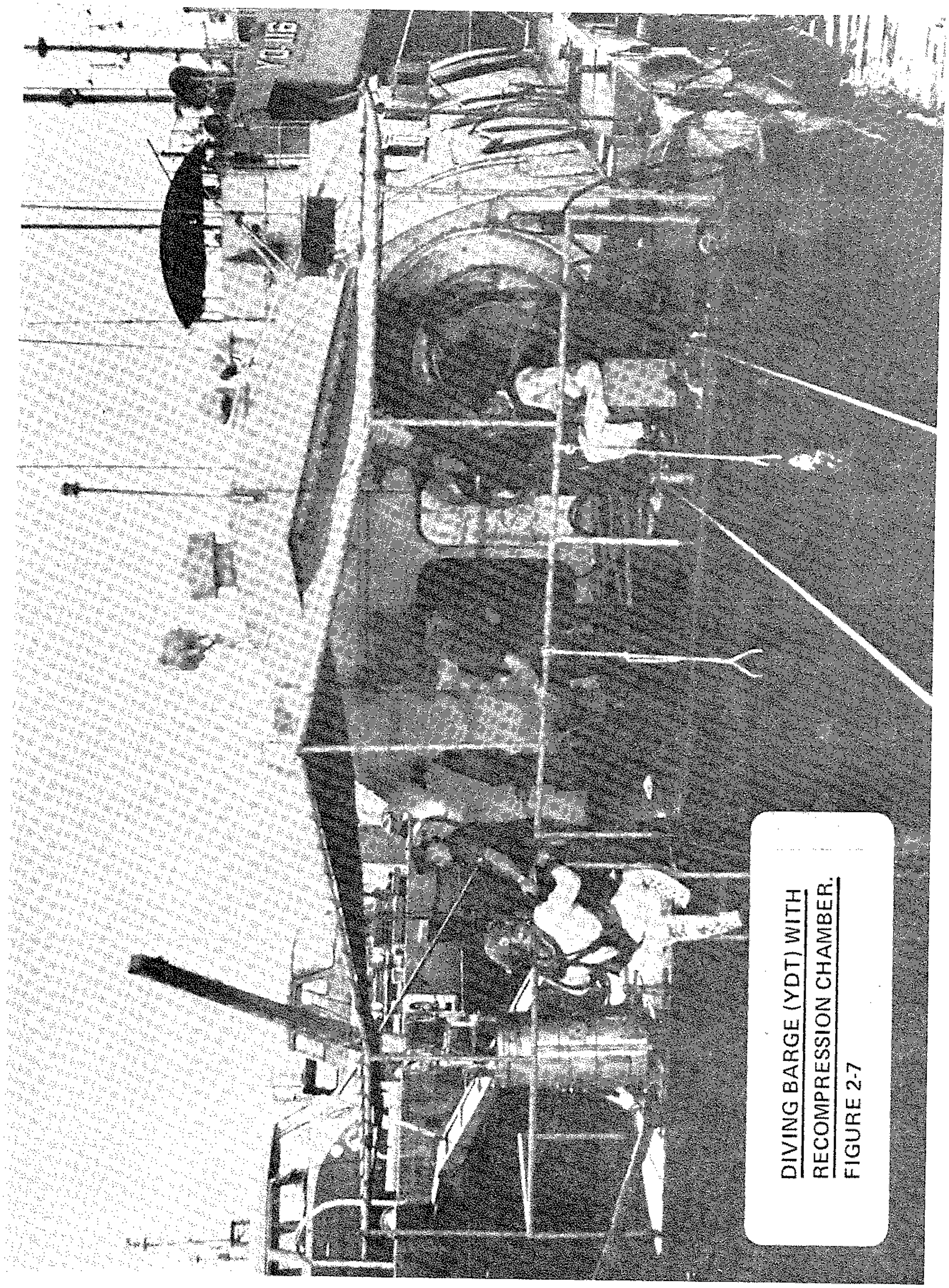
The US NAVY Diving Manual requires that all diving operations be carefully supervised by qualified personnel designated by the Commanding Officer. The responsibility of this designated Diving Officer will be to ensure that proper procedures and safety precautions are met.

Diving operations must be conducted from an appropriately outfitted vessel. The characteristics of the vessel must be set by the requirements of the diving task. Whether it is a small barge (YDT) in shallow water, as shown in Figures 2-7 and 2-8, or a diving ship (Figure 2-9), the adequacy of the moorings is a very important consideration. Security against dragging is of paramount importance when diving operations are in progress. It is not always possible to bring divers immediately to the surface even though they could be decompressed in the ship's recompression chamber. There could be a situation in which one or more divers were inside a wreck and it would take several minutes for them to get clear before being hauled to the surface.

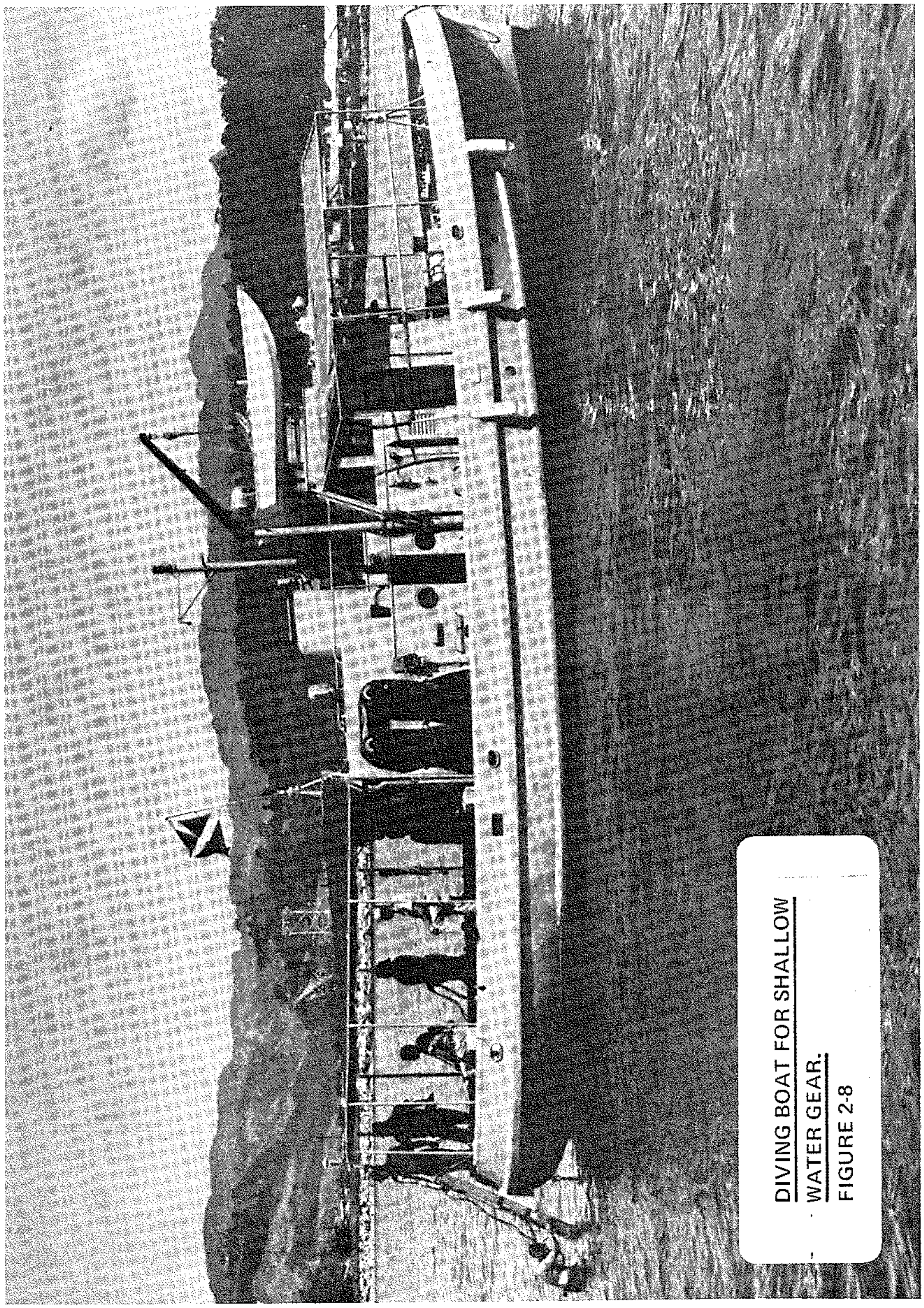
A salvage vessel engaged in diving in deep or exposed areas of rough water cannot rely entirely upon the moor to hold position. A tug (ATF, ATA, YTB) should be assigned to the salvage task force. The tug can carry out a variety of jobs, one of which would be to keep the diving ship in position if heavy weather threatened to drag the moorings while divers were down. The assisting tug is essential to the salvage effort. It will also be able to help in planting the moorings, and if necessary, adjust them afterwards. The tug can be used to bring out barges carrying the cable and heavy anchors used in deep water moors or to tow the submersible pontoons to the salvage site. Next to the salvage vessel itself, the tug is one of the most useful ships the Salvage Officer has.

2.5. Surface Support Ships

The salvage force will have other ships assigned, depending upon the plan of operation. If the salvage plan calls for sealing up compartments in preparation for dewatering, machine shop facilities will be required to fabricate patches, salvage fittings, or other material germane to the task. If such extensive salvage work has to be performed at a distance from a naval shipyard or other suitable industrial plant, a suitably equipped repair ship, tender, or repair barge should be included in the salvage force.



DIVING BARGE (YDT) WITH RECOMPRESSION CHAMBER.
FIGURE 2-7



DIVING BOAT FOR SHALLOW WATER GEAR.
FIGURE 2-8

Other ships and craft may be required for special missions: for example, picket boats to keep shipping away from the area; high speed launches to ferry personnel to and from shore; and work barges for rigging and for use as a work platform for foaming operations.

The types of vessels with which a Salvage Officer will be involved will be the ASR, ARS, YMLC, ATS, and the lift ship or barge.

2.5.1. Submarine Rescue Ship (ASR)

Of the two classes of submarine rescue vessels, the CHANTICLEER class is the largest, displacing 2300 tons, full load. The ships in this class are quite seaworthy for open sea, deep water diving. The ASR's principal mission is submarine rescue and deep diving support.

These ships can place 4- and 6-point moors using 4000-pound Danforth anchors and 3/4-inch dielock anchor chain. The mooring lines from the buoys to the ship use 7-inch nylon. The ASR's carry enough ground tackle to place a 6-point moor in about 1000 feet of water.

Figure 2-9 is a line diagram of the ASR class of ship showing the arrangement of winches, booms and deck space for diving operations. The general characteristics of this ship are as follows:

Length overall	251-1/2	feet
Beam overall	42	feet
Full load displacement	2,300	tons
Full load draft at deepest point	17	feet
Speed (cruising)	10	knots
Speed (maximum)	14	knots
Range	9,600	miles
Boom capacities	two 25-foot booms rated at 10,000 lbs	
	two 32-foot booms rated at 5,000 lbs	
	one 61-foot 11-inch boom rated at 25,000 lbs	

Additional features and facilities on board the ASR include:

1. One McCann submarine rescue chamber.
2. Two double lock recompression chambers (200 psi operating pressure).
3. HeO_2 diving equipment to sustain divers to 380-foot depths.
4. 110 cylinders (22,000 cubic feet) mixed gas (HeO_2, 16 to 20% oxygen).
5. 40 cylinders (8,000 cubic feet) of oxygen for decompression or bends treatments.
6. Eight fathoms 1-1/2-inch dielock and 108 shots of 3/4-inch dielock chain.
7. Four 4000-lb Danforth LWT anchors.
8. Four mooring buoys (spuds) 21 feet by 46-1/4-inch diameter.

2.5.2. Ocean Rescue and Salvage Ship (ARS)

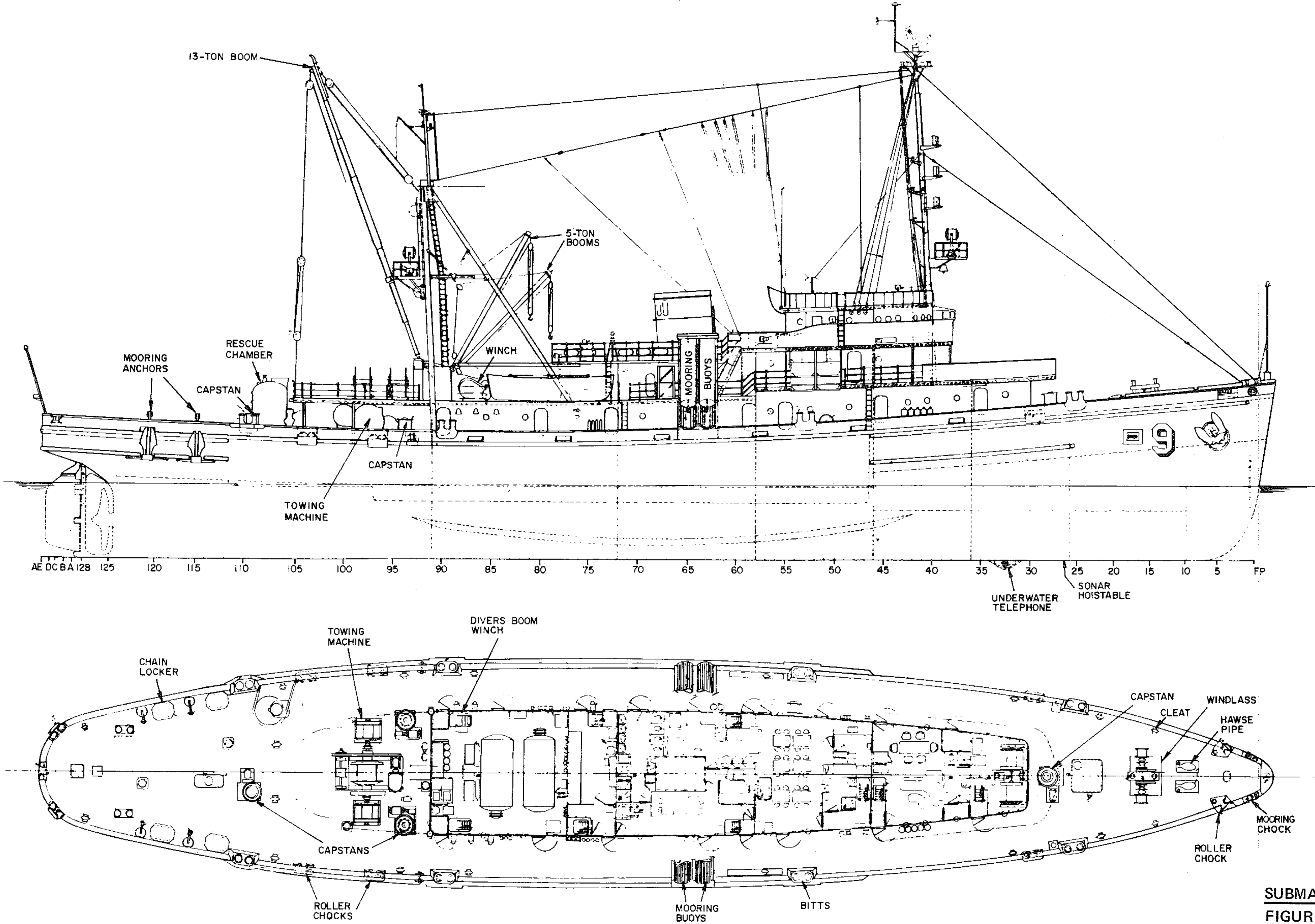
The ARS is similar to the submarine rescue ship (ASR), and is sometimes confused with it. The mission of the ARS is one of salvage, and it can be used as an operational control center by the Salvage Officer. There are presently thirteen ARS ocean salvage ships in commission in the NAVY; they are of two classes, ARS 6, and ARS 38. The ESCAPE(ARS 6 class) characteristics are:

Length overall	213-1/2	feet
Beam overall	43	feet
Draft, deepest point at full load	16	feet
Displacement, full load	2,000	tons
Speed (cruising)	11	knots
(maximum)	15	knots
Range	8,000	miles

The general specialized equipment and facilities of the ARS ships included the following:

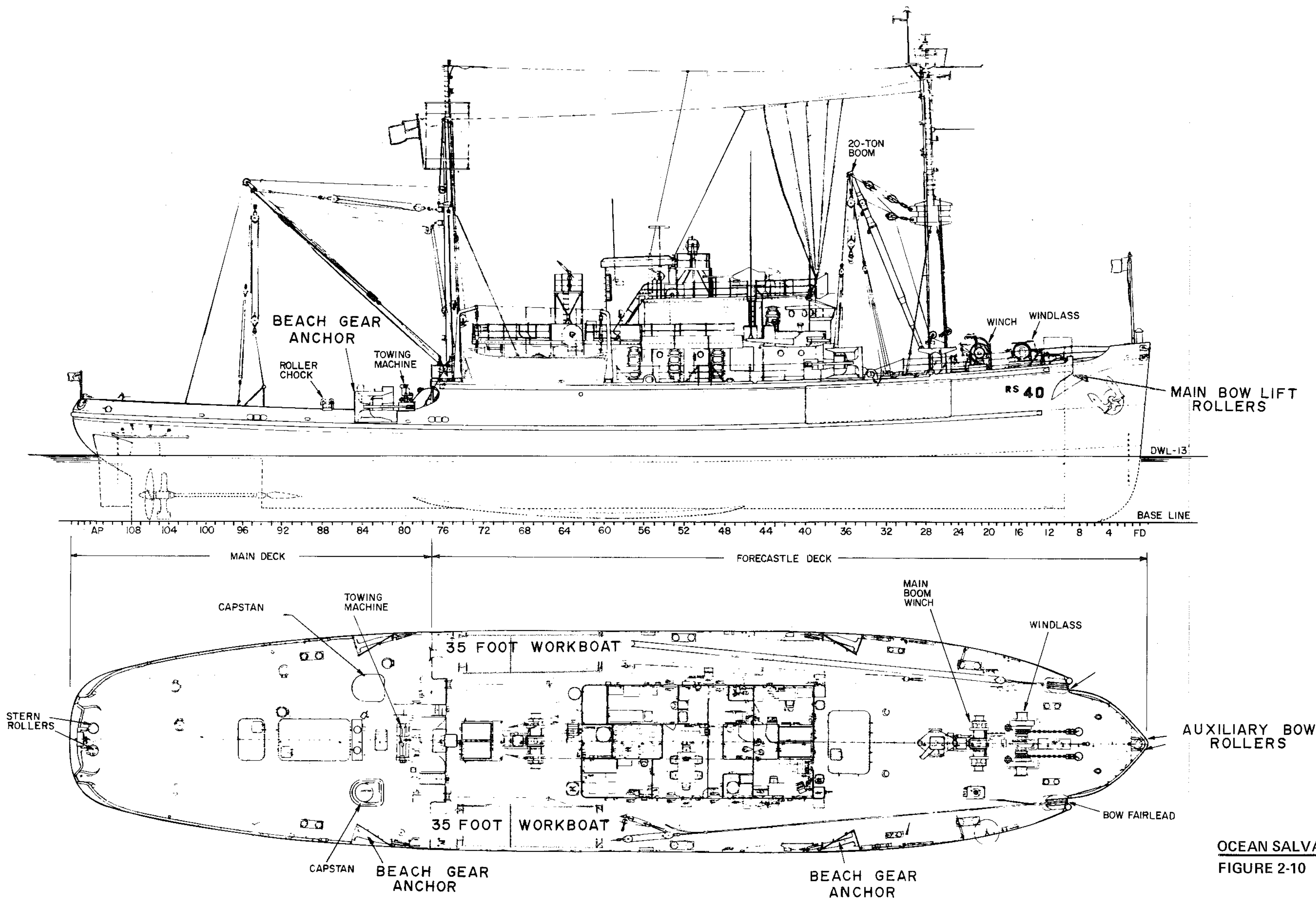
1. Lifting capabilities:

   (ARS 6 class) two booms, 8- and 10-ton capacity.
   (ARS 38 class) two booms, 10- and 20-ton capacity.



SUBMARINE RESCUE SHIP (ASR).

FIGURE 2-9



OCEAN SALVAGE SHIP (ARS).

FIGURE 2-10

Two main bow lift stations, port and starboard, each rated at 75 tons (total 150 tons); two auxiliary bow lift stations, port and starboard, each rated at 50 tons.

2. Boats. Two 35-foot salvage work boats.

3. Diver support. One double recompression chamber; two diving stations aft for air diving only.

4. Salvage equipment. One automatic towing machine rated at 40,000 pounds with 2100 feet of 2-inch wire; two fixed fire pumps which will deliver 1000 GPM each; four portable fire pumps. In addition, there are generators, compressors, welding machines, pumps, eight sets of beach gear, and extensive rigging for mooring the ship.

2.5.3. Lifting Barges (YMLC)

Two former ARSD lifting ships were converted to non self-propelled lifting barges. The hulls are converted LSM landing craft with over-the-throat bow lift stations and two bow horns. (Figure 2-11 shows the general arrangement of the deck area and the elevation profile.) The general specifications of the YMLC are:

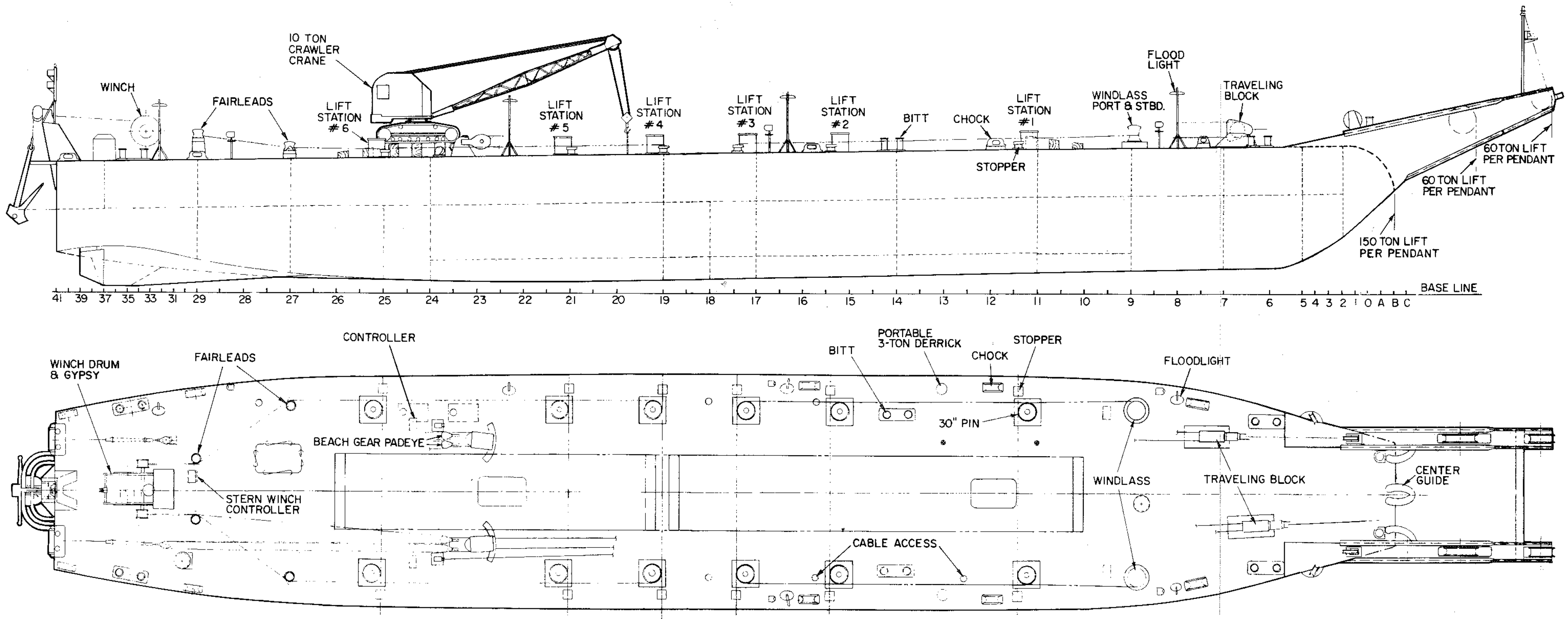
Length overall	225 feet
Beam overall	35 feet
Displacement	1,280 tons

The lift characteristics of the YMLC barge are as follows:

1. Bow lift horns each have two pairs of lift sheaves with 60 tons lift on each pendant. The lift capacity of each pendant on the over-the-throat station is 150 tons.

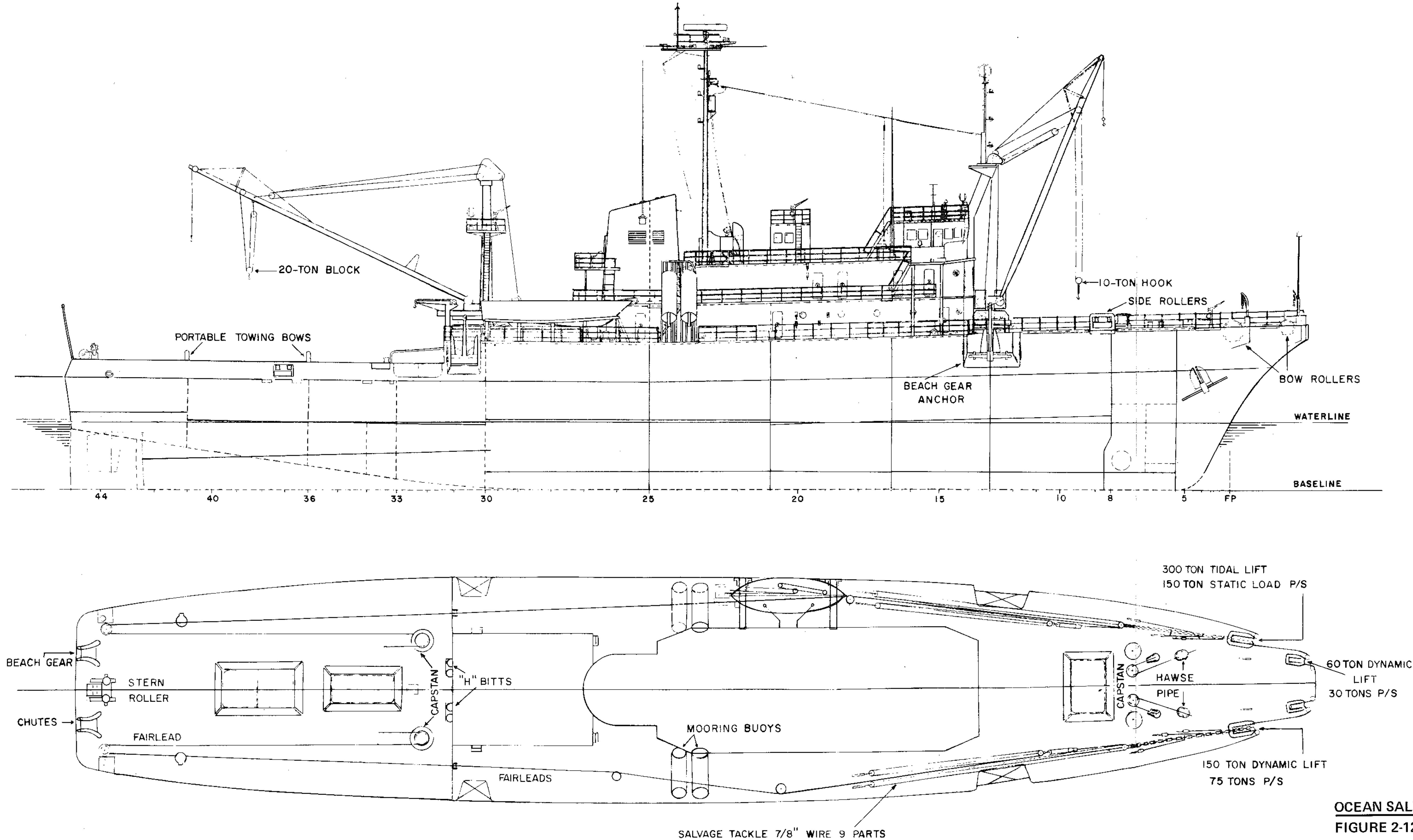
2. The hull girder is designed for six lift stations on both sides. Each station has a lift capacity of 100 tons.

3. A lift of 300 tons can be made by deballasting and changing the draft by 5.6 feet. The tons per inch immersion is approximately 4.5 tons.



YMLC LIFT CRAFT.

FIGURE 2-11



OCEAN SALVAGE TUG (ATS).

FIGURE 2-12

Other equipment on the lift barge includes a diving locker and diving compressors (two 100 psi at 50 CFM). The salvage air system has two compressors (100 psi at 100 CFM and one 250 psi at 250 CFM). The salvage pumps used for deballasting have a capacity of 1500 GPM.

2.5.4. Ocean Salvage Tug (ATS)

The ATS is the largest and most modern salvage ship in the US NAVY; it is better equipped for salvage and ocean towing than the previously described ARS. To assist the salvage task force the ATS has two workshops outfitted for handling sheetmetal, carpentry, pipe fitting, cutting and welding. The diving capability includes deep-sea air and mixed gas systems. The ATS can handle deep diving saturated diver systems; this greatly increases the diving capability and on-the-bottom work time of divers.

Two bow lift stations can make lifts up to 150 tons (see Figure 2-12). The general characteristics of the ATS are:

Length overall	282 feet 8 inches
Beam overall	50 feet
Displacement, full load	2,929 tons
Draft, full load	14 feet 6 inches
Range, (cruising)	13 knots - 10,000 miles

Salvage Facilities

1. Two Bow Lift Stations. The forward, or auxiliary bow rollers will each lift 30 tons. The after or main bow rollers will each lift a dynamic load of 75 tons, or a static lift of 150 tons. Trimming of the hull for tidal lifts can be effected by the use of the ballast tanks fore and aft.

2. Automatic Towing Machine. An automatic towing machine has two primary towing drums each carrying 3000 feet of 2-1/4-inch diameter towing cable, and capable of developing line pulls from 30,000 pounds at 120 feet per minute to 200,000 pounds at 20 feet per minute with both drive units engaged to one drum. The auxiliary drum shall be capable of developing a line pull of 30,000 pounds at 150 feet per minute with a maximum line speed of 400 feet per minute. The auxiliary drum carries 5000 feet of 1-inch towing cable.

3. Compressed Air Systems. The compressed air systems for diver support and salvage work total 122, 10-cubic-foot air flasks rated at 5000 psig. The oxygen/helium mixed gas bank has 29, 10-cubic-foot storage flasks at 3000 psig. There are three high pressure flask banks for storing various mixtures during oxygen-helium diving operations. Two high-pressure (5000 psig) air compressors supply the salvage, divers's air, and mixed gas air banks.

2.6. Underwater Tools and Methods of Employment

The work to be performed by divers at salvage sites will range from purely observation missions to such complicated tasks as clearing wreckage, installing patches, and rigging hoses, cables or chain slings. Work to be done on the bottom, by a diver, must be well planned and supported in order to minimize bottom time and effort of the diver. Items such as patches, pipe fittings, or rigging should be made up with a diver's limitations,and the problems of working at depth,in mind. The governing philosophy when planning underwater work should always be one of trying to eliminate the diver entirely, and if this is not possible, to reduce his work to the minimum level.

The basic work tasks to be performed by a diver can be described in four general classifications: cutting, joining, lifting, tunneling and materials application. Before discussing tools and methods of accomplishing these tasks, a review of the diver's environment is worth considering.

A diver rigged in a deep-sea outfit is restricted in his movements and the amount of exertion he can apply to an object. The weight of the heavy diving outfit is supported in the water by the amount of air that is maintained in the suit. A diver properly trimmed and on a reasonably level platform can make direct lifts, but to move an object at shoulder or helmet level laterally is quite difficult. Such movement causes the diver to be thrown off balance or causes him to swing his body out of position. What would be a relatively simple effort on the surface becomes much more difficult underwater. Tasks such as hauling lengths of cables across a deck or positioning a salvage hatch can be made easier with the assistance of the salvage vessel. As an example, a 50-foot length of 1-inch diameter steel cable weighs nearly 100 lbs. To haul it into position, a line from the salvage ship, reeved through a snatch block secured to a fixture on the wreck, could be pulled by the ship's winch. However, before the surface ship accomplishes such work, the divers must often be brought to the surface.

Another example of minimizing physical effort is in the method of cutting. Underwater cutting is generally done by oxygen-arc torches, or for larger objects, explosive shaped charges, detonating cord, and velocity cable cutters can be used.

Attachment, too, must be made quickly and securely. Explosive velocity tools which can fire studs or pins through steel are used rather than having the diver bolt on fittings.

2.6.1. Tools for Cutting

Conventional tools such as hacksaws, bolt cutters, and chisels can be used as the occasion demands. There are also some specialized tools that are used for underwater cutting. For clearing away light rigging, such as radio antennas, use can be made of a hook (Figure 2-13) which is connected by a line to the winch of the salvage vessel. Additionally, velocity power tool attachments for cutting are available (see Paragraph 2.6.2.).

For cutting through steel plates or burning holes, the oxygen-arc electrode is the most frequently used method. While the oxygen-hydrogen torch is still carried by diving ships, its use is very rare.

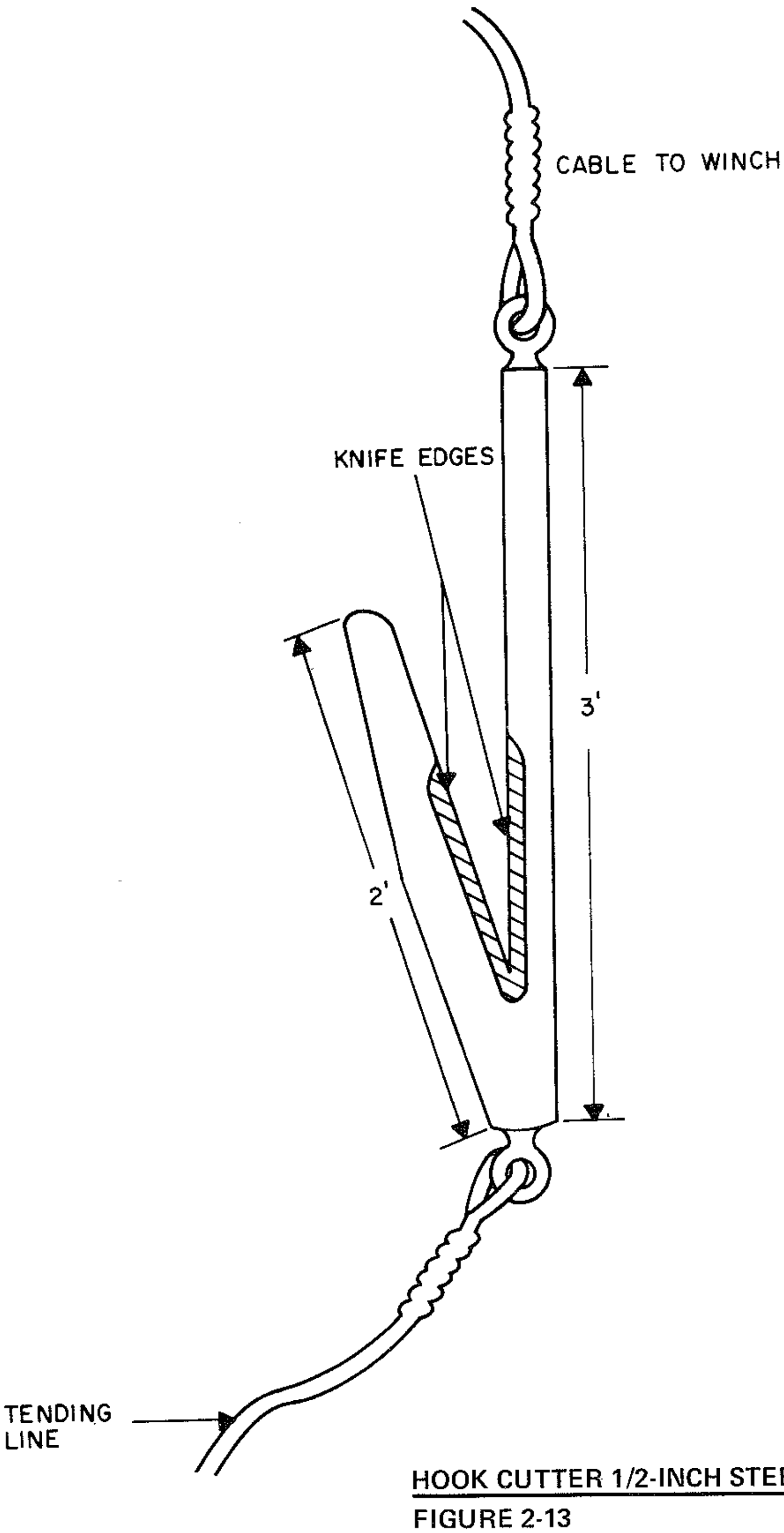
2.6.2. Tools for Joining

Welding

Underwater welding can be performed using the oxygen-arc electrode method. NAVSHIPS publication 250-692-9, "Underwater Cutting and Welding," describes in detail the techniques for using the specially designed electrode holders, or for making up a holder from shipboard materials. Good, strong welds are very difficult to execute underwater. Before any confidence is placed in the load-bearing ability of an underwater weld, the skill of the welder should be tested, and, as feasible, the weld itself should be tested by continuously increasing the force upon it until finally the total load is imposed.

Velocity Power Tools

Velocity power tools are used for cutting steel cables, punching holes, mounting padeyes, and installing hollow studs for use as air connections. These tools use an explosive charge as the source of power to fire units into steel plates. The name, velocity power, is derived from the fact that the cutter or stud is retained in the barrel by either a shear pin or friction catch until the full force of the explosion



HOOK CUTTER 1/2-INCH STEEL STOCK.
FIGURE 2-13

is reached. The holding unit then releases the projectile which travels down the barrel at tremendous velocity. These units can accomplish a great amount of work independent of the surrounding atmosphere. The following examples of velocity power tools are used by NAVY salvage forces:

1. Cable cutters are readily available for cutting 1/16-inch to 1-1/2-inch diameter steel wire rope. Special cable cutters can be provided for wire rope up to 3-1/2 inches in diameter. (Figures 2-14 through 2-16 illustrate these tools.)

2. The lightweight power driver, Mine Safety Appliance Co. Model NUD-38, (Figures 2-17 and 2-18) can be used for pinning light patches or installing small padeyes.

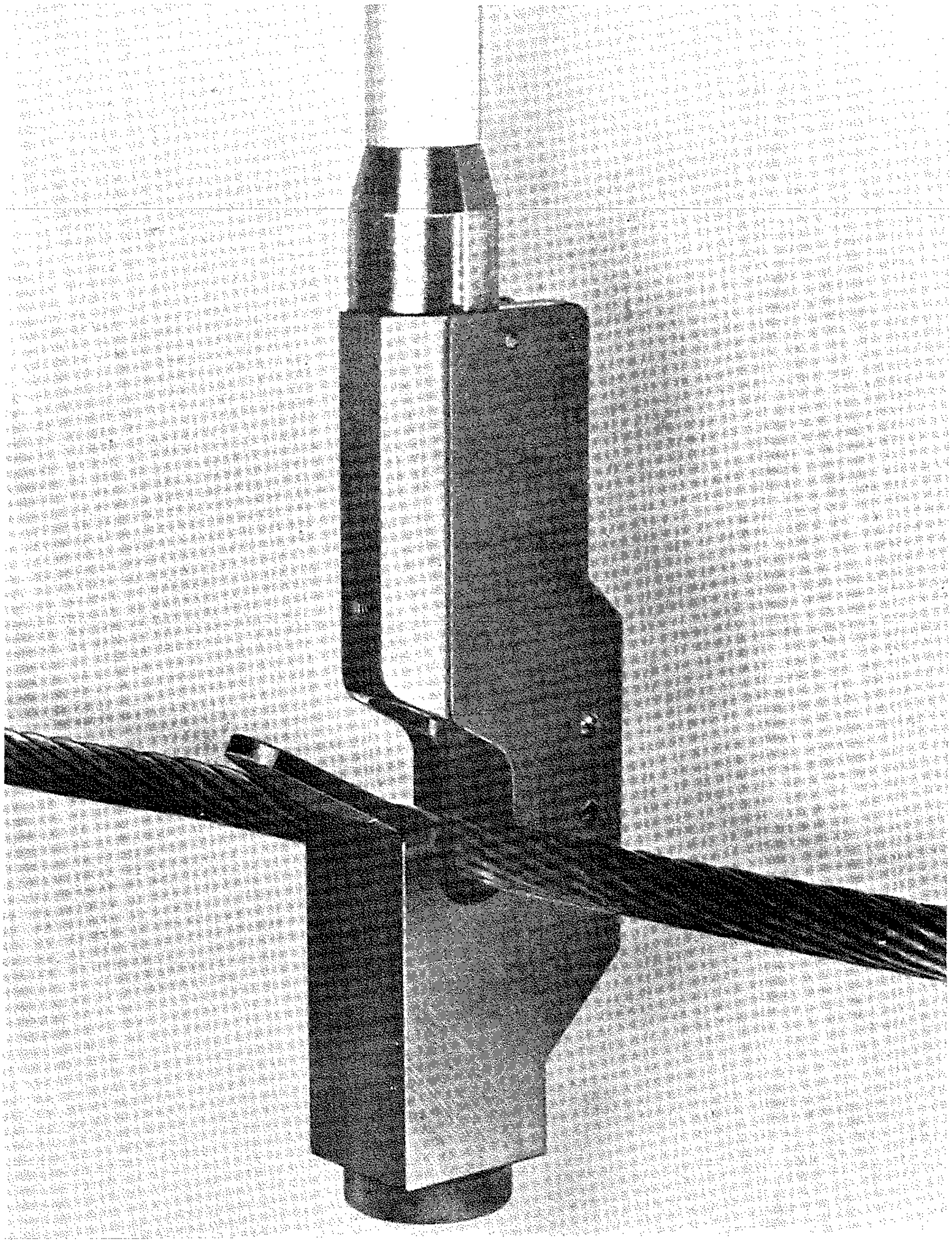
The maximum depth in which the lightweight driver can be used is 300 feet. The strength of the solid studs (Figure 2-19) used with the lightweight driver, NUD-38, when installed in structural steel plate, i.e., tensil strengths 50,000 to 60,000 psi, is as follows:

Plate thickness	Average pull-out strength
1/4 inch	3,000 lbs
3/8 inch	3,500 lbs
1/2 inch	4,000 lbs

3. The Mine Safety Appliance Co. Model D driver (Figures 2-20 and 2-21) is designed for use in depths up to 1000 feet and employs larger, solid or hollow stud components.

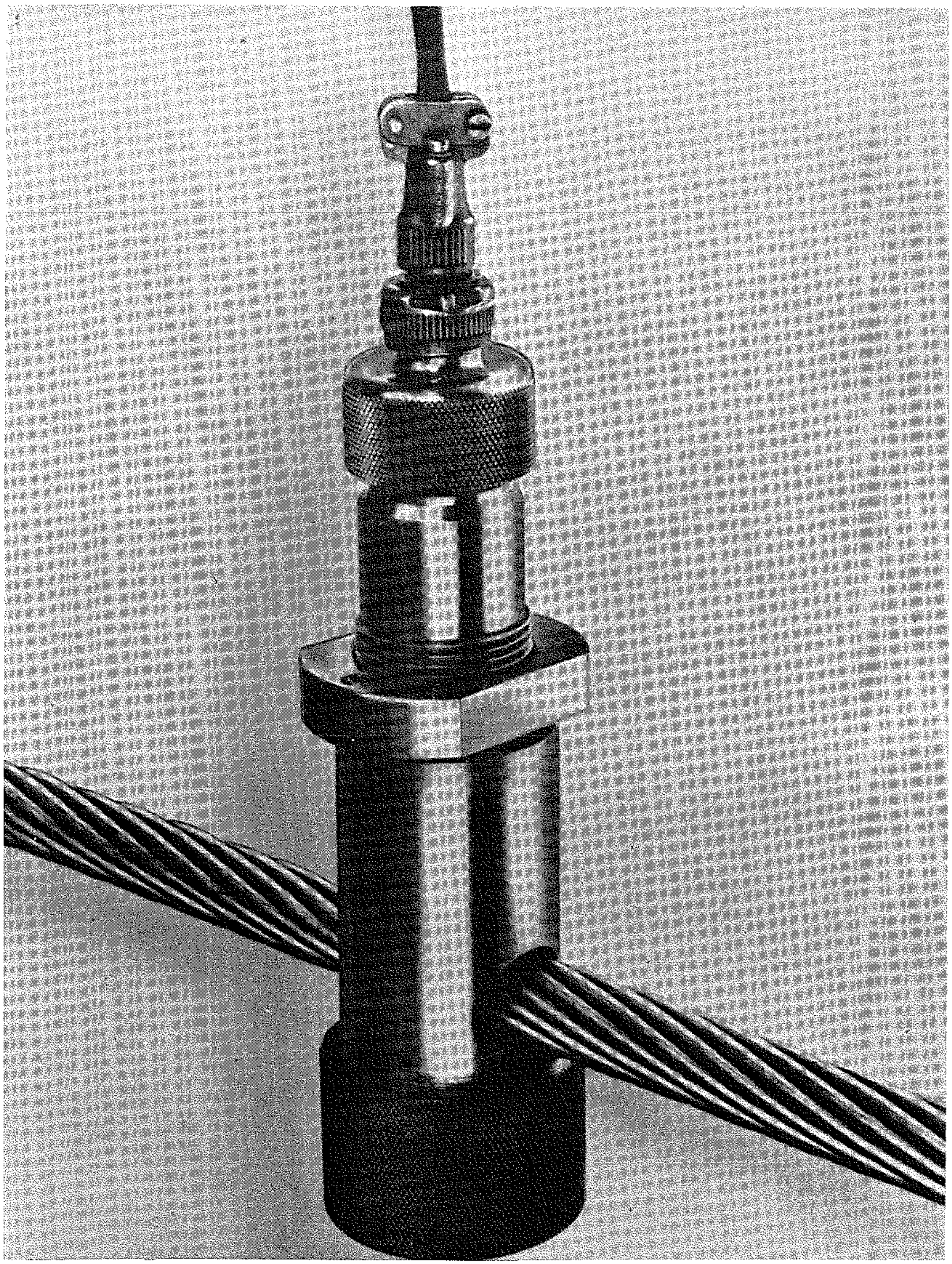
The stud is fired from a sealed barrel that contains the expanding gases and reduces explosive shock in the water. The Model D has a wide range of stud components (Figure 2-22), including both a hollow stud and a hole punch for plate up to 1/2-inch in thickness. The strength of driven solid studs in structural steel plate of approximately 50,000 psi yield strength is as follows:

Plate thickness	Average pull-out strength
3/8 inch	8,000 lbs
1/2 inch	14,000 lbs
5/8 inch	16,000 lbs
3/4 inch	19,000 lbs
7/8 inch	22,000 lbs
1 inch	26,000 lbs
1-1/8 inch	29,000 lbs

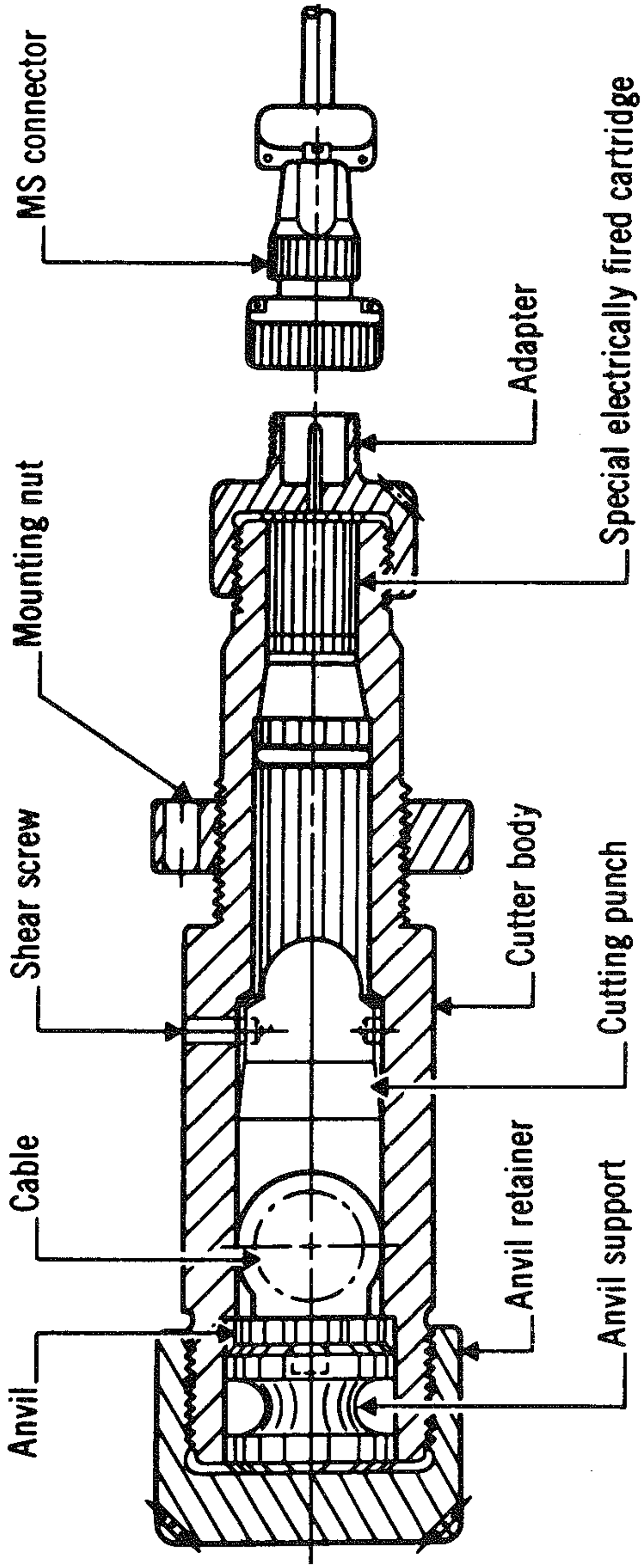


POLE C FRAME CABLE CUTTER.

FIGURE 2-14

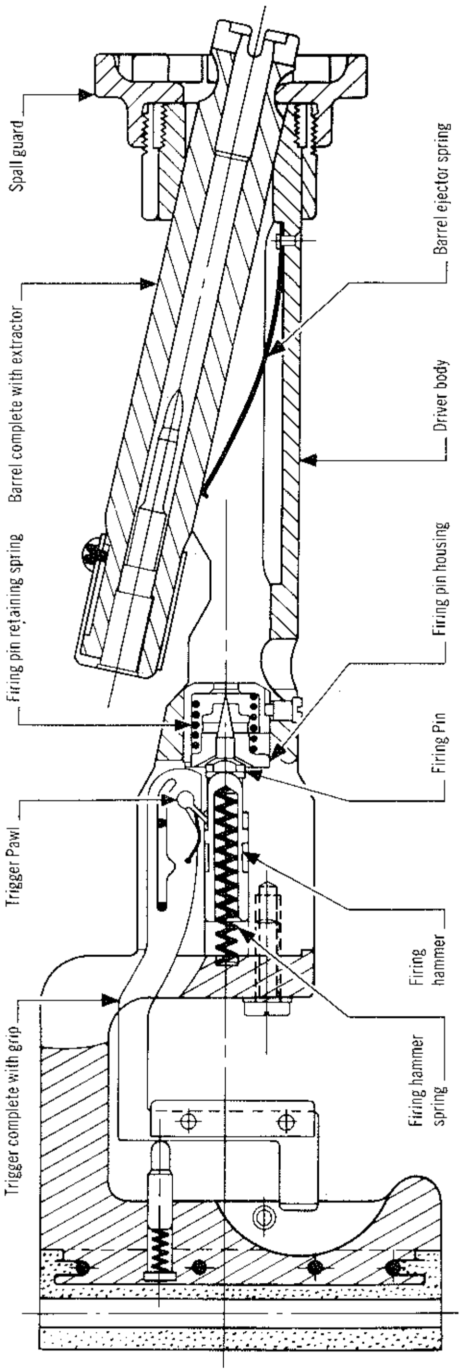


U-SLOT CABLE CUTTER.
FIGURE 2-15



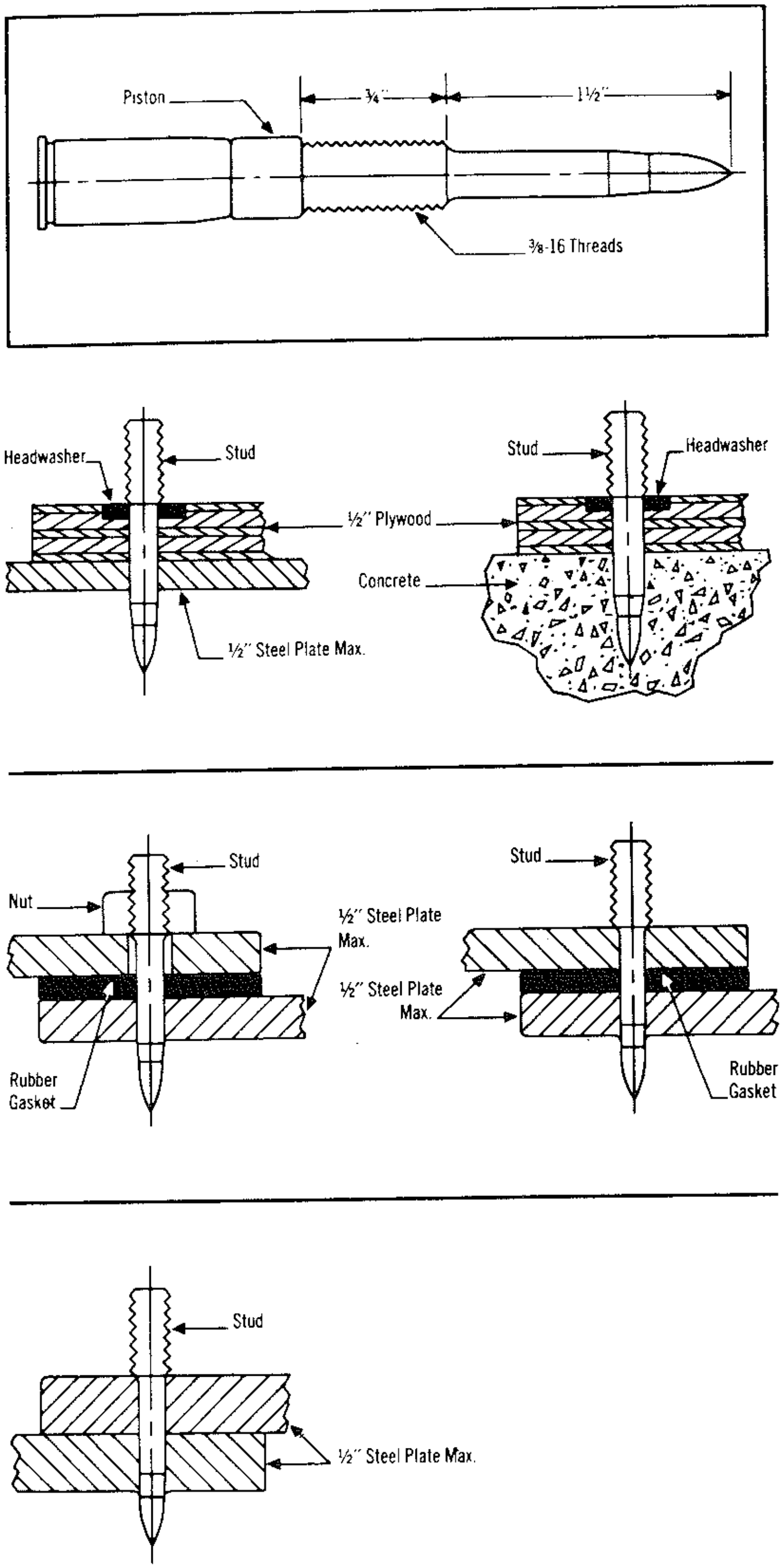
OUTLINE DRAWING OF U-SLOT CABLE CUTTER.
FIGURE 2-16

NUD 38 DRIVER.
FIGURE 2-17



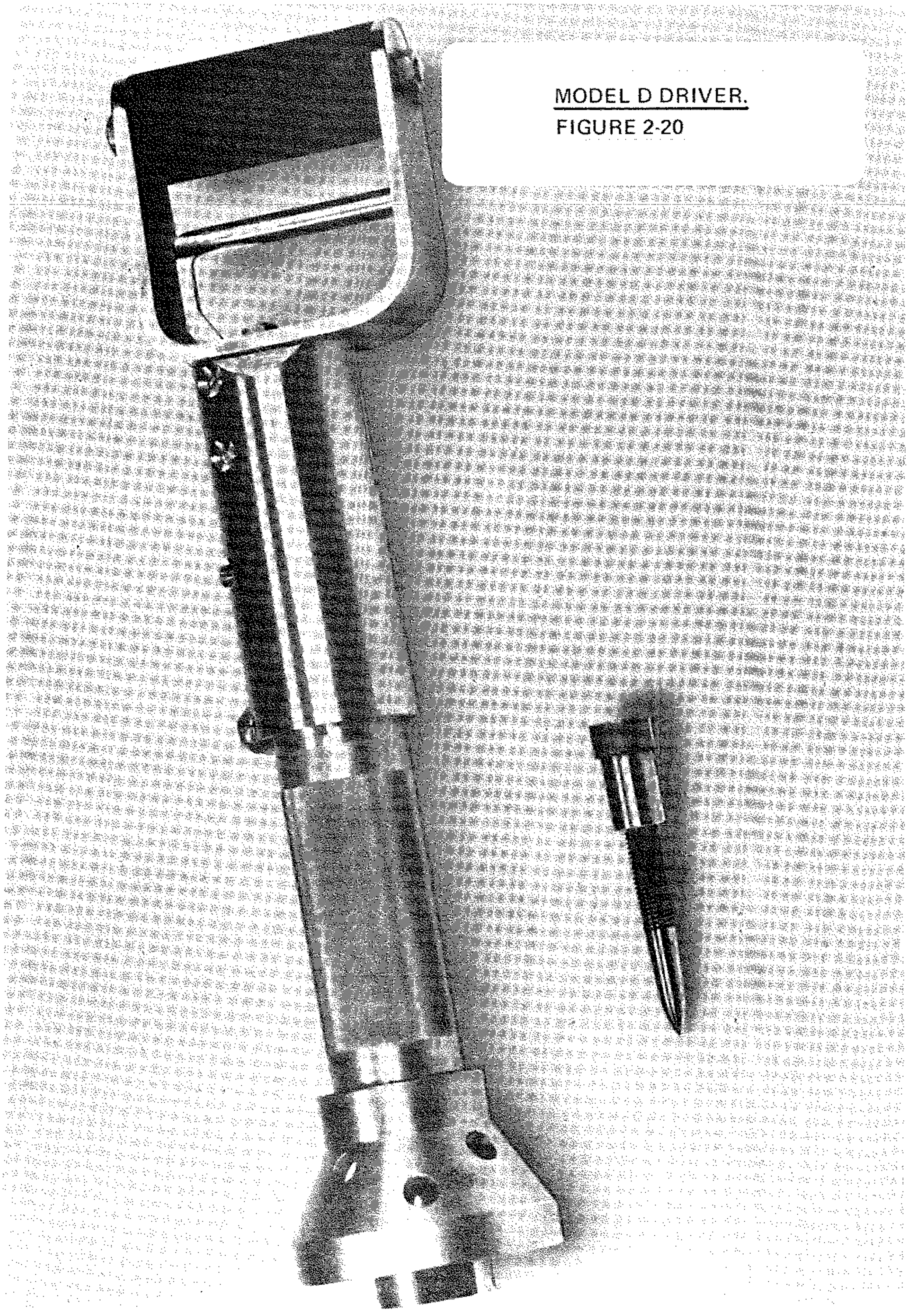
OUTLINE DRAWING OF NUD 38 DRIVER.

FIGURE 2-18

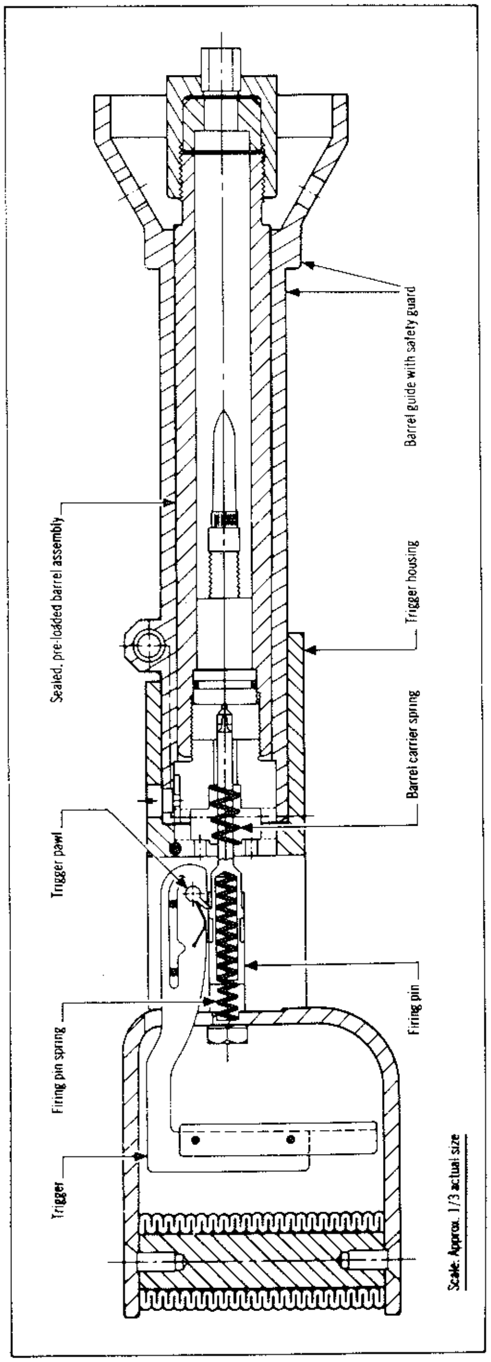


STUD CHART FOR NUD 38 DRIVER.

FIGURE 2-19

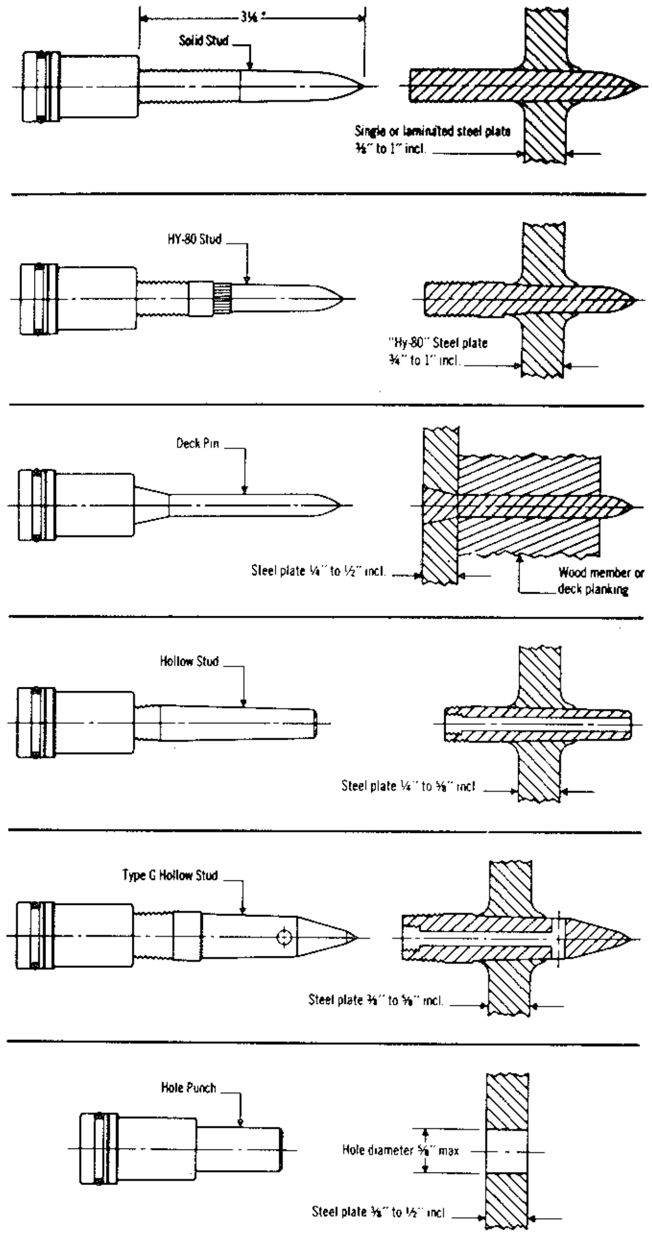


MODEL D DRIVER.
FIGURE 2-20



OUTLINE DRAWING OF MODEL D DRIVER.

FIGURE 2-21



Strength of Driven Solid Studs in Structural Steel Plate

Plate Thickness	Average Pull-Out Strength
⅜"	8,000 lbs.
½"	14,000 lbs.
⅝"	16,000 lbs.
¾"	19,000 lbs.
⅞"	22,000 lbs.
1"	26,000 lbs.
1⅛"	29,000 lbs.

STUD CHART FOR MODEL D DRIVER.

FIGURE 2-22

4. Special prefabricated, velocity-powered padeyes for use underwater have been developed by Naval Ordnance Laboratory, White Oak, Maryland, and manufactured by the Mine Safety Appliance Co. These will greatly facilitate salvage operations. These padeyes (Figure 2-23) will have magnets to hold the component in place, thus reducing the time required for installation.

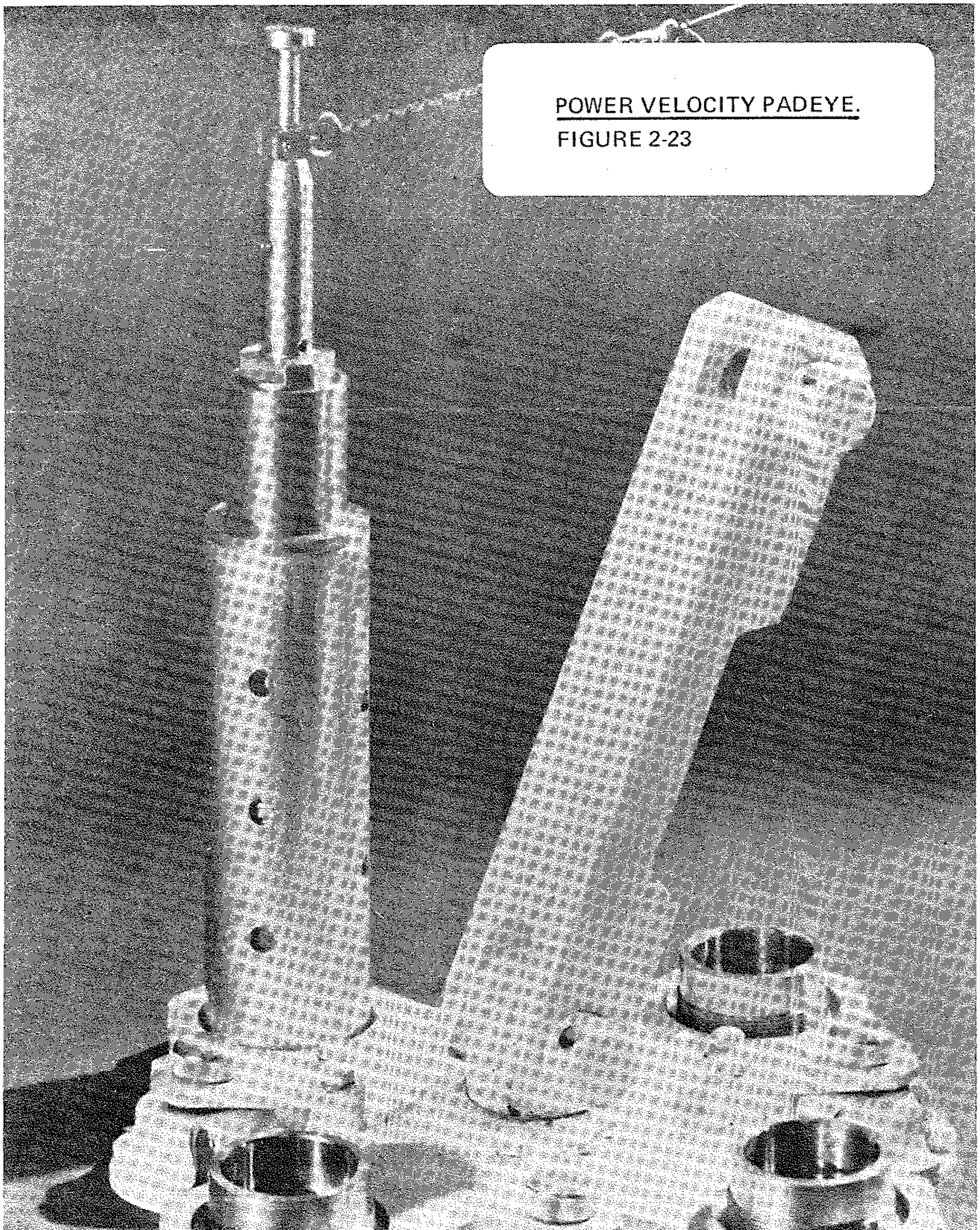
2.6.3. Lifting

Lifting of heavy objects on a salvage job is usually done by the winch and booms of the salvage vessel. If a diver is assisting in such work, it is necessary to bring him to the surface or ensure that he is well clear before beginning a lift from the surface. Where short distances of vertical movement are needed, a chain fall can be used if there is a support from which to suspend it. Extremely heavy objects to be moved only a few inches can be raised by hydraulic jacks. The NAVY uses jacks that have a 60-ton lift capacity for a distance of 18 inches. There are, however, commercial jacks of 80 and 100 tons lift in existence.

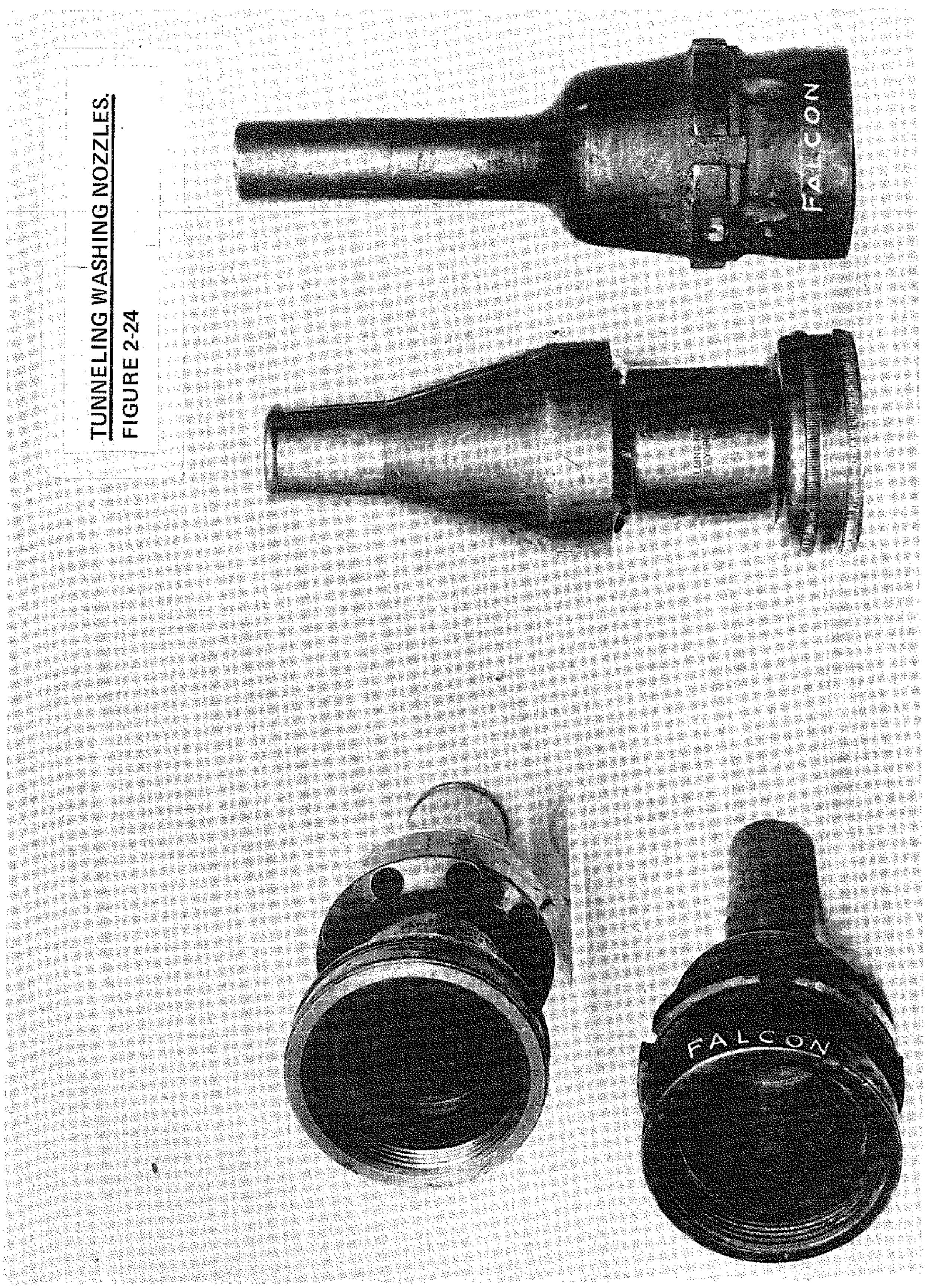
2.6.4. Tunneling Tools

When lifting cables or slings cannot be swept under a submarine, it is necessary to dig a tunnel. Usually, water pressure applied through a fire hose to a nozzle will suffice. In the case of USS S-51 salvage (Appendix C), tunnels had to be washed through hard clay and mud. The divers experienced considerable difficulty in handling the nozzle reaction or back pressure. To counteract the reaction force of this pressure, the nozzle was modified by drilling five small holes about the base radius of the nozzle. These small jets were angled back so that the thrust of the jets would balance the nozzle reaction and the debris cut out by the nozzle would be washed out of the tunnel (see Figures 2-24 and 2-25).

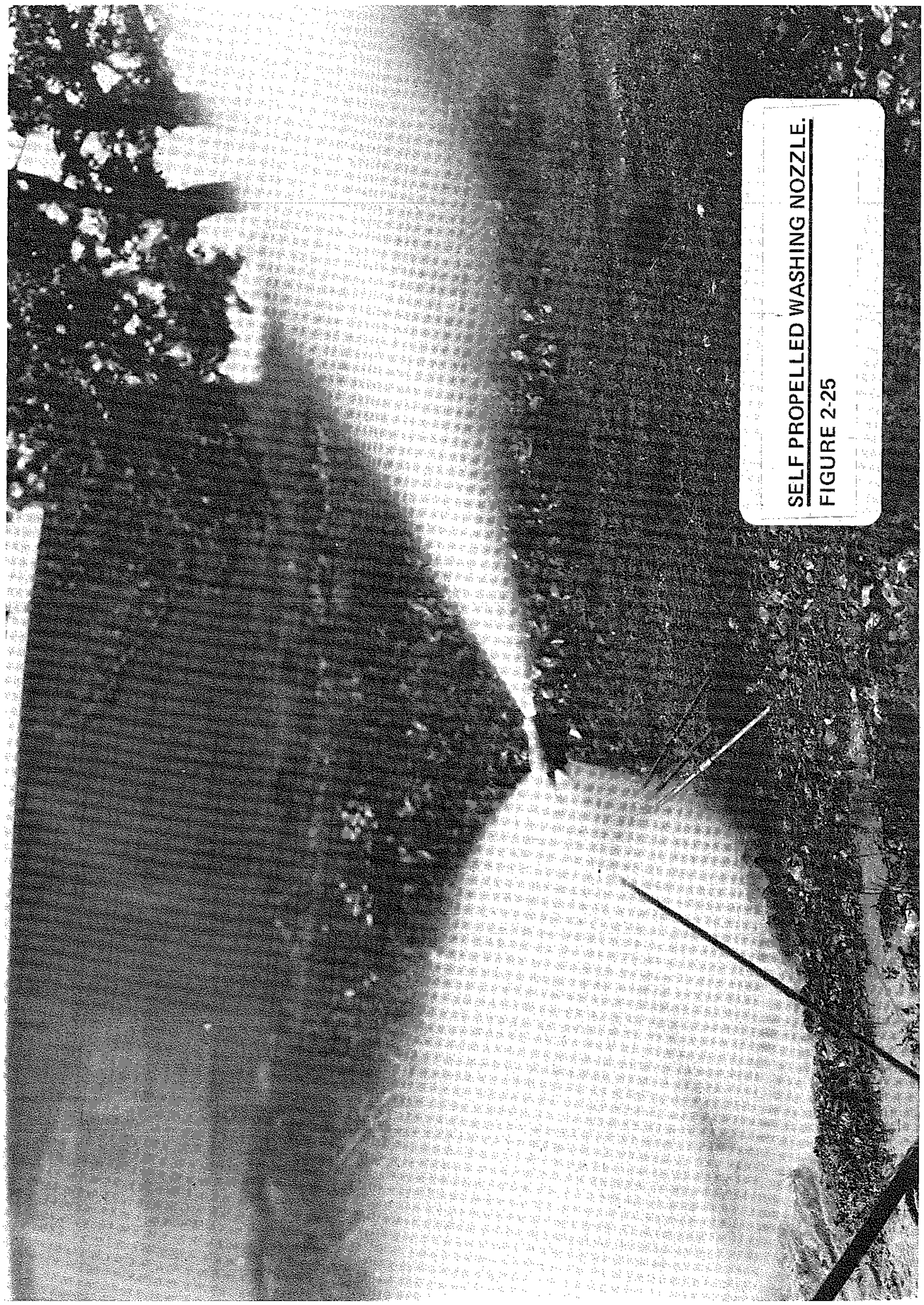
Chapter 7 describes the tunneling lance that was used for salvage of USS SQUALUS. In that instance, the depth of the wreck in the mud was such as to require a very deep tunnel of about 12 feet. The danger of tunnel collapse while a diver was working in it was unacceptable. Therefore, a lance was devised which was made up in pipe sections and curved to follow the shape of the hull.



POWER VELOCITY PADEYE.
FIGURE 2-23



TUNNELING WASHING NOZZLES.
FIGURE 2-24



SELF PROPELLED WASHING NOZZLE.
FIGURE 2-25

2.6.5. Cement Gun

Another tool that may be required by the Salvage Officer will be the cement gun. In some cases of sealing up compartments in preparation for dewatering, it is not possible to apply a patch or close the opening because of its inaccessibility to the diver or the hull contour. To plug up such openings, cement is used, as in the salvage of USS S-51 when the hull ventilation valve could not be sealed. (Figures 2-26 and 2-27 illustrate a type of cement gun that can be employed underwater.) Chapter 6 describes the technique of injecting cement into fittings and recommends the mixture to be used.

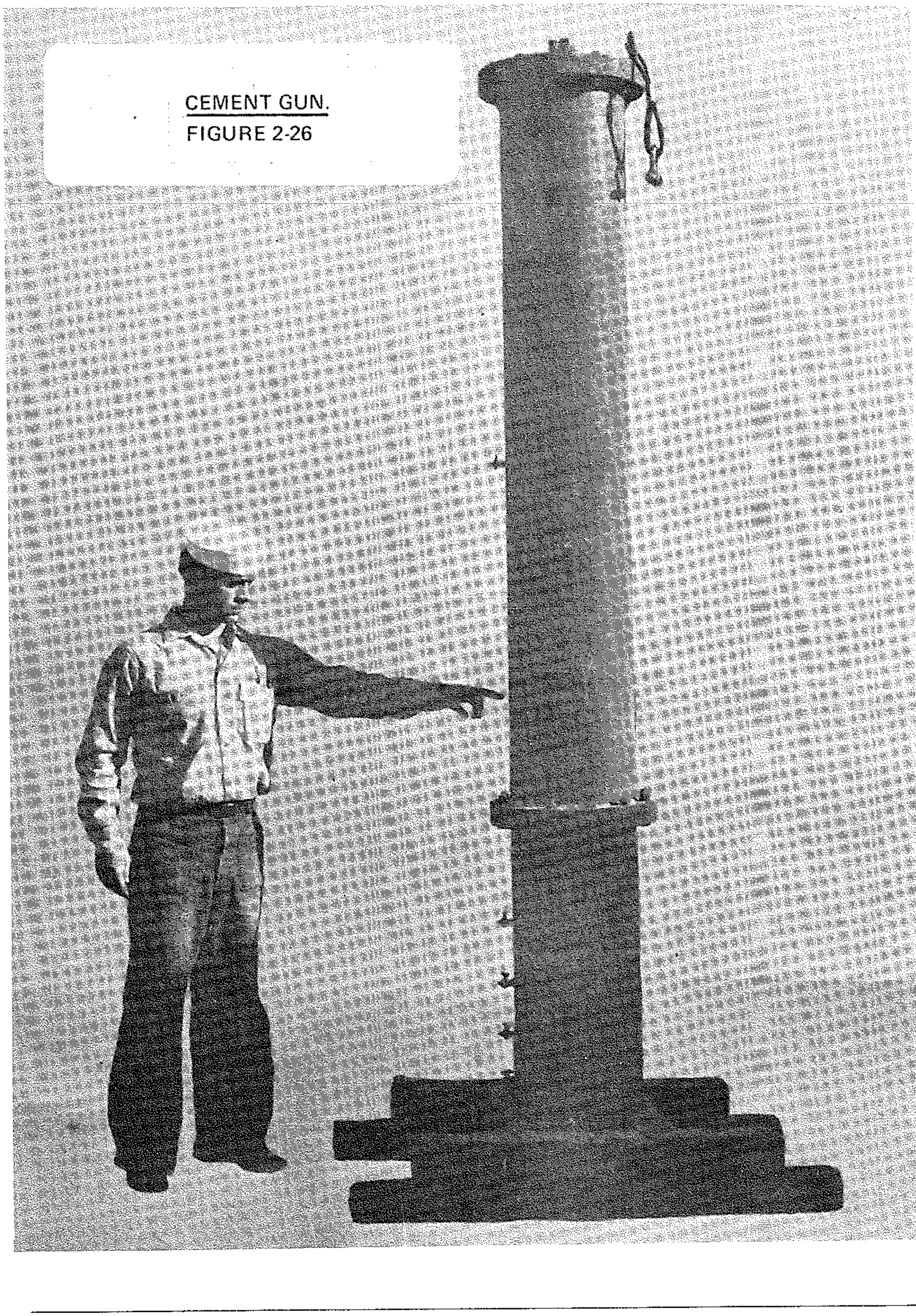
2.6.6. Special Fittings

In every salvage operation the need for special fittings which are not available frequently arises. These fittings, therefore, must be designed to suit the immediate problem, bearing in mind the need for minimizing work by divers. It is improbable that closure of an irregular opening, such as holes caused by collisions, would be undertaken on the bottom. However, it may be necessary to design fittings to close smaller openings such as a sea chest or pipe penetration. The most common openings that a submarine Salvage Officer may encounter of this nature will be hatches and air induction lines. Two techniques which have been used in salvage work are described in the following paragraphs.

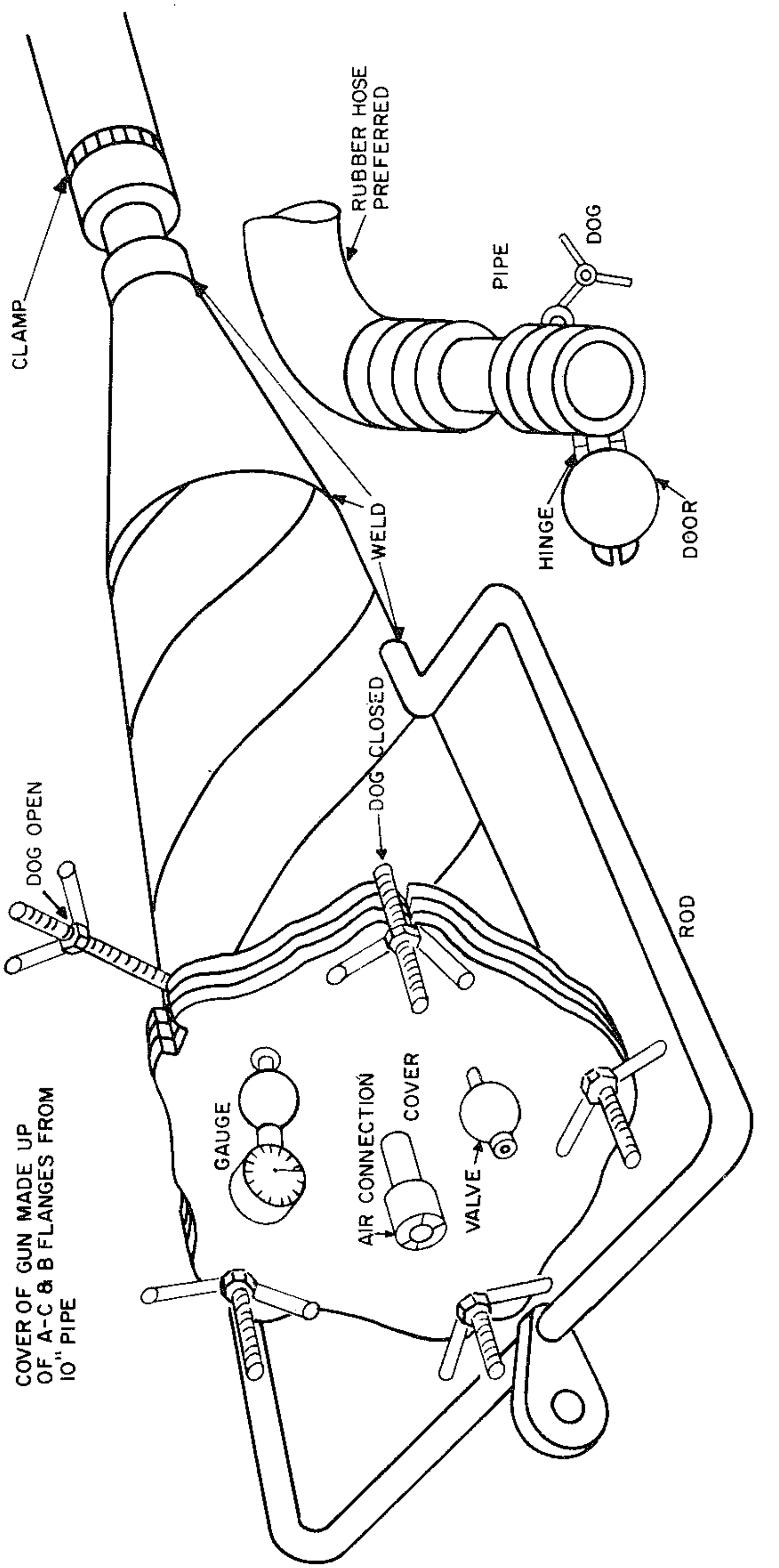
2.6.7. Salvage Hatch Cover

This is a metal plate large enough to cover the hatch and designed to hold at least 15 psi internal pressure. A flexible spill pipe 2-1/2 inches in diameter and of sufficient length to reach the lowest point in the compartment is mounted in the plate. The spill pipe is fitted with a strainer and check and stop valves. On the external side of the salvage hatch is a fitting for connecting to a salvage air hose. Before securing the hatch with hook bolts or strongbacks, it is placed near the hatch to be sealed. A diver is then sent inside the compartment to position the spill pipe as low as possible.

The compartment may then be blown down, provided all other openings have been made tight against internal pressure.

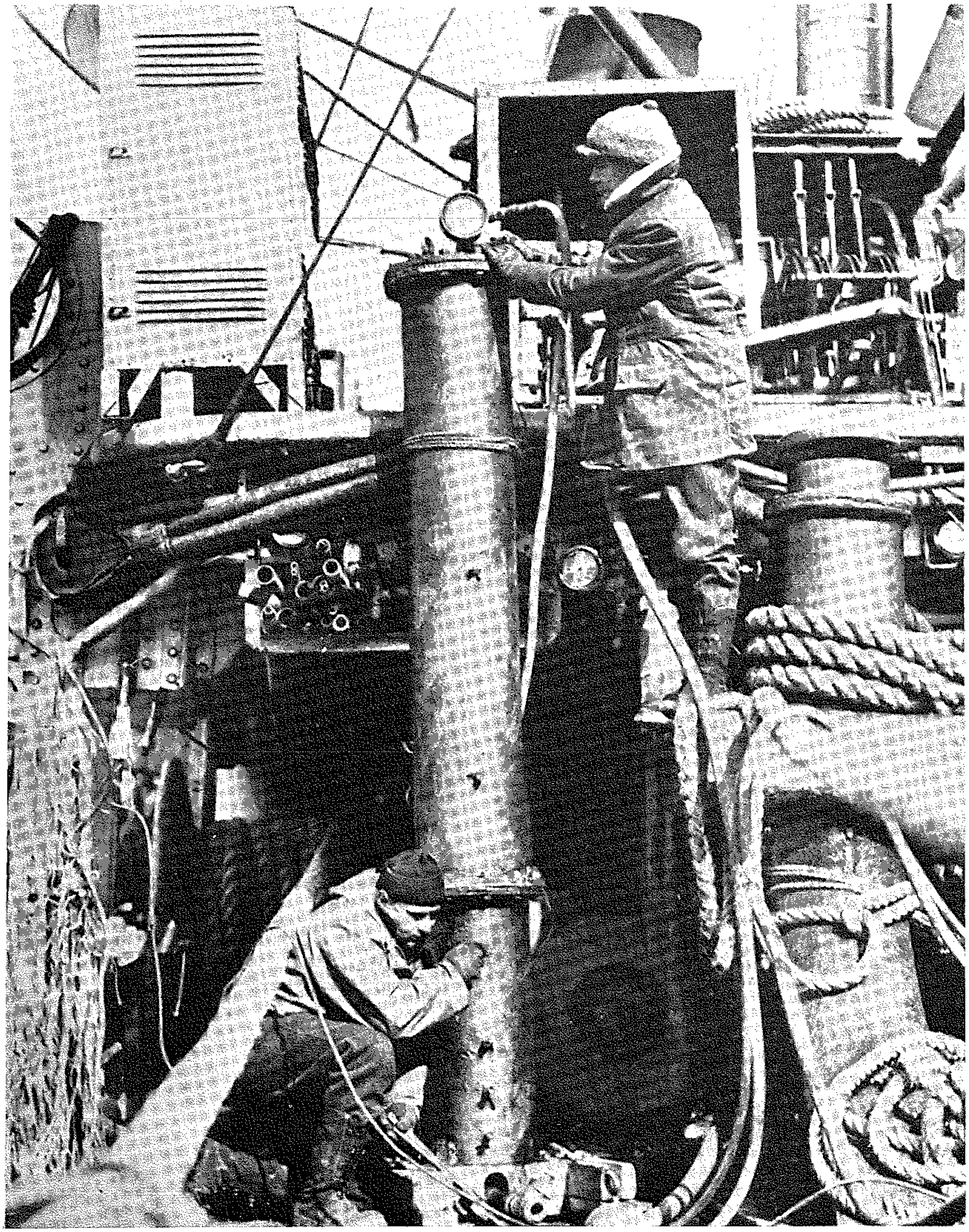


CEMENT GUN.
FIGURE 2-26



CEMENT GUN CONFIGURATION.

FIGURE 2-27



CEMENT GUN ON BOARD FALCON AS
USED IN S-4 SALVAGE.
FIGURE 2-28

2.6.8. Cofferdams

Cofferdams have been used on several occasions; in particular on submarines sunk in shallow water. This fitting is merely an extension above the surface of the water to afford a means of pumping the space dry. Of course, the opening, through which the compartment flooded, must first be closed up.

Another technique employing the cofferdam involves sealing an irregular opening, such as an air induction valve fitting, which cannot be gagged shut. In such a case, a cofferdam designed and constructed in advance could be used as a retainer for cement fill and would more properly be described as a patch.

3. Mooring

3.1. Introduction

The purpose of this chapter is two-fold: first, it is intended to acquaint the prospective Salvage Officer with the essentials of the theory of mooring so that he may better understand the forces and phenomena involved. Secondly, it is to equip the Salvage Officer with rudimentary tools that may help him evaluate the effect of changing any element of a predesigned moor.

The design of a moor is a complex problem and should be handled by those well versed in the art of mooring design. In the NAVY, this function is fulfilled by the Naval Ship Systems Command. In most salvage cases which require moors of greater capability than those provided by the standard ASR moor, sufficient time will be available for a detailed moor design by that group.

The Salvage Officer may very well find that he has inherited a moor from the rescue phase. In that case, it undoubtedly will be a standard ASR moor. It is hoped that this chapter will provide a sufficient understanding of moors in general, and the ASR moor in particular, so that the Salvage Officer may make temporary adjustments to the moor to meet the salvage requirements, if the situation so dictates.

In dealing with the problems of mooring, the following subjects will be treated:

- Forces acting upon a moored ship.
- Dynamic moors.
- Static moors.
- Anchor and bottom phenomena.
- Catenaries and mooring rigs,
  - Simple catenaries
  - Compound catenaries.
- The standard ASR moor.
- Available mooring equipment.

3.2. Forces Acting Upon a Moored Ship

The forces acting upon a moored ship are attributes of three phenomena:

- Wind
- Wave
- Current

3.2.1. Wind Forces

Wind forces actually have a three-fold effect in that they not only apply a force to that portion of the ship which rises above the waterline, but they also create waves and can create surface current. To estimate the force that the wind imparts on a moored ship, due strictly to the wind velocity alone, model tests are run at the Naval Ship Research and Development Center for each ship type. In extrapolating the wind forces from the scale model to full size, the following formulation is used:

$$D_W = (k_B)(A_A)(W_R^2) \qquad \text{(Equation 3-1)}$$

where:

D_W = drag due to wind velocity

k_B = dimensional coefficient for drag of a given ship with a beam aspect

A_A = the projected profile area of the ship above the waterline (ft^2)

W_R = the maximum wind velocity encountered in the moor (kts)

The values of k_B generally vary between 0.003 and 0.0042. A value of k_B of 0.004 is recommended for estimating the force on any given ship type if a more refined coefficient is not available.(1)

NOTE: Superscript numbers in parentheses refer to entries in the list of References.

Surface water currents due to natural wind may be estimated, recognizing that data exists which indicates the surface current may be 1.5 to 3.0 percent of the sustained wind velocity and is more or less uniform for the draft of a conventional ship.

3.2.2. Wave Forces

Wave forces acting upon a moored ship are fluctuating in nature and stem from three characteristics of the wave; these characteristics are:

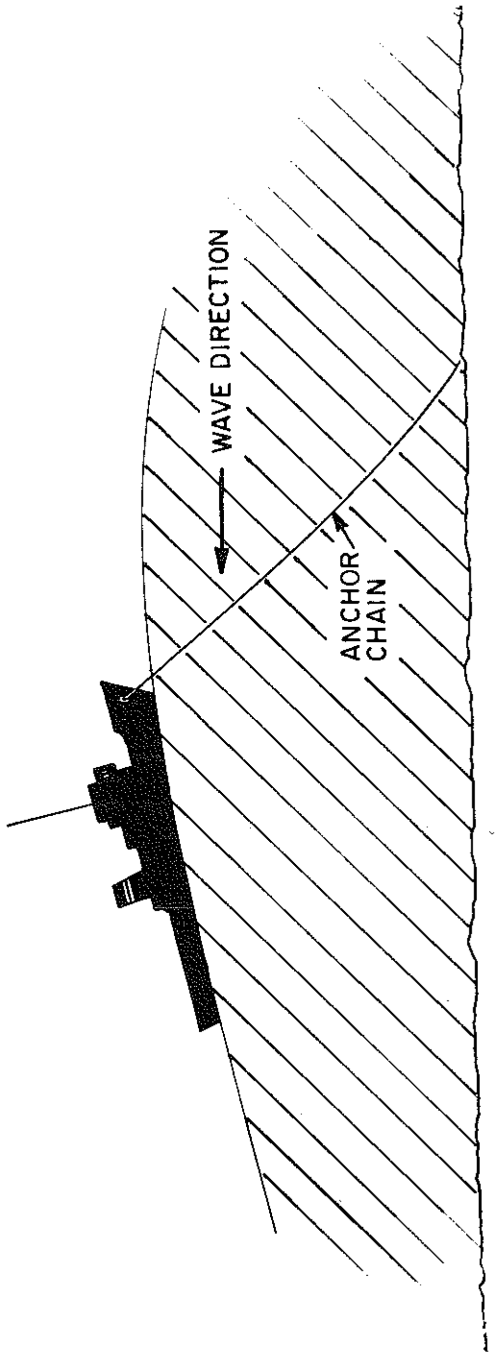
1. Heave of the ship as it is buoyed up by an on-coming wave.
2. The sloped surface of the wave which, as the wave approaches, causes the ship to attempt to slide down the sloped face of the wave (Figure 3-1).
3. Increased velocity of the water due to orbital motion as the wave crest passes.

The wave forces are periodic in nature and the "ship-mooring leg - anchor" system reacts very much as a weight on a spring. In this analogy the ship corresponds to the weight, and the spring is represented by the catenary in the mooring leg. The problem of analyzing the transitory force on the mooring leg when it is disturbed by the wave force is complex, and any solution is peculiar to a given situation only. Obviously, the possible situations that may exist are infinite. For this reason, moors are usually designed neglecting the wave forces, and a sufficient safety factor is utilized to make the moor adequate under most situations. The important thing for the Salvage Officer to note is that a moor which is adequate for a steady state wind or current condition, may drag or part under specific wave conditions that may accompany the wind and/or current.

3.2.3. Current

The current acting upon the ship produces forces due to skin friction. The basic formulas for wind and for current are similar, but since the specific gravity of water is many times that of air, the forces induced by even slow ocean currents may exceed those produced by extremely high winds.

An additional complicating factor is that currents do not normally coincide with wind direction. Mooring equations, normally utilized, assume that the moor lies in one vertical plane. If the wind drag on the ship does not coincide with the current, the drag caused by the ocean current on the mooring leg will probably cause it to move out of a single plane; the problem will become a three-dimensional analysis of the catenary. Few analysts are equipped to cope with this problem, and any mooring problem involving a significant current should be referred to the Naval Ship Systems Command.



SLOPE DRAG DUE TO WAVES.
FIGURE 3-1

As has previously been noted, current forces may exceed wind forces, and any choice that must be made between heading into the wind or heading into the current should be decided in favor of the current.

A very crude formula for estimating the drag imposed by a current upon a given ship is:

$$D_c = 0.3\ AV_c^2 = \text{beam aspect} \qquad \text{(Equation 3-2)}$$

$$D_c = 0.016\ AV_c^2 = \text{bow aspect}$$

where:

D_c = drag of current (lbs)

A = wetted surface of ship bottom (ft^2)

V_c = velocity of current (kts) (see Reference 2.)

3.3. Dynamic Moors

Dynamic moors are being utilized for deep water problems in increasing numbers. Two examples are CUSS I, used in a prototype drilling operation which was to be the prelude to MOHOLE, and a support ship for the CURV vehicle which is under the operational control of NOTS, Pasadena.

The dynamic moor consists of propulsion devices that will permit propulsive forces to be applied to the ship in any direction so as to hold the ship stationary against the forces of wind and sea. In addition, a dynamic moor requires some kind of sensing device which will accurately locate the ship with respect to the desired position on the bottom. The dynamic moor is a relatively expensive solution to the mooring problem, and, therefore, from a cost effectiveness viewpoint, is not attractive for mooring problems of 1,000 feet or less. Should salvage mooring requirements exceed 1,000 feet, the dynamic moor may become more attractive and at some future date replace the static moor. One problem which must be avoided, should salvage operations utilize a dynamic moor, is the entanglement of salvage lines in the propulsive devices of the dynamic mooring system. (3)

3.4. Static Moor

Since the static moor is the only moor currently of interest to the Salvage Officer, it will be treated in greater detail than was the dynamic moor.

The static moor consists of some attachment to the ocean bottom, usually an anchor; a mooring leg consisting of one or more chains or wires; and, finally, a buoy or the ship itself. Multi-leg moors usually terminate in surface buoys and the ship makes fast these buoys.

3.4.1. Anchors

In temporary moors, such as those encountered in salvage, anchors are usually used. These anchors are available in several sizes and shapes. Those most commonly encountered in salvage work are described in Table 3-1.

The ability of an anchor to hold to the ocean bottom depends on a number of factors:

1. Fluke shape.
2. Fluke angle with respect to the shank.
3. Type of ocean bottom.
4. Angle of pull exerted on the shank measured in the vertical plane.
5. Distance anchor is dragged over the bottom to permit it to dig in.

The important parameter in the shape of the fluke is the moment of the fluke area about the trunion. The greater the fluke moment, the greater is the anchor's holding power. Since a family of anchors, such as the LWT or the Eells, all have basically the same shape and proportion, the holding power of a given anchor in each of these types is approximately proportional to the anchor weight for any given bottom or direction of pull.

The holding power of an anchor may be estimated using the formula:

$$H = k\ (\text{anchor wt}) \qquad \text{(Equation 3-3)}$$

where:

H = anchor holding power (lbs.)

k = a constant peculiar to an anchor family and the ocean bottom involved (see Table 3-2)

The maximum angle which the fluke makes with the shank affects the holding power of an anchor on any given bottom.

TABLE 3-1

TABLE OF ANCHORS

Type	Weight	Maximum Holding Power (Sand)	Remarks
LWT	4,000 lb	75,000 lb	Used in standard ASR Moor
LWT "Wedge Block"	6,000 lb	106,000 lb	4 each on ATS and ARS ship types
LWT "Wedge Block"	10,000 lb	175,000 lb	In Emergency Ship Salvage Pools
LWT "Wedge Block"	25,000 lb	430,000 lb	In Emergency Ship Salvage Pools
Eells	8,000 lb	80,000 lb	4 each in ATS and ARS ship type

TABLE 3-2

ANCHOR TYPES AND HOLDING POWER

	Ocean Bottom		
Anchor Type	k for mud	k for sand	k for coral
Navy Standard	3.50 lb/lb	7 lb/lb	3.0 lb/lb
LWT (Model A.1, Full Fluke)	2.5 lb/lb	18.5 lb/lb	7.0 lb/lb
Eells	1.5 lb/lb	10 lb/lb	5.0 lb/lb

NOTE: This Table is based on NAVY data obtained in tests at Little Creek and Yorktown, Virginia, and at Key West, Florida, in October and November 1956.

The optimum fluke angle is not the same for all bottoms, and experiments have indicated that for a mud bottom the maximum holding power is attained when the fluke angle is approximately 50°, whereas on a sand bottom the optimum angle appears to be about 30°. (Figure 3-2 illustrates the effect of fluke angle on the two bottoms.) It is this variance in the fluke angle that has led to the development of the LWT "Wedge Block" anchor which may be adjusted to a maximum angle of either 30° or 50°, depending upon whether the holding ground is to be sand or mud.

The maximum holding power of an anchor is developed when the pull exerted is parallel to the ocean bottom. If the anchor end of the mooring leg rises so that the angle of pull begins to assume finite values, the flukes of the anchor tend to break out of the bottom. Another way of visualizing the same problem is to realize that pull at positive angles raises the shank and is effectively reducing the angle that the flukes make with respect to the ocean bottom, thus the holding power decreases. (Figure 3-3 illustrates the effect of the angle of pull on the holding power of an anchor.)

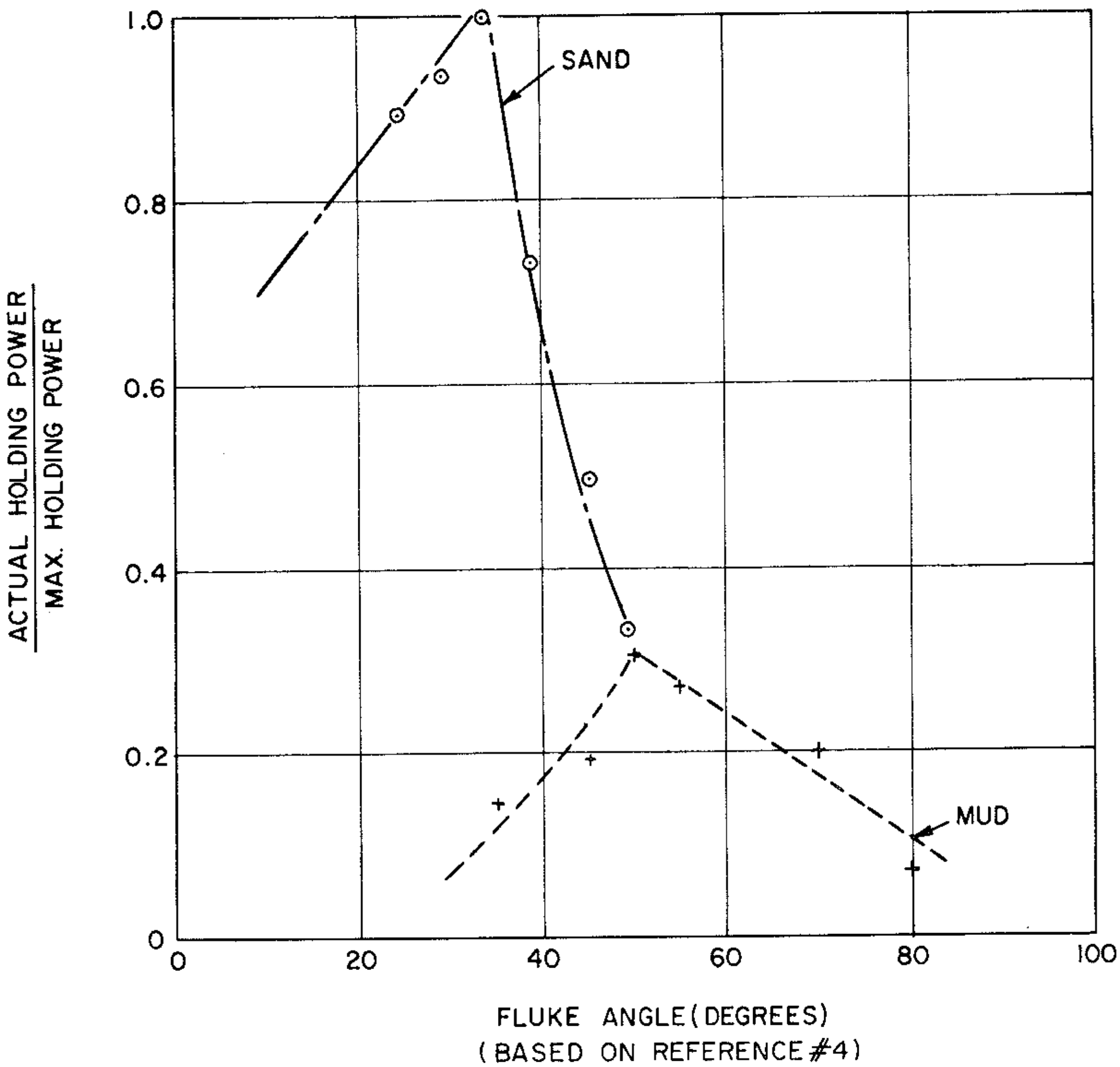
An anchor does not immediately develop its full holding capability; it must be pulled over the bottom for a distance before it develops. The distance involved varies from approximately 40 to 100 feet, depending upon the ocean bottom, anchor size, and other factors. (Figure 3-4 illustrates the effect of anchor drag upon holding power.) The essential point for the Salvage Officer is that in laying a moor, the mooring leg should be subjected to a strain so that the anchor can begin to dig itself in and develop holding power.

Anchors are usually sized to accommodate the drag forces imposed by the ship on the moor. The anchor should develop a minimum holding power that is at least equal to the maximum drag force which the ship will place upon the moor, and which occurs under the most adverse condition in which the ship will be required to stay on station. If these forces are greater than the holding power of the anchor, two or more mooring legs may be required in the general direction from which the most adverse wind or current conditions are anticipated.

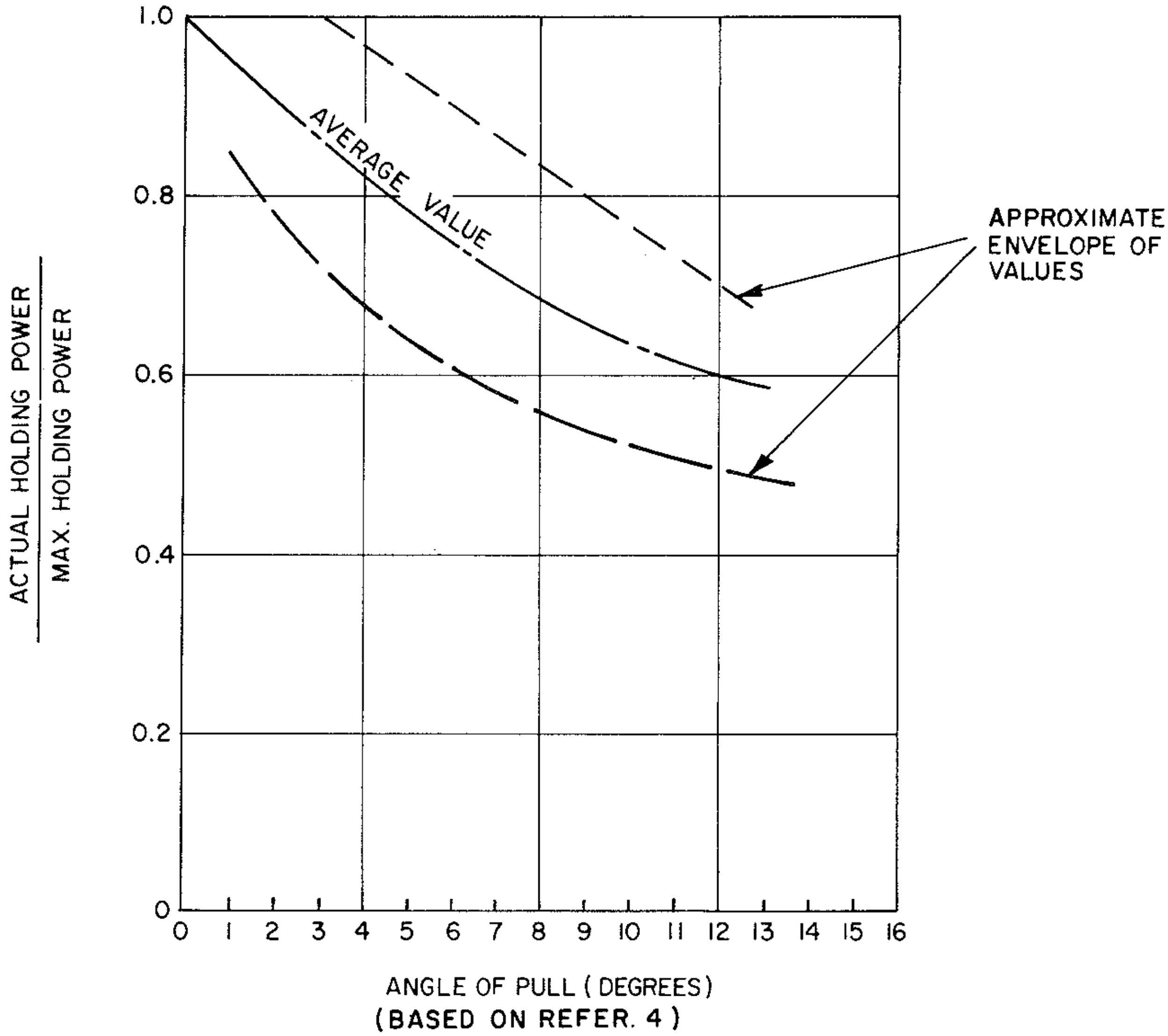
3.4.2. Catenaries

Simple Catenaries

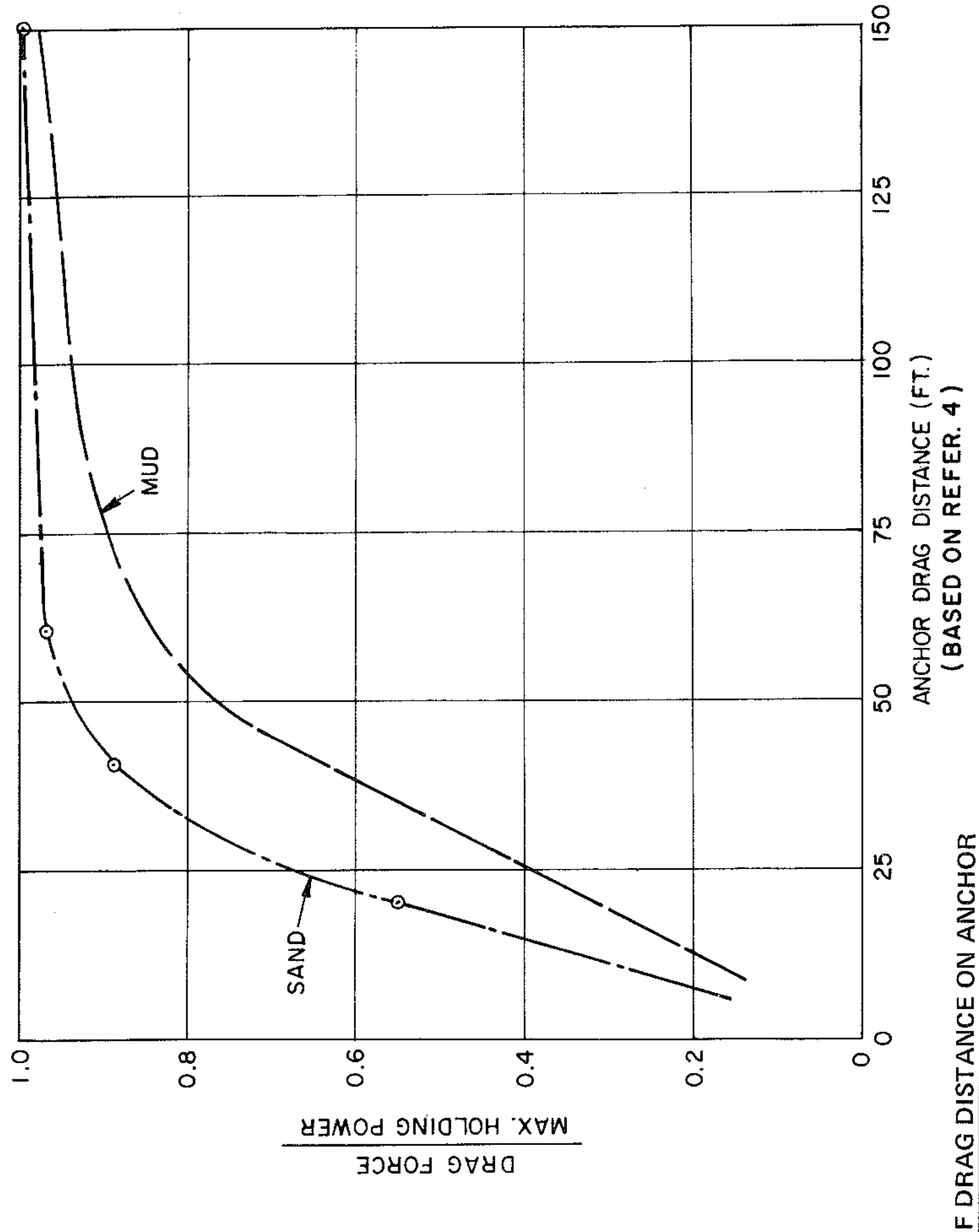
The curve described by any line having finite weight and subjected to tension is known as a catenary.



ANCHOR HOLDING POWER AS A FUNCTION OF FLUKE ANGLE WITH BOTTOM.
FIGURE 3-2



HOLDING POWER AS A FUNCTION OF ANGLE OF PULL.
FIGURE 3-3



EFFECT OF DRAG DISTANCE ON ANCHOR HOLDING POWER.
FIGURE 3-4

The mathematical equation of a catenary is well defined and is encountered in engineering problems in many fields. A simple moor involving an anchor, a single mooring line, and either a ship or a buoy at the surface may be described using the following equations: (5)

$$Y = {}^{H}/_{W} (\sec \theta_b - \sec \theta_o) \qquad \text{(Equation 3-4)}$$

$$S = {}^{H}/_{W} (\tan \theta_b - \tan \theta_o) \qquad \text{(Equation 3-5)}$$

$$X = {}^{H}/_{W} \ln \frac{\tan (^{\pi}/_4 + \frac{\theta_b}{2})}{\tan (^{\pi}/_4 + \frac{\theta_o}{2})} \qquad \text{(Equation 3-6)}$$

(see Figure 3-5)

where:

- S = scope of mooring leg (ft)
- Y = vertical projection of mooring leg (ft)
- X = horizontal projection of mooring leg (ft)
- H = holding power (lbs)
- W = WT/FT in sea water of mooring leg ($^{lbs}/_{ft}$)
- θ_b = angle of tangent to mooring leg with respect to horizontal (at the buoy)
- θ_o = angle of tangent to mooring leg (at the anchor) with respect to horizontal. (5)
- ln = the natural logarithm (i.e., to the base e).

Figure 3-5 illustrates a simple catenary and the nomenclature involved in the equations. As indicated in the previous discussion, in order for the anchor to develop its maximum holding power, the angle which the catenary makes with the bottom at the anchor (θ_o) should be 0 degrees. In shallow waters this can be obtained using reasonable scopes of chain or line.

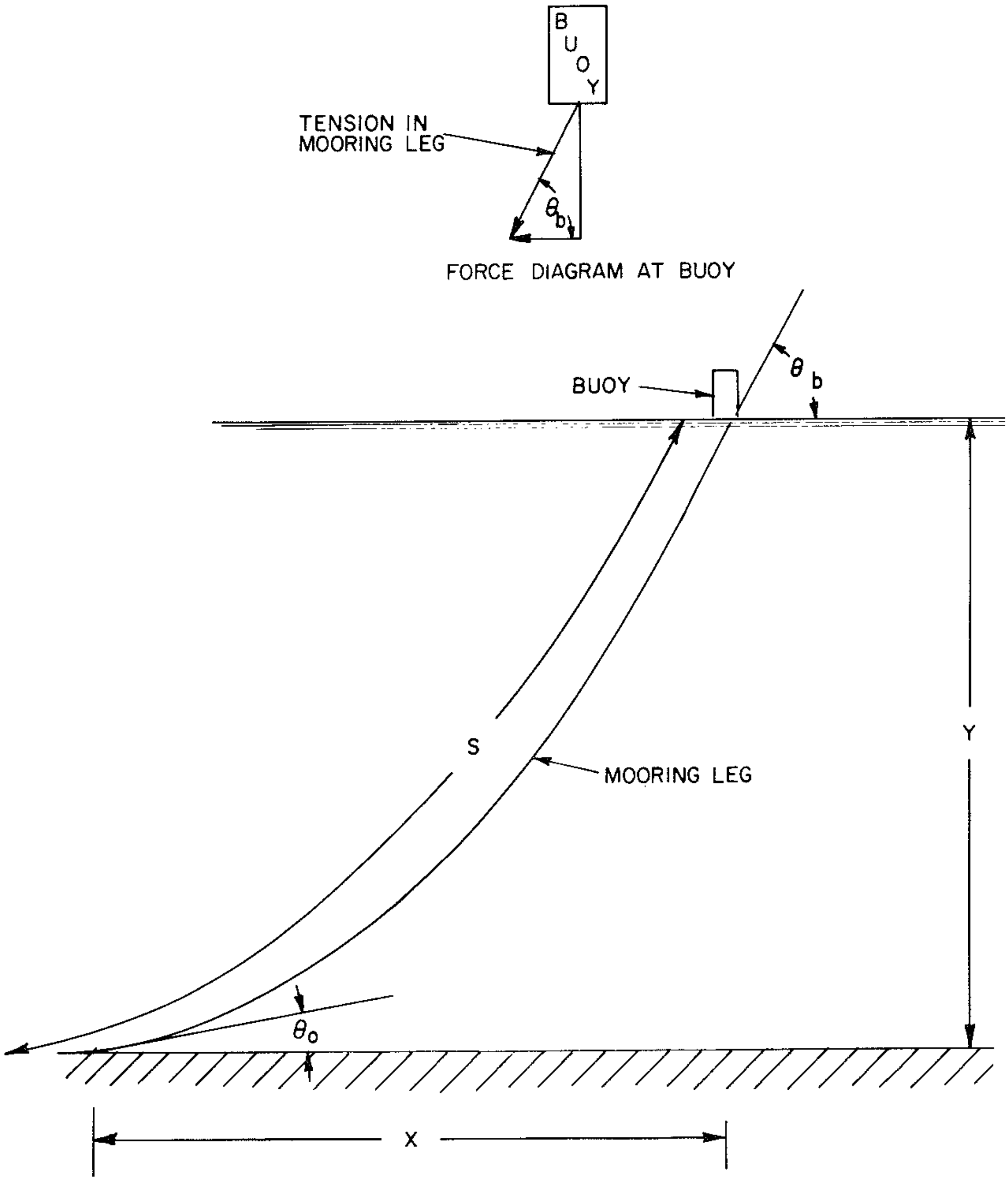
An example of a solution for a simple catenary problem involving the terms listed above is:

given:

water depth = 650 ft

scope = 27 shots, 3/4-inch chain

bottom slope and angle of pull (θ_o)= 0^o



GEOMETRY OF A MOORING LEG.
FIGURE 3-5

Example 3-1. Find Holding Power

$$\frac{Y}{S} = \frac{(\sec \theta_b - \sec \theta_o)}{(\tan \theta_b - \tan \theta_o)} \qquad \text{(Equation 3-7)}$$

$$H = {}^{WT}/_{\tan \theta_b} \qquad \text{(Equation 3-8)}$$

solution:

$$\frac{Y}{S} = \frac{\text{depth}}{\text{scope}} = \frac{650 \text{ ft}}{27 \text{ shots} \times 90 \; {}^{ft}/_{shot}}$$

$$\frac{Y}{S} = \frac{650}{2430} = 0.268$$

enter Figure 3-6 with 0.268 and find that

$$\theta_b = 30^o \text{ on } \theta_o = 0 \text{ line}$$

$$W_T = 27 \text{ shots} \times 478 \; {}^{lbs}/_{shot} \text{ (sea water)} = 12{,}900 \text{ lbs}$$

enter Figure 3-7 using

$$W_T = 12{,}900 \text{ and } \theta_b = 30^o$$

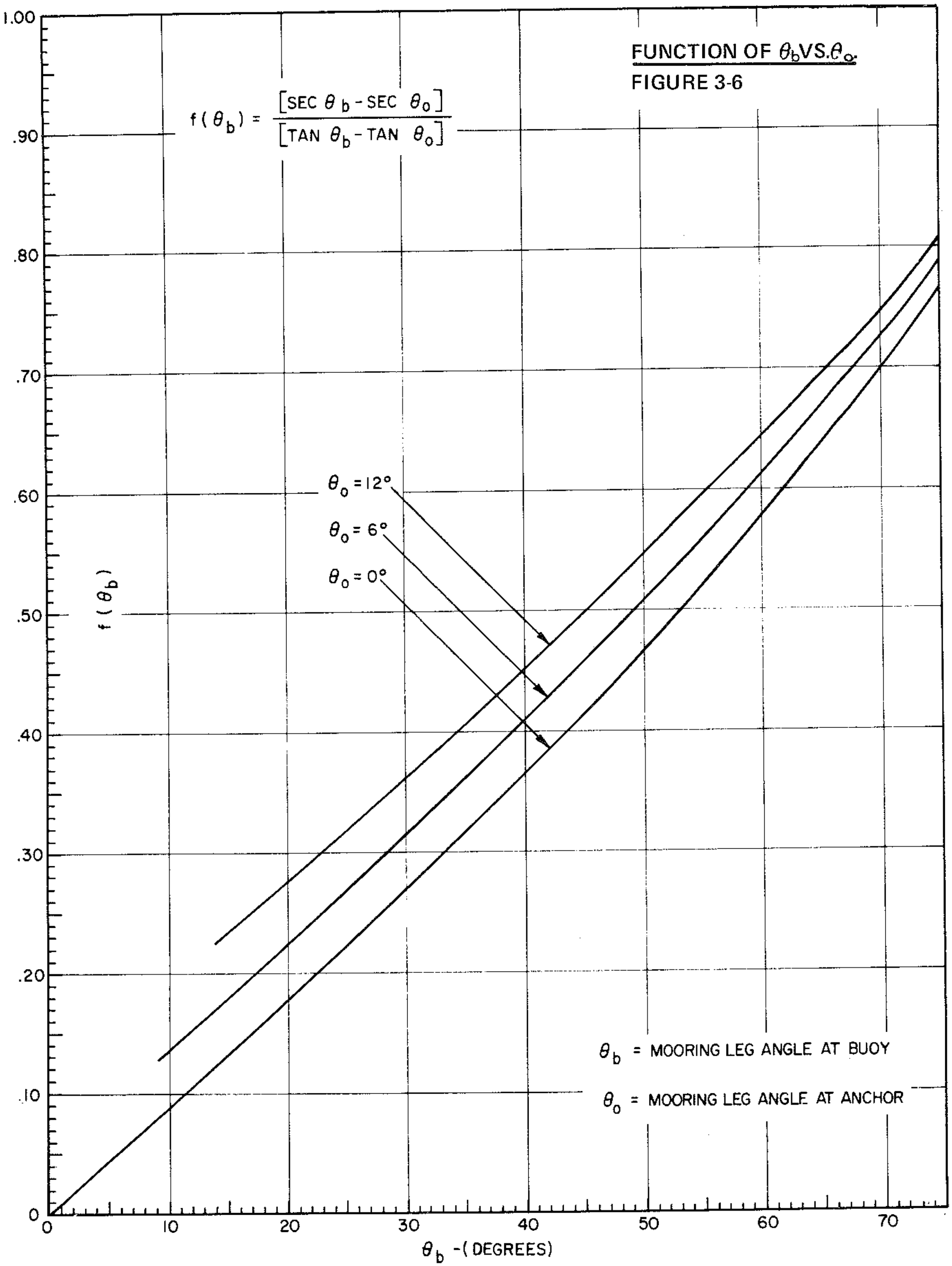
Connect these points with a straight line and extend the line to the holding power scale.

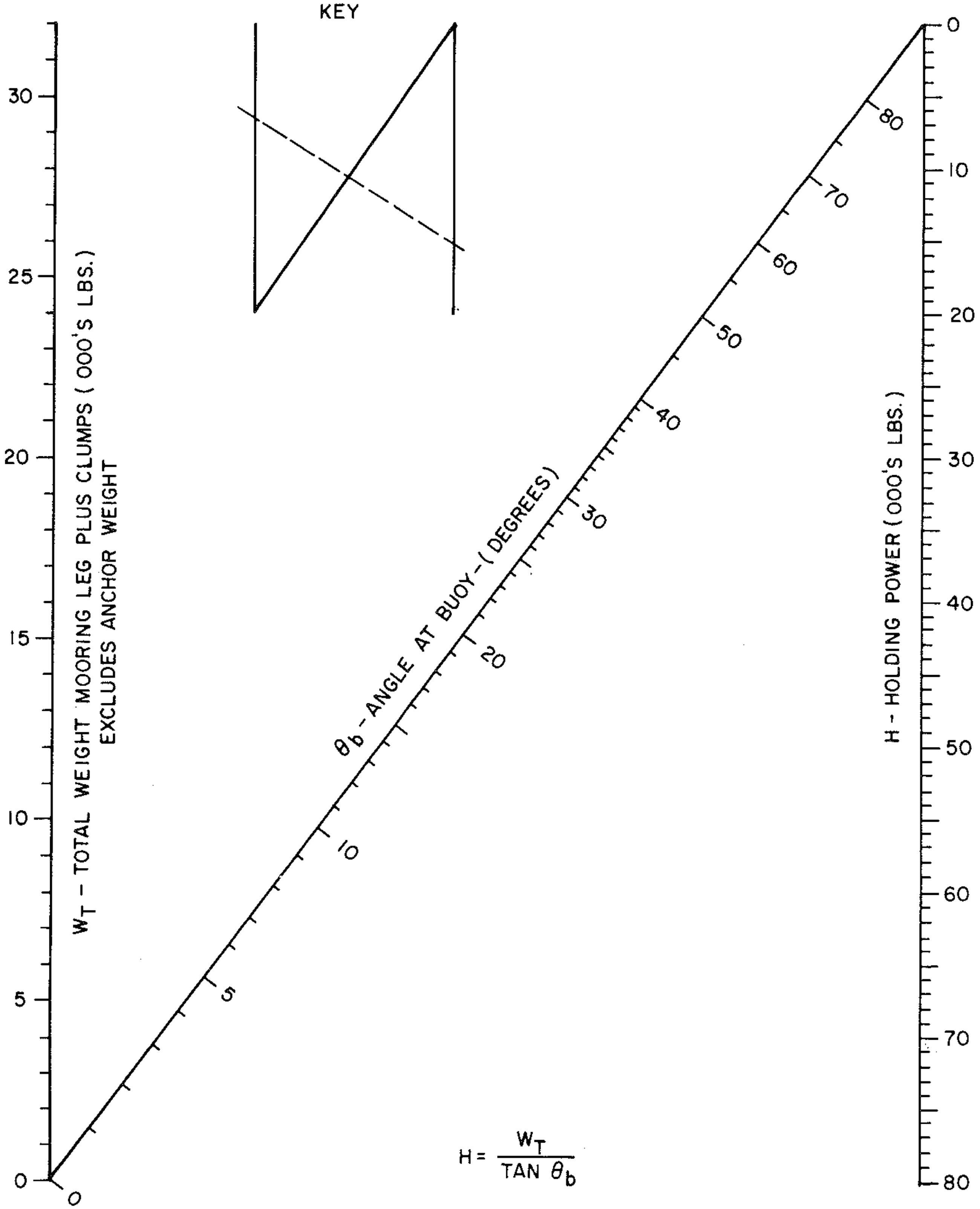
read

$$H = 22{,}300 \text{ lbs}$$

Compound Catenaries

As water depth increases, the length of the scope of chain required to let the anchor develop its full holding power becomes great. This condition tends to make the mooring designer think in terms of adding weights at the lower end of the mooring line in order to modify the catenary and make it tangent to the ocean bottom at the anchor, permitting shorter mooring legs to be used. Using clumps or chains of different weights for various segments of the mooring leg transforms the simple catenary problem into one involving a compound catenary. The basic equations which describe a compound catenary are the same as equations 3-4 through 3-8.


FUNCTION OF θb VS. θo.
FIGURE 3-6
f(θb) = [SEC θb - SEC θo] / [TAN θb - TAN θo]
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
f(θb)
θo = 12°
θo = 6°
θo = 0°
θb = MOORING LEG ANGLE AT BUOY
θo = MOORING LEG ANGLE AT ANCHOR
0
10
20
30
40
50
60
70
θb - (DEGREES)



MOORING LEG HOLDING POWER NOMOGRAPH.
FIGURE 3-7

These equations, however, must be applied to each segment of the mooring leg. For example, if a mooring leg is assembled using 27 shots (2430 feet) of 3/4-inch chain and one shot (90 feet) of 2-1/4-inch chain, then each of these two segments must be treated as a simple catenary. The two catenaries may be related to each other by imposing two conditions:

Condition I:

If equation 3-4 is solved for both segments, then the sum of the results is equal to the depth of the water in which the moor is placed (see Figure 3-8).

$$Y_a = \frac{H}{W_a} (\sec \theta_1 - \sec \theta_o) \qquad \text{(Equation 3-9)}$$

$$Y_b = \frac{H}{W_b} (\sec \theta_2 - \sec \theta_1) \qquad \text{(Equation 3-10)}$$

$$\text{depth} = Y_a + Y_b \qquad \text{(Equation 3-11)}$$

Condition II:

The angles at the ends of the catenary segments may be related by the following equation:

$\tan \theta_o$ - must be assumed. It is usually assumed to be zero. Therefore, $\theta_o = 0$, and the catenary is tangent to a horizontal ocean bottom.

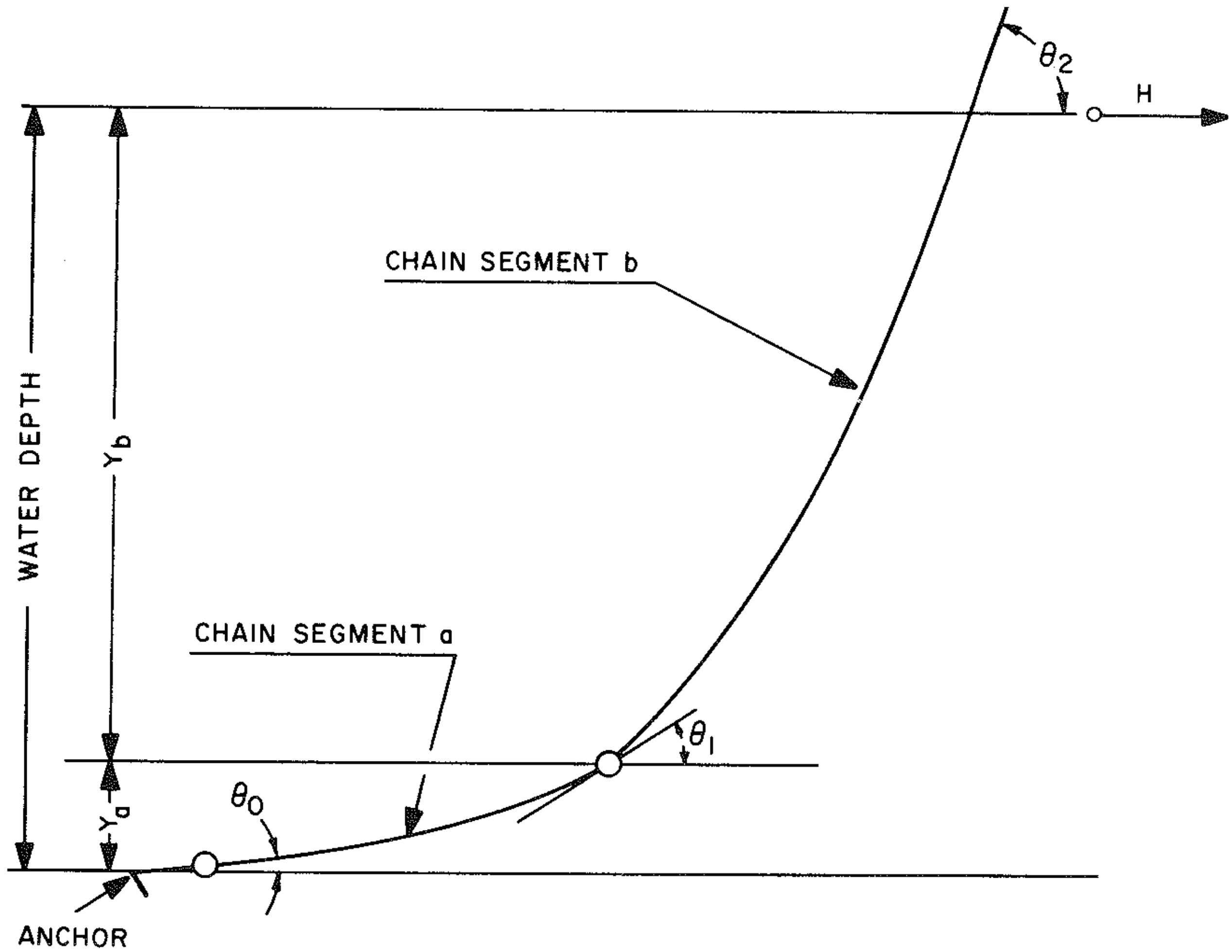
$$\tan \theta_1 = \frac{S_a W_a}{H} + \tan \theta_o \qquad \text{(Equation 3-12)}$$

$$\tan \theta_2 = \frac{S_b W_b}{H} + \tan \theta_1$$

therefore,

$$\tan \theta_2 = \frac{S_b W_b}{H} + \frac{S_a W_a}{H} + \tan \theta_o \qquad \text{(Equation 3-13)}$$

Because of the nature of the equations, they cannot be simplified into a direct solution of holding power. It becomes a matter of assuming various values of holding power and solving for the depth of water associated with this holding power.



S_a = SCOPE OF SEGMENT a (FT)

S_b = SCOPE OF SEGMENT b (FT)

W_a = WEIGHT PER FOOT IN WATER OF CHAIN a (LB/FT)

W_b = WEIGHT PER FOOT IN WATER OF CHAIN b (LB/FT)

H = HOLDING POWER (LBS)

Y_a = VERTICAL PROJECTION OF CHAIN a (FT)

Y_b = VERTICAL PROJECTION OF CHAIN b (FT)

SEC θ_0 = SECANT OF ANGLE θ_0

TAN θ_0 = TARGET OF ANGLE θ_0

θ_0 = ANGLE OF ANCHOR CHAIN AT THE ANCHOR

θ_1 = ANGLE OF CHAIN a AND CHAIN b AT THEIR JUNCTURE

θ_2 = ANGLE OF CHAIN b AT THE WATER SURFACE

CATENARY NOMENCLATURE.

FIGURE 3-8

A plot of holding power versus depth may then be made and the desired solution of holding power for the given depth may be located on that curve. Figure 3-9 is a plot of depth versus holding power for a standard ASR moor using 27 shots of 3/4-inch chain (curve B). A second plot is given of holding power versus depth for a moor consisting of 27 shots of 3/4-inch chain with a 90-foot section of 2-1/4-inch chain added (curve B).

To illustrate the manner in which the points are calculated in order to determine the curve of holding power versus depth, the following example is a calculation of one point in curve A of Figure 3-9.

Example 3-2

given:

$S_a = 90$ ft

$W_a = 43.1$ lbs/ft in water (49.6 lbs in air)

$S_b = 2430$ ft

$W_a = 5.31$ lbs/ft in water (6.11 lbs in air)

assume:

$\theta_o = 0^o$

therefore:

$\sec\theta_o = 1.0000, \tan\theta_o = 0.0000$

$H = 30{,}000$ lbs

$$\tan\theta_1 = \frac{S_a W_a}{H} + \tan\theta_o = \frac{3879}{30{,}000} + 0 = 0.1293$$ (from eq. 3-12)

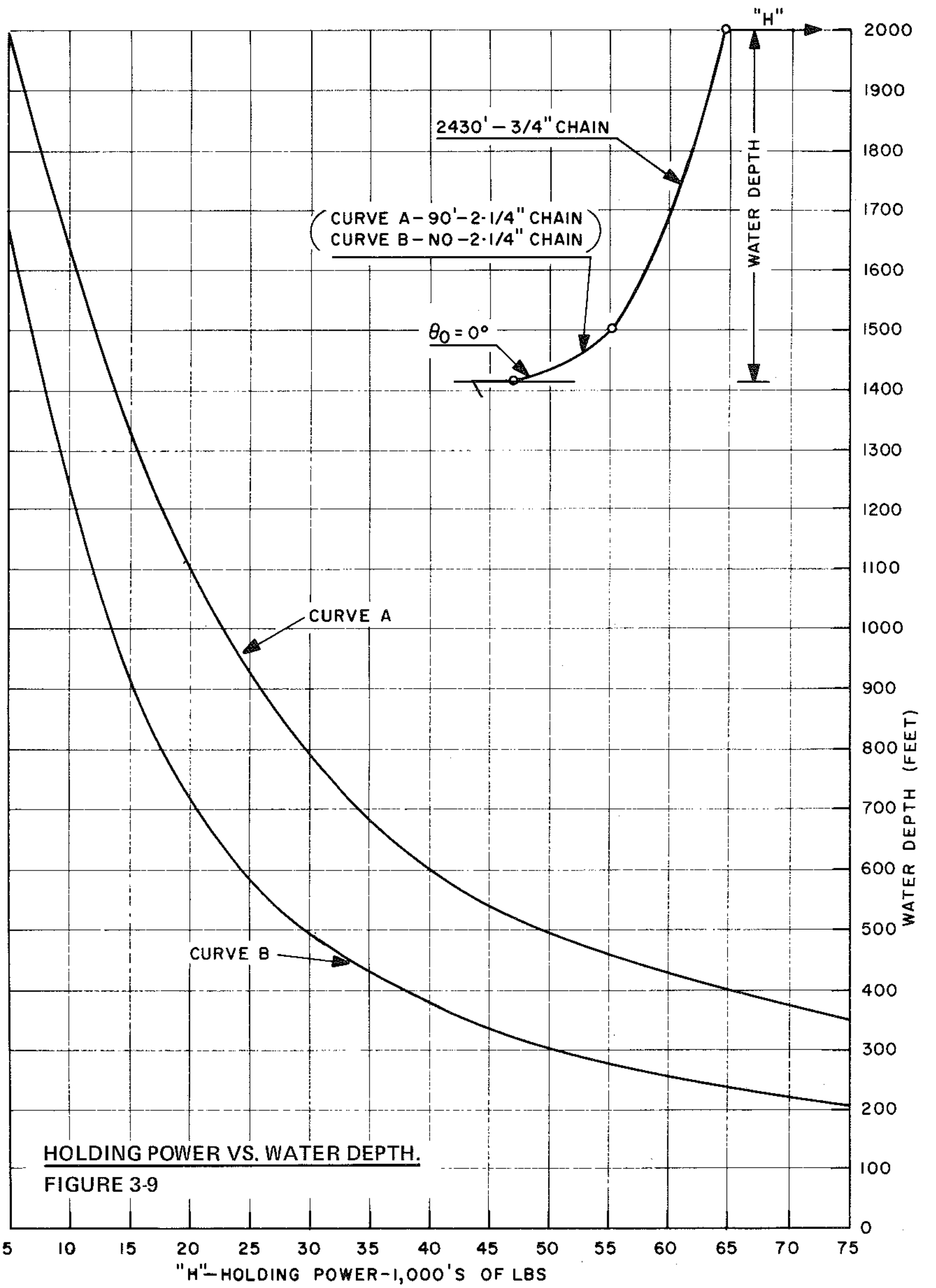
$\theta_1 = 7^o\ 22'$ | from Trigonometric Tables

$\sec\theta_1 = 1.0083$ |

$$\tan\theta_2 = \frac{S_b W_b}{H} + \frac{S_a W_a}{H} + \tan\theta_o = \frac{3879 - 12903}{H} + 0$$

(from eq. 3-13)

$$\tan\theta_2 = \frac{16782}{30{,}000} = .5594$$



HOLDING POWER VS. WATER DEPTH.

FIGURE 3-9

$$\theta_2 = 29^\circ\ 13' \qquad \text{from Trigonometric Tables}$$

$$\sec \theta_2 = 1.1458$$

$$Y_a = \frac{H}{W_a} (\sec \theta_1 - \sec \theta_o) \qquad \text{(from eq. 3-9)}$$

$$Y_a = \frac{30,000}{43.1} (1.0083 - 1.0000) = 5.78 \text{ ft}$$

round off Y_a to 6.0 ft

$$Y_b = \frac{H}{W_b} (\sec \theta_2 - \sec \theta_1) \qquad \text{(from eq. 3-10)}$$

$$Y_b = \frac{30,000}{5.31} (1.1458 - 1.0083)$$

$$Y_b = 777 \text{ ft}$$

$$\text{water depth} = Y_a + Y_b \qquad \text{(from eq. 3-11)}$$

$$\text{water depth} = 777 + 6 \text{ ft}$$

$$\text{water depth} = 783 \text{ ft}$$

Returning for a moment to Figure 3-9, it should be noted that curve B was calculated using the method set forth in Example 3-1. Curve A was calculated using the method of Example 3-2. These two examples were chosen to permit a direct comparison of the holding power of a standard ASR moor at any given depth to the holding power which could be developed by simply adding one 90-foot shot of 2-1/4-inch chain between the standard ASR moor leg and the anchor.

The previous sections of this chapter have dealt with some of the factors affecting holding power, but it may be well to reiterate at this time that the holding power calculated using equations 3-3 through 3-13 merely represents that horizontal force which would create a catenary under static conditions described by those formulas.

Any number of conditions may prevent the moor from behaving as predicted by catenary calculations. These conditions include the following:

1. An anchor of inadequate holding power for bottom conditions actually encountered is employed.

2. Dynamic forces imposed by wind, wave, or current impose excessive transient forces on the anchor or tend to cause it to break out.

3. Current conditions are such that the catenary is not two dimensional as assumed by Equations 3-3 through 3-13, but is actually a three-dimensional curve.

Having listed some of the factors which will influence the actual behavior of the moor, it is well to restate the aim of this chapter which is not to make the reader a mooring designer, but to equip the Salvage Officer with rudimentary tools that may help him evaluate the effect of changing any element of a pre-designed moor.

3.5. The ASR Moor

The ASR moor consists of a 4,000-pound LWT anchor and the required scope of 3/4-inch dielock chain. Each ASR is provided with 108 shots so that in a four-leg moor, an ASR could deploy 27 shots of chain on each leg. The ASR moor is generally laid out in a circle whose diameter depends upon the depth of water in which the moor is to be deployed. Each leg is generally dropped at points corresponding to 0 degrees, 90 degrees, 180 degrees, and 270 degrees about the circle parameter. (Refer to the NWP search and rescue series for information concerning the laying of a moor.)

3.6. Mooring Equipment

To supplement mooring equipment available on a salvage ship, the Salvage Officer can request the use of emergency equipment stockpiled and available on a loan basis from the many Emergency Ship Salvage Pools (ESSP), and Material Bases.

NOTE: A list of Emergency Ship Salvage Pools and Material Bases is presented in Table 3-3. All materials stored in the above mentioned pools are listed in allowance and inventory control lists every six months. These inventory lists are available to the Salvage Officer; he should request them when he is contemplating a loan of equipment.

The following equipment is generally available in the emergency pools and can be obtained to supplement the salvage equipment on the site:

Item	Description
Anchor	8,000 lb. Eells
Anchor	6,000 lb. LWT
Chain	2-1/4-inch
Wire rope	1-5/8-inch x 600 feet (& x 300 feet)
Wire rope	5/8-inch x 1200 feet

Salvage pools can supply much additional equipment which may be necessary for the moor.

TABLE 3-3

LOCATION OF EMERGENCY SHIP SALVAGE POOLS AND MATERIAL BASES

<u>Salvage Material Pools</u>:

NSD Newport Annex, Bayonne, New Jersey, USA
U.S. Naval Supply Center, Oakland, California, USA
U.S. Naval Supply Center, Pearl Harbor, Hawaii, USA
U.S. Naval Supply Depot, Guam, Mariana Islands
U.S. Naval Supply Depot, Subic Bay, Republic of the-Philippines
U.S. Naval Supply Depot, Guantanamo Bay, Cuba
U.S. Naval Station, Rodman, Canal Zone
U.S. Naval Station, San Juan, Puerto Rico

<u>Salvage Material Bases (Fleet controlled)</u>:

Camp Darby, Livorno, Italy
U.S. Naval Ship Repair Facility, Yokosuka, Japan
Fleet Activities (SRD), Sasebo, Japan
U.S. Naval Support Activity, Danang, Republic of Vietnam
Philadelphia Naval Shipyard, Philadelphia, Pennsylvania, USA
Long Beach Naval Shipyard, Long Beach, California, USA
San Francisco Bay Naval Shipyard, Hunters Point Division,-San Francisco, California, USA
Puget Sound Naval Shipyard, Bremerton, Washington, USA
Boston Naval Shipyard, Boston, Massachusetts, USA
Charleston Naval Shipyard, Charleston, South Carolina, USA
Destroyer Submarine Base, Norfolk, Virginia, USA
U.S. Naval Station, Adak, Alaska, USA

<u>Submarine Salvage Material Pools (Pontoons and associated equipment)</u>:

Boston Naval Shipyard, Boston, Massachusetts, USA
Charleston Naval Shipyard, Charleston, South Carolina, USA
Pearl Harbor Naval Shipyard, Pearl Harbor, Hawaii
Naval Base, San Diego, California, USA

<u>Special Salvage Material Pools</u>:

(Load Measuring Instruments) Naval Ship Research and Development Center, Carderock, Maryland, USA
(Underwater Gas Generators) Naval Ordnance Test Station,-China Lake, California, USA
(Foam-in-Salvage) San Francisco, California, USA

4. Determination of a Lift

4.1. Historical Review

Appendices A through I disclose the diversity of lift requirements in the salvage operations of the last fifty years.

4.1.1. F-4 (1915)

As reported in Appendix A, this lift was 260 dead-weight tons. The hull was fully flooded as shown in the figure preceding the Appendices.

4.1.2. S-5 (1920)

S-5 surface displacement was 875 tons. Since the lift was unsuccessful, the amount of buoyancy remaining, upon completion of the rescue operation, was never determined. Appendix B gives more details on the salvage of S-5.

4.1.3. S-51 (1925)

This completely flooded hull was an 800-ton lift and since the hull had sunk 5 feet deep in clay (Appendix C), a 25 percent margin was added for breakout. It was anticipated that 350 tons of lift would be obtained by blowing tanks and compartments, and the balance of lift would be provided by eight 80-ton pontoons. Nine and one-half months later, many new lifting schemes had been devised. Hard work in sealing compartments and tanks resulted in gaining more than 350 tons; however, it was still necessary to provide eight 80-ton pontoons and two 60-ton pontoons.

The major factor in the decision to increase the pontoon lift force available was the uncertainty as to the movement of the center of gravity of the submarine and its contents as it assumed various angles during the lift.

4.1.4. S-4 (1927)

Salvage of S-4 (described in Appendix D) was accomplished satisfactorily after correct calculation of lift requirements. Divers entering the compartments verified that they were completely flooded. Hence, the weight to be lifted and its center of gravity were accurately known. Six 80-ton pontoons were successfully used to augment self-lift, and good control was maintained (see Appendix D). Experience gained in the successful lift of S-51 was put to good use.

4.1.5. USS SQUALUS (1939)

LCDR F.A. Tusler's report, a source of material for Appendix E, shows that the control requirements were initially underestimated. The submarine's weight and its center of gravity at the completion of the rescue operation were assumed to be fairly accurate based upon reports from the survivors. First calculations showed the need for seven pontoons: five 80-ton pontoons at the stern and two 80-ton pontoons at the bow with all main ballast tanks and fuel oil tanks blown empty with a very small margin. The first attempt to lift was made on 13 July 1939, and, as results proved, there were too few control pontoons (see Paragraph 5.2.3.). Again, valuable experience was gained, i.e., an adequate margin of control lift must be allowed for unknown conditions. Since the lift on 13 July fully illustrates the need for an adequate margin of lift control, a detailed discussion follows.

The external lift on 13 July used all of the lift which was available. Providing a greater margin of control would have required a delay in the operation until additional lifting wire could be manufactured. Calculations of the moments of the weight to be lifted and of the lifting forces indicated that one control pontoon at the bow would be sufficient. The loss of buoyancy when the pontoon reached the surface would slightly more than compensate for the gain in buoyancy of the main ballast tanks, i.e., the tanks would gain in buoyancy as the depth decreased and the ship leveled off. The calculations were accomplished using the following assumptions:

1. The stern was to be lifted first, and

2. The bow was assumed to leave the bottom at the instant the forwardmost ballast tank was blown to the level at which the air in the tank would expel the remaining water; the water was expelled by expanding air to the volume of the tank as the submarine rose to ride on the control pontoon. This was the most unfavorable condition, since it created the greatest excess buoyancy as the submarine was lifted.

Even though the predicted momentum of the ship might cause it to rise above the desired level, it was expected that partial reflooding of the main ballast tanks, as the ship took an up angle, would cause her to settle back in the forward slings with the forward control pontoon supporting some of the submarine's weight.

When the lift was made, the stern lifted as planned. The forward main ballast tanks were blown and the bow lifted, but failed to stop, until it penetrated the surface.

The submarine assumed an "up angle" of some 45 to 50 degrees throwing the major portion of the lift upon the after slings, parting one of them. The bow sling slipped loose and SQUALUS settled back to the bottom stern first. (See Figure E-1 in Appendix E.)

Later analysis of this first lift attempt revealed that the initial assumption of the location of the submarine's center of gravity was in error. Though correct at the time of the rescue operations, it did not represent the facts at the time of the first lift.

After salvage had been accomplished, it was discovered that a 1/4-inch gage line from No. 3 ballast tank had been burned through during the discharge of the after electrical storage battery. This was caused by a short circuit due to the water. As a result, air leaked from the tank into the flooded compartments and water was blown from these compartments through the induction line after the stern had been lifted and while the ship had a large down angle. The air bubble in these interconnected compartments became fairly large and traveled to the after torpedo room. Then, as the bow lifted, the bubble migrated forward which generated unforeseen excess buoyancy forward. This incident illustrates how a minor item of missing information on the condition of the ship can significantly affect the success of the salvage operation.

A successful lift from 240 feet was made on 12 August, 1939, using ten pontoons: three lift pontoons (Paragraph 5.2.3.), three control pontoons at the stern, and one lift pontoon with three control pontoons at the bow. A lift from 160 feet was also successful on 17 August using one less lift pontoon at the stern. During the last lift from a depth of 92 feet, a list resulted from static instability, causing air to spill from the main ballast tanks. As a result, SQUALUS, having already reached the surface, sank back to the bottom. A second attempt on the same day was successful, after the blowing sequence was modified to ensure that the bow pontoons would continue to be loaded, and provide static stability for the ship after they reached the surface.

4.1.6. THETIS (1939)

This salvage operation was conducted utilizing a merchant ship which had been specifically modified for the lifting phase. The operation took place in an area where the scope of tide was in excess of 20 feet. Utilizing the lift ship and tides, THETIS was lifted in four stages as the tide flooded and was grounded at high tide to prepare for the next lift.

the total deadweight of THETIS was about 1000 tons. (Appendix F describes the lift methods used.)

4.1.7. TRUCULENT (1950)

This salvage operation was conducted utilizing two large lift ships each having 600 tons lift capacity. The deadweight lift requirement was reduced from 950 tons to 800 tons by blowing dry the main ballast tanks. (Appendix G describes this salvage operation.)

4.1.8. German Submarine, HAI (1966)

On 15 September 1966, the German submarine HAI sank in the North Sea in 145 feet of water. Within a few days the hull was raised by MAGNUS III, a new sea-going crane possessing improved sea-keeping qualities. The salvage operation was hampered by 7-foot waves on the first day, but a 57-foot lift and a 130-mile tow to Helgoland at a speed of two knots was completed by 21 September. The lift requirement was estimated to be 210 tons. This compares to HAI's surface displacement of 250 tons.

4.2. Determining Deadweight and Center of Gravity

The first step in making a salvage plan is to determine the weight to be lifted as well as its center of gravity. When operating at sea, a submarine is kept in diving trim, that is, near neutral buoyancy when the main ballast tanks are flooded. Therefore, the weight to be lifted is:

1. The weight of the water that has entered the main compartments.
2. The water and oil tanks that are vented to the main compartment, or whose boundaries are not able to withstand the pressure in the adjacent compartments.

4.2.1. Computing the Lift Requirements

The lift requirements consist of these weights plus sufficient lift to initially break the submarine free from any bottom mud suction (breakout force) to which it may be subjected. An additional lift capability must be provided to control the submarine's attitude after it has broken free of the bottom, and to allow for the uncertainties that surround the submarine's actual state of flooding at the time of lift. (See Paragraph 4.1.5. SQUALUS.)

4.2.2. Gathering of Pertinent Data

The survivors of the crew may be able to furnish information concerning the amount of flooding and the status of bulkheads and external closures. The crews of S-5 and SQUALUS were able to give the Salvage Officer much of the required information. However, if such firsthand information cannot be obtained concerning the extent of flooded compartments, the compartment air salvage fittings may be used as described in the following paragraphs.

4.2.3. Use of Air Salvage Fittings

All U.S. submarines are provided with two air salvage fittings in each compartment: one leading to a point high in the compartment; the other to a low point. The high air salvage line is suitable for:

1. Supplying water and liquid food to entrapped personnel.
2. For supplying or exhausting air from the compartment.

The low salvage line may be used for supplying air or removing water from the compartment by pumping or blowing. A strainer protects this line against blockage by debris.

A hose from the salvage ship to the high salvage fitting on the submarine can reveal the extent of water in a compartment and the condition of the bulkhead closures. For example, by blowing air for a short time through the hose to clear it of water, and then securing the air, the pressure at the terminal of the salvage connection inside the ship may be determined via the manifold pressure gage. The first indication that the compartment is open to the sea is when the pressure in the compartment is the same as sea pressure at that depth. This may be further checked by attempting to vent down the compartment. If the pressure cannot be changed materially, then the compartment is certainly open to the sea. Accurate pressure readings in this manner must be through a hose that has had all water blown from it.

To determine whether or not the bulkheads are tight, compare the pressure in various watertight compartments and attempt to change the pressure in one compartment at a time. If they are not tight, rates of pressure change may give some clue as to whether there are large openings or only small leaks.

When changing the pressure in compartments, keep the pressure down to about 2/3 of the bulkhead design pressure, since these bulkheads are designed to permit a considerable amount of permanent distortion before failure. Connecting a differential pressure gage across the high and low salvage lines at the salvage manifold (Figure 4-1) and blowing the hoses clear of water will usually determine the height of the water above the end of the low salvage connection. It should be noted that this method is applicable only at depths shallow enough to permit the hose to be subjected to the external pressure differential of water at depth, and one atmosphere inside the hose without collapsing. It is also possible to determine whether or not the compartment is open to the sea. An accurate reading of the water level may be obtained by knowing:

1. The height and longitudinal and transverse positions of the low salvage connection.
2. The attitude of the ship.
3. The pressure differential.

The position of the salvage connection can be determined from the building or planning yard, or from a sister ship built at the same yard. The attitude of the ship can be determined by sending down open-ended air hoses to known points on the ship, blowing them clear of water, and observing the differential pressure. If possible, the differential pressure gage should be one with a full-scale reading of about 25 psi.

The volume of air as well as the amount of compartment water which is not open to the sea can be calculated with somewhat less accuracy by admitting air to the compartment from an air bank of known volume. This can be accomplished by using a hose attached to the high salvage connection and observing the pressures in the compartment and air bank before and after transferring the air. By delaying the second pressure observations for several hours until the air bank and compartment temperatures have returned to the ambient temperature, the accuracy of the observation will be improved. If several compartments are connected to each other, only the total volume of water in all the interconnected compartments can be determined using the above method.

It should be noted that internal pressure cannot be contained since hull closures such as hatches and air induction and exhaust valves are not able to maintain an internal pressure in excess of sea pressure in the submarine.

D_1 = WATER DEPTH OF HIGH SALVAGE DECK CONNECTION

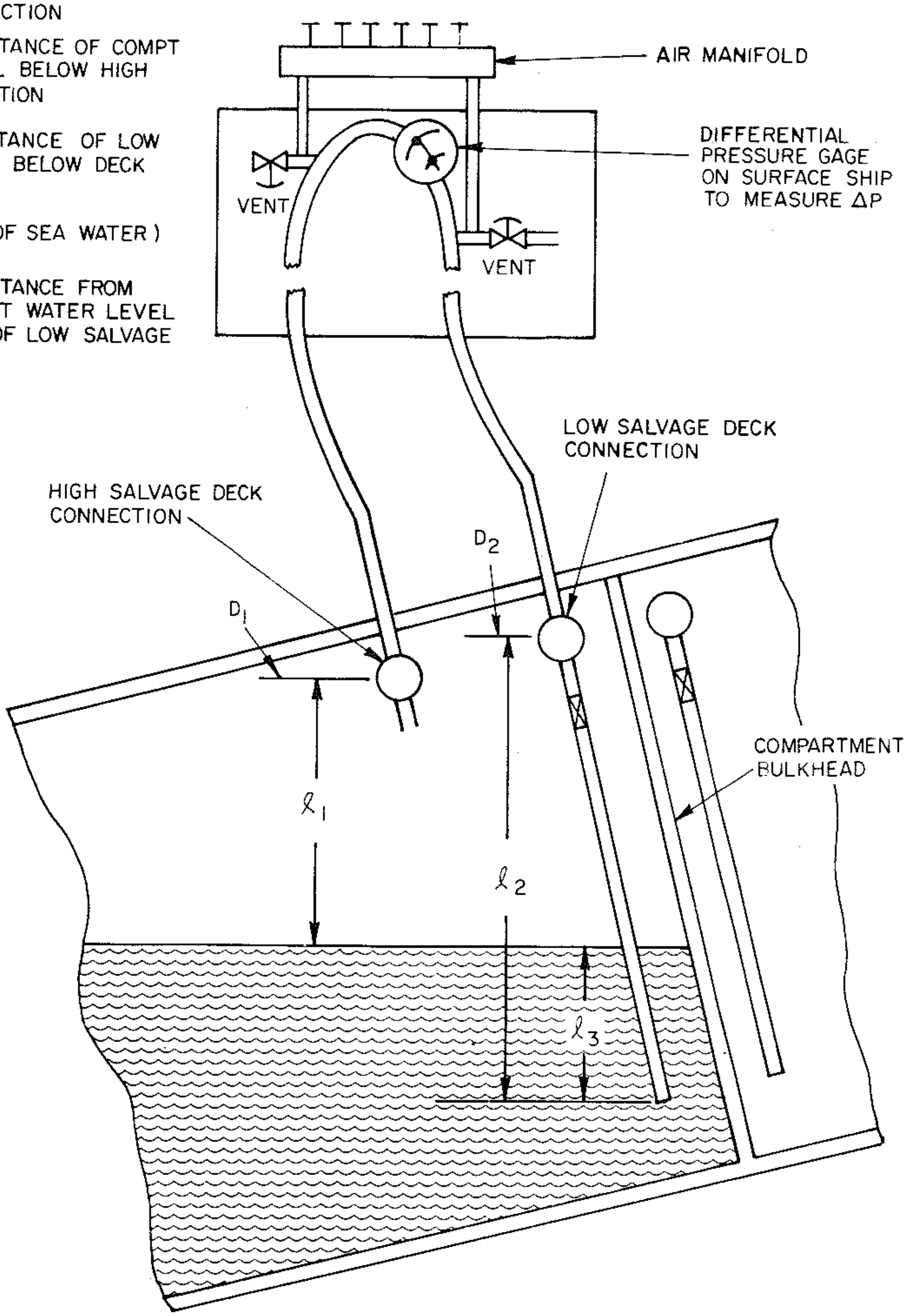
D_2 = WATER DEPTH OF LOW SALVAGE DEPTH CONNECTION

ℓ_1 = VERTICAL DISTANCE OF COMPT WATER LEVEL BELOW HIGH DECK CONNECTION

ℓ_2 = VERTICAL DISTANCE OF LOW PIPE BOTTOM BELOW DECK CONNECTION

$\Delta P = \ell_3$ (IN FEET OF SEA WATER)

ℓ_3 = VERTICAL DISTANCE FROM COMPARTMENT WATER LEVEL TO BOTTOM OF LOW SALVAGE PIPE



DETERMINATION OF COMPARTMENT CONDITION AND EXTENT OF FLOODING.

FIGURE 4-1

However, by building up the internal pressure to somewhat below that of sea pressure at the depth of the compartment, the water can be pumped out through the low salvage connection by means of a pump on the salvage vessel.

4.3. Types of Lift

The types of lift available from which the Salvage Officer can develop his plan include:

1. Surface Lift (see Chapter 7)
   a. Lift ship (ARS, ATS)
   b. Non-self-propelled barges (YMLC)
   c. Floating cranes
2. Pontoons
   a. Rigid (see Chapter 5)
      (1) Lift
      (2) Control
   b. Collapsible (see Chapter 7)
3. Self-Lift (see Chapter 6)
   a. Main ballast tanks
   b. Fuel tanks (on diesel-driven submarines)
   c. Reduction of level of water in main compartments
   d. Variable ballast tanks

The advantages and limitations of the three types of surface lift are discussed in Chapter 7. Chapter 5 describes the operation of rigid pontoons. Experience gained in the Chesapeake Bay salvage of U-1105, as reported in Reference 6, reveals a degree of unreliability in the collapsible pontoons of the late 1940's and 1950's. These rubber fabric pontoons appear to have been vulnerable to punctures and to seams bursting when used in the vicinity of heavy salvage equipment and wrecks.

4.4. Developing the Lift Plan

As previously mentioned, an operational submarine is normally kept in diving trim, and as a result, is in neutral buoyancy when the main ballast tanks are flooded. Therefore, the weight to be lifted is the weight of all the water that has entered the main compartments, and those water and oil tanks whose interior boundaries are not able to withstand the pressure in adjacent compartments.

To these weights must be added the forces required to break the submarine free of the suction effect of the bottom with a margin suitable for the existing conditions.

The steps leading to a firm lift plan are:

1. Determine, as accurately as possible, the water level in each compartment. Consider means of securing dry compartments against slow flooding, such as mechanically clamping openings or reducing the pressure differential by pressurizing compartments with compressed air. If this latter method is used, the Salvage Officer must ensure that the differential pressure across watertight bulkheads does not exceed 2/3 of the bulkhead design pressure. He must also be aware of the possibility of loosing a major closure device since submarine closures seat with sea pressure. Air pressure, coupled with a sudden change in submarine depth, will produce a differential pressure opposite to that for which closures are designed.

2. Calculate the weight and center of gravity of the water in each compartment.

3. Estimate breakout force and its center of gravity. Consider this as a weight to be lifted.

4. Establish margins and their centers of gravity for steps 2 and 3. These margins, when added to the weights and breakout force, will give the largest lift that can reasonably be expected. The amount of the margins depends on:

   a. The Salvage Officer's level of confidence in the data which formed the basis of the calculations.

   b. His knowledge of the bottom conditions.

5. Decide which end will be lifted first and the height of the lift. This decision may be affected by the slope of the keel in way of the slings, or by the ease of guarding against slippage of the slings in one or the other direction. If any free surface is present in the ship or its tanks, it must be compensated for by the lift control devices used.

6. Decide the probable position of the bottom reaction point at the end to be lifted last.

7. Calculate moments of weights and breakout force (allowing for uncertainties which exist) about this bottom reaction point.

The sum of these weights and moments must be within the lift capability of the lift system.

8. Estimate the weight of water that can be removed from each ballast tank, its center of gravity, and its moment about the bottom reaction point.

9. Subtract these tank and compartment buoyancies, and their moments from the total weight to be lifted and its moment. The result is the smallest amount of external lift that must be provided and its moment.

10. Decide on possible methods of attaching increments of external lift, points of attachment, and the maximum amount of lift that can be applied to each attachment.

11. Using the method of trial and error, assign lifting forces to the attachment points and calculate their moments about the pivot point. Add the increments of external lift and their moments, starting at the end to be lifted first, until the lifting moments are greater than the moment obtained in step 9. When this amount of lift force is applied, the first end should rise. The lift system at this time will be supporting the raised end of the submarine and will be less than the maximum lift force prior to breakout by at least the amount of breakout force which was required.

12. Assuming that the first end has been raised the desired distance by the action of step 11, recalculate the weights and centers of gravity of the water in the compartments and tanks about the bottom reaction point. Summarize the weights and moments without any breakout force.

<u>CAUTION</u>: It is not possible to ascertain exactly how much applied moment is needed to break out and lift the end to be raised first. It is therefore wise to assume that the tank, or compartment supplying the largest increment of buoyancy, has been blown down to that point at which the air in the tank is sufficient to expel all remaining water by expansion as the submarine is lifted. As previously noted, this will define the maximum amount of compensation for excess buoyancy. To ensure that no greater excess buoyancy is created, dewater tanks and compartments one at a time.

13. Establish lift control requirements. Compensation for excess buoyancy is accomplished by reducing the lifting force. If the lift control mechanism is by means of pontoons, the reduction in lift force is achieved by providing an adequate number of control pontoons.

When these reach the surface, their buoyancy will be reduced by the amount needed to establish equilibrium. A considerable lift force should still be required of the control pontoons even after the first end reaches equilibrium. If the lift force requirement for the control pontoons approaches zero, the ship will probably continue to rise out of control.

14. Next, consider the end remaining on the bottom. Using the weights obtained in step 12, calculate the moments of those weights about the point at which the surface control pontoons are attached to the submarine.

15. Apply increments of buoyancy in succession, starting from the lower end, until the lifting force moment is equal to the weight moment, plus any allowance for uncertainty. By this time, the lower end should rise.

16. Assuming that the end to be raised last has reached the desired depth, recalculate the weights and moment of the water in the ship and in the tanks. As in step 12, assume that the lower end of the submarine left the bottom at the most unfavorable time and that excess buoyancy will be created as the ship rises. The lift force must be decreased with control pontoons as in step 13. At this time, the applied lift will equal the negative buoyancy of the submarine. When either end of the submarine is raised, the control pontoons at that end must always be required to provide some finite lift force after equilibrium is established. If the lift force requirements for the control pontoons diminish to zero, attitude control of the submarine will be lost as in the 13 July 1939 lift of SQUALUS. (See Appendix E.)

If lift ships are available, they must be used for controlling the lift of each end. In such a case, the lifting takes place more slowly and the lift applied by the surface lift ships must be such that a condition of equilibrium exists at all times, especially at the time of breakout when there may be a sudden and large reduction in the amount of lift required.

Satisfactory solutions in the foregoing steps constitute the preliminary lift plan. In this discussion, it has been assumed that the ship will be lifted by an amount less than the depth of the water, as the control is more critical in this case.

4.5. Self-Lift vs. External Lift

In deciding between self-lift and external lift, the Salvage Officer is guided by the size and number of external lifting devices available, the amount of work and time required to attach them, and the amount of work and time required to create self-lift. Generally, large amounts of self-lift can be created by dewatering the main ballast tanks and they are often easily obtained.

Often the submarine will be deficient in transverse static stability. This may not be apparent before the submarine arrives at the surface because an external lift applied by an increment of buoyancy, which is attached to the submarine above its center of gravity, will improve static stability. On 13 September 1939, SQUALUS was raised to the surface on two occasions. During the first lift, the second (bow) end to be raised arrived at the surface, and the expansion of air and free surface effects made the bow so light that no lift was required from the bow pontoons.

The ship, even with the stern pontoons at the surface, was unstable and heeled over sufficiently to spill air from the main ballast tanks and allow them to reflood until the stern sank. The bow was then lowered to the bottom by venting the ballast tanks. The submarine was rolled upright by partially blowing the ballast tanks on the low side and was raised again, this time successfully with no heeling.

No change was made in the SQUALUS lift scheme for this last lift except to alter the sequence in which the tanks were blown. This time the tanks were blown in a sequence such that the bow would leave the bottom when one tank was almost completely empty and the buoyancy gained during the ascent would be minimized. The bow pontoons were thus fairly well loaded after they reached the surface, and in this condition, would contribute to the static stability of the ship by an amount which made the ship remain upright after she reached the surface.

This instance also illustrates the fact that whenever an entire submarine, or even just one end, is lifted from the bottom, knowledge of the lifting forces and moments greatly improves the knowledge of the weight and center of gravity of the water in the ship. The submarine can be effectively weighed by observing the draft of pontoons on the surface and calculating their actual lift at the time.

Since a submarine on the bottom has no waterplane, the longitudinal $\overline{GM}$ cannot be greater than the vertical distance between the center of gravity and the center of buoyancy.

This figure is reduced by the effect of any free surface in the compartments or tanks; thus, the longitudinal $\overline{GM}$ may safely be considered either insignificant or negative. The attitude of the ship is therefore controlled by the balance between the lifting forces and the weight of the ship and their moments. As the ship is being raised, expansion of the entrapped air bubble in compartments open to the sea may blow water from the compartments and cause a reduction in the weight to be lifted. The moment of the reduction will depend on the depth of the water and on the distance the ship is lifted.

If a free surface exists in any tank or compartment, there will be a change in the center of gravity of the water in way of the free surface. This change will depend not on the depth, but on the angle through which the ship rotates and the length of the space possessing the free surface. It may be large if bulkhead doors are open and the free surface extends over more than one compartment.

In this chapter, the effect of the expansion of an entrapped air bubble and the effect of a free surface were estimated in steps 12 and 16 of section 4.4. The calculation of weights and moments made in those steps must take into account the changes in weights and moments which have been discussed in this section.

4.6. Calculating the Flooded Weight

In calculating the weight of water in any compartment, it is necessary to apply a permeability factor to the gross volume of the compartment. This factor will differ for each compartment of each class of submarine. The floodable volume of each compartment may be obtained from the shipyard that prepared the working plans of the ship.

For a survey of the situation, and to arrive at a tentative plan of salvage, permeability factors of 0.85 for machinery spaces and 0.92 for living spaces are sufficiently accurate, but for a final salvage plan, the actual factors should be obtained and used.

4.7. Bottom Breakout Force

The deadweight of the submarine must be overcome with lifting forces - buoyant or mechanical - to lift the sunken submarine from the bottom; often, additional force is required to break the bottom mud suction. Salvors have encountered bottom suction forces in operations of years past; some insight into this force can be obtained by review of available reports.

The available literature does not address itself to the specific problem of freeing objects from the ocean bottom; mention of the problem is, however, made, but no numerical evaluation of the force is indicated. Following is a brief review of several salvage operations with apparent bottom suction (breakout) considerations:

SÖDRA SVERIGE

The SÖDRA SVERIGE, a cargo-passenger steamship with an 800-ton displacement, sank in the Baltic Sea in 1895 in a depth of 185 feet. The ship came to rest at a sharp angle from the vertical and during the course of a year sank about 10 feet into the clay bottom. Calculations indicated that the ship had a submerged weight of 600 tons and that a force of 960 tons would be sufficient to break it loose from the bottom. Sixteen wooden pontoons, each having a lifting force of 60 tons, were attached to the ship and pumped out. This was sufficient to righten the ship and raise it off the bottom.

LIBERTÉ

The French battleship LIBERTÉ, with an 8,000-ton displacement, sank in the harbor at Toulon in 1911. The salvage effort extended over a period of 14 years. During the long period of submergence, the wreck settled into the mud and Crapaud (1925) reports that "a considerable part of the task of the salvors consisted in breaking this contact and freeing the hulk so that it could be lifted and towed away." No information was given to permit an estimation of the breakout force.

S-51

The S-51 was a 1,230-ton submarine which sank in 1925 approximately 14 miles east of Block Island. The depth at the site was 132 feet and the submerged weight was estimated to be 1,000 tons. The boat came to rest on a clay bottom with an 11-degree port list.

Ellsberg (1927) estimated that the breakout force was about 8,000 tons, "a force so large we could never hope to overcome it by direct lift." His plan, which was executed successfully, was to "break the suction by letting water in between hull and clay in two ways - first, by rolling the boat to starboard, and second, by lifting her one end (stern) first."

S-4

The S-4 was an 830-ton submarine which sank in 1927 in 102 feet of water off Provincetown. It was initially and intermittently buried in a very permeable mud to a depth of 7 or 8 feet. The S-4, whose submerged weight amounted to 722 tons, was raised by lifting the stern first. Saunders (1929) states that "the bottom had an upper layer of very soft slit or mud not more than one foot deep. Underneath this, the bottom was more soft than hard, of a decidedly sand character, mixed with minute shells. The texture of the bottom was sufficiently coarse to permit the passage of water through it...yet sufficiently firm to hold its position when excavating tunnels underneath the vessel. Due to the permeable characteristic of the bottom, it is estimated that the so-called 'suction effect' on the S-4 was practically nil." As a matter of fact, there are no indications that breakout was a problem.

USS SQUALUS

The salvage of the USS SQUALUS is perhaps the most widely reported and documented of all submarine salvage operations. The USS SQUALUS, which sank in 1939 about 5 miles south of the Isles of Shoals off Portsmouth Harbor, was a 1,450-displacement boat having a submerged weight of 1,100 tons. The boat came to rest with a 10-degree-up angle in 240 feet of water on a mud bottom in which the stern was buried up to the superstructure deck. The entire operation consisted of five separate attempted lifts, three of which were from a mud bottom. Only the first lift is pertinent to this report. No estimate of the breakout force is reported; however, in a review of the events describing the unsuccessful lift of 13 July, Tusler (1940) indicates that the "unknown amount of mud suction tending to hold the bow down" was one of the main factors contributing to the failure. Previous to the attempted lift, Tusler states that "the bow had sunk down an unknown amount into the soft mud of the bottom, but due to the shape of the bow, it was thought that the mud suction would be relatively insignificant." In any event during each attempted lift, the USS SQUALUS was raised by lifting one end first.

USS LAFAYETTE (ex SS NORMANDIE)

The SS NORMANDIE was a 65,000-ton passenger vessel which sank in 49 feet of water adjacent to Pier 88, New York City Harbor. The submerged weight was estimated to be 50,000 tons. The vessel came to rest lying on one side in an organic river mud which was about 25 feet thick and which was underlain by a gray organic silty clay having a compressive strength of from 0.3 to 0.6 ton/ft^2. (This operation is of interest since it appears to have been the first time the principles of soil mechanics were considered in a salvage operation of this type).

It was anticipated that breaking contact between the ship's hull and the mud would be a serious problem. Accordingly, in addition to pumping out some 15,000 tons of mud which had entered the hull through the cargo doors and portholes, numerous porthole patches were fitted with pipes through which water and compressed air could be jetted to disintegrate the mud. The flotation of the vessel was preceded by a rotation or turning operation. Masters (1954) notes that during the rotation operation, the air and water jets were set to work, although the vessel did not stick as expected.

PHOENIXES

The PHOENIXES were 200-foot-long floating caisons of reinforced concrete which were to be sunk in a line off the Normandy beaches to provide a breakwater during the European invasion. Each unit was 60 feet wide, 60 feet high, and displaced 6,000 tons. They were divided into watertight compartments and fitted with valves for controllable flooding. Approximately 100 of these PHOENIXES were purposely sunk in staging areas off the south coast of England prior to invasion. The first attempt to refloat a PHOENIX by pumping failed. It was determined that the mud bottom suction was holding the PHOENIX down. The traditional method of breaking this contact is to apply buoyancy to one end and to use the ship as a lever. In this manner the contact is broken along the bottom, eventually freeing the vessel from the mud. However, in the case of the PHOENIXES there was not enough time to allow this system to work, because the rising tides would submerge the pump platforms before the lever action could be made effective. A second alternative is to jet air or water underneath the sunken vessel to partially reduce the contact and lessen the holding force. In the case of the PHOENIXES, compressed air was employed (all pumps were being used to empty the flooded compartments) to reduce the holding force to allow the excess buoyancy to float the PHOENIXES.

In addition to the case histories cited above, there are many other records of maritime salvage operations in which a ship has been raised from a mud bottom under very unfavorable circumstances. The background provided herein is not intended to be an all-inclusive treatment of salvage. Only those cases in which the breakout force was alluded to in the published literature were selected. It is worthy of note, however, that the published record (Bowman, 1964) of the salvage of the entire German High Seas Fleet, which was scuttled at Scapa Flow, does not mention that breakout was a problem. Further, the U.S. NAVY's experience with the ex-German submarine 1105 did not disclose the breakout problem, although the tests were carried out with the submarine eventually lying on a mud bottom.

NOTE: A comprehensive study on bottom breakout forces has been conducted by the Naval Civil Engineering Laboratory, Port Hueneme, California. The Technical Report R-591 of June 1968, titled "Ocean Bottom Breakout Forces" is the source of much material presented here. The R-591 report should be consulted for additional information.

4.7.1. Theoretical Considerations of Bottom Breakout Forces

Classical theory of soil mechanics and foundation engineering assumes that stress conditions alone determine the state of failure of a material, irrespective of the load duration and stress history of the specific soil/module situation. Field experimentation, theoretical analysis, and empirical data indicate that time is a necessary and real function deserving due consideration in the definitive breakout equation; the load duration, as applied to the breakout problem, is a major factor.

In the classical theories, one or two of such material parameters as yield stress, Young's modulus, or Poisson's ratio are sufficient to describe the behavior of an isotropic material; such simplifications are inadequate to predict breakout behavior.

Highly complex theories are rarely applicable in soil engineering problems; the advent of modern computers does not alter this premise. Theoretical calculation of soil engineering problems, and specifically those of breakout forces, is complexed by factors of unknown patterns of nonhomogeneity of soils in the particular application and the inability of mathematical models to deal with unknown parameters.

4.7.2. Mathematical Definition of Bottom Breakout Forces

Beginning with a very simple formulation of the mechanics of bottom breakout, the following equation may be expressed:

$$F = KCA \qquad \text{(Equation 1)}$$

where

F = breakout force

C = cohesion, or alternatively a measure of the vane shear strength

A = horizontal projection of the contact area

K = constant which is a function of object size, object shape, time duration of applied force, rate force is applied, soil sensitivity, and the elapsed time which the object has been in place after the initial disturbance. Soil sensitivity may be defined as the ratio of cohesion of undisturbed soil to cohesion of disturbed soil at constant water content.

Thus, we may write

$$\frac{F}{CA} = k$$

or

$$\log \frac{F}{CA} = \log k \qquad \text{(Equation 2)}$$

Letting C and k take on slightly different meanings, we may write

$$\frac{F}{\underline{C}A} = Qe^{-R(t-t_o)} \qquad \text{(Equation 3)}$$

where

$\underline{C}$ = effective average cohesion along the failure surface at the instant of breakout

Q = constant

R = slope of the "failure line" when log ($F/\underline{C}$ A) is plotted versus time, t

t = time allowed for breakout, or alternatively the elapsed time during which the breakout force is applied

t_o = reference time in minutes

The constants Q and R are functions of the load duration or strain rate. In Equation 3, when $t = \infty$, the force required for breakout is a minimum. Conversely, as t is allowed to approach zero, that is, as the time allowed for breakout becomes increasingly short, the force requirement reaches a maximum constant value.

The quantity $\underline{C}$ requires some comment since it is also a time-dependent function which is related to the soil sensitivity. It may be estimated by an equation of the type:

$$\underline{C} = \frac{C}{s} + \left(C - \frac{C}{s}\right)\left[1 - e^{-bt/(t-t_1)}\right] \qquad \text{(Equation 4)}$$

where

s = degree of soil sensitivity

b = numerical constant used to force $\underline{C} = C$ for very large t, in keeping with our knowledge of thixotropic material behavior

t_1 = reference time related to the thixotropic behavior of a material in regaining a stated percentage of its strength after initial disturbance

To illustrate that Equation 4 is approximately correct, we note that:

(1)

for $t = 0$, then $\underline{C} = C/s$,

(2)

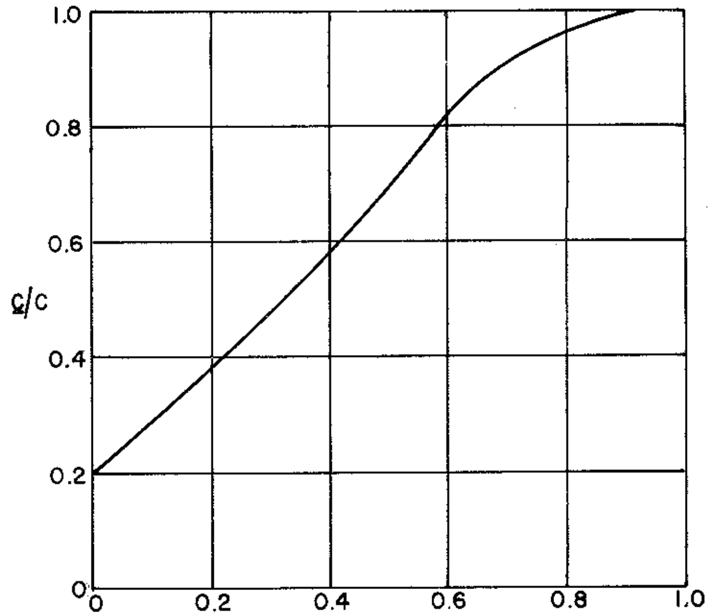
for $t = t_1$, $\underline{C} = C$, and

(3)

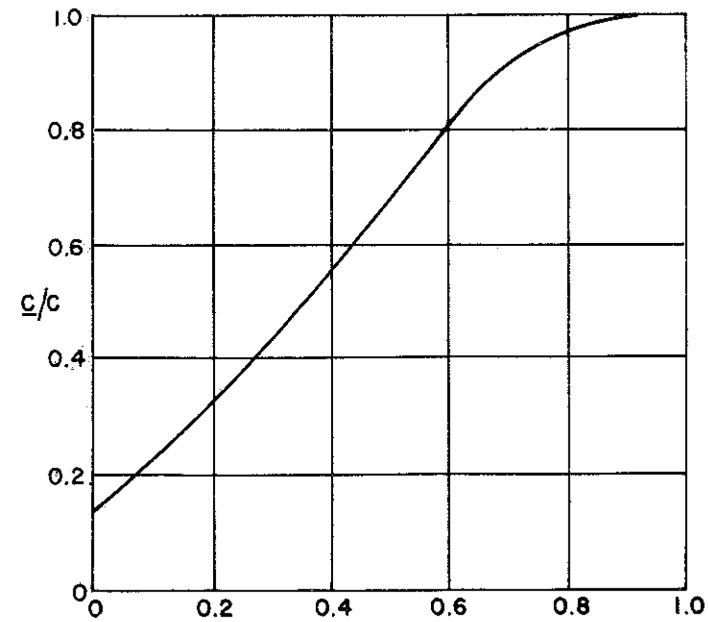
for very large t,

$\underline{C} = C$ even for relatively small values of b.

Dimensionless graphs of Equation 4 are shown in Figures 4-2 and 4-3 for values of b = 1.0 and s = 5.0 and 8.0, respectively. Experimental information on the validity of Equation 4 seems to be nonexistent. In addition, the reference time t_1 seems to be highly variable, being very short (that is, on the order of minutes) for such thixotropic materials as drilling muds and perhaps very long (that is, measured by geologic time) for many deep marine sediments.



DIMENSIONLESS GRAPH OF EQUATION 4
FOR b = 1.0, s = 5.0.
FIGURE 4-2



DIMENSIONLESS GRAPH OF EQUATION 4
FOR b = 1.0, s = 8.0.
FIGURE 4-3

On the basis of experimental test results we may estimate s, C, t_1, t_o, and the constants Q and R, and then compute the force F required to extract the specimen as a function of time, t. For example:

$$F = \underline{C}AQe^{-R(t-t_o)} \qquad \text{(Equation 5)}$$

or for maximum C

$$F = CAQe^{-R(t-t_o)} \qquad \text{(Equation 6)}$$

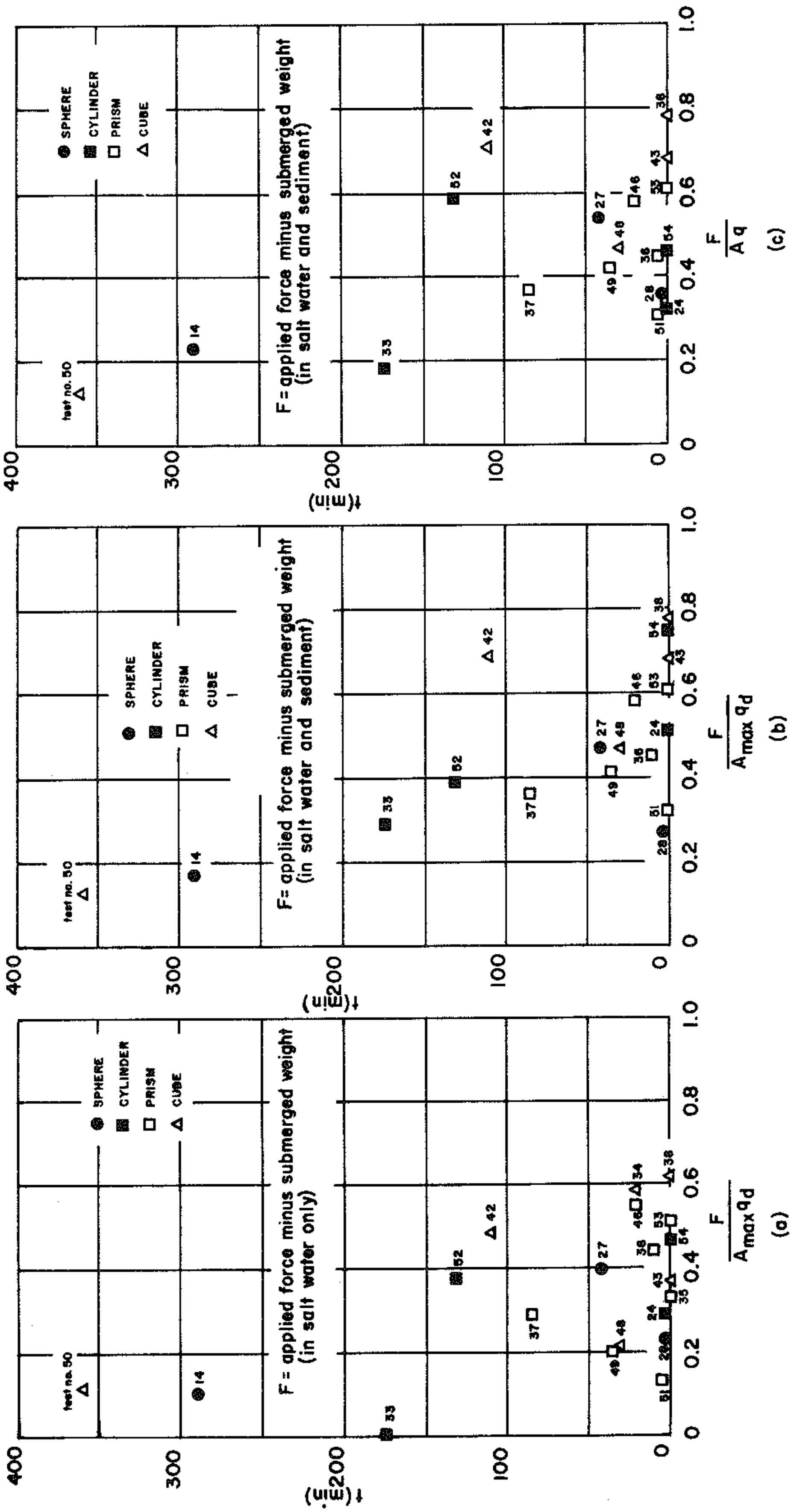
<u>NOTE:</u> It is to be emphasized that the reference times are those determined from large-scale field tests.

The foregoing illustrates how the field data may be analyzed and used for predicting breakout, assuming that scale effect is negligible. In connection with the data reduction, it was found that the cohesion, C, as obtained by vane shear tests, showed marked variability. Thus, as an alternative measure of the sediment strength, it was expedient to use the quantity q_d, which is defined as the average supporting pressure provided by the soil to maintain the embedded object in static equilibrium, in all of the data reduction since it exhibited very consistent trends. In a sense this is fortunate since the problem then becomes completely determinate, being no longer dependent on external measurements. (A summary of field data is presented in graphical form in Figures 4-4 and 4-5.)

Figures 4-5a, 4-5b, and 4-5c are semilogarithmic graphs of the data appearing in Figures 4-4a, 4-4b, and 4-4c respectively. The elapsed time over which the maximum force was applied appears as the ordinate in all figures.
In Figures 4-4a and 4-4b, the abscissa is the dimensionless quantity, $F/A_{max}\ q_d$); in Figure 4-4c, the abscissa is F/Aq_d). In Figures 4-4b, 4-4c, 4-5b, and 4-5c, the force F represents the net breakout force, which is the applied force minus the submerged weight of the object, not only that portion submerged in salt water, but also that portion of the object embedded in the bottom sediment.

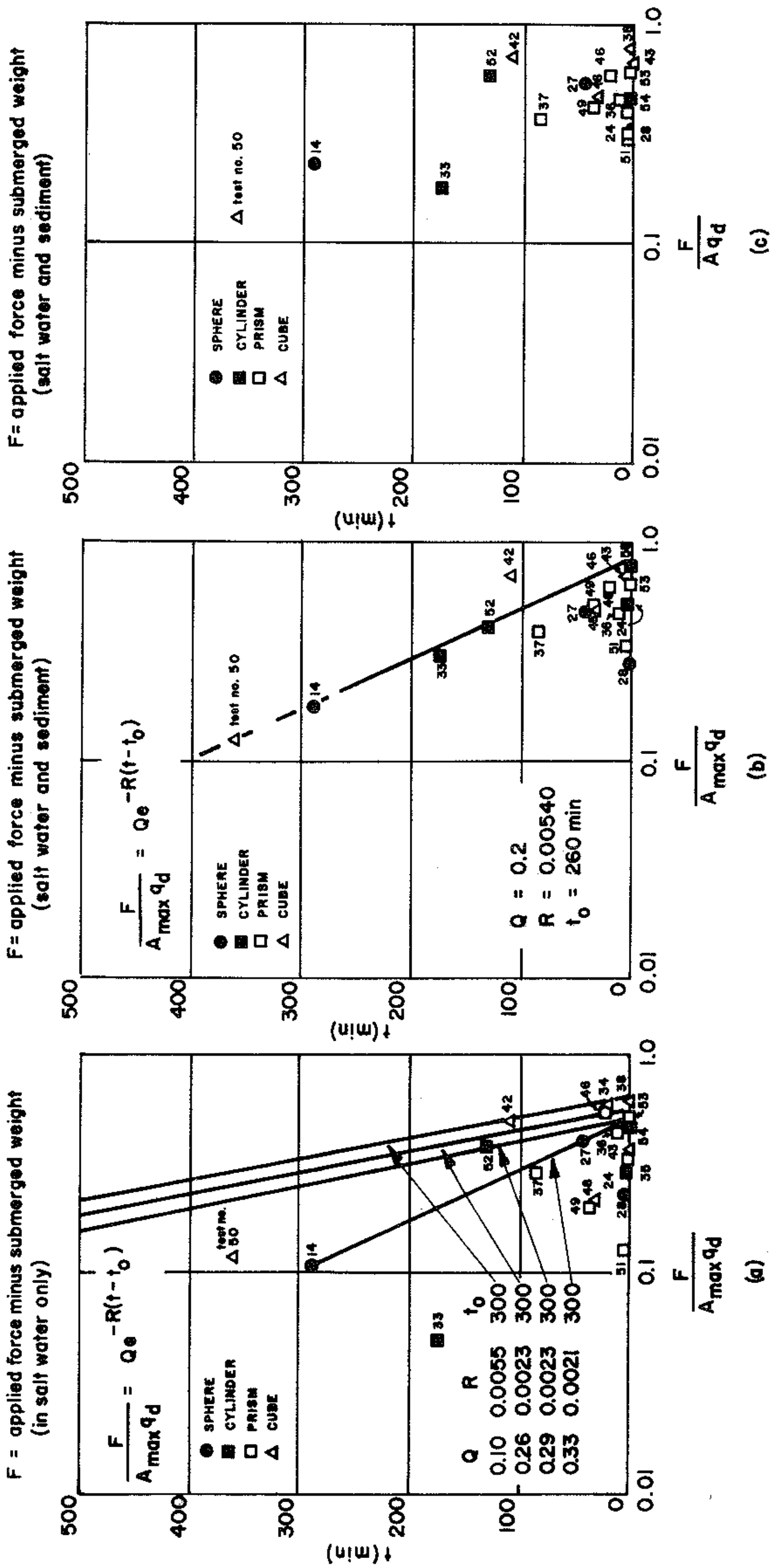
Figure 4-5a indicates some of the trends in selected data from field tests. The coefficients Q, R, and t_o used in Equation 5 are also shown on the figure. Although the data are extremely limited, the figure indicates that the forces required to extract the cube and the prism are higher than those for the cylinder and sphere. This seems to be in agreement with previous field experience.

Figure 4-5b exhibits the clearest consistent relationships for all of the included data.



DATA SELECTED FROM FIELD BREAKOUT EXPERIMENTS.

FIGURE 4-4



DATA SELECTED FROM FIELD BREAKOUT EXPERIMENTS PLOTTED ON SEMILOGARITHMIC GRAPHS.

FIGURE 4-5

That is, the trends shown in Figure 4-5a for the various shaped objects appear to be almost entirely obscured when the numerator in the abscissa is reduced by an amount equal to the submerged weight of the volume of sediment displaced by the embedded object. From these data, the equation for computing breakout has been determined to be:

$$F = 0.20 q_d A_{max} e^{-0.00540(t-260)} \qquad \text{(Equation 7)}$$

where

A_{max} = horizontal projection of the maximum contact area

for $t = 0$, Equation 7 reduces to

$$F = 0.81 q_d A_{max} \qquad \text{(Equation 8)}$$

for $t = 260$ minutes, the breakout force requirement becomes

$$F = 0.20 q_d A_{max} \qquad \text{(Equation 9)}$$

CAUTION: It is to be emphasized that relationships such as appear in Figures 4-5a, 4-5b, and 4-5c, of which Equation 7 is typical, are based on only one type of sediment (that is, that found in San Francisco Bay) and one size of test objects, all of which were similar both from characteristic length and bearing load.

4.7.3. Determination of Bottom Breakout Forces

The theoretical procedure considers neither the effects of remolding or the increase in strength due to consolidation. In the San Francisco Bay tests (upon which the empirical constants were determined), the maximum bearing loads were very high; much higher than the capacity of the soil near the surface to support such loads. Thus, the soil in the immediate vicinity of the test object was disturbed and remolded to a considerable degree. Moreover, the object penetrated a certain distance until the bearing loads were reduced to a level within the capability of the soil to support the imposed loads. There is a natural increase in strength with depth due primarily to an increase in bulk density and a decrease in water content. However, the strength of the soil is also affected by the presence of the object in two opposing ways. One, referred to previously, is the reduction in strength due to remolding. The other is the gain in strength due to consolidation. Both effects occur on vastly different time scales.

The loss in strength due to remolding takes place instantaneously, whereas the gain in strength due to consolidation is a long-term process depending initially to a large extent on the permeability of the soil. It seems likely that for a given object two worst situations are possible:

1. The shallow-penetration case, occurs when the soil has a high shear strength which is almost but not quite matched by the imposed bearing loads. This ensures a close bonding of the object skin surface to the sedimentary layer without inducing a strength reduction in the soil.

2. The deep-penetration case, occurs when penetration has been so deep that the volume of displaced soil becomes sufficiently large so as to completely dominate the breakout process.

The latter situation is not to be confused with the volume of material lying between the failure surface and the object boundary, which is a function of the gross dimensions of the object. We are concerned here with a given geometry.

In the theoretical approach, the computational scheme permits loads of any magnitude to be applied to any or all mass points. Again, in the cited example, equal loads were applied to the mass points located on the boundary geometry. Thus, unequal relative movement between the mass points on the boundary are permitted, whereas in fact, such unequal movements are realized only for flexible membranes.

It is difficult, at best, to calculate the effective value of bottom breakout forces by use of theoretical analysis; the use of empirical data to formulate a field-value equation to describe breakout is equally limited. Studies, to date, offer information and data so that a summation of pertinent facts can be made; some are:

1. A numerical method of predicting strains, stresses, and displacements in an elastic - perfectly plastic medium subject to loads applied to an arbitrary boundary geometry was found to be useful in developing a theoretical prediction of breakout forces.

2. A complicated computer program, which uses a lumped parameter model of the material and an iterative technique to obtain solutions, was found to be an integral part of the theoretical procedure. The program requires use of a high-speed large-memory-capacity computer. The programs used in computer study of breakout can be found in Appendixes C - to G, of "Ocean Bottom Breakout Forces." R-591. NCEL.

3. The computational procedure traces the development of the stress and displacement fields in an elastic - perfectly plastic material under conditions of plane strain, with specified boundary conditions and force-controlled loading.

4. Results yielded by the computational procedure were found to be verified by separate photoelastic studies, at least within the elastic range.

5. Data from breakout tests with large specimens in San Francisco Bay were found to develop the following empirical formula:

$$F = 0.20 A_{max} q_d e^{-0.00540(t-260)} \qquad \text{(Equation 10)}$$

The geometry of the breakout object seemed to have relatively little effect on the breakout force.

6. The ocean bottom breakout force of an object of simple geometry can be estimated by means of an analytical method that uses numerical calculation by high-speed computers. The method takes into account the plastic behavior of soil beyond the elastic strain range.

7. The following empirical formula may be used to describe the breakout force for an ocean bottom soil:

$$F = Q A_{max} q_d e^{-R(t-t_o)} \qquad \text{(Equation 11)}$$

When a computer is not available, the empirical formula should be used to determine the breakout force. The constants Q, R, and t_o can be derived from a limited number of in-situ field test data.

<u>NOTE:</u> Technical Report R-635, "Ocean Sediment Holding Strength against breakout of Embedded Objects" published by the US Naval Civil Engineering Laboratory presents additional test data and theoretical solution to the bottom breakout problem.

5. Lifting and Towing

5.1. Salvage Equipment

Table 5-1 at the end of this chapter is a complete list of equipment stored at Submarine Salvage Material Bases for operation with the submersible structural pontoons. Following Tables 5-1 and 5-2, are drawings A through I showing various components used in pontoon operations.

5.2. Submersible Structural Pontoons

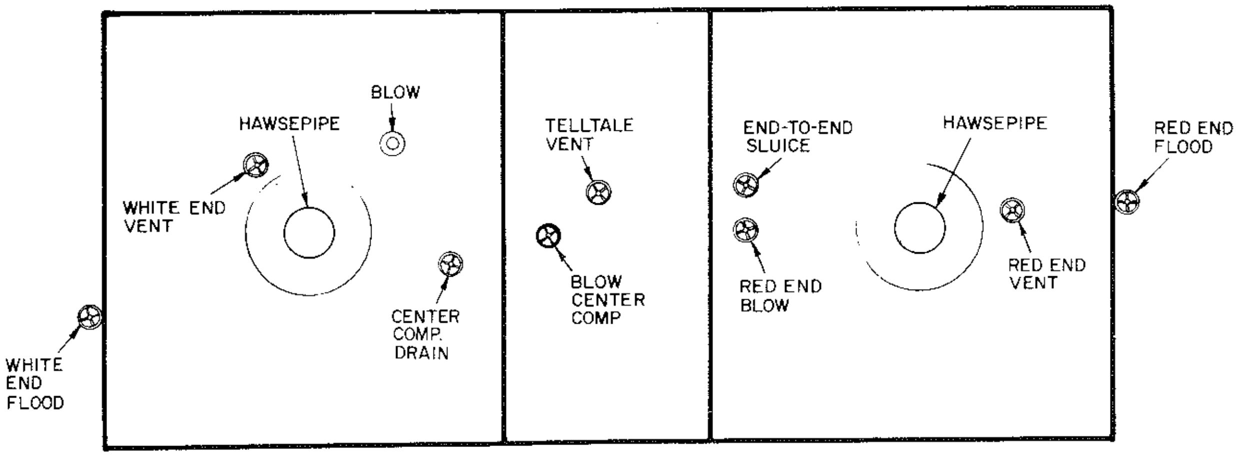
5.2.1. General Description

The submarine structural pontoons are cylindrical in shape and of steel construction. This steel shell is covered by 3-inch planking and the ends of the pontoons have timbers mounted to act as fenders, thereby protecting the flood and relief valves. Each pontoon is subdivided into three watertight compartments. The two end compartments have the same capacity, and, together, provide the main lifting force. The center compartment is of such size that when dry and with the end compartments flooded, it will support most of the weight of the pontoon which is from 35 to 40 tons. In this condition, the pontoon has about 3.5 tons in negative buoyancy, and is positioned for attachment to the slings by the 5-inch lowering lines. When all compartments are blown dry, the pontoons will furnish lifts of 80, 85, and 90 tons, depending upon the type (see Table 5-2).

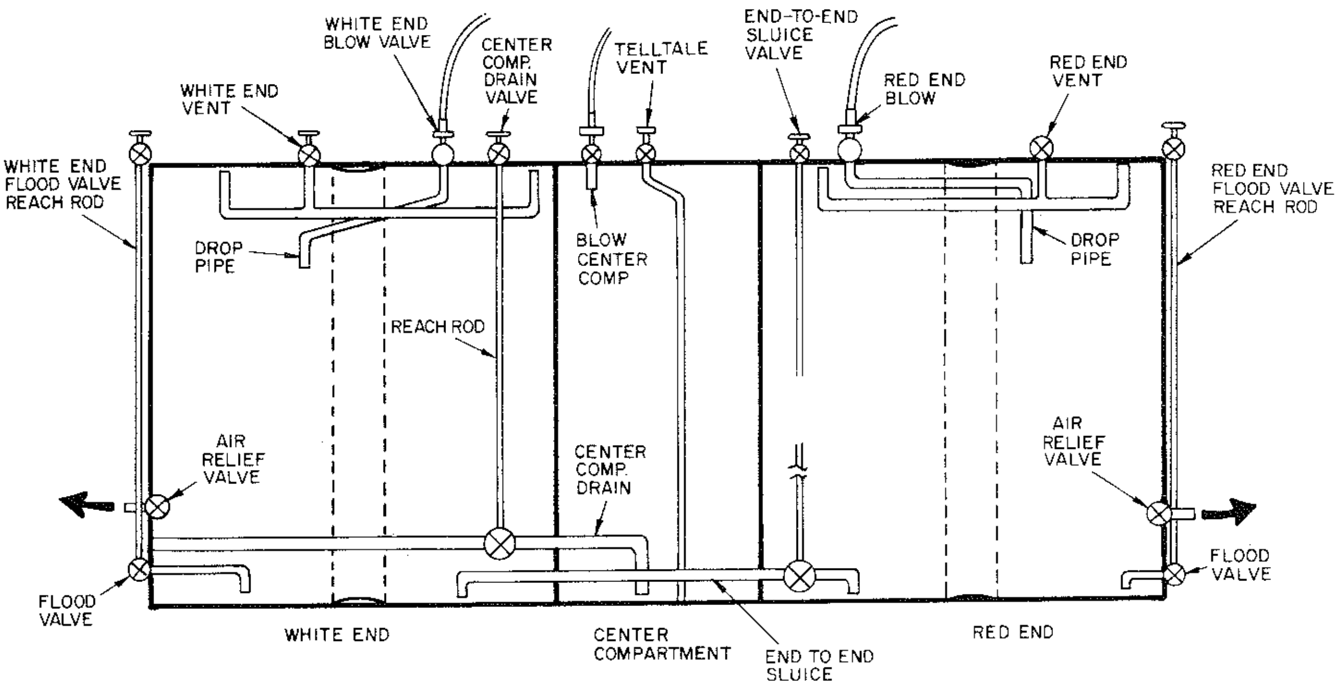
There are three older types (Figures 5-1, 5-2 and 5-3) of pontoons in existence (structural numbers YSP 1, 2, and 3) that have a lifting capacity of 60 tons, and some newer type III pontoons with a 90-ton lift (Figure 5-4).

Each end compartment has blow, vent, flood, and relief valves. The center compartment has blow and telltale vent valves and the type I pontoons also have a center compartment drain valve.

The end compartment vent valves are used only for completely filling the end compartments so as to destroy all free surface and make the pontoon negatively buoyant. Thus, the pontoon may be lowered into position, or the cable clamps or chain stoppers (see Chapter 7) may be freed should it be necessary to remove the pontoon from the slings.



TOP VIEW



ELEVATION VIEW

MAXIMUM INTERNAL PRESSURE - 30 P.S.I., RELIEF VALVES CAN BE GAGGED CLOSED BY SCREW ON EACH VALVE.

STRUCTURAL NO'S. 3,5,6,7, 9 & 10:

- LENGTH OVERALL - 34'-0 7/8"
- DIA. OVERALL - 13'-1 3/4"
- LIFTING CAPACITY - 85 TONS
- WEIGHT, DRY - 38.4 TONS
- NEGATIVE BUOYANCY WITH END COMP'TS FLOODED AND CENTER COMP'T. DRY - 3.64 TONS
- BALLASTED WITH CONCRETE IN BOTTOM

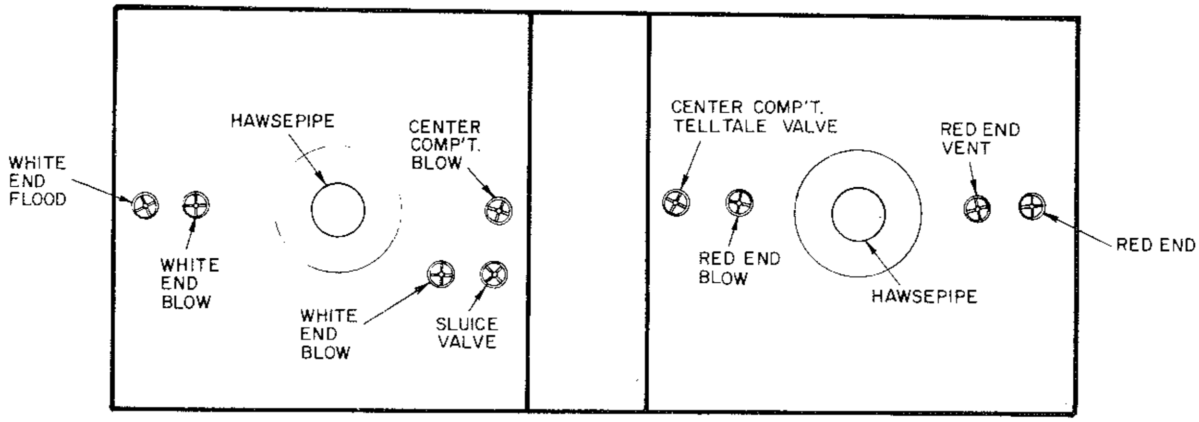
STRUCTURAL NO'S 1 & 2 - SAME GENERAL FEATURES AS OTHER PONTOONS BUT WITH THE FOLLOWING DIMENSIONS:

LENGTH - 32'-0"
DIAMETER - 11'-0"
LIFTING CAPACITY - 60 TONS
WEIGHT, DRY - 35 TONS

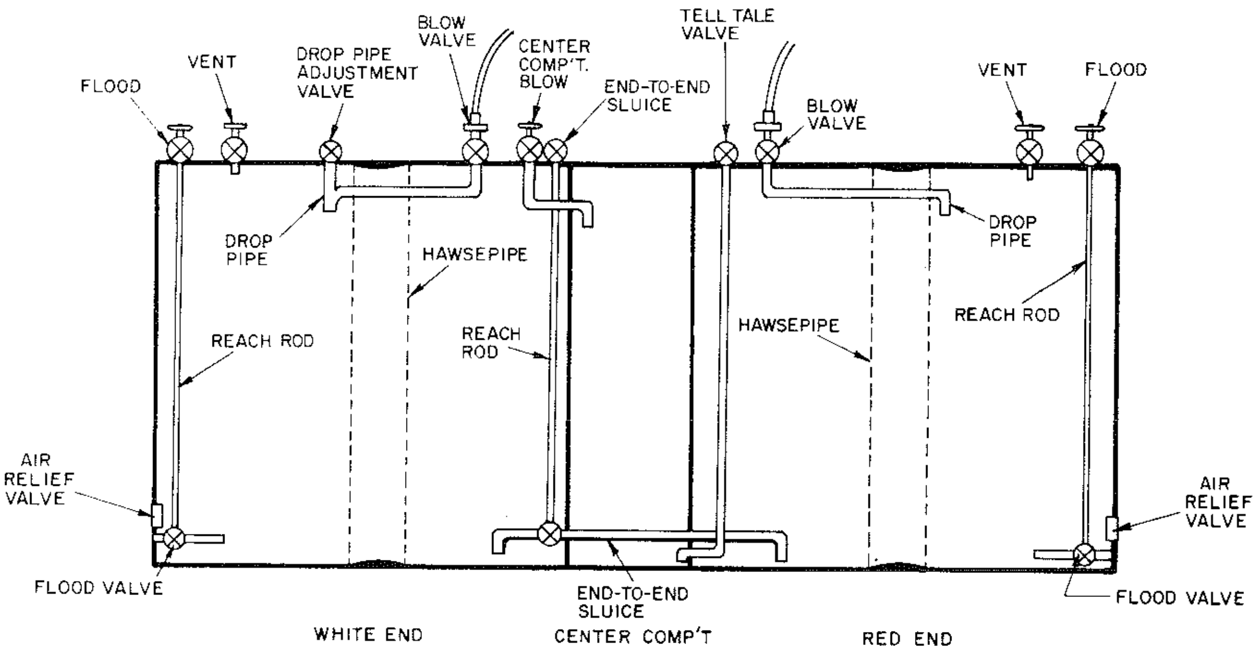
VALVE HANDWHEELS ARE SAME AS TYPE II & III.

TYPE I SALVAGE PONTOON.

FIGURE 5-1



TOP VIEW



ELEVATION VIEW

MAXIMUM PRESSURE, END COMPARTMENTS – 30 P.S.I., MAXIMUM PRESSURE, CENTER COMPARTMENT – 75 P.S.I.

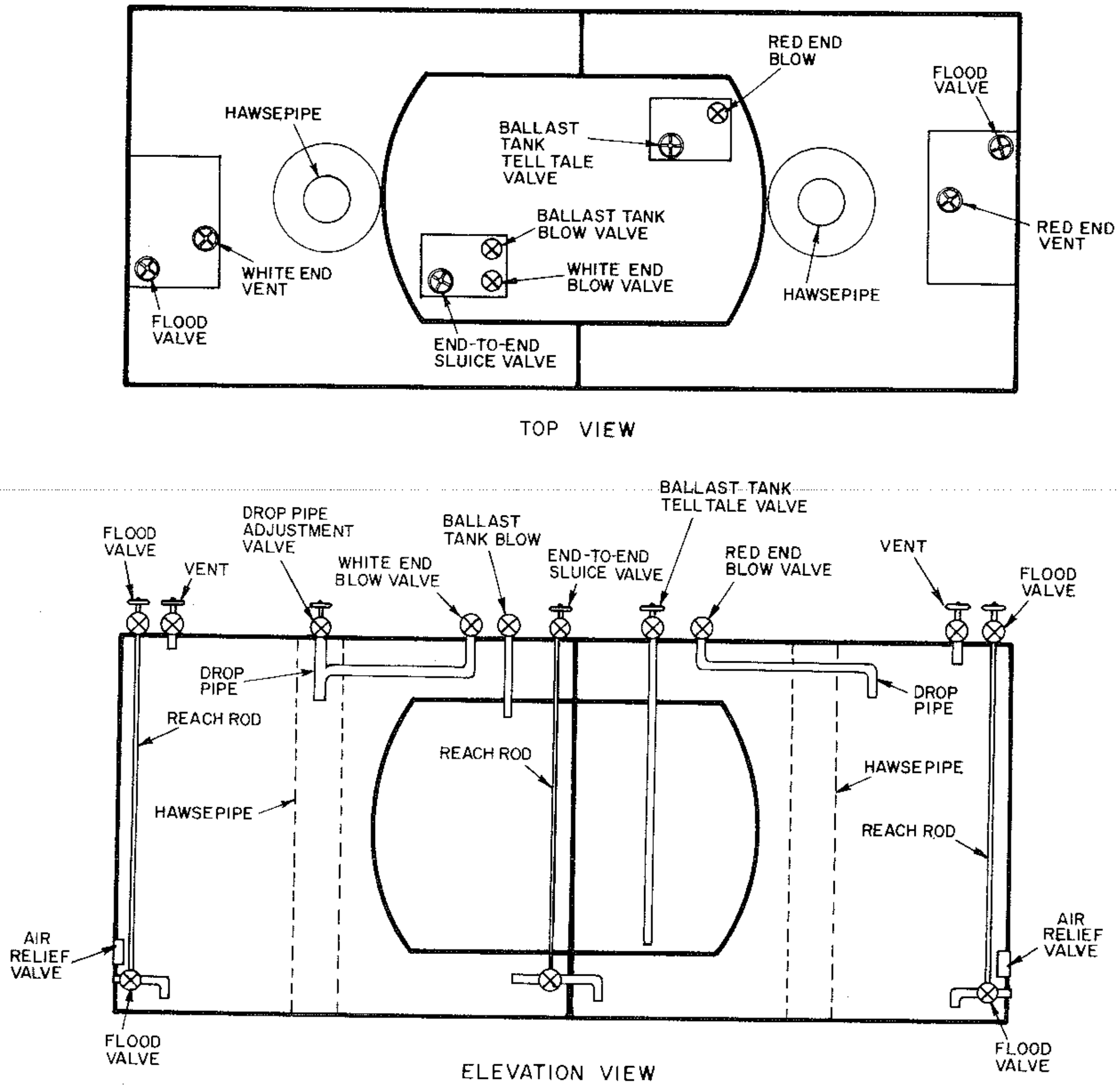
- STRUCTURAL NOS. 11-60
- LENGTH – 32'-0"
- DIAMETER – 12'-6"
- LIFTING CAPACITY – 80 TONS
- WEIGHT, DRY – 35-40 TONS
- NEGATIVE BUOYANCY, WITH END COMPARTMENTS FLOODED TO END OF BLOW PIPES – ABOUT 3.5 TONS

VALVE HANDWHEELS

- ROUND – TELLTALE AIR VENT, CENTER COMP'T.
  – AIR VENT, END COMP'TS.
- SQUARE – BLOW VALVES, END COMP'TS.
- TRIANGULAR – BLOW, CENTER COMP'T.
- T-WRENCH, PORTABLE – OPERATING RODS TO:
  SLUICE VALVE
  FLOOD VALVES, END COMP'T.

TYPE II SALVAGE PONTOON.

FIGURE 5-2



MAXIMUM PRESSURE, END COMPARTMENTS - 30 P.S.I., MAXIMUM PRESSURE, CENTER COMPARTMENT - 75 P.S.I.

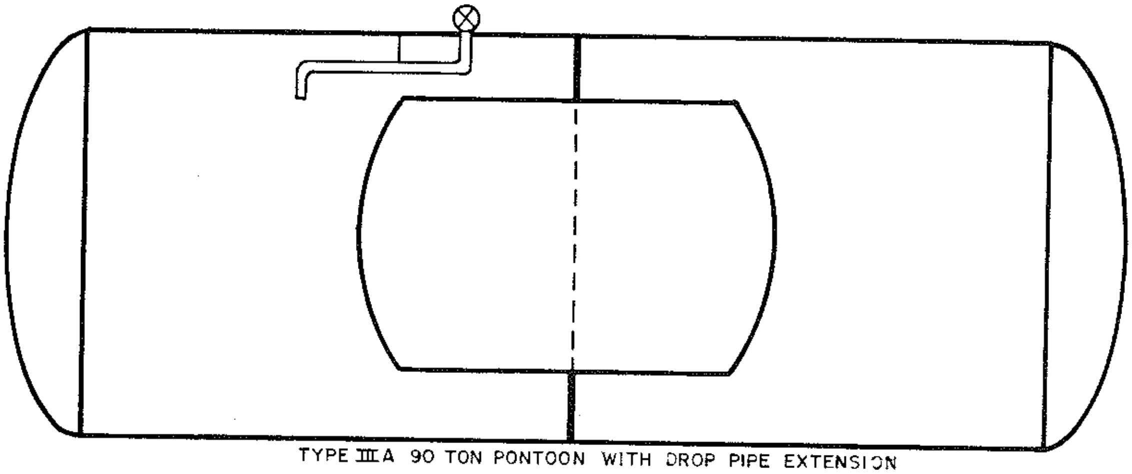
- STRUCTURAL NOS. 61-75
- LENGTH - 32'-0"
- DIAMETER - 12'-6"
- LIFTING CAPACITY - 80 TONS
- WEIGHT, DRY - 35-40 TONS
- NEGATIVE BUOYANCY, WITH END COMPARTMENTS FLOODED TO END OF BLOW PIPES - ABOUT 3.5 TONS

VALVE HANDWHEELS

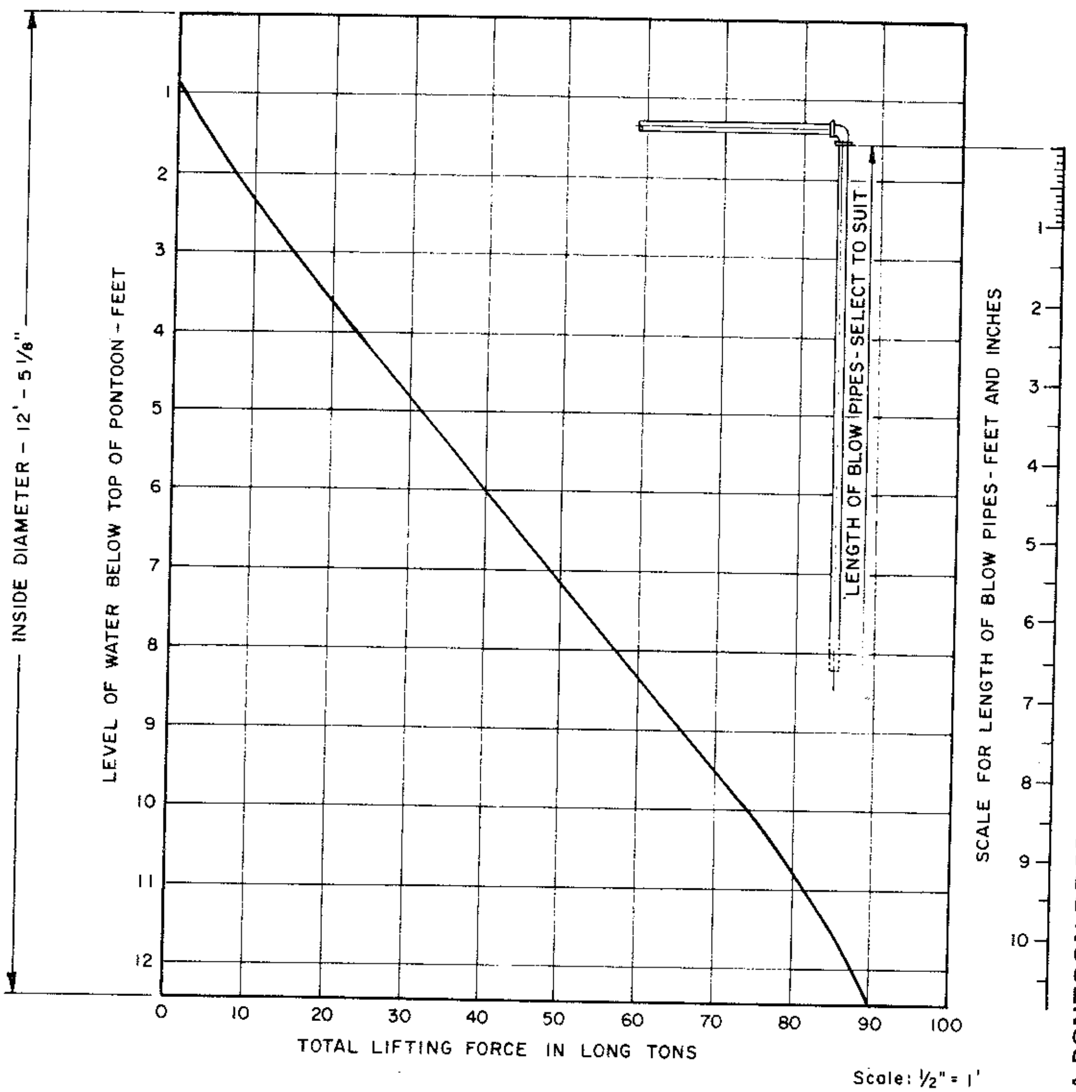
- ROUND - TELLTALE AIR VENT, CENTER COMP'T.
  - AIR VENT, END COMP'TS.
- SQUARE - BLOW VALVES, END COMP'TS.
- TRIANGULAR - BLOW, CENTER COMP'T.
- T-WRENCH, PORTABLE - OPERATING RODS TO:
  SLUICE VALVE
  FLOOD VALVES, END COMP'T.

TYPE III SALVAGE PONTOON.

FIGURE 5-3



TYPE III A 90 TON PONTOON WITH DROP PIPE EXTENSION

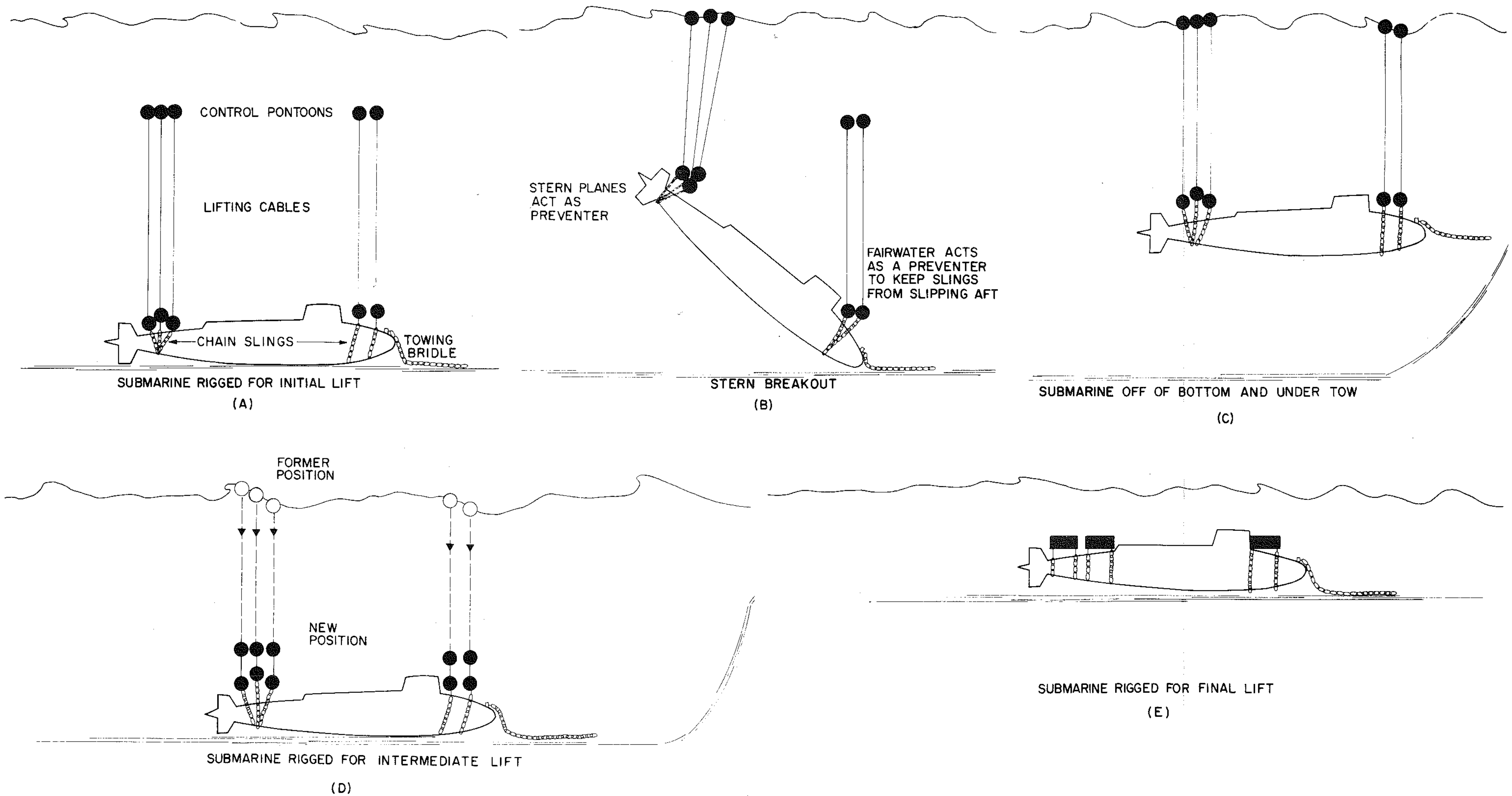


USE OF ADJUSTABLE BLOW PIPE

FROM CURVE OF TOTAL LIFTING FORCE VS. LENGTH OF BLOW PIPE, SELECT LENGTH OF PIPES FOR THE LIFT DESIRED, AND SCREW THESE LENGTHS OF PIPE INTO ELBOW AT END OF HORIZONTAL SECTIONS OF BLOW (AIR SUPPLY) PIPES.

TYPE III-A PONTOON DROP PIPE EXTENSION CURVE.

FIGURE 5-4



SUBMARINE LIFTING SEQUENCE.
FIGURE 5-5

The end compartment blow valves are used for dewatering the pontoon and venting to a predetermined level of positive buoyancy. End compartment flood valves admit sea water or discharge it when blown with high pressure air. The relief valves permit the expanding air to escape as the pontoon rises. The end compartments contain hawsepipes through which the lifting chains or the heavy wire slings are passed. These chains or cables form a cradle by which the sunken submarine is lifted. (Figure 5-5(A) through (E) illustrates various lifts, i.e., initial lift, breakout, under tow, intermediate lift, and final lift.

The center compartment blow valve is used for pressurizing the center compartment. A telltale vent pipe leads to the bottom of this space and is used to determine if the center compartment is free of water. Any residual water can thus be blown up through the vent pipe.

Drop pipes extend from the blow valves of the red and white compartments in various lengths, depending upon the adjustment or type of pontoon. The height of the ends of the drop pipes will determine the amount of air space or lift when the compartment is vented back through it. The purpose of this is to provide various positive buoyancies so that the pontoon can be positioned over the submarine and hold the slings taut. These drop pipes are adjusted prior to pontoon lowering operations and must take into account the length of chain and wire rope slings so as to determine the weight that will be supported. In operation, the pontoons are blown below the ends of the drop pipes, then vented back, as described in Paragraph 5.2.8.

There are three types of drop pipes installed on the pontoons. The type I pontoon (Figure 5-1) has a fixed drop pipe that is essentially an extension of the blow line into the compartment and cannot be adjusted. This drop pipe will give 9-1/2 to 10 tons of positive buoyancy. The type II and III pontoons (Figures 5-2 and 5-3) have adjustable drop pipes that range from 3-1/2 to 5 tons lift. The adjustment for these drop pipes is a small handwheel on top of the pontoon. The post-war type III (90-ton) pontoons have sets of pipe extensions that can be screwed into place prior to employment at sea. These drop pipe extensions will provide lift increments from approximately 1 to 55 tons, or the maximum of 90 tons (see Figure 5-4).

Prior to deployment, the Salvage Officer should inspect each pontoon drop pipe configuration and have the adjustment made to suit his requirements. Once set, the drop pipe adjustment must not be altered without the authorization of the Salvage Officer.

The positive buoyancy for which the drop pipes are set may be checked by venting down the end compartments through the blow valves while the pontoon is afloat on the surface and observing accurately the external water line.

The flood and sluice valves are operated from the top of the pontoon by means of reach rods. The pontoon is made to apply its lift to the sling by displacing the water from the end compartments using compressed air supplied through hoses which are connected to the pontoon blow valves.

5.2.2. Tests

Every two years, the pontoons are to be inspected to ensure that all parts function properly. At the same time, each compartment shall be air tested at 10 or 25 psi, held for 10 minutes without leakage. When air-testing pontoons 61 through 75 (type III), the end compartments must be tested simultaneously by leaving the sluice valve open. Reports of these tests are to be submitted to the Naval Ship Systems Command in the tabular form as shown in Figure 5-6.

The following is applicable to these tests:

1. Accurate, properly tested gages should be used. Full pressure shall be maintained for at least 10 minutes. No compartment is to be considered satisfactory until it has met this requirement. If a drop in pressure is indicated by the gages, leaks should be located and permanently corrected.

2. When tests are completed, all valves should be shut and wired, and compartments thoroughly dried. A suitable dessicant, such as Silica Gel, should be placed in the compartments and the manhole gaskets coated with white lead before replacing and securing the cover. A 10 psi air test should again be conducted to ensure tightness of the manhole cover.

3. Pontoons should be stored on an angle to prevent an accumulation of water in manhole and valve recesses.

4. Caution should be exercised in entering pontoons that have been sealed for long periods of time, as with any confined space. Noxious gasses or oxygen levels too low to support life are common in such void spaces.

TESTED BY ______________ AT __________________ DATE ___________________

PONTOON NO.	AIR PRESSURE - 10 PSI	HELD FOR 10 MINUTES WITH NO PRESSURE DROP

WHITE END	RED END	CENTER COMPT. OR CENTER BUOYANCY TANK

RESULT	STEPS TO COR-RECT	RESULT	STEPS TO COR-RECT	RESULTS	STEPS TO COR-RECT	REMARKS

REPORT FORM FOR SUBMARINE SALVAGE PONTOON TEST.

FIGURE 5-6

5.2.3. Use of Submersible Structural Pontoons

Control Pontoons

Unless a submarine is to be raised in one step, as would be the case in shallow water, control pontoons will most likely be utilized. Control is achieved by setting the pontoons below the surface an amount that is equal to the distance it is desired to raise each end of the submarine. When the control pontoons reach the surface, they will arrive at drafts which will automatically establish a condition of equilibrium with the total moment of all list forces required to counterbalance the weight and moment of the lift. For this equilibrium to be established, it is necessary that at the time the end leaves the bottom, the total lifting moment of the control pontoons at each end of the ship be greater than the moment required for breakout. This can be accomplished by blowing down those compartments and tanks on the submarine which will provide self-lift first. Second, the control pontoons would be blown completely to obtain their total lift before the lift pontoons rigged nearer the submarine are blown (see Figure 5-5). The axis of the control pontoons should be set athwartships to simplify resetting each between intermediate lifts.

Lift Pontoons

Lift pontoons are those whose external lift is needed to make up the positive buoyancy not available through self-lift or lift control. Lift pontoons are set at depths which will require the least adjustment after attachment to the slings, and, thus, will minimize work of the divers. Pontoons that can be set in positions which remain suitable for all lifts, including the final lift to the surface, should be set with the axis parallel to the submarine, otherwise it is more convenient to set them with the axis at right angles to the centerline of the submarine.

5.2.4. Rigging Pontoons for Tow to Salvage Area

The following steps should be taken to prepare the pontoons for tow to the salvage area:

1. Remove dessicant from each compartment and replace manhole covers.

2. Check operation of all valves and valve mechanisms; lubricate liberally. Verify dimension of drop pipe from top of tank and record.

3. Check relief valve setting and adjust to relieve at 8 psi.

4. Test each compartment as specified in Paragraph 5.2.2. Leave pressure in compartments.

5. Close all valves; leave relief valves gagged.

6. Tow as shown in Table 5-1, Drawing A.

NOTE: Drawings A to I are found at the end of Table 5-2 in this chapter.

5.2.5. Delivery and Responsibility

Transportation of the submersible pontoons to the salvage site is normally accomplished by towing, but if the distance is great, they may be placed on the main deck of a ship, such as a tanker, an LST, or a barge, in such a manner that they can be unloaded by rolling them over the side. Pontoons should be delivered to the salvage vessel with the white end forward. This provides a uniform arrangement, allows quick orientation of handling gear, and speeds up the operation.

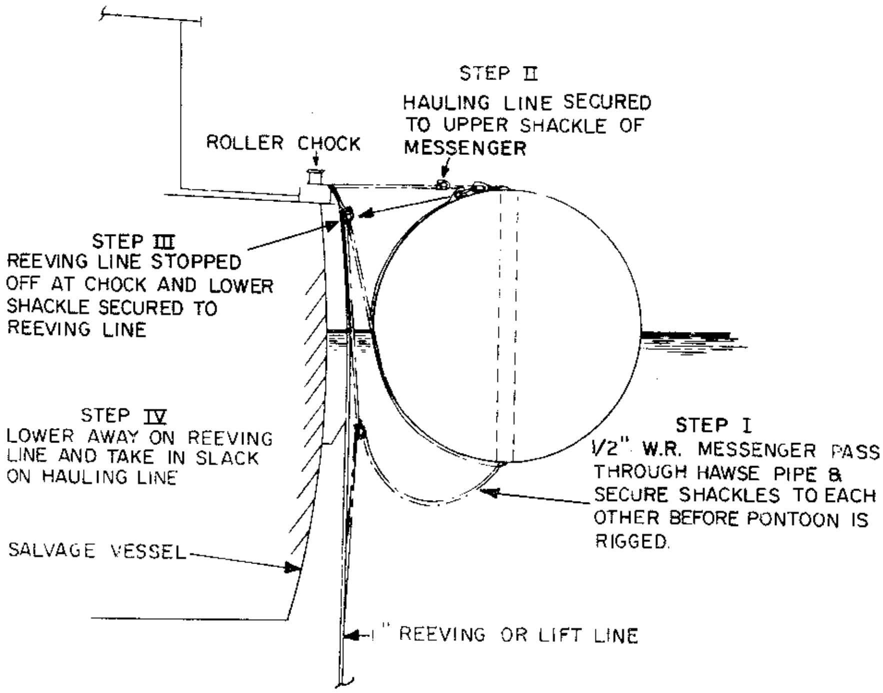
Responsibility for the pontoons belongs to the Commanding Officer of the salvage vessel. He must assign key persons to take charge of the pontoons. A system which has proven very satisfactory provides for assignment of one person to the white end of the pontoon and one person to the red end. These two men should be responsible for rigging and handling the respective pontoon ends from start to completion of the operation. The Salvage Officer should control the air supply and personally check the setting of all valves.

5.2.6. Preparation for Lowering

1. Thread a 1/2-inch diameter wire rope messenger, piece 35 (NOTE: Piece numbers refer to equipment in Table 5-1), through each hawsepipe and shackle two ends of each messenger together. If desired, this may be done before launching and prior to tow. If possible, this messenger should be placed so as to come between the pontoon and the ship. The pontoon is now ready to accept the 1-inch diameter reeving lines, piece 27 or 23 (Figure 5-7).

2. Vent down end compartments to atmospheric pressure (see step 4 of Paragraph 5.2.4.).

3. Attach air hoses, piece 44, to white and red end blow valves on the pontoon and to salvage vessel's air manifold.



METHOD OF PASSING REEVING LINES AND TAIL LINES THROUGH PONTOON HAWSEPIPE.
FIGURE 5-7

Lash hoses as near the blow connections on the pontoon as possible; this is to protect blow valve fittings.

4. Remove gag screws from relief valves and stow screws on salvage vessel.

5. Secure pelican hooks on nylon rope lowering line to long links on pontoon.

6. Attach 1-inch wire to reeving lines, piece 27 or 23, and haul through pontoon hawsepipes by means of the 1/2-inch wire rope messenger (see step 1). Keep all slack out of slings until pontoons have been attached to them and blown to positive buoyancy.

7. If the pontoon is to be attached to wire slings, slip cable clamps, piece 14, over combination wires until they rest on hawsepipe. However, if the pontoon is to be secured directly to the chain, omit the cable clamp but lash chain stoppers, piece 15 or 16, to pontoon near the hawsepipes before lowering.

8. To partially flood the pontoon, set valves as follows:

a. White end vent .... shut

b. White end blow .... open

c. White end flood .... open

d. Center compartment blow ...... shut

e. Center compartment flood, structural No. 1-10 only .... shut

f. End-to-end sluice .... shut

g. Red end vent .... shut

h. Red end blow .... open

i. Red end flood .... open

9. Check that the center compartment is clear of water by observing the telltale vent, then shut the telltale vent valve.

10. If the pontoon is to be at a depth of 200 feet or less, build up the pressure in it to 15 psig, close the center compartment blow valve, and remove the hose. The pontoons should not be set to depths greater than 200 feet unless relief valves have been installed on the center compartment.

If relief valves have been installed on the center compartment and the pontoon is to be set at a depth greater than 200 feet, attach a blowing hose to the center compartment blow valve and to the salvage vessel's blow and vent manifold and open the center compartment blow valve.

11. To complete flooding of the pontoon, open the white and red end vent valves; vent also through the hoses attached to the white and red end blow valves.

12. As the pontoon sinks, maintain it level and just below the surface by means of the lowering lines. Close the vent valves on the salvage vessel when venting through the hose stops. When all venting stops, close the red and white end vent valves.

13. If the pontoon is being set with its axis parallel to the submarine's centerline, open the end-to-end sluice and close the flood valve nearest to the end of the submarine being raised first. If the pontoon's axis is athwart the submarine's centerline, leave sluice valve closed.

14. The pontoon is now ready for lowering with both end compartments completely flooded and the center compartment entirely free of water and with an air pressure of 15 psig.

5.2.7. Pontoon Lowering and Setting

1. Pay out the lowering lines and hoses evenly until the pontoon reaches the desired depth. The lowering lines and hoses should be marked either by painting or with manila rope yarn in order that the depth of the pontoon can be quickly ascertained.

2. If the pontoon has relief valves fitted to the center compartment and is to be set at a depth greater than 200 feet, the pressure in the center compartment must be kept at about 5 psi greater than the mean depth of the pontoon.

3. Send divers down to report on the attitude of the pontoon and its absolute depth as well as its depth with respect to other pontoons previously set.

4. Adjust the pontoon depth and trim as necessary.

5. Have the divers secure chain stoppers to link of lifting chain at top of hawsepipe, or see that the wire rope cable clamps (flower pots) are seated at the top of the hawsepipe.

This will depend on whether chain or wire rope slings are being used. Have the divers tap the wedges on the cable clamps with a hammer to ensure that they are seated.

6. If a hose is attached to the center compartment blow valve, shut the blow valve, turn off the air, and vent down and remove the hose.

7. Divers now return to the surface.

5.2.8. Pontoons - Positive Buoyancy

1. A pontoon that is placed with its axis athwart the submarine's centerline, with the two ends of a single sling through its two hawsepipes, can be secured with positive buoyancy as soon as the diver is out of the water. To do this, simultaneously blow the white and red ends with compressed air for a short length of time. Secure the air and vent back the blow lines. If there is a small puff of air, but no sustained venting, then the water level has not been lowered to the end of the internal drop pipes. Blowing for a short time and venting back should then be repeated until the venting continues for an appreciable length of time and then suddenly stops. This indicates that the water level in the end compartments is at the level of the end of the drop pipes and the pontoon has been blown to positive buoyancy, and that the lowering lines may be removed. Slacking the lowering lines affords a further check on the buoyancy of the pontoon.

2. If the pontoons are being placed parallel to the submarine's centerline and with the two ends of the slings leading to two different pontoons, the first pontoon of each pair must be held with negative buoyancy while the second is being lowered (refer to steps in Paragraph 5.2.6). The four ends of the two pontoons must be blown to positive buoyancy while at the same time holding taut the four ends of the slings to prevent the slings from being hauled under the submarine by the first pontoon to reach positive buoyancy.

3. Divers should then go down and observe any leakage of air from the pontoon or connections. Take steps to correct any air leakage which may occur.

4. Trip the pelican hooks and retrieve the lowering lines. At this, the divers may be brought out of the water.

5. Tag and buoy-off the blowing hoses. The pontoon will need no further attention until the wreck is ready to be lifted.

6. Tag and buoy-off sling reeving lines.

7. At this stage, tow lines should be rigged to the submarine and to the surface craft and buoys placed in the direction of intended tow.

5.3. Breaking the Submarine Free of the Bottom

If conditions are such that the lift required to break the submarine free of the bottom may be large, and pontoons are used for control during breakout, the breakout will be accomplished as follows (refer to Figure 5-5B):

1. Recover buoyed-off hoses and connect to salvage vessel blowing manifold.

2. Blow completely all control pontoons on the end of the vessel which is to be lifted first.

3. Blow completely, in succession, remaining pontoons and tanks on the end to be lifted first until that end is lifted.

4. Secure open flood valves and sluice valve on surfaced pontoons.

5. Blow control pontoons on other end of submarine.

6. Blow, in succession, remaining pontoons and tanks on other end of submarine.

7. While blowing to lift the second end of the submarine, the draft of the control pontoons on the end, which was lifted first, should be observed to see that the blowing in progress does not unload those control pontoons. If necessary, submerged pontoons or tanks at the raised end should be reflooded to keep the control pontoons loaded to about one-half of their full lifting capacities.

8. When the second end lifts, close the flood and sluice valves on the surfaced pontoons.

9. After the breakout lift, the submarine is towed into shallower water and grounded.

5.4. Intermediate Lifts

After both ends of the submarine are afloat, observation of the draft of the control pontoon will give information as to the load being carried by them.

If the amount of water in the submerged pontoons and tanks can be accurately ascertained, the weight and longitudinal center of gravity of the submarine may be calculated and the distribution of lift can be altered if required in subsequent steps.

If suitable lifting vessels are not available and pontoons are to be used for succeeding phases of the salvage operation, proceed as follows (Figure 5-5D). After grounding the submarine following the breakout lift, only enough of the lower pontoons and/or tanks should be flooded to hold the ship firmly on the bottom while removing or resetting the control pontoons. By so limiting the negative buoyancy of the submarine, a large breakout force during the next lift can be avoided.

The revised salvage plan may permit removal of one or more pontoons because of the more accurate information available and/or the reduced breakout force required. The procedure for removing a pontoon is as follows:

1. Pick up and hold slings taut.

2. Rig pontoon lowering lines.

3. Install 1/2-inch diameter wire rope lines as bridles on the cable clamp wedges and take tension on bridle if wire slings are being used.

4. Open pontoon end compartment flood and vent valves and flood pontoon until cable clamps or chain stoppers are free.

5. Remove cable clamps or chain stoppers.

6. Haul pontoon to surface.

7. Blow pontoon dry.

8. Remove slings or reeving lines from hawsepipes.

If pontoons are to be used for control during the next lift, they should be reset to the new lower position on the slings. This is accomplished by first freeing the cable clamps (steps 1 to 5), then lowering the pontoon and setting it as described in Paragraph 5.2.6., steps 1, 2, 3, 4 and 6.

Proceed to make the lift as described in Paragraph 5.3., steps 1 through 9.

If surface lift ships, cranes, or barges are available, the more accurate information now available and the smaller breakout force to be encountered on the next lift will permit them to be used for control with safety. In this case, proceed as follows:

1. Remove those control pontoons no longer needed.

2. Reset other control pontoons which are needed, in addition to the surface lift, to a lower position on their slings.

3. Take one sling at each end of the submarine to a lift ship.

4. Take maximum lift permitted by available lifting vessels and sea conditions on each lift ship.

5. Blow pontoons and tanks until both ends can be lifted. Take care that pontoons do not come up beneath the lift craft.

6. Monitor loads on surface-lifting gear to ensure that they are carrying a load, otherwise the submarine may become light enough to float without any surface lift.

7. Continue lifting until pontoons arrive at the surface. Keep the submarine reasonably level during lift to minimize the effect of free surface.

8. As the lift progresses, tow the submarine shoreward and adjust the lift by surface ships so as to keep the submarine just above the bottom.

9. When the submarine has been raised to the least depth at which the salvage vessels can move freely over her at all stages of the tide, stop the lift and continue to tow shoreward until the submarine grounds; then rig for the final lift.

5.5. Towing

Towing should be at a very slow speed so as to avoid damage to the lifting gear when the submarine grounds. The towing vessel pulls the submarine and one of the lift ships, which is in turn towing the buoys for the sling reeving lines and the other lift ship. The second lift ship should be towing a small tug or other craft which will prevent her from overriding the tow. Hoses to the pontoons and to the submarine should be retained on the salvage vessel which has been furnishing air for the salvage operation.

Presumably, the salvage vessel is one or both of the lift ships; but even if it is another vessel, it should be towed by the second lift ship or a large towing vessel attached to the second lift ship. In this case, the salvage ship should be towing the small tug mentioned above.

If the lift has been made with pontoons for control, the towing vessel should tow the submarine only. The salvage vessel is towed by the submarine and, in turn, tows some craft which can prevent her from overriding the submarine and pontoons.

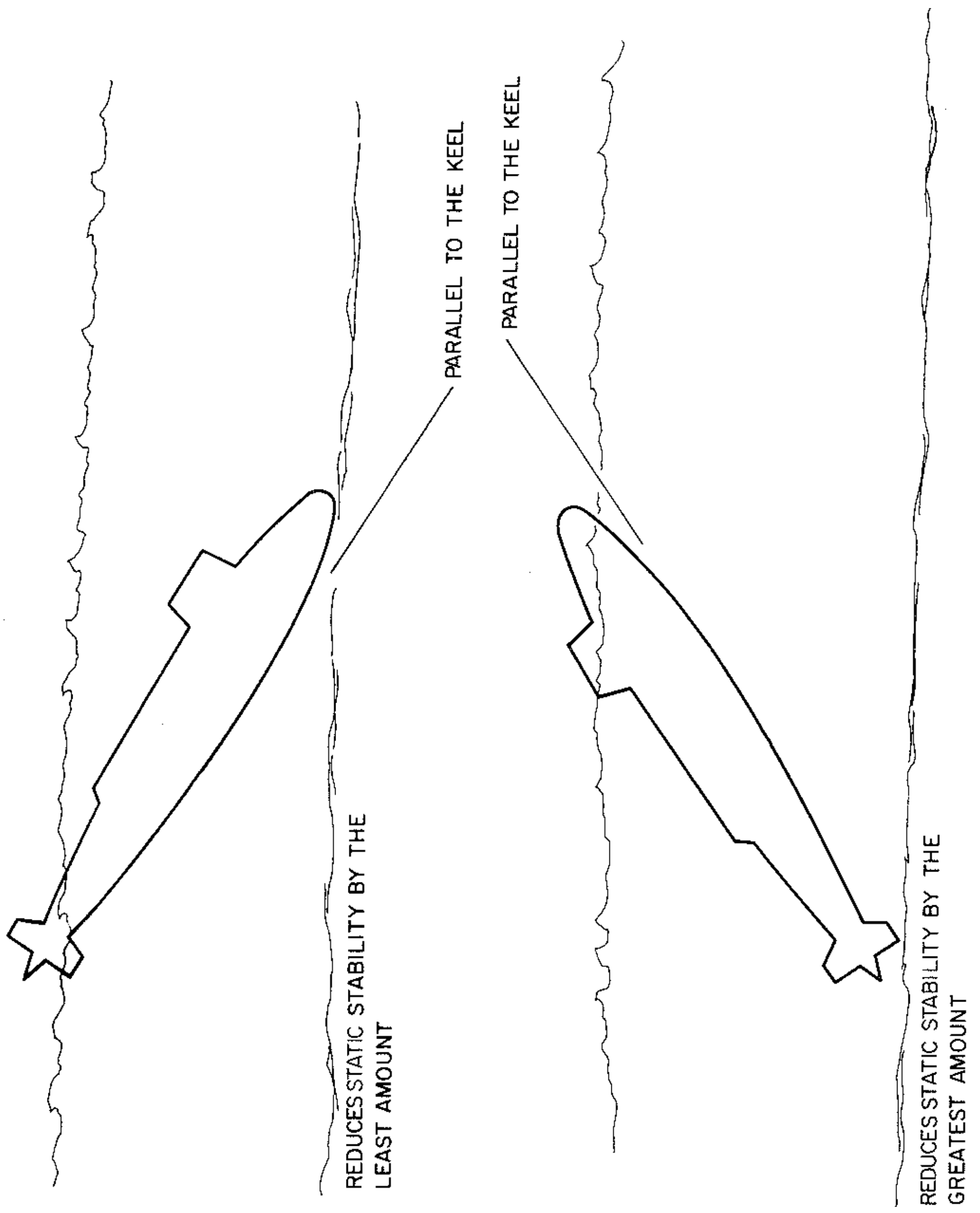
5.6. Final Lift to the Surface

For the final lift it is necessary to bring the submarine to a draft which will permit it to enter the selected harbor. Pontoons must now be placed longitudinally and alongside the submarine (Figure 5-5E). Since there will not be room to place one pontoon above another on the same slings, and two slings will now be needed for each pair of pontoons, additional slings will probably be needed. Messenger wires for these slings can be swept under the submarine before final grounding and after the last intermediate lift, to obviate tunneling for the new slings.

Since only a single level above the bottom of the submarine is now available for pontoons, space may not be available for enough pontoons to make the lift without some additional self-buoyancy. (Refer to Chapter 6 for means of providing self-lift.)

Even though it may be possible to float the submarine using self-lift, stability considerations may render it desirable to use some pontoons for the final lift. For this lift, it will usually be better to raise the stern first. When the first end has been surfaced, that part of the submarine which is resting on the bottom, and at which the bottom or ground reaction is applied, will generally be at a higher waterline plane on the submarine if it is at the bow, than if it is at the stern (bottom of the rudder); it will therefore cause less reduction in stability in this condition (Figure 5-8).

Since the improvement in stability provided by the pontoons can be transmitted to the submarine only by the friction of the slings, the pontoons at each end should be fully blown before lifting that end so that the slings will be well loaded when the first end lifts. While the other end is being made buoyant, the pontoons on the surface should be kept loaded to near capacity by reducing the self-lift or lift pontoon buoyancy at that end, if necessary.



GROUND REACTION AT BREAKOUT.

FIGURE 5-8

When the second end leaves the bottom, the change in attitude is likely to cause further blowing of residual water from tanks which could not be fully blown with only one end of the submarine on the surface. In addition to this gain in buoyancy, the tank being blown at the time the ship leaves the bottom will be further blown by the expanding air in it. The sequence of blowing tanks and compartments should be such as to minimize the gain in buoyancy as the second end rises.

After the second end of the submarine has been raised, its pontoons should also be kept well loaded so as to maintain adequate stability during the tow into port.

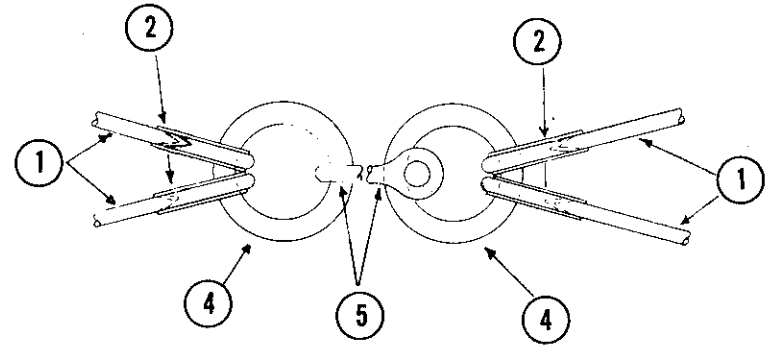
5.7. Towing the Submarine into Port

After the final lift to the surface, the towline should be from the towing vessel to the submarine. A towline is needed from the stern of the submarine to the salvage vessel which controls the venting and blowing of tanks and pontoons to ensure keeping the salvage vessel near enough to the submarine to avoid danger of breaking the hoses.

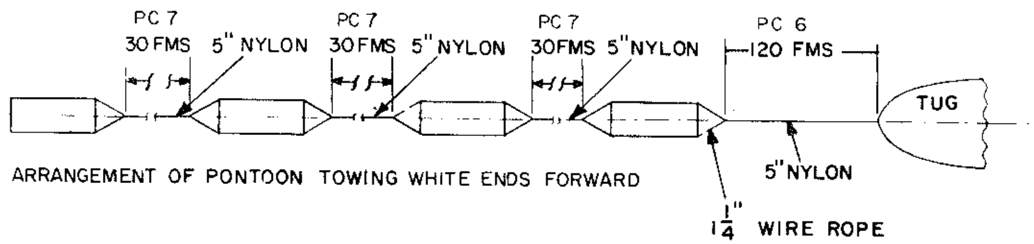
TABLE 5-1

SUBMARINE SALVAGE MATERIAL POOL
EQUIPMENT LIST

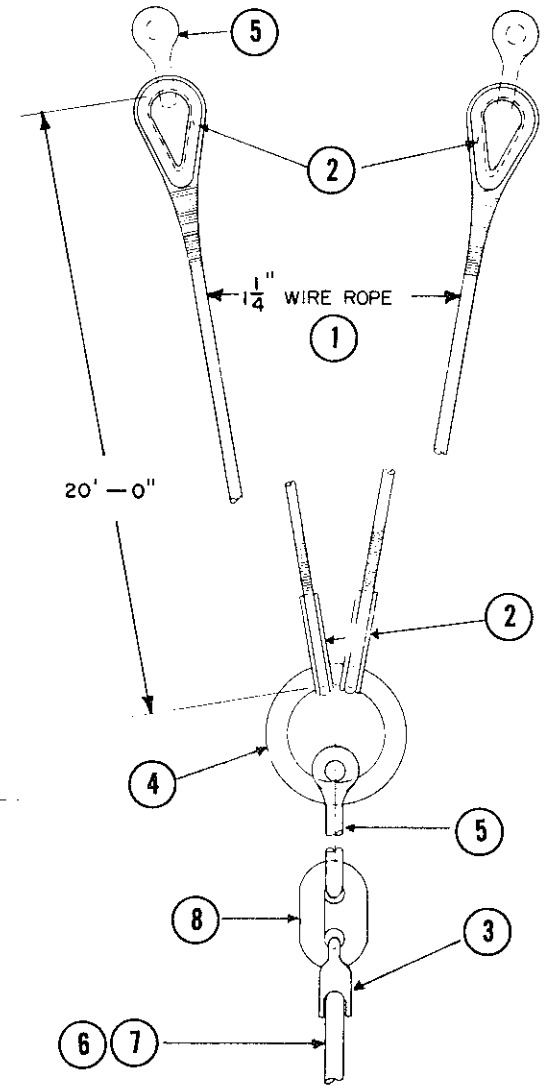
Pc No.	Equipment	Amount Required	Specifications or Federal Stock No.	Remarks
	Pontoon Towing Bridle Assembly			
1	Towing Bridle, 1-1/4" Wire Rope	28	9Z4010-286-7640	6X25 IPS Fiber Core Preformed Wire Rope-Mil.RR-W-410
2	Thimble, Wire Rope 1-1/4"	56	9Z4030-266-0075	For Pc 1;Mil.FF-T-276 Galvanized
3	Rope Coupling for 5" Circ Nylon Rope	16	Stainless Steel	BuShips Dwg S805-2130889
4	Towing Ring	14	Med Steel	U.S. Navy Drop Forging Die Book No. 3307-B
5	Shackle,Chain Type 1-3/4" Galvanized	42	9Z4030-290-4092	Chain Shackle - Safety, Bolt Type, BuShips Dwg S2500-921727 & 921728
6	Towing Line 5" Circ Nylon Rope	2	9Z4020-752-8880	100 Fathoms Long; Mil. R-17343
7	Towing Line 5" Circ Nylon Rope	6	9Z4020-752-8880	30 Fathoms Long; Mil. R-17343
	NOTE: Items 6 and 7 are held by supply activities because of their short life and will have to be requisitioned when needed.			
8	Link, Detachable 2-3/4" Dielock	14	None - (retain G-4010-149-5638 for Identification)	BuShips Dwg 2603-921790



BRIDLES SHACKLED TOGETHER



ARRANGEMENT OF PONTOON TOWING WHITE ENDS FORWARD



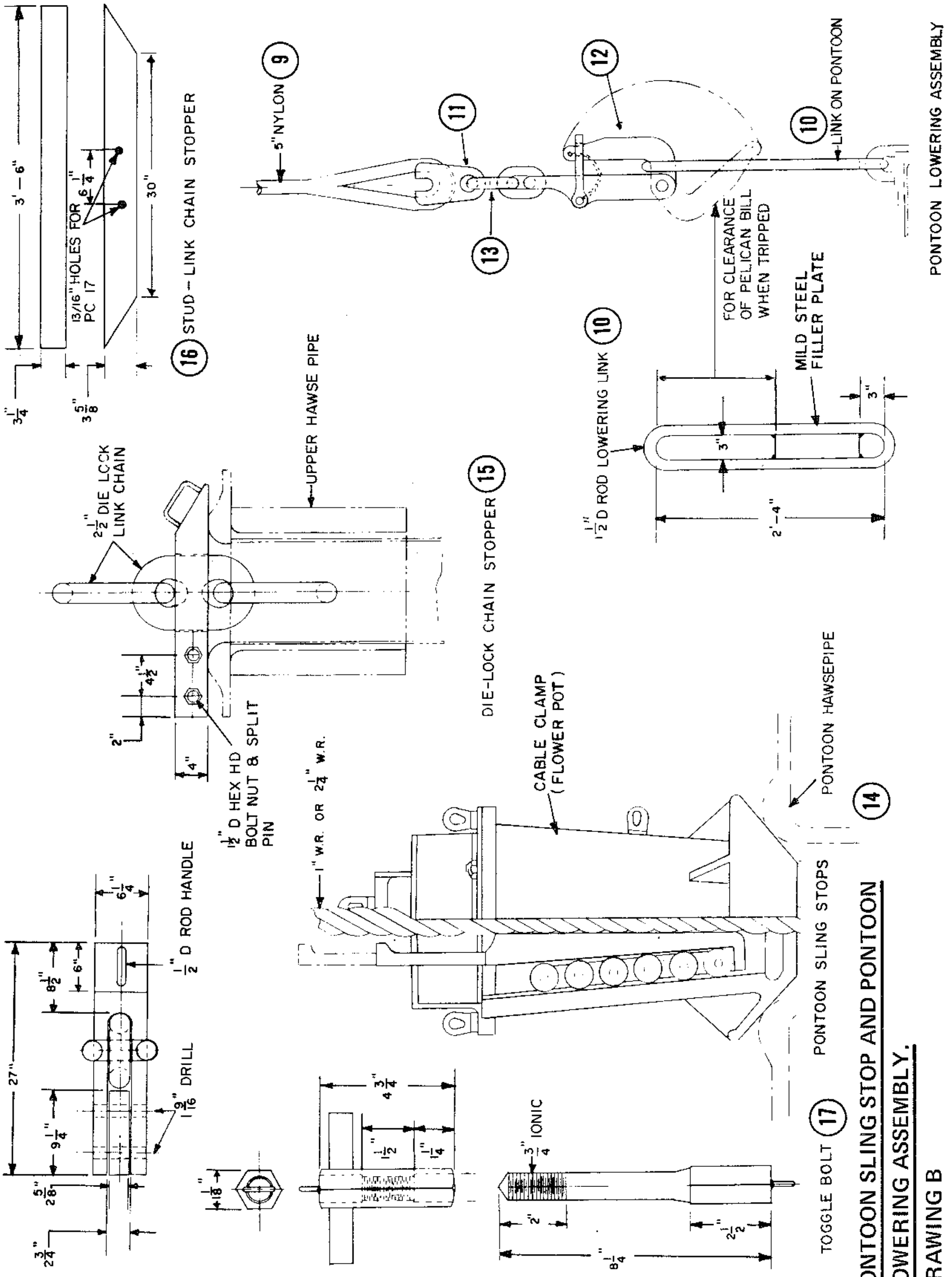
PONTOON TOWING BRIDLE

PONTOON TOWING BRIDLE ASSEMBLY.
DRAWING A

TABLE 5-1 (Cont)

Pc No.	Equipment	Amount Required	Specifications or Federal Stock No.	Remarks
		Pontoon Lowering Assembly		
9	Lowering Line, 5" Circ Nylon Rope	6	9Z4020-752-8880	100 Fathoms Long, Mil. R-17343 Rope Coupling One End - Pc 11
10	Lowering Link/Stiffener	25 (5 spare)	Med Steel	Fabricate and Attach to Pontoon as shown
11	Rope Coupling for 5" Circ Nylon Rope	6	Stainless Steel	BuShips Dwg, S805-2130889
12	Pelican Hook, 1-3/4" Swing Release	6	9Z4030-369-3976	BuShips Dwg, S2605-852066
13	Link, Detachable	12	None-(Retain G-4010-149-5642 for Identification)	1-5/8" Dia Dielock 1-1/4" Dia Dielock BuShips Dwg S-2603-921790
		Pontoon Sling Stops		
14	Cable Clamps(Flower Pot)	20		BuShips Dwg 149232
15	Chain Stopper, Complete	40	Med Steel	Fabricate as Shown, for 2-1/2" Dielock Chain
16	Chain Stopper, Stud-Link	40	Med Steel	Fabricate as Shown, for Stud-Link Chain
17	Toggle Bolt	100	Med Steel	Use with Pc 16

NOTE: (Applicable to items 15, 16 and 17) All new lifting chain Pc-25 will be dielock link chain, and new chain stoppers, Pc 15, are required when used. The stocking of stud-link chain stoppers, Pc-16 & 17 will be maintained until dielock link chain completely replaces the stud-link chain.

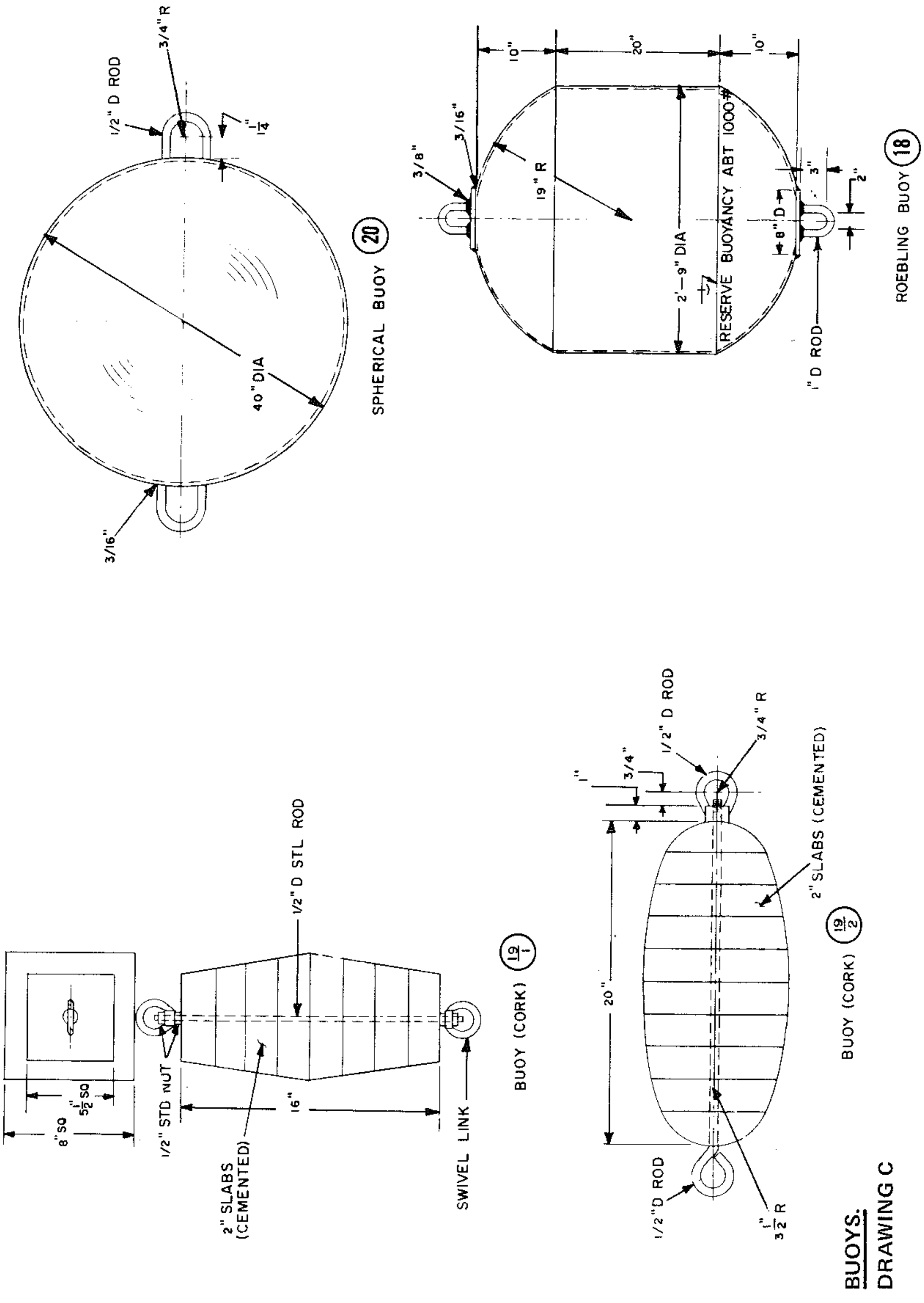


PONTOON SLING STOP AND PONTOON LOWERING ASSEMBLY.

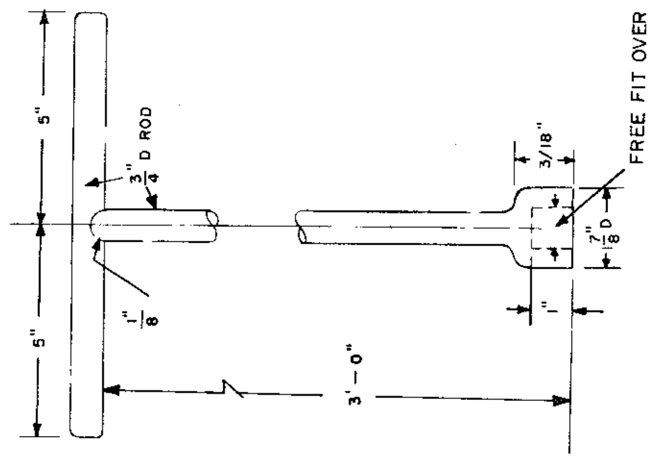
DRAWING B

TABLE 5-1 (Cont)

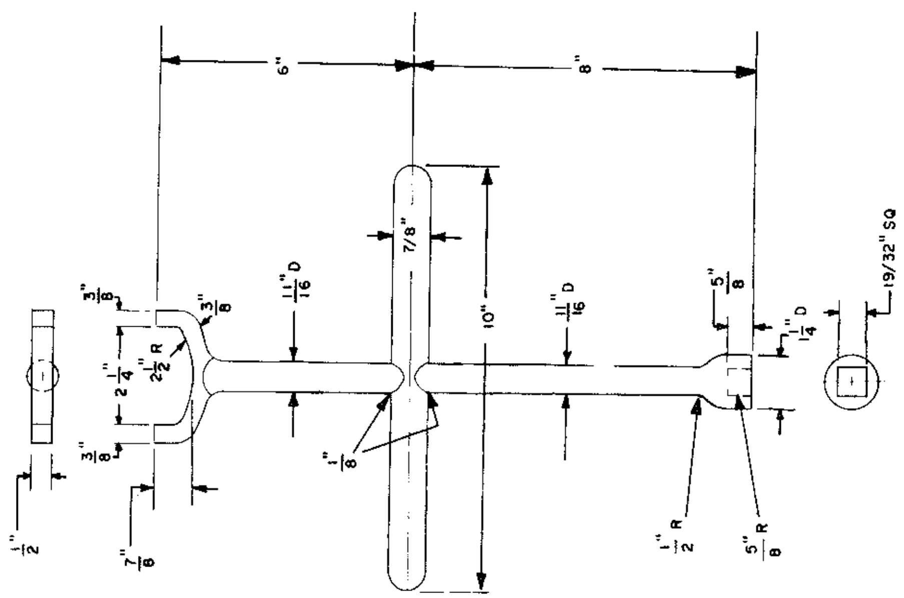
Pc No.	Equipment	Amount Required	Specifications or Federal Stock No.	Remarks
			Buoys	
18	Roebling Buoy	10	Med Steel	Fabricate as Shown
19	Diver's Marker Buoy (Cork)	100	Cork	BuShips Dwg S9400-921-598
20	Spherical Buoy	25	Med Steel	Fabricate as Shown
	NOTE: Harbor defense, 36-inch diameter buoy is an acceptable substitute.			
			Special Wrenches	
21	Wrench, for Submarine Salvage Deck Fittings	12	9Q5120-371-8696	Or as Shown
22	Wrench, for Pontoon Flood Valves	6	Med Steel	Fabricate as Shown



BUOYS.
DRAWING C



PONTOON FLOOD VALVE WRENCH (22)

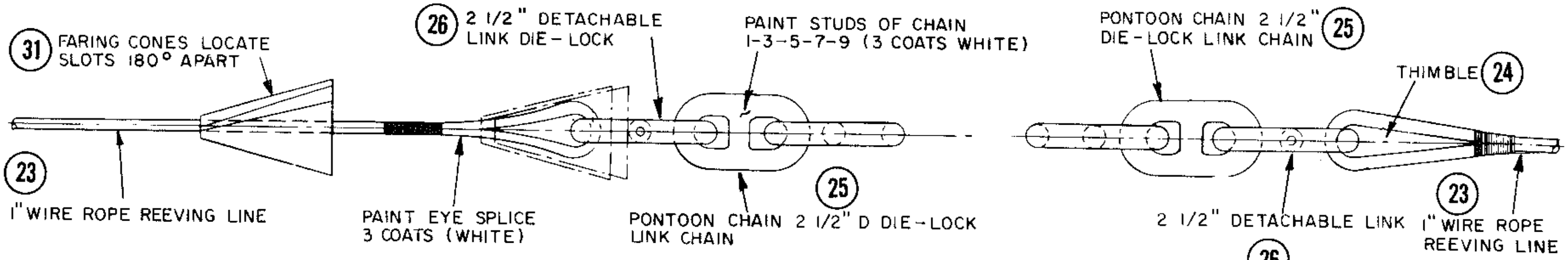


WRENCH FOR SALVAGE DECK FITTINGS (21)

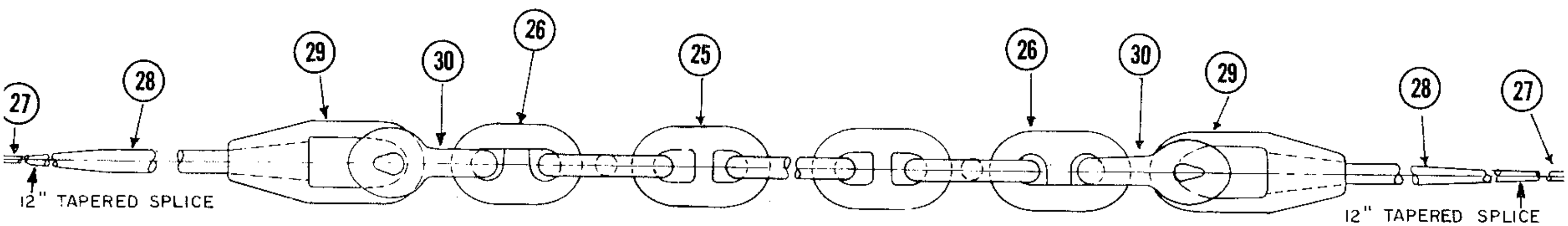
SPECIAL WRENCHES.
DRAWING D

TABLE 5-1 (Cont)

Pc No.	Equipment	Amount Required	Specifications or Federal Stock No.	Remarks
		Handling Lines and Chain		
23	Reeving Line, Shallow Lift 1" Wire Rope	12	9Z4010-272-8846	6x25, IWRC, IPS, Preformed, 300 Feet Long, Thimble One End, Pc 24. Mil.RR-W-410
24	Thimble, Wire Rope 1"	12	9Z4030-266-0071	Galvanized, Mil. FF-T-276, for Pc 23
25	Chain, Lifting Sling, 2-1/2" Dielock	12	2H4010-165-5627	25 Fathoms Long, BuShips Dwg S2603-860341
26	Link, Detachable 2-1/2" Dia Dielock	45	1H4010-165-5627	BuShips Dwg S2603-860062
27	Reeving Line, Deep Lift, 1" Wire Rope	20	9Z4010-272-8846	6x25, IWRC, IPS, Preformed, 600 Feet, One End Spliced to Pc 28. Mil. RR-W-410
28	Lifting Line, 2-1/4" Dia Wire Rope	20		6x37, IPS Fiber Core, Pre-formed, 250 Feet, One End Spliced to Pc 27, Closed Socket One End, Pc 29. Mil. RR-W-410
29	Socket, Closed, 2-1/4"	20	9Z4030-221-0776	For Pc 28. Galvanized. Mil. RR-S-550
30	Shackle, Chain Type 2-7/8" Connecting	20	9Z4030-164-6662	With Pc 29, BuShips Dwg 601-1992102



DETAIL OF PONTOON CHAIN
AND LIFT LINES FOR SHALLOW WATER OPERATION

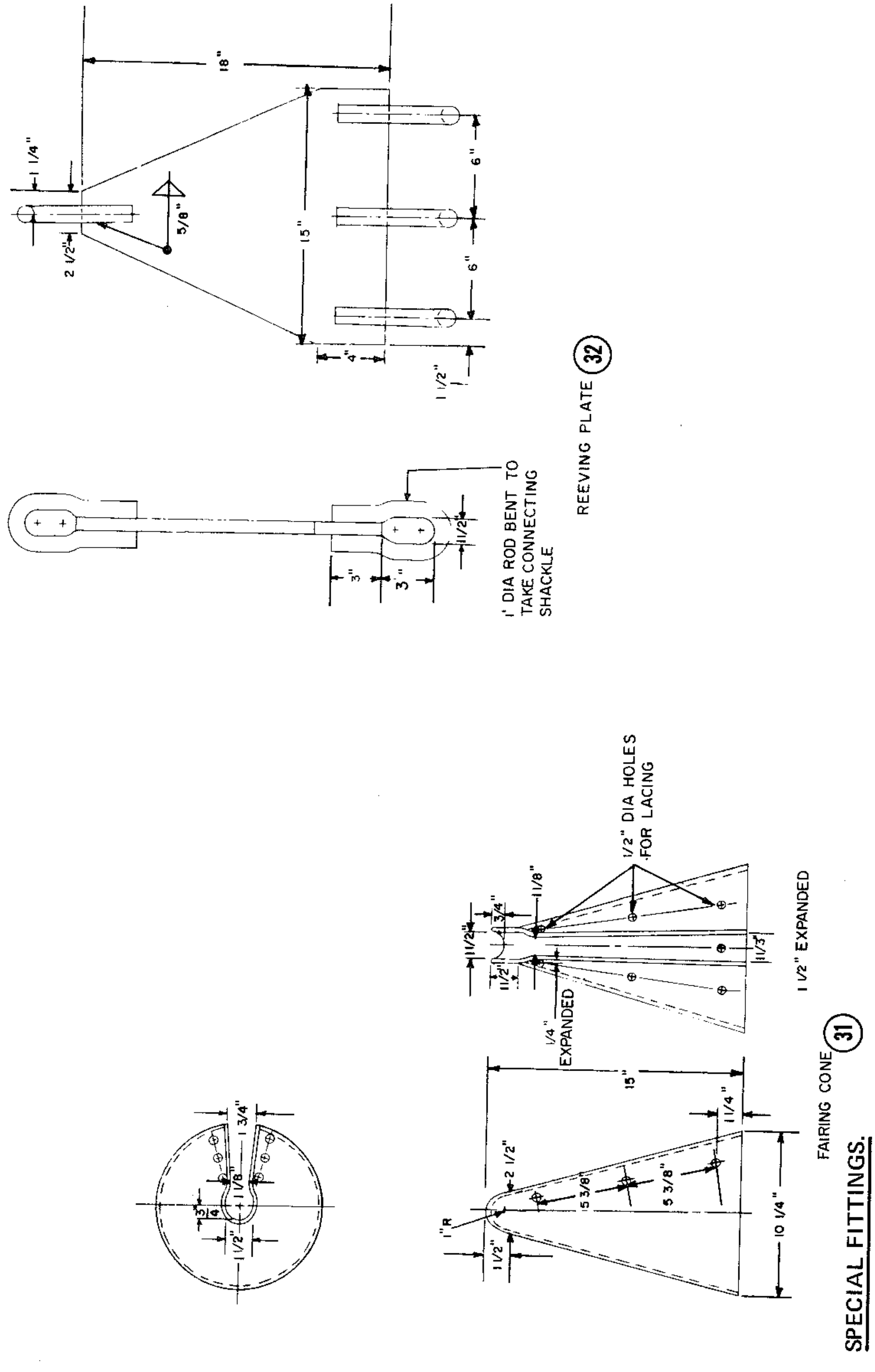


ASS'Y OF PONTOON CHAIN &
COMBINATION LIFTING AND REEVING LINES

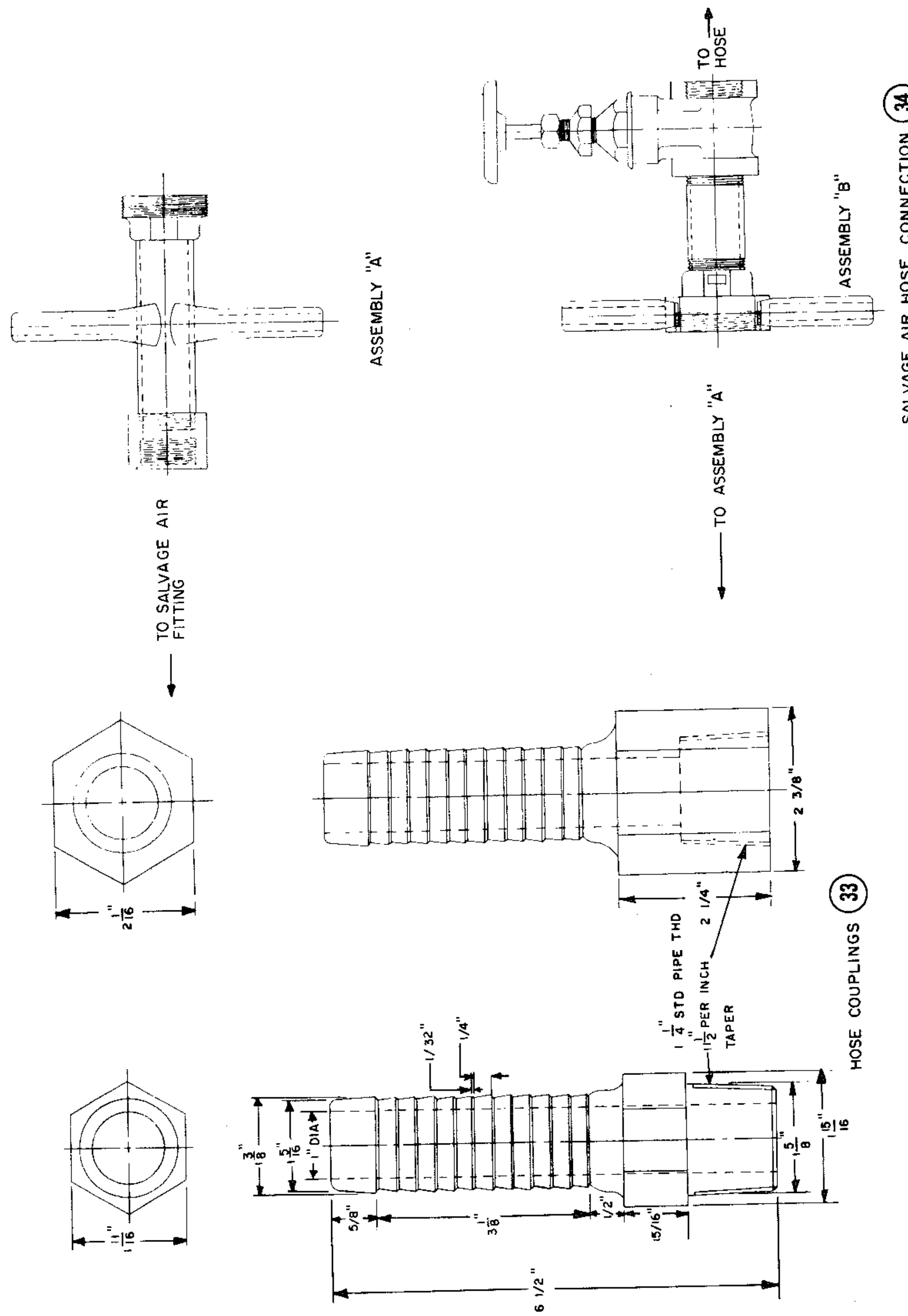
HANDLING LINES AND CHAIN.
DRAWING E

TABLE 5-1 (Cont)

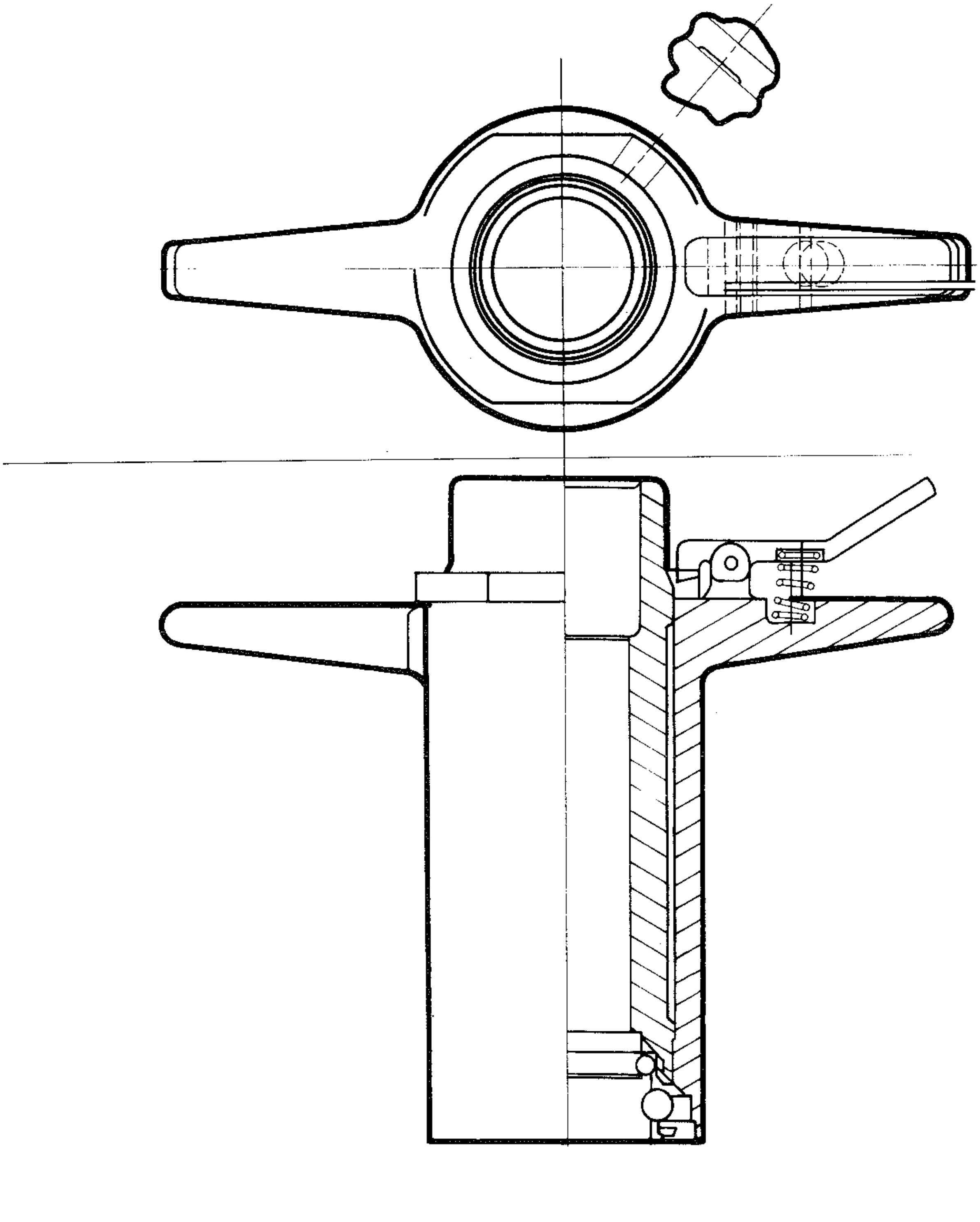
Pc No.	Equipment	Amount Required	Specifications or Federal Stock No.	Remarks
			Special Fittings	
31	Fairing Cone	30	Med Steel	Fabricate as Shown
32	Reeving Plate, Complete	2	Med Steel	Fabricate as Shown
			Hose Fittings	
33	Air Hose Couplings	450 (50 Spare)	Brass	Fabricate as Shown, 225 Male & 225 Female
34	Air Hose Salvage Connection Assembly	100	9C4730-241-8102	BuShips Dwg SN9400-921627
			Other Equipment	
35	Reeving Line, Messenger 1/2" Wire Rope	20	9Z4010-286-7718	6x37 IPS, Fiber Core, Pre-formed, 36 Feet long, Thimble Both Ends- Pc 36, Mil. RR-W-410
36	Thimble, Wire Rope 1/2"	40	9Z4030-266-0066	For Pc 35. Galvanized. Mil. FF-T-276
37	Shackle, 3/4", Screw Anchor	40	9Z4030-242-5575	With Pc 36. Mil. RR-C-271
38	Reeving Wire, 1/4" Wire Rope	3	9Z4010-273-2901	6x19 IPS, Fiber Core, Pre-formed, 80 feet long, Use with Salvage Lance. Mil. RR-R-571, Pc 41



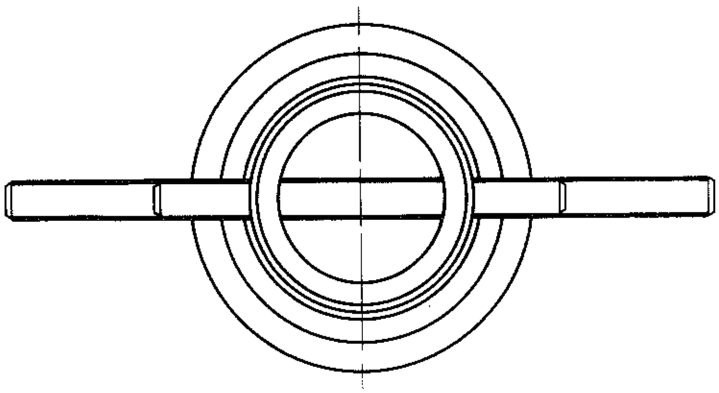
SPECIAL FITTINGS.
DRAWING F

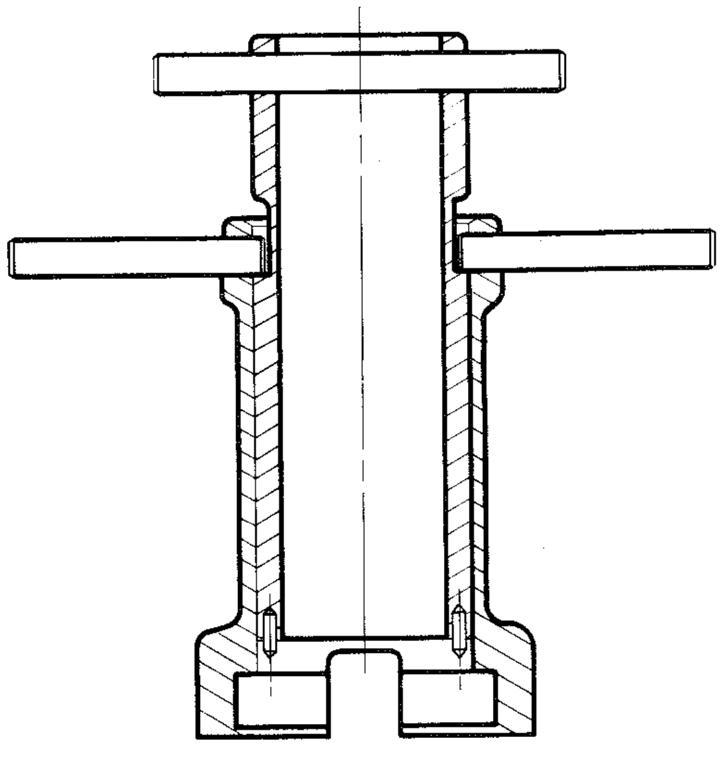


HOSE FITTINGS.
DRAWING G



QUICK RELEASE COUPLING ASSEMBLY
ROYLYN 7714, AIR SALVAGE.
DRAWING H





SUBMARINE ROYLYN CAP REMOVAL
TOOL, AIR SALVAGE.
DRAWING I

TABLE 5-1 (Cont)

Pc No.	Equipment	Amount Required	Specifications or Federal Stock No.	Remarks
			Other Equipment	
39	Thimble, Wire Rope 1/4"	6	9Z4030-266-0062	For Pc 38. Galvanized. Mil.FF-T-276
40	Tool Sets for Dielock Chain Links	2	1H4010-272-8705	Use with Pc 13 & 26
41	Salvage Lance	2	None-(Retain H4220-151-7712 for Identification)	BuShips Dwg 365240
42	Washing Nozzle	2		Falcon Type, BuShips Dwg 138917
43	Cement Gun	2	Med Steel	BuShips Dwg 147043
44	Air Hose, 1-1/4" Dia	200	9C4720-230-6522	50-Foot Lengths. Mil.H2699, Type B, Working 100 psi; Burst 600 psi
45	Air Hose Clamps	1300		For Pc 44 and 33.Mil.F-2808
46	Fire Hose, 2-1/2" Dia	20	9C4210-202-8188	50-Foot Lengths
	NOTE: Items -- 44 and 46 are held by supply activities because of their short life and will have to be requisitioned when they are needed.			
47	Special Air Coupling Assembly	40	1H4730-789-0215	Roylyn Corp.,Glendale,Calif. Part No.7714. Will be required for New Type Salvage Nipples on Submarines
48	Cap Removal Tool, Air Salvage	5		Part No. 0160-0003

TABLE 5-2

DISPOSITION OF SUBMERSIBLE PONTOONS

Structural No. & Type	Net Lift (tons)	Net Wt. (tons)	Length (ft.)	Diameter (ft.)	Location
2,3,6,7,9, 10, Type I	85	38.4	34' 7/8"	13' 13/4"	1st Naval District Boston, Mass.
31,32, Type III	80	35	32	12-1/2'	1st Naval District Boston, Mass.
63 & 64 Type IIIA	90		34	13	1st Naval District Boston, Mass.
1,11,12,14 Type II	80	40.1	32	12-1/2'	Supervisor of Shipbuilding, Conversion and Repair San Diego, California
15,19,53, 54, 55 Type III	80	35	32	12-1/2'	Supervisor of Shipbuilding, Conversion and Repair San Diego, California
75 Type IIIA	90		34	13	Supervisor of Shipbuilding, Conversion and Repair San Diego, California
65 to 74 Type IIIA	90		34	13	14th Naval District Pearl Harbor Naval Shipyard Pearl Harbor, Hawaii
33 to 40 Type III	80	35	32	12-1/2'	Charleston Naval Shipyard Charleston, South Carolina
61, 62 Type IIIA	90		34	13	Charleston Naval Shipyard Charleston, South Carolina

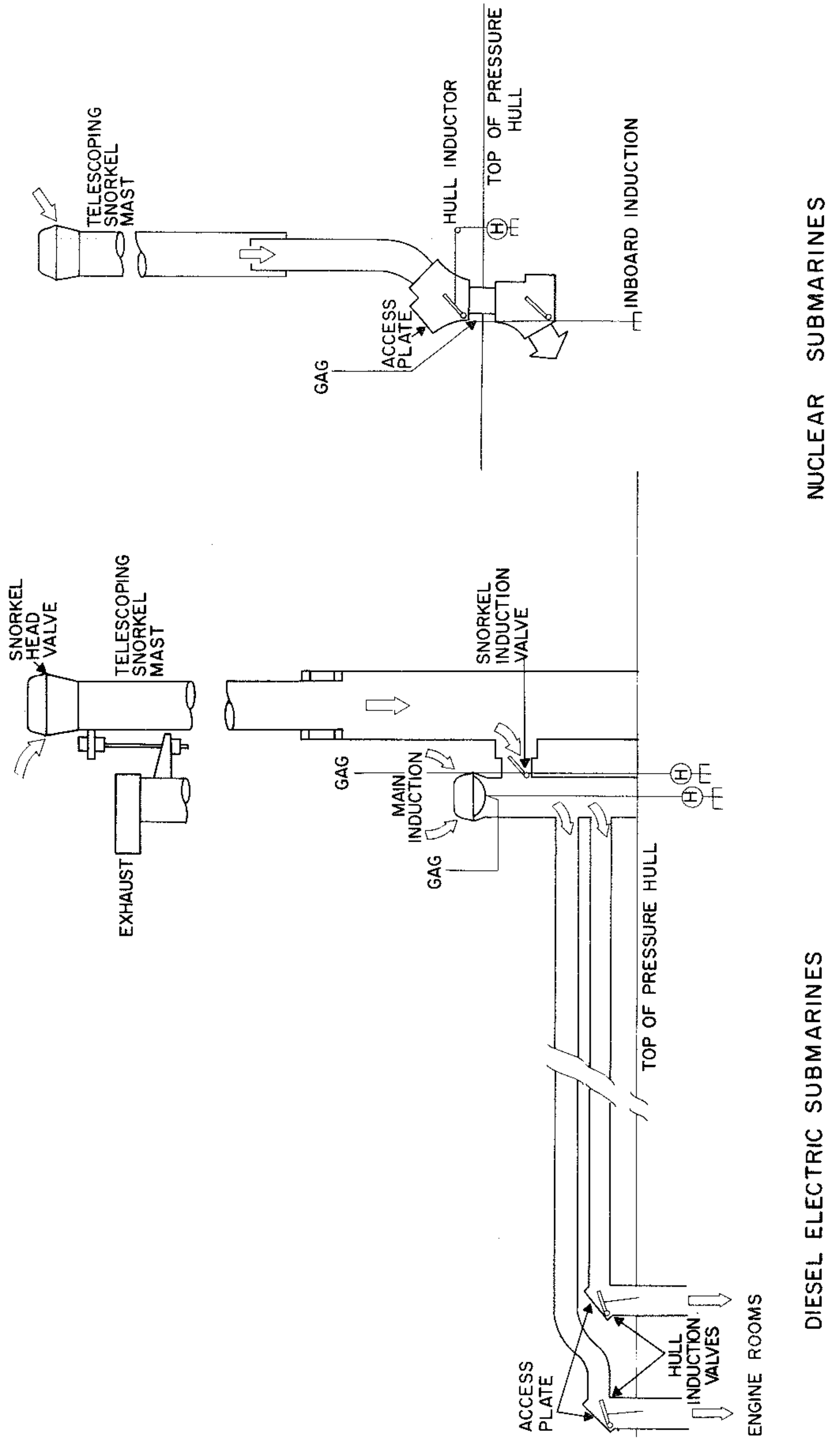
6. Submarine Self-Lift

6.1. Introduction

Since submarines are built to withstand hydrostatic pressures, they are most easily adapted to generation of self-lift. In almost all cases of submarine salvage, one or more of the internal watertight compartments will be subjected to flooding. If this flooding was the result of failure by the crew to seal the compartments during a normal evolution, divers can usually seal the opening(s) and produce some self-lift utilizing the buoyancy of interior compartments and ballast tanks. WARNING: if several compartments have been flooded, it is probable that the submarine will become unstable at some stage of the operation, especially if one end of the submarine is subjected to a large ground reaction.

Each submarine is made up of a number of watertight compartments, some of which are surrounded by tanks. Some of the tanks (main ballast) are used to submerge and surface the submarine during normal operations. The volume of tanks is determined by the type, size and configuration of the submarine. The older, diesel-electric (fleet-type) submarines have a large main ballast tank capacity because they operate much of the time on the surface, and, therefore, require more reserve buoyancy. In addition, they have a large fuel supply. Nuclear submarines, which are submerged much of the time, have relatively small main ballast tanks outside the pressure hull, and a small amount of fuel. Thus, more self-lift can be obtained from the tanks of a diesel-electric submarine than from those of a nuclear-powered submarine.

The conventional method of obtaining self-lift is by introducing compressed air into a compartment or tank. To do this, the space that is to be dewatered must be sufficiently sealed to hold air pressure of a few pounds over that of ambient sea pressure. Main ballast tanks that are intact can be blown down if the vents are closed and there is an opening at the bottom through which the water may be expelled. Internal compartments, however, have large openings and piping systems which make them more difficult to seal. The hatches, valves in air induction piping, and exhaust lines penetrating the pressure hull all seat with sea pressure. Even if these fittings are undamaged and closed, they must be gagged shut in order to hold an air pressure in the compartment (see Figure 6-1). The gagging gear provided for induction valves is often difficult for divers to operate since access plates must be removed in order to reach the gag nut which holds the valve shut.



SUBMARINE AIR INDUCTION SYSTEM.

FIGURE 6-1

6.2. Compartments

Internal compartment watertight integrity with respect to adjacent internal compartments is achieved by watertight doors, stop valves in piping, and flapper valves in ventilation lines. These internal closures may not be accessible for the purpose of gagging. The internal compartment may possibly be dewatered in this case by pumping. This can be accomplished by connecting the salvage pump to the compartment low salvage fitting. The internal compartment air pressure may then be raised to ambient sea pressure using the high salvage fitting. The small size of the salvage air lines makes this a slow process, and, therefore, it should be started well in advance of the planned lift operation. Figure 6-2 is a typical diagram of a submarine compartment salvage air system.

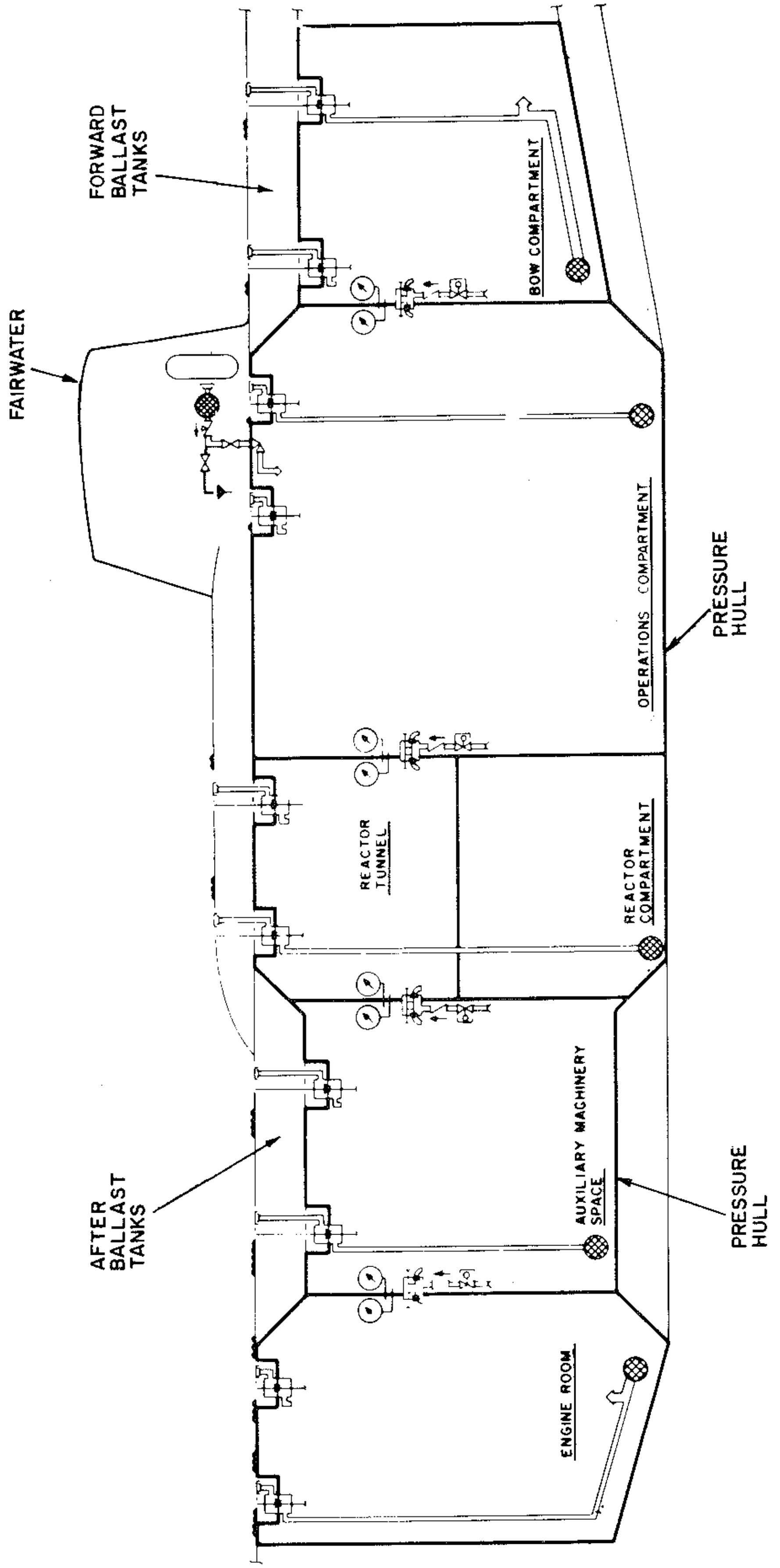
If a compartment is open to the sea through an unknown source, it may be possible to locate the leak by blowing the water level down until escaping bubbles pinpoint it. Whether or not self-lift can be obtained from such a compartment will depend upon the circumstances.

The use of salvage hatch covers requires that a diver be sent inside the submarine. This operation should be undertaken only if the low salvage line becomes blocked and then only if self-lift from such compartments is needed in order to raise the ship. This method of obtaining self-lift frequently involves a great deal of work by divers.

A vulnerable part of the submarine is the ventilation induction system. A typical ventilation system is illustrated in Figure 6-1. Details of the induction valves on a modern submarine are shown in Figure 6-3. In the past, it has been possible to seal ventilation valves with cement when gagging proved unsuccessful. Removal of the access plate exposes the valve disc and permits cement to be placed in the area above the disc. A bin or cofferdam constructed around the valve will allow a quantity of cement to be placed in and around the valve. The weight of this seal aids in holding the disc on its seat and permits air pressure to be maintained in the compartment. The diesel engine exhaust system, shown in Figures 6-4 and 6-5, is in many ways similar to the ventilation induction system and may be closed or sealed in the same manner.

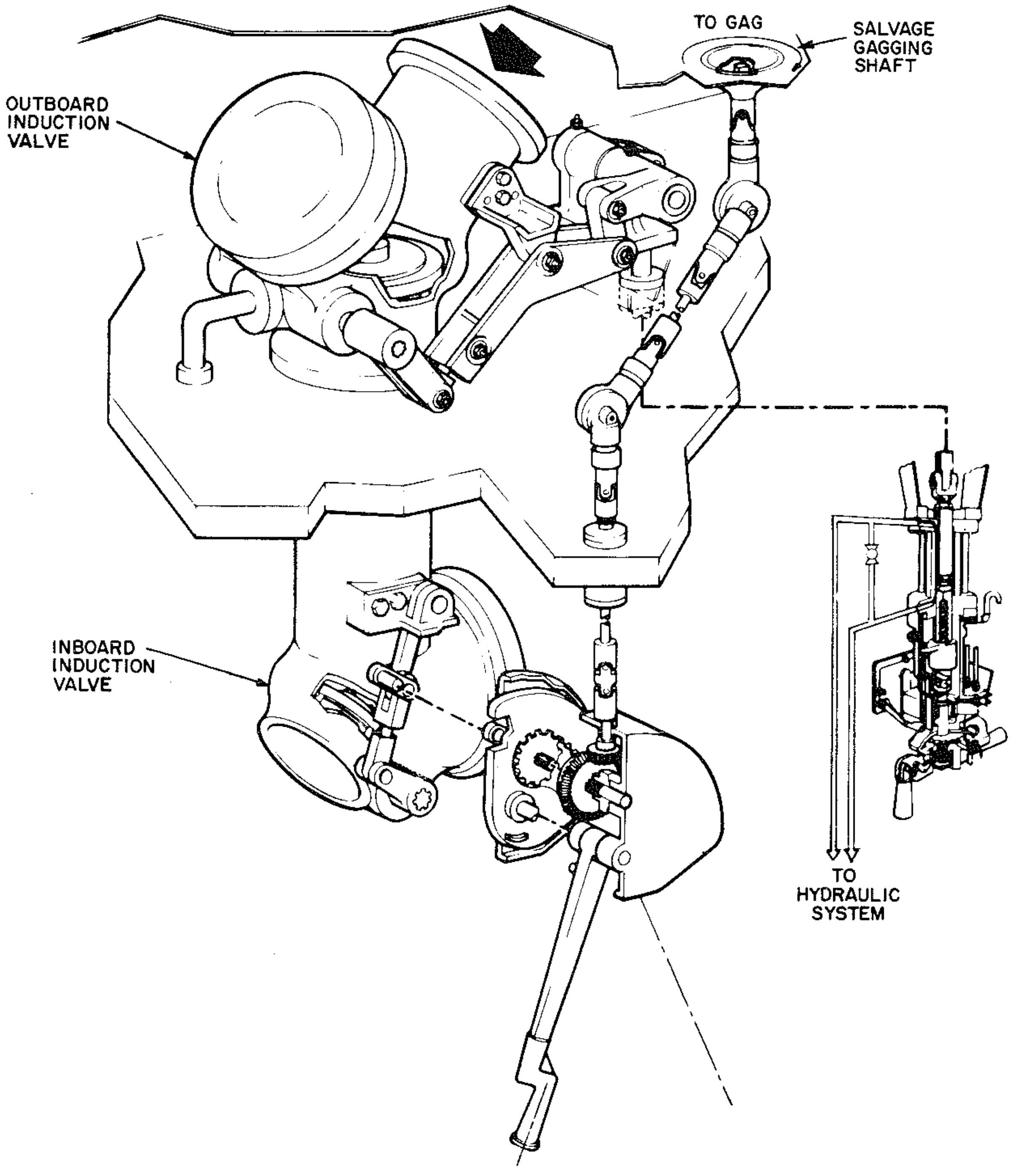
6.3. Main Ballast Tanks

Salvage air connections for main ballast tanks are available on most U.S. NAVY submarines with hull numbers lower than 571.



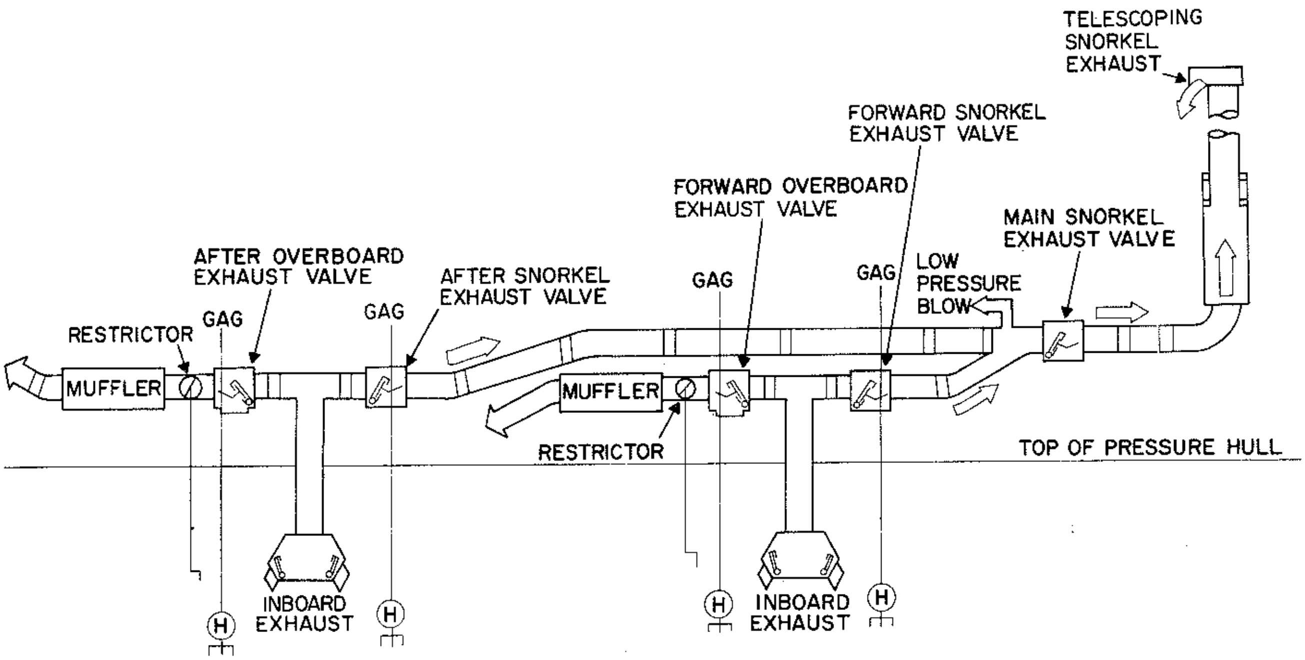
SALVAGE AIR SYSTEM.

FIGURE 6-2

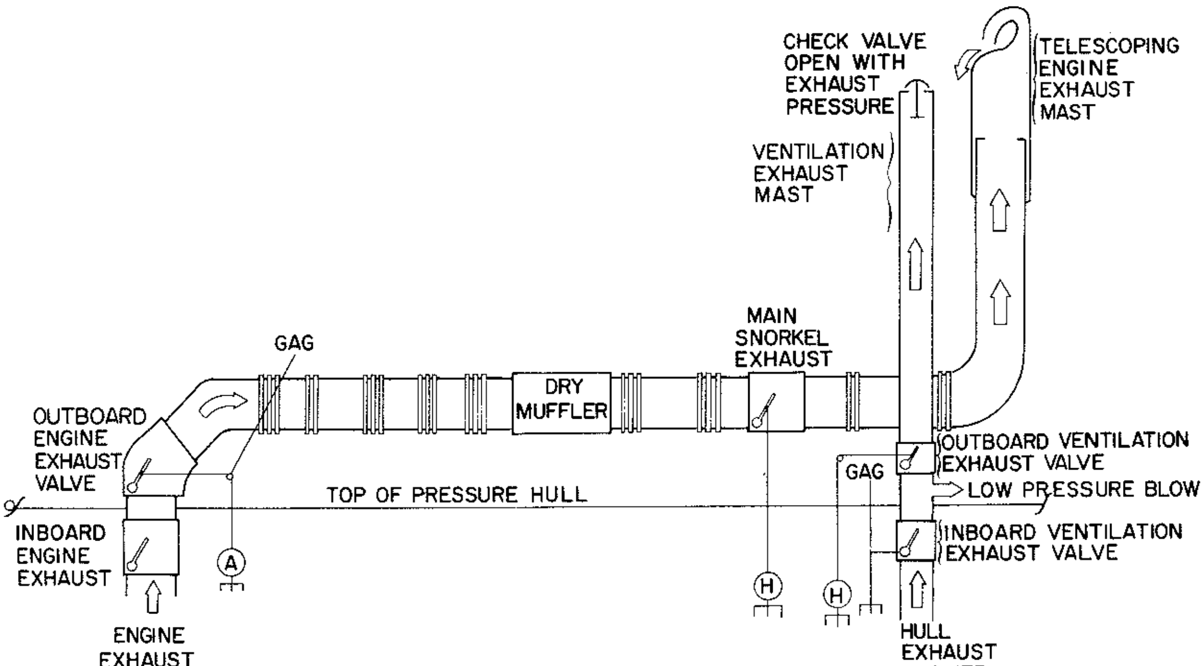


INBOARD AND OUTBOARD INDUCTION VALVES.

FIGURE 6-3



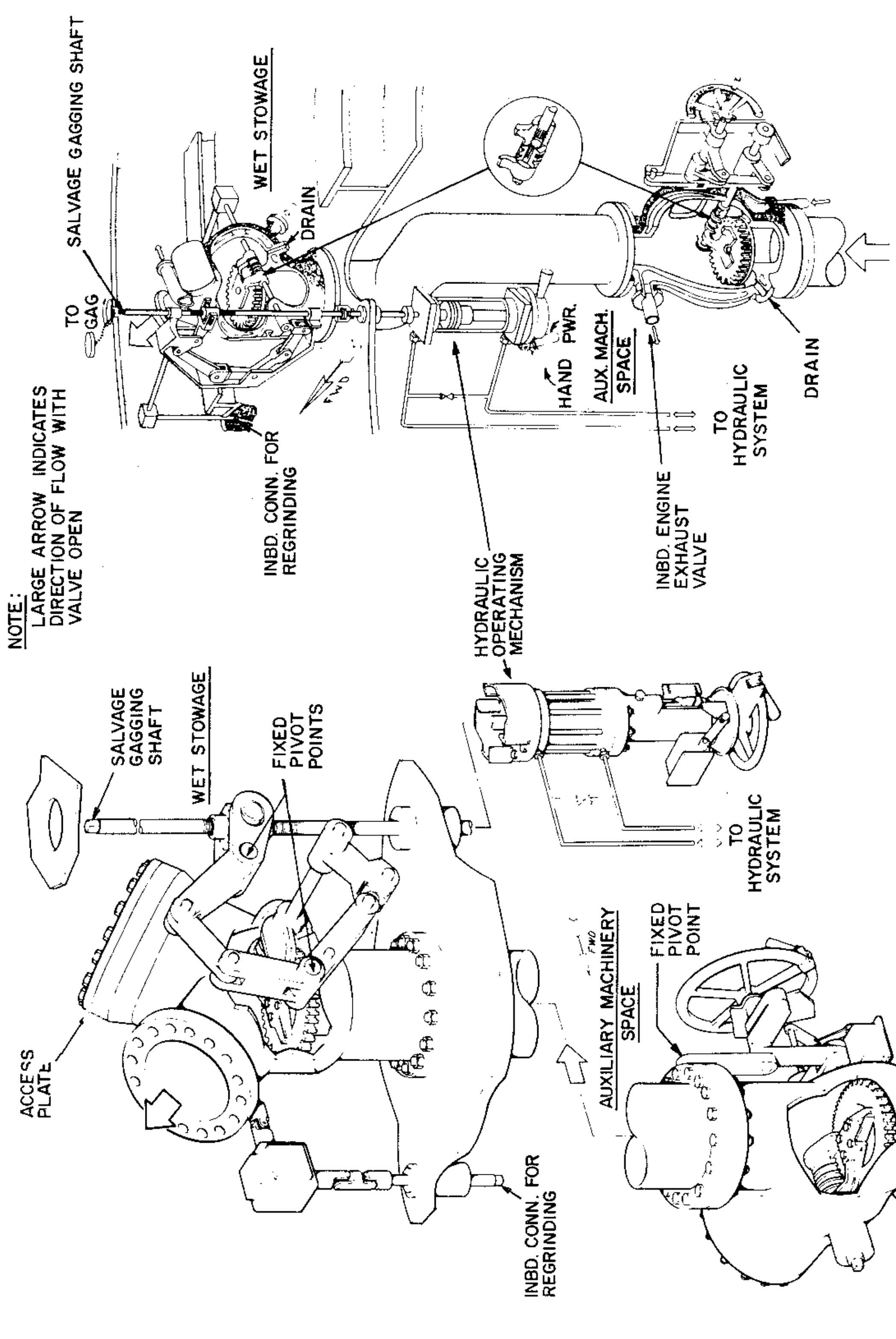
DIESEL ELECTRIC SUBMARINE
EQUIPPED WITH SNORKEL



NUCLEAR SUBMARINE EXHAUST SYSTEM

TYPICAL SUBMARINE EXHAUST SYSTEM.

FIGURE 6-4



(A.) INBD. & OUTBD. ENGINE EXHAUST VALVES, SSBN599 CLASS

(B.) INBD. & OUTBD. ENGINE SNORKEL EXHAUST VALVES, SSN588 CLASS

TYPICAL SNORKEL AND ENGINE EXHAUST VALVES.

FIGURE 6-5

A considerable amount of buoyancy can be gained from those tanks that are intact and whose main vents are closed or are capable of being closed. Blowing the main ballast tanks may also assist in breaking the bottom suction if the flood holes are below the mud line. Main ballast tanks that do not have salvage air connections can be blown by use of temporary air fittings installed with a velocity power tool, as discussed in Chapter 2, or by placing an air hose through the flood opening.

6.4. Fuel Oil Tanks

The fuel oil system differs widely on various classes of submarines. Before attempting to obtain self-lift with fuel tanks, a study of the fuel system plans and an inspection of a sister ship from the same building yard should be made.

The external fuel tanks are always kept full of fuel oil or sea water, as this part of the hull cannot support full sea pressure. Such tanks are kept equalized with sea pressure through the salt water compensation line and the fuel filling and transfer line. This system has inboard vent valves for ensuring that all air is vented from the tanks; these are normally locked shut. Submarines constructed before USS NAUTILUS (SSN 571) are provided with salvage air connections at the top of all fuel oil tanks.

To avoid contamination of the salvage area, oil in the fuel tanks should be transferred to the tanks of one of the ships in the salvage force through the salvage hose. When the hose has been attached and the salvage valve has been opened, the oil will run out of the upper end of the hose.
The height above the surface to which the oil will flow depends upon the depth of the submarine and the specific gravity of the oil. After the oil has been removed, the water which displaced it can be blown down using compressed air.

6.5. Fuel Ballast Tanks

Fuel ballast tanks are designed to be used for either fuel oil storage or as main ballast tanks. These tanks have main vent risers, and are connected to the fuel oil compensating line. The flood valves are large flapper valves that seat with sea pressure. If these tanks are being used as main ballast tanks and the flood valves are open, the tank may be dewatered by blowing, as with any undamaged ballast tank. If the flood valves are closed and buried in the bottom mud, the salvage divers will have to cut holes as low as possible in the tanks to allow the water to be expelled.

If the tanks are full of fuel, they can be emptied by installing a hose fitting with a velocity power tool, cutting flood holes, and allowing the oil to be forced out as discussed in Paragraph 6.4.

6.6. Variable Ballast Tanks

It is much more difficult to obtain any buoyancy from the variable ballast tanks as they are located within the pressure hull and are connected to the trim line as well as the bilge drain line. It would be difficult for the Salvage Officer to know the condition of these systems before the submarine sank. It may be possible that by blowing water from one tank, it would be transferred to another, the variable ballast tanks, which include the auxiliary tanks and the forward and after trim tanks, are much smaller than the main ballast tanks. The amount of work required of divers to prepare the variable tanks for dewatering generally is comparable to that required for blowing down a main compartment, but the lift gained is considerably smaller. These tanks should be the last spaces considered for obtaining self-lift.

6.7. Salvage Foam

A recent development has been the application of generated-in-place foams to displace water from within salvable objects. This technique of generating self-lift can significantly reduce the external lift requirement.

The present state-of-the-art limits the practical usage of foam systems to depths of less than 100 feet, although specially compounded foams have been used with varying success down to 200 feet and present studies are attempting to lower the use depth to the 400-foot range.

The most successful system used to date is based on a two-component urethane foam supplied in self-contained pressurized containers. In application, each component is forced under pressure from the surface through separate hoses to the submerged salvage site. There, the components are mixed and released into the submergence atmosphere where initial foaming takes place. The initial foaming produces a cream-like mass and is initiated by the expansion of an extremely low boiling liquid contained within one of the components. In this state, the foam, although not fully expanded to its final low density, has excellent insulation properties. As a large mass is formed within a compartment, the generation of exothermic heat takes place due to the nature of the chemical curing reaction.

This heat further expands the foam to its final density by vaporizing a second low boiling liquid component. This expansion is created with enough pressure to displace the water from within the sunken object.

After the gas generation cycle is completed, a cure period is required to allow the foam to reach its maximum strength. The length of this cure period depends upon the nature of the chemical reaction and the ambient temperature conditions. The ultimate aim of the foam system is to replace water from within an object with a foam of minimum density and which has sufficient strength to prevent cell rupture and the subsequent loss of entrapped gas as the hydrostatic pressure decreases during ascent. At the shallower depth, low density foams are capable of sufficient cell strength; but as the depth increases, a corresponding increase in the foam density must also be maintained.

A listing of the advantages of foam over compressed air includes the following:

1. Foam expands very little during ascent - air requires venting to prevent structural damage from increasing internal pressure.

2. Foam eliminates the free surface effect, thus tending to preserve static stability of the object during ascent; air may cause static instability.

3. Foam requires little or no elaborate sealing or shoring procedures before application. Deck loading is, at times, reduced because the foam can adhere to structures within the compartments, distributing the buoyancy forces. Foam will not spill through small, undetected leaks because of its viscous nature - whereas air is more difficult to contain.

4. Foam can be selectively distributed throughout the interior of the salvable object to optimize its effect upon trim and submerged stability.

5. Because of the compressive strength of the foam, it may be used to increase the longitudinal strength in areas where the load is compressive.

A major disadvantage of foam, compared with compressed air, is its reduced buoyancy per cubic foot. In addition, it has several inherent disadvantages which limit its application in most salvage operations; some of these are:

1. It requires sensitive pumping, proportioning, and mixing controls, and technical personnel for operation, to produce reliable foam.

2. Foam density increases with increasing hydropressure and decreasing ambient temperature.

3. The placement of the foam in a sunken object requires divers to be located at the submerged salvage site during application.

4. The average density and density distribution of the foam is difficult to measure after it has been generated in place.

5. The total buoyancy of the foam is continuously being reduced with time, at pressure, because of water absorption and reduction of its initial volume.

6. Trapped gases may result during the foam generation cycle or the ascent, and produce buoyancy changes and internal structural loads due to their expansion. This would tend to nullify the first advantage.

7. After salvage, the material is more difficult to remove than air or water and special equipment may be required for this operation.

8. Generated-in-place foams are a "one-shot" operation and, as such, are costly. At an estimated cost of 50 to 75¢ per pound for the chemical, the total cost increases rapidly with increasing foam density.

In each specific salvage operation, the necessity of employing generated-in-place foams must be evaluated against their relative disadvantages.

6.8. Hose Requirements and Handling

The hose normally used by salvage vessels to raise submarines is supplied in 50-foot lengths. The hose presently available has an inner diameter of 1-1/4 inches and an outer diameter of 2-1/16 inches. Working pressure is 100 psi, and the burst pressure is 600 psi. If it must be used at a pressure exceeding the rated working pressure, the period of such increased pressure should be limited to as short a period of time as possible.

The length of hose required for each task will depend upon the depth of the water. At least 200 feet more than is needed to run from the submarine to the surface should be used to enable the salvage vessel to move a short distance away from directly over the submarine.

On some salvage jobs it has been found advantageous to bring the salvage hoses together at a common point on the submarine and then lead them to the surface from this point.

The number of hoses required would be one for each compartment being used to provide self-lift, one for each tank to be blown, an additional one for each compartment which is to be pumped out, and two or possibly three for each pontoon.

When making up the hose, a globe valve is usually mounted on each end. A fitting (piece 34 of Table 5-1), suitable for the point of attachment on the submarine, is mounted on the lower end. When pressurized, the hose is slightly buoyant. After the hose is attached, it is then lashed to the submarine to avoid having it pull on the salvage air connection. It may then be buoyed off when not in use.

6.9. Dewatering of Tanks and Components

As the preparatory work on each tank is completed, the tank should be tested by blowing it down to ensure that the self-lift will actually be available when the submarine is to be lifted. After such tests, enough of the tanks should be reflooded to avoid any possibility that the submarine can become light enough for either end to leave the bottom prematurely while other compartment and tanks are being so tested.

It is safe to assume that, if all tanks are fully flooded, the main compartments can be dewatered as much as possible through the low salvage lines or the salvage hatch cover spill pipes without making the submarine too light to remain on the bottom. It is therefore usually unnecessary to reflood the main compartments after dewatering them.

If the salvage plan calls for the use of pontoons because of external lift requirements to improve static stability of the submarine, then enough water must be left in the main compartments to keep the submarine on the bottom until such pontoons have been completely blown down. The tanks and/or lift pontoons should then be used to provide the final increment of lift.

6.10. Past Salvage Operations

When viewing the self-lift aspects of past salvage operations, it is apparent that self-lift alone was never successful except when the submarine was near enough to the surface to be entered through hatches which were, or could be, extended via cofferdams to a point above the water. The interior could then be pumped out completely, the free surface in compartments eliminated, and the ship refloated with little danger of static instability.

Not all of the successful salvage operations on submarines in deep water have employed self-lift, but all of them have employed external lift. It is probable that for the large nuclear submarines, insufficient external lifting facilities would be available to obviate the need for self-lift. Where a choice exists between self-lift and external lift, the one which requires the least preparatory work is recommended.

7. Submarine External Lift

7.1. The Need for External Lift

External lift must be provided when:

1. It is not possible to provide enough self-lift to raise both ends of the submarine.

2. The submarine is to be lifted a distance which is less than the distance to the surface.

3. The submarine is statically unstable or may become statically unstable at anytime during the salvage operation. This is most likely to occur when one end has been raised and the other end is resting heavily on the bottom.

Even if none of the above factors are present, external lift may be desirable because it happens to be easier than obtaining self-lift.

7.2. Providing External Lift

Sources of external lift include surface vessels (such as lift ships and barges), floating cranes, and submersible pontoons. Lift ships such as the ARS or ATS described in Chapter 2 have sheaves at the bow through which the lift cables are led to winches on deck. These lifting cables are hauled in by the winches or with a block and tackle purchase arrangement.

Lift barges (YMLC) have several lift stations in each side and are generally used in pairs. The wire cable slings are rigged between them and hoisting is accomplished by block and tackle power on deck. Lift ships and barges have floodable spaces permitting large changes in draft, in combination with tidal action, to make lifts. The procedure is for the vessel to flood down the ballast tanks at low tide and take a strain on the lifting cables. As the tide comes in, the ballast tanks are pumped out, lifting the submarine. It is then towed into shallower water until the submarine grounds; the operation is then repeated, as necessary, until the submarine reaches shoal water; it is then made watertight and dewatered. The amount of lift obtained on each side or over the bow is reduced by the stretch of the slings and the sinkage of the lifting vessel. Thus, such lifts are not very effective except in areas where there is an appreciable rise and fall of tide.

Floating cranes are generally less seaworthy than other lifting vessels because of the height of the crane boom.

However, floating cranes have an advantage in boom reach, and, thus, need not be positioned directly over the submarine.

Submersible structural pontoons can furnish a major external lift force of pre-calculated amounts. Once attachment is made, the pontoon is a valuable tool to the Salvage Officer. When it is in position over the submarine, prior to the actual lift, the pontoon is not affected by sea state and can be left for long periods while other pontoons are being rigged. Rigid submersible pontoons have proven useful on four actual submarine salvage jobs, as reported in the Appendices.

Collapsible pontoons of rubber and fabric have been used on a test and evaluation basis only. They were used in a salvage exercise involving the ex-German submarines U-1105 and U-3008 after the ships had been sunk by explosive charges. The advantages of collapsible pontoons lie in the ease of transporting them to the salvage site and of handling them during placement. Experience with the collapsible pontoons in these cases revealed them to be vulnerable to damage and unreliable as designed. In spite of ideal weather conditions, a great deal of trouble was encountered; seams gave way or the fabric was punctured, causing subsequent loss of lift. Pontoons of various lift capacities, up to 50 tons each, were used during these tests. There is some promise that collapsible pontoons of multi-ply construction, such as are used in commercial containers, may prove to be satisfactory. These containers consist of high strength, tire cord fabric and sheets of molded synthetic rubber. Many of these containers have been in use for ten years during which time they have been subjected to rough handling. They were effectively used in salvage of the drydock AFDM 2 in the Mississippi River off New Orleans which was completed in August of 1966.

7.3. Attachments to the Hull

The attachment of slings for applying external lift to the submarine may be the most difficult and time-consuming part of the salvage operation, particularly in water which is of such depth that only a limited amount of work can be performed by divers. In past submarine salvage operations, the slings were placed under the bottom of the submarine since there were no appendages strong enough for heavy lifts.

7.3.1. Attachment Points

In the case of the 585, 593, 598 and later classes of submarines, the fairwater planes, as well as the stern planes, can withstand an applied load of approximately 700 tons on each side if the load is applied within 2 feet of the superstructure (Figure 7-1). The shape of the planes is not favorable to the attachment of slings, however, and if so used, would probably result in the slings becoming jammed between the planes and the permanent structure. Access hatches of the type having a bayonet joint locking device may be removed and replaced by fittings suitable for the attachment of slings. Each dummy hatch in this case would have an approximate lift capacity of 300 tons. Such devices should be considered only for compartments that are known to be flooded. There are no other appendages or features on U.S. submarines suitable for the attachment of slings.

7.3.2. Methods of Placing Slings

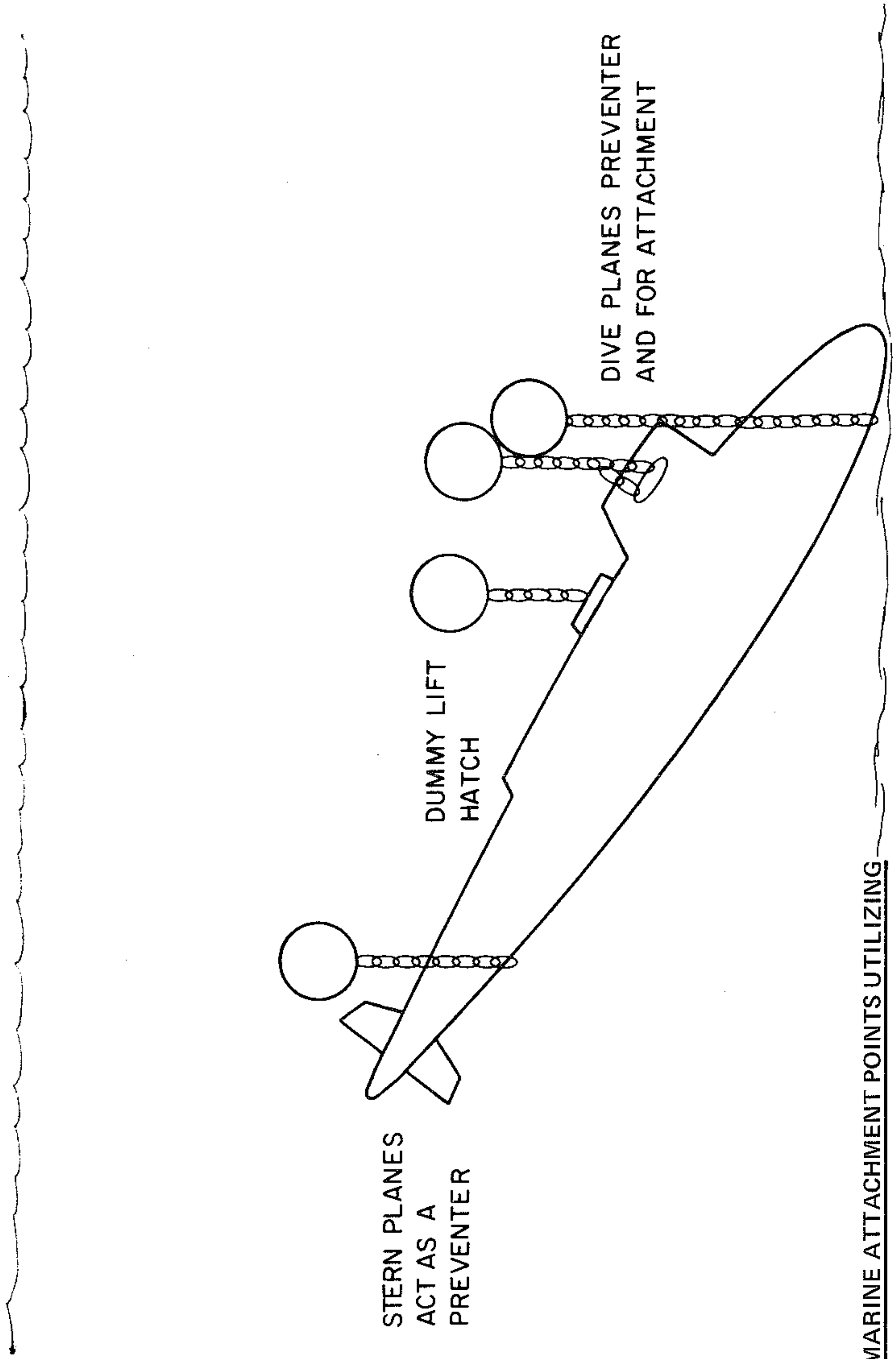
Three methods successfully used in the past for placing slings under sunken submarines are discussed in the following paragraphs.

Sweeping of Slings

The rudder and propellers at the stern of a submarine may make it very difficult to sweep a sling or even a messenger wire under the stern from aft, particularly if the stern is partially buried in the bottom. In the deep-water phase of the F-4 salvage, however, it was possible to sweep slings under the stern on some occasions. When this could not be done, the forward end of the submarine was lifted and held clear of the bottom by means of the forward slings while the after slings were swept from bow to stern. During that salvage operation, most of the lifting slings were placed by sweeping them under the submarine. This involved a great deal of handling of heavy wire and chain. During the salvage of subsequent U.S. submarines, messenger wires were passed under the submarine and used to haul slings into place. The use of messenger lines removed some of the difficulties connected with the handling of heavy and awkward slings.

Tunneling under the Submarine

In the final phase of the F-4 salvage, tunnels for three of the slings were dug under the submarine through coral and sand. The shallow depth of 48 feet made it possible for divers to work for long periods of time. The tunnels were dug with fire hoses and crowbars and the coral debris was washed away by use of water pressure pumped down through fire hoses.



SUBMARINE ATTACHMENT POINTS UTILIZING EXISTING APPENDAGES.

FIGURE 7-1

For the later salvage operations on S-51 and S-4, the tunnels had to be cut through mud, clay and sand. The balanced washing nozzle, described in Chapter 2, was developed during the S-51 salvage after the divers encountered difficulty in handling the standard 2-1/2-inch fire hose nozzle using pressure high enough to cut through the hard clay. The tunnels were dug from both sides so as to join under the centerline of the submarine.

Tunneling with a Lance

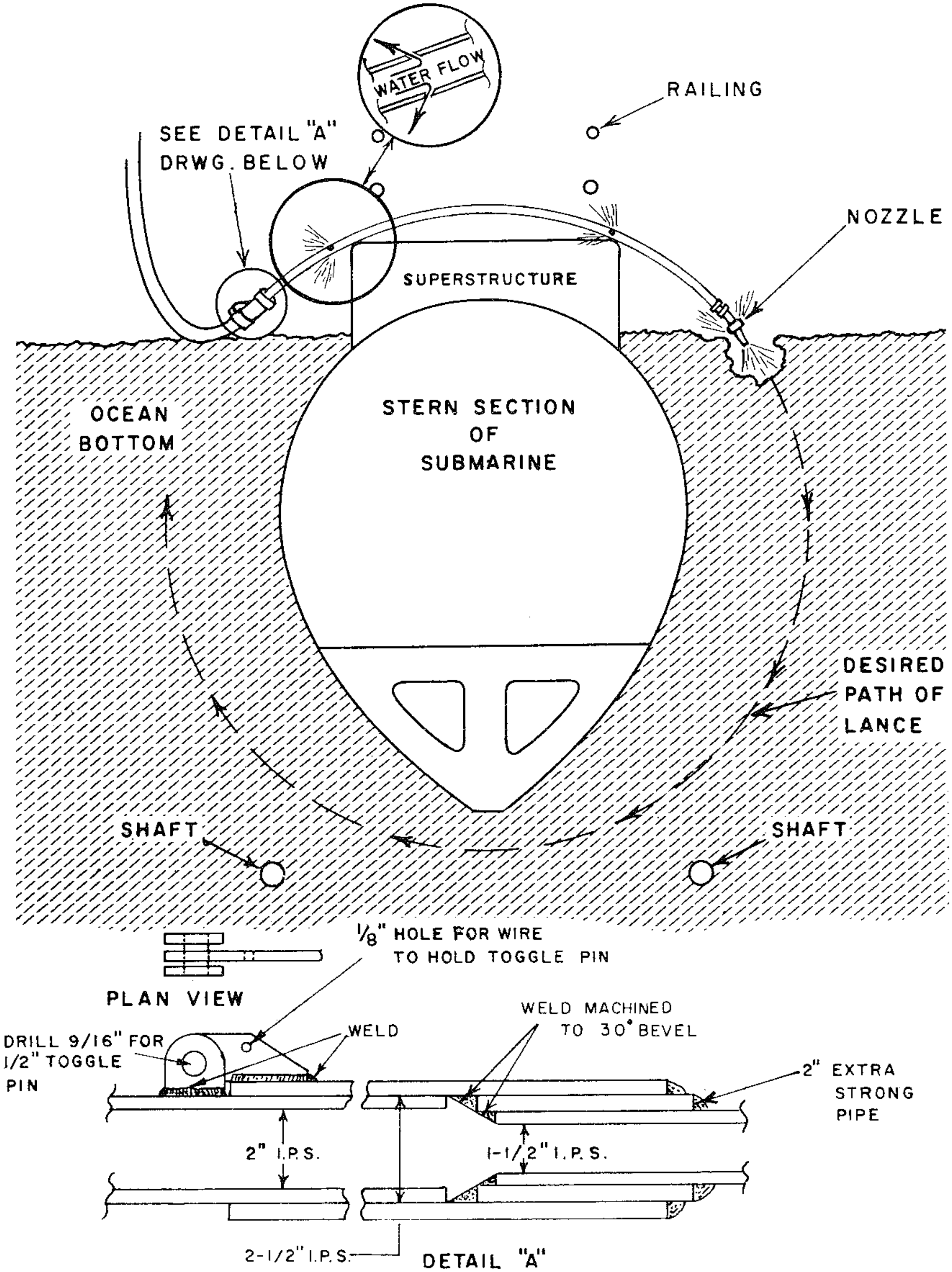
The depth of 240 feet in the SQUALUS salvage was sufficient to discourage tunneling by divers. Bottom-time in such depths was very short, and there was a danger of the tunnel walls collapsing, entrapping a diver. Also, the hull at the stern of SQUALUS was buried quite deep, which meant that a diver would be working several feet below the sea floor.

In order to reeve a messenger wire for a sling at the stern of SQUALUS, a special lance was devised. This consisted of pipe sections that could be fitted together from the deck of the submarine by a diver. Each section of the lance was curved so that the assembled sections would tend to tunnel following the shape of the hull. The tunnel was cut so that it passed between the hull and the propeller shafts. This permitted the shafts to act as preventers for the slings.

Any lance that may be used for tunneling will need to be designed according to the particular salvage problem. However, a review of the lance operation on SQUALUS might be useful to the Salvage Officer.

Operation 1

The first section of the lance was of 1-1/2-inch diameter pipe bent to the radius of the desired path which was below the bottom of the ship and inboard of the shafts. Its length permitted it to be placed across the deck of the submarine (a span of about 15 feet) by a diver, and to be in contact with both sides of the deck to more accurately guide it, as shown in Figure 7-2. In this position and pointing athwartships, the lance was pushed around the submarine's side by the diver, who at all times kept it in contact with the two sides of the deck as water pressure cut through the sand and clay.



TUNNELING LANCE OPERATION I.

FIGURE 7-2

Operation 2

When the first section of the lance had advanced to the position shown in Figure 7-3, pumping was stopped, and the hose disconnected and hauled to the surface. There, a shorter 7-foot section was attached and sent down to the diver to be joined to the first section, after which, pumping was resumed. In this manner, four of the short sections were added and the lance was advanced to the position shown in Figure 7-4. The inside of the nozzle and the joints in the nozzle were beveled so that a 1/4-inch diameter rod could be passed through the lance without encountering obstructions.

Operation 3

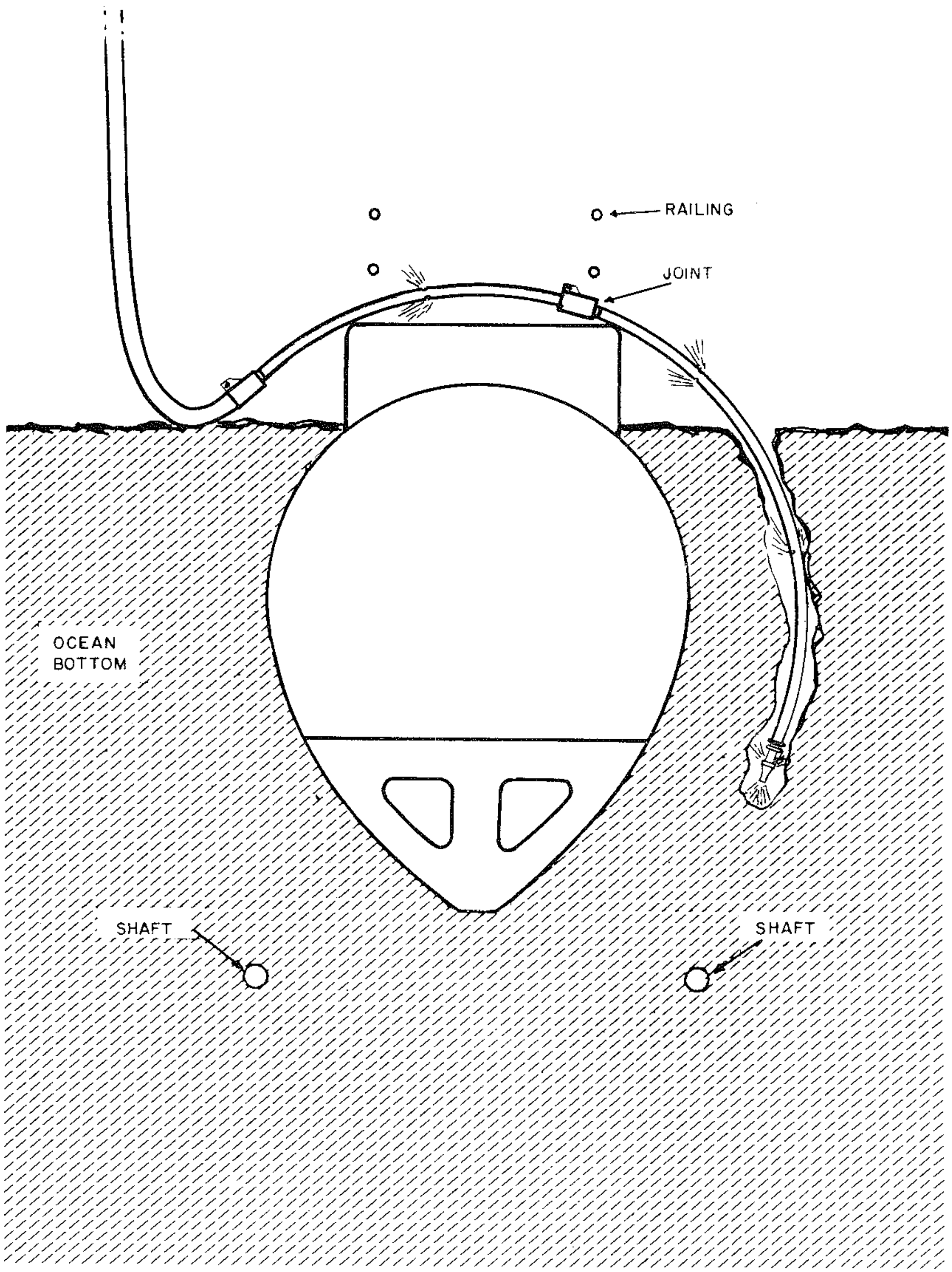
The hose and last section of the lance were then removed and sent to the surface, leaving the lance as shown in Figure 7-4. A 1/4-inch diameter rod, 60 feet long, and with a 3/16-inch diameter wire rope attached, was pushed through the lance and sent to the surface. Then, 7/16-inch wire rope was spliced to the 3/16-inch wire and hauled through the lance. A 1-inch wire rope was spliced to the 7/16-inch wire. Since the 1-inch wire was too large to pass through the lance, a stop, which would engage the end of the lance, was clamped to the 7/16-inch wire just ahead of the splice. The 7/16-inch wire then hauled the lance out and left the 1-inch messenger wire under the submarine with both ends at the surface. The 1-inch messenger line was then used to haul the slings into place.

Operation 4

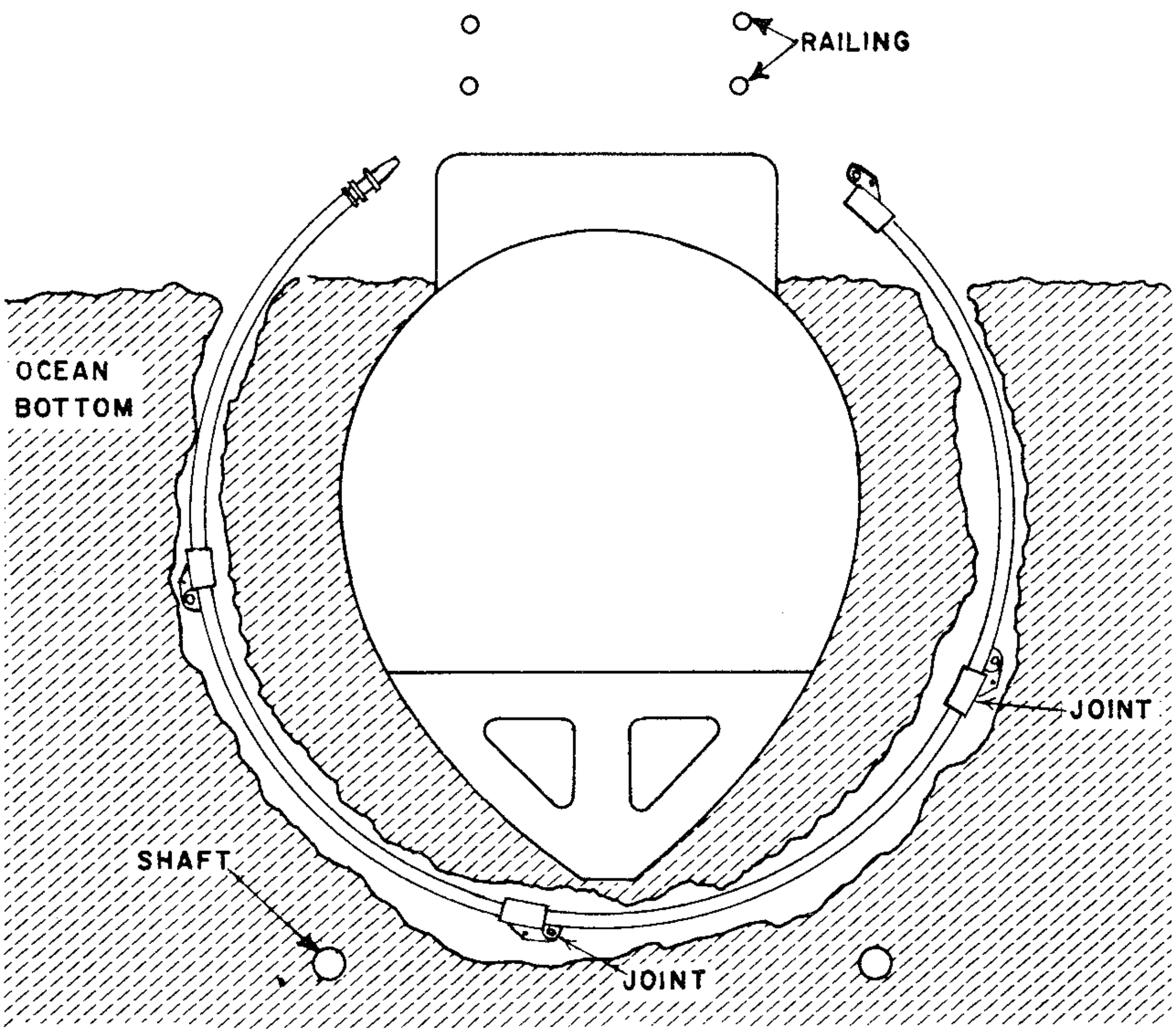
When more than one sling is to be hauled into place, a reeving plate (Figure 7-5) should be used. During SQUALUS salvage operations, it was found desirable to make up three complete slings of the proper lengths (2-1/2-inch lifting wire, 1-inch reeving wire, and 2-1/2-inch chain) to suit the salvage plan (Table 5-1, Drawing E) and to haul them into place at one time. Once hauled into place, and the ends of each sling equalized, they may be buoyed off until ready for use.

7.3.3. Spare Messenger Lines

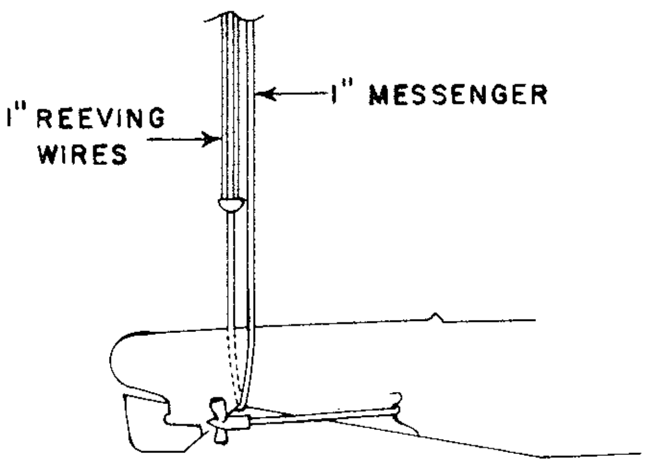
Once a sling, or even a messenger line, has been placed under the submarine, a spare messenger of 1-inch diameter wire rope should be pulled under the ship and buoyed off, or laid out on the bottom in such a manner that it can be retrieved and used for hauling in a new sling should one break. This should be accomplished at each position at which slings are to be used.



TUNNELING LANCE OPERATION 2.
FIGURE 7-3



TUNNELING LANCE OPERATION 3.
FIGURE 7-4



FINAL ARRANGEMENT OF
REEVING WIRES.
FIGURE 7-5

7.4. Slings

7.4.1. Description

Experience obtained during F-4 salvage indicated that wire rope slings tend to break under the submarine. This prompted the subsequent practice of utilizing chains for that part of the sling in contact with the submarine (Figure 7-1).

Wire rope slings in contact with a submarine hull not only have a tendency to break, but also have the disadvantage of rolling at angles less than those at which a chain sling will slip. If the pontoons are to be placed near the submarine, no lifting wire is needed above the chain slings. If, however, it is desirable to set the pontoons at some distance above the hull for use as control pontoons or to keep the divers at shallower depths, the use of wire rope in conjunction with chain slings is recommended. Wire rope has a greater strength-to-weight ratio than does chain. Extending the length of chains by using wire rope rather than chain results in a lighter, more easily handled sling-pontoon combination.

To facilitate positioning the slings under the submarine, a length of 1-inch reeving line, long enough to reach the surface when the sling is in place, should be shackled or spliced to each end of the wire or chain slings. The upper end of the reeving line should have an eye splice which can be secured to a buoy when not in use. When the reeving line is in use, its length may be extended as desired by shackling it to other lengths of 1-inch wire.

7.4.2. Rigging of Slings

When the first messenger line has been placed under the submarine, it should be used to haul into place under the submarine a 1-inch messenger wire and a spare 1-inch wire. This 1-inch wire is shackled to the reeving line of the sling and used to haul the sling under the submarine. If several slings are to be placed through a single tunnel, all of the slings should be hauled through the tunnel at the same time. Table 5-1, Drawing F, shows a reeving plate suitable for hauling in three slings at one time. The leading end of the chain part of the sling should have a fairing cone such as that also shown in 5-1(F).

The slings are normally made up to suit the salvage operation and then sent to the salvage scene. In SQUALUS salvage, a barge was used to transport the slings to the site.

When the slings were ready to be hauled under the submarine, the barge was brought alongside the salvage vessel. The slings were led across the salvage vessel and shackled to the 1-inch wire under the submarine. They were then paid out under control and kept free of slack while the 1-inch wire was being used to haul them into place.

7.4.3. Preventers

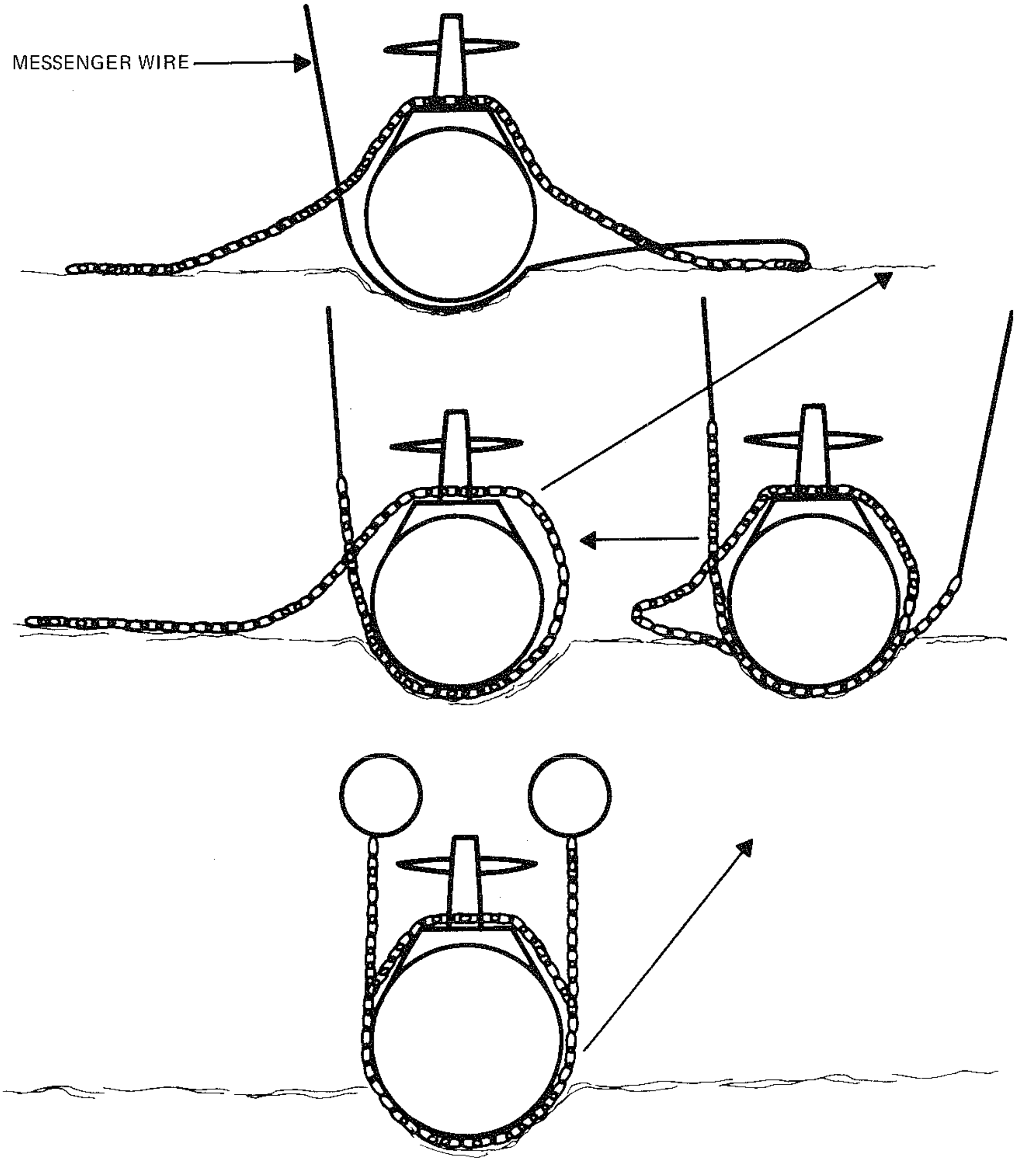
If the horizontal angle of the keel exceeds 10 degrees during breakout, it will be necessary to secure the slings against slipping toward the end which has been raised first. This may be done by rigging preventers between the slings and fixed points on the ship. By raising the same end first each time a lift is made, the preventers need be effective in only one direction. Since the rigging of preventers requires hard, physical work, their use should be weighed against the effort of making additional, shorter lifts.

7.4.4. Temporary Attachments

Temporary attachments of lines will be necessary for various purposes such as measuring aids, lifelines and diver descent. Where ladder rungs, grabs, padeyes, hatch bails, or hand-wheels, or other suitable appendages are not available for securing such lines, a suitable attachment may be obtained by installing a C-clamp in a superstructure flood or vent hole. Another method would be to install a threaded stud with a power velocity tool or to weld a padeye to the hull.

Sling slippage may also be prevented by taking a full turn of the sling around the submarine. This is done by laying out the full length of the sling across the top of the submarine at right angles to the centerline. The center of the sling should be at the centerline of the submarine. The two ends of the sling are then hauled under the submarine and led to the surface by messenger wires that have previously been rigged under the submarine (Figure 7-6). The chain part of the sling must be long enough so that the ends clear the submarine.

Before rigging preventers, however, the possiblility of placing slings and pontoons in such positions that preventers will not be needed should be considered (Figure 7-1 illustrates an arrangement in which slings are restrained from slipping by the use of fixed parts of the ship).



METHOD OF RIGGING FULL TURN
OF SLING AROUND A HULL.
FIGURE 7-6

7.5. Rigging for Supplemental Surface Lift

If bottom conditions are such that the maximum breakout force can be predicted with confidence, then control pontoons may be eliminated and a lift ship may be used for breakout. Under these circumstances, the lift ship capacity must be well in excess of the breakout force anticipated. It is also feasible to use a lift ship at one end of the submarine and control pontoons at the other end, though a lift ship at each end is more desirable from the standpoint of positive control during breakout. The advantages of using lift ships as the force for breakout lie in the fact that control is available at all stages of the lift and the Salvage Officer may be provided with immediate knowledge of the magnitude of the weight being lifted. In this manner, the Salvage Officer can avoid any major changes of trim angle or unprogrammed depth changes of the submarine. Thus, the problems of free surface and expansion of air in the submarine compartments and tanks may be detected and controlled.

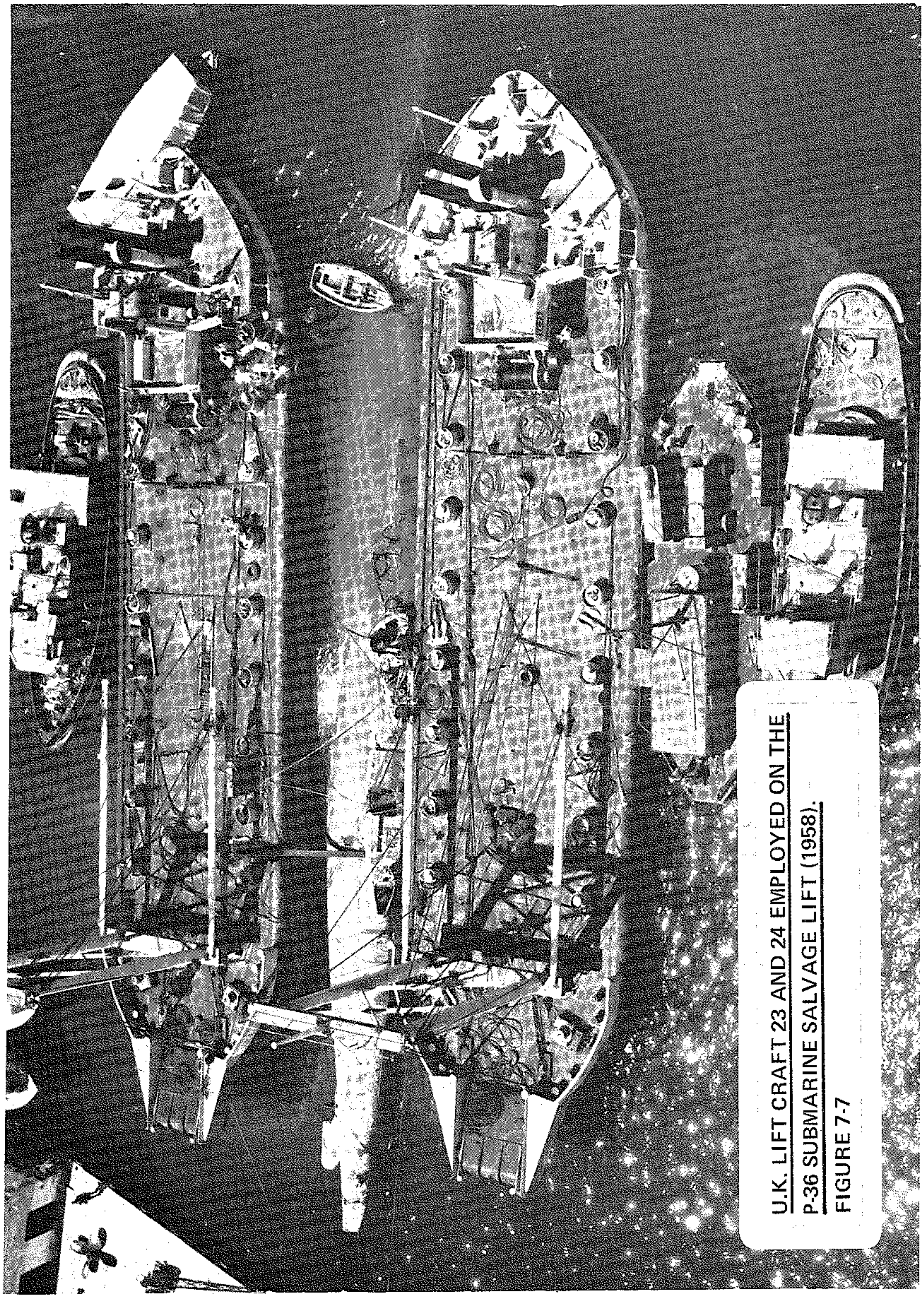
When a surface lift ship is to be used, a separate sling, without pontoons attached, should be available at each lift point. If the surface lift is provided by salvage vessels such as ARS, YMLC, or ATS, the lifting can be continuous except for the short period needed to rig for a new purchase. When the submarine has been lifted clear of the bottom, it should be towed toward shallower water, keeping only a small distance between the submarine and the bottom. The loss due to a broken sling or other mishap will thus be minimized.

If the lifting is done with cranes and the depth of water exceeds the distance they can lift, it will be necessary to place the submarine on the bottom to shorten the slings.

NOTE: Figure 7-9 illustrates a lift situation using submersible pontoons secured close to the submarine's hull, an ATS lift ship, and tidal action.

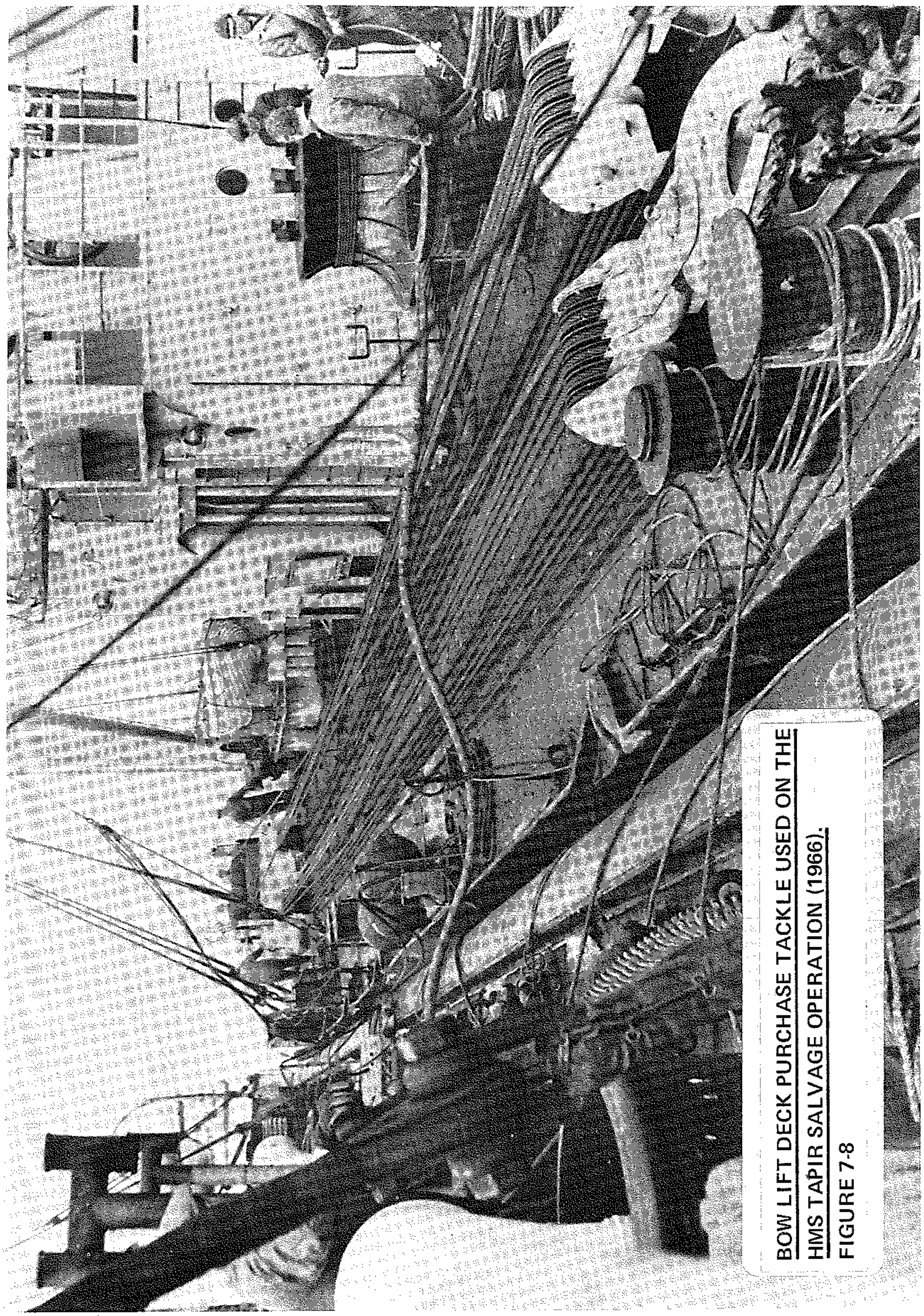
7.6. Air Requirements

A large quantity of air is usually required to blow water from tanks and pontoons while buoyancy is being provided to lift the submarine. The amount of air required depends upon the depth of the pontoon or tank and on the amount of buoyancy needed. The time required to obtain the buoyancy can be shortened greatly if fully charged air banks are available in addition to the air compressors on the salvage ship. If a submarine is assigned to the salvage force, her air banks may be a source of a large amount of high pressure air. In such a case, the submarine would feed her air to the air manifold on the salvage vessel, where regulation of blowing operations will be controlled and monitored. (Figure 7-10 may assist the Salvage Officer in estimating the air requirement for his salvage operation).



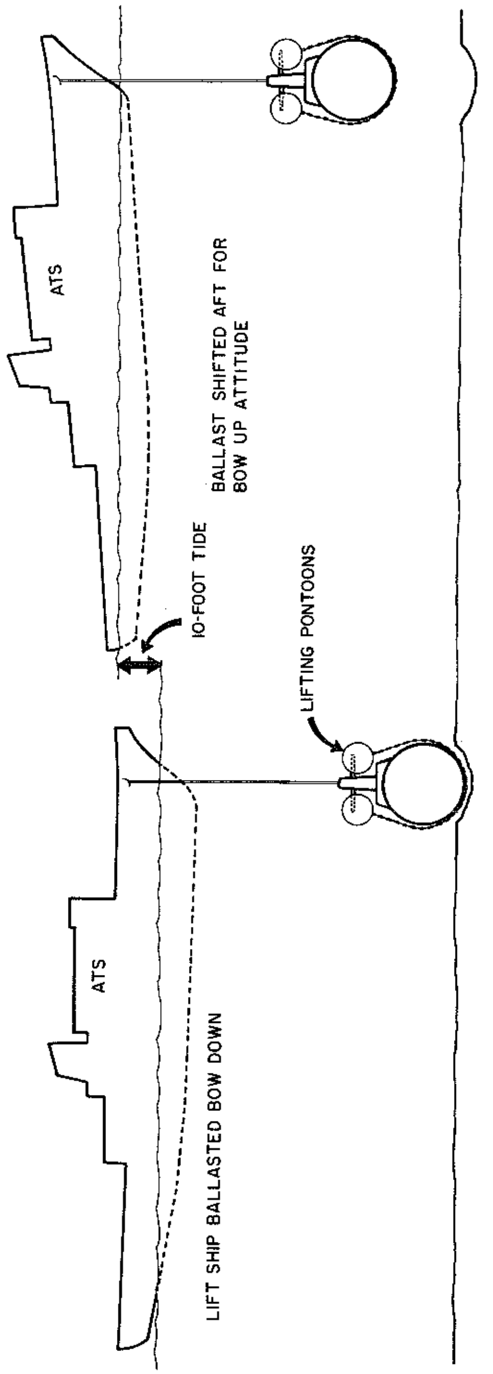
U.K. LIFT CRAFT 23 AND 24 EMPLOYED ON THE P-36 SUBMARINE SALVAGE LIFT (1958).

FIGURE 7-7

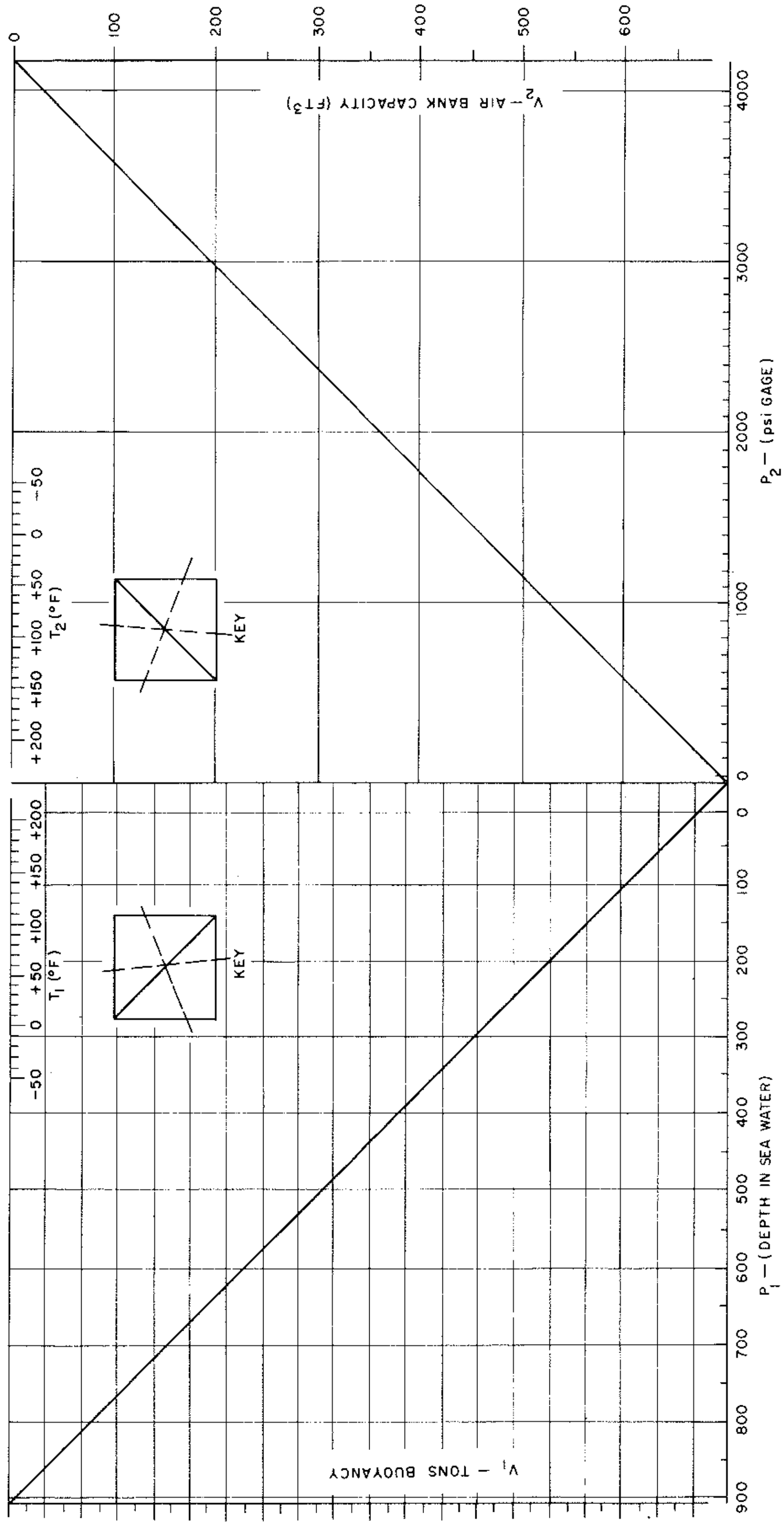


BOW LIFT DECK PURCHASE TACKLE USED ON THE HMS TAPIR SALVAGE OPERATION (1966).

FIGURE 7-8



SUBMARINE LIFT BY SURFACE SHIP.
FIGURE 7-9



SALVAGE AIR REQUIREMENT NOMOGRAM.

FIGURE 7-10

8. Future Developments in Submarine Salvage

8.1. Introduction

The history of submarine salvage reveals that salving techniques lag the requirements for each situation. The Appendices of this manual furnish evidence supporting such a statement. As this manual is written, the climate appears to be undergoing subtle changes for many and varied reasons in the fields of economics, world politics, and military defense. The ground work for these changes was laid before the tragic loss of THRESHER in April 1963. That incident coupled with such subsequent events as the loss of a nuclear weapon off Palomares, Spain, in 1965 have all high-lighted the need of the United States for increased ocean capabilities in the fields of search, salvage, and small object recovery.

Capability still lags requirements in these fields, but it appears that a concerted effort is underway to reverse this status. Evidence of this change is seen in the establishment of the Deep Submergence Systems Project (PM-11) in the Office of the Chief of Naval Material in July 1966. (The project was created and began functioning in 1964, but until July 1966, it was a branch of the Special Projects Office, Bureau of Weapons.) In 1966, the Office of the NAVY's Oceanographer was transferred to the Office of the Chief of Naval Operations. His duties were expanded and encompass the U.S. NAVY's efforts in the field of Ocean Engineering. The importance of salvage in these two organizations is emphasized by the prominent role that the Supervisor of Salvage plays in the DSSP Steering Task Group and his appointment to fill, as an additional duty, the role of Ocean Engineer on the Oceanographer's staff.

8.2. Factors Shaping Salvage Requirements

The factors which may shape the salvage requirements of the future may be grouped into two major categories, viz., technological and political. Some of the factors in each of the categories which have been shaping possible salvage requirements are as follows:

Technology

Depth - The increase in operating depth of military submarines in the immediate post World War II period. This was followed by the development of small research submarines capable of depths up to 15,000 feet.

Size - Submarine size has been following divergent courses with the attack class and fleet ballistic missile submarines increasing in submerged displacement and the deeper research and non-combatant types tending to be confined to the lower end of the displacement scale. Submarines have continued to increase in physical size and displacement tonnage. The U.S. NAVY has lost several submarines in deep water, and there have been many stranding situations (see USS GUARDFISH SSN 612 aground in Figure 8.1.).

Submerged Endurance - With the advent of the nuclear propulsion plant, the submerged endurance of military submarines has drastically increased, rendering them somewhat less vulnerable to collision in the open sea. This possibility has not been completely eliminated, however, as the several surface ship/nuclear submarine collisions demonstrate. Fortunately, none of these has resulted in serious damage or in a salvage operation. Nuclear power has also made possible under-ice operations in the polar regions.

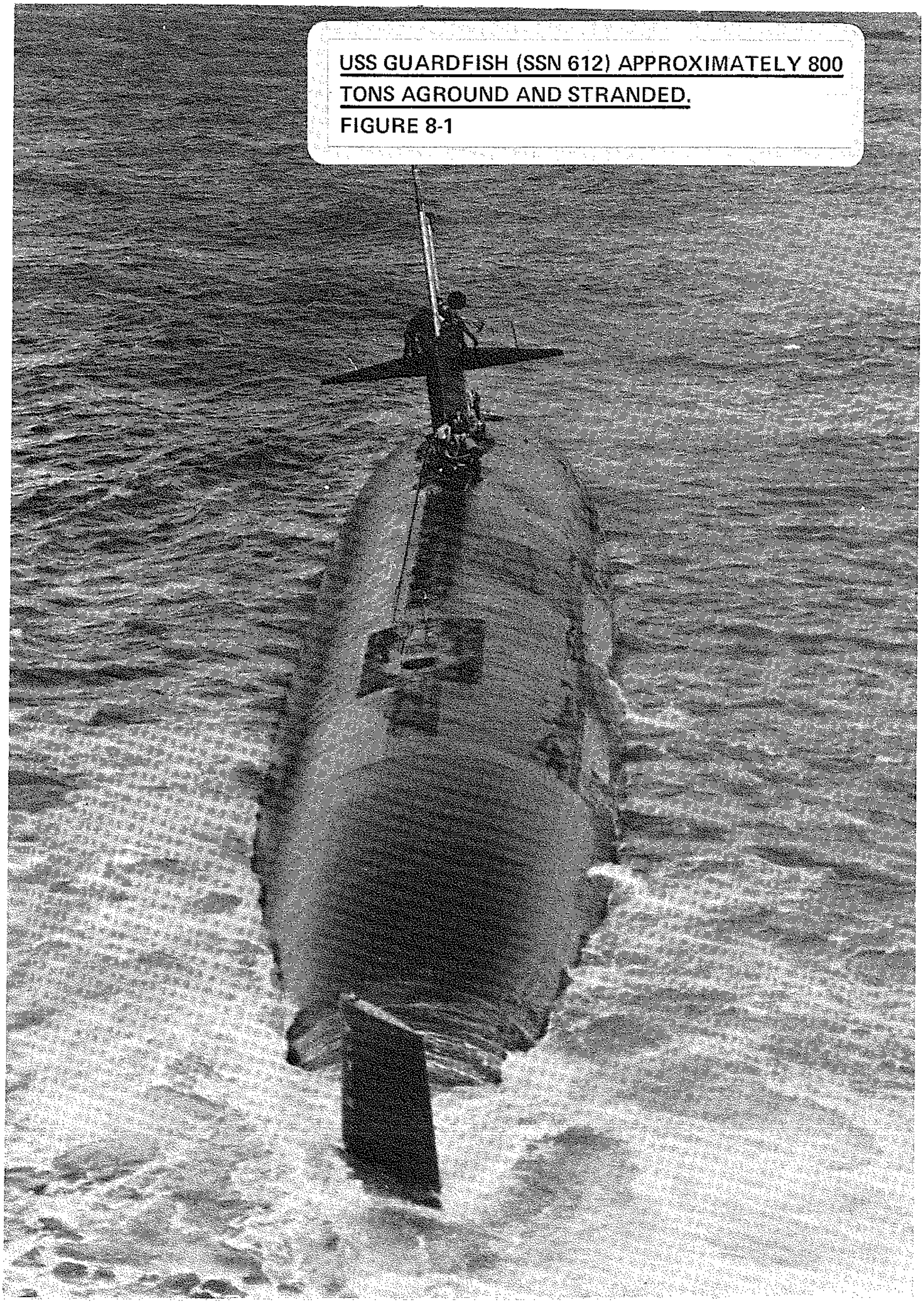
Political

Military Alliances - In the post World War II period, the United States has followed a course which is completely counter to the isolationist policies of the post World War I period. Such military alliances as NATO and SEATO have expanded the areas of normal operation of U.S. submarines to a world-wide basis.

Nuclear Policies of Foreign Nations - The attitude of some foreign nations toward any vessel which is powered by nuclear energy may have a profound effect on the salvage requirements of the future. In this regard, the exclusion of SEA DRAGON and other nuclear submarines from many foreign ports, as noted by contemporary news articles, as well as the exclusion of SAVANNAH are cases in point. The exigency of a salvage operation of a nuclear device or atomic submarine can be easily seen. The soverign power controlling the sea area in which a nuclear source is lost may insist upon immediate removal. Public reaction to the real or supposed dangers of nuclear contamination to fisheries and mercantile traffic usually leaves no room for delay.

The net results of these factors seem to indicate that future salvage requirements may involve any or all of the following elements:

1. Greater lift capacity.
2. Increased depth capability.



USS GUARDFISH (SSN 612) APPROXIMATELY 800 TONS AGROUND AND STRANDED.
FIGURE 8-1

3. Operation in areas remote from the continental United States.

4. Inability to use the continental shelf adjoining foreign shores in the traditional lift-by-stages operation followed by grounding in shallower waters.

5. Operation in more hostile sea environments than normally encountered in the continental shelf areas of the United States.

6. Ability to salvage in areas normally covered by ocean ice.

8.3. Salvage Phases

Before proceeding, it may be well to organize the discussion which follows by first defining the phases of a salvage operation. Although this may be somewhat arbitrary, the operational phases of salvage can be said to consist of:

- Location
- Moor
- Survey
- Attachment
- Lift

Two more phases may be added, viz., the towing phase and final placement phase. Neither of these two phases is currently undergoing any development; therefore, they will not be treated further.

8.3.1. Location

This phase of the operation usually occurs before the decision to salvage has been made. In submarine salvage operations it has usually occurred as part of a rescue operation. A description of the devices available to assist in the location of sunken submarines may be found in the appropriate Search and Rescue publications. In the case of the search for THRESHER and SCORPION, the scientific community was particularly well equipped for the task having at their disposal precision sounding devices, deep ocean magnetometers, deep ocean photographic sleds, and the bathyscaph TRIESTE.

8.3.2. Moor

At the present time there are no specific developments planned in the field of special submarine salvage moors. There is, however, a study planned which will result in the definition of a general computer solution of the catenary equations, using inputs of soil characteristics, wind drag on the ship, bottom contours, and mooring leg orientations. The solution of these equations will yield anchor size, clump weights, chain sizes, and buoy characteristics for the desired holding power of the moor. This computer solution will be used in conjunction with the data processing equipment described in paragraph 8.4.2.

8.3.3. Survey

After the submarine has been located and the diver support ship moored, a survey of the salvage site and of the submarine itself must be undertaken. To assist in this undertaking, several studies are being conducted. One study deals with the difficult problem of providing the diver with means of locating himself with respect to the submarine. Unless he can see some distinctive mark or appendage, the diver has no means of determining his distance from the submarine's bow or his height above the keel. This study is being conducted to develop a method whereby a diver is able to locate positions on the wreck with respect to the wreck itself. Some of the methods under consideration include simple knotted lines, light arrays, and underwater sound devices.

A second and related problem is the determination of the submarine's condition. What compartments and tanks are flooded? What is the up or down angle and heel? How deeply is it imbedded in the mud? These questions must be answered before the Salvage Officer can proceed to calculate the amount and distribution of lift forces and to predict the breakout force that may be encountered. To assist in obtaining answers to these questions, devices are being developed to measure compartment water level. The attitude of the submarine will be measured by instruments also under development.

8.3.4. Attachment

In reviewing the phases of salvage, one concludes that the key element and limiting factor in salvage at continental shelf depths is the attachment phase. With few exceptions, the attachment to the salvage object has been accomplished using divers, hence the limits at which a diver can work have traditionally set the depths at which a major salvage can be conducted.

For this reason the major area of development is extending the depth and work capability and limiting depth of divers. The Deep Submergence Systems Project's Man-in-the-Sea Program is the U.S. NAVY's major development program in this field. The Experimental Diving Unit is a major contributor to the program. The program's goal is to permit men to live and work in an environment corresponding to a submerged depth of 600 feet.

In addition to the Man-in-the-Sea Program, a diver system is being developed for the specific purpose of supporting Large Object Salvage. This system consists of a pressurized surface habitat (Deck Decompression Chamber); a pressurized elevator device to transport the divers between the surface habitat and the work site (Personnel Transfer Capsule); a refuge with enough gas and power to sustain divers for a limited period (Refuge Tent); and the associated equipment necessary to make the system operate. The system is similar in most respects to the diving system described in paragraph 2.3, except that the design depth is 850 feet.

Other developments in the attachment phase include:

Tunneling Systems - Tunneling systems in past salvage operations have been almost exclusively confined to water jets used to penetrate mud and clay ocean bottoms. Development is proceeding on a tunneling system capable of penetrating coral and rock.

Dummy Hatch - In a preliminary study of the salvage attachment problem, it appeared that a dummy hatch could be easily designed which would withstand lifting forces of up to 300 tons. Such a hatch is to be designed and tested and may be available in the future as an attachment device.

Explosively Powered Devices - Powered devices, such as explosively attachable padeyes and barbs, are presently being investigated for diver use.

Diver Propulsion Vehicles - To assist divers in proceeding about their work in survey and attachment, a propulsion unit to aid in carrying loads horizontally against a current of up to one knot is being developed.

General Purpose Power Source and Hand Tools - These devices are being developed in conjunction with the experience gained from the SEALAB tests conducted under the Man-in-the-Sea Program. The purpose of this development is to provide the diver with a variety of tools to use in his survey and attachment tasks.

Buoyancy Transport Device - The purpose of developing a buoyancy transport device is to provide the diver with a means of lifting and transporting items possessing large negative buoyancies.

Underwater Welding and Cutting - An investigative effort is being conducted in order to provide the diver with improved underwater cutting and welding equipment which will be effective to depths of 850 feet.

Shaped Explosive Cutting Charges - As an alternate means of underwater cutting in salvage operations, an investigation into the feasibility of using shaped explosive charges is being conducted.

Underwater Lights - A research and development effort is planned to produce an optimum underwater lighting system for use by divers during salvage operations.

8.3.5. Lift

After attachment is completed and calculation of the lift force magnitude and distribution is made, as well as determination of the breakout and control forces required, the lift phase begins. The traditional means of lifting are described in Chapter 5 and the Appendices. The development program in this field includes:

Lift Barges - Non-self-propelled YLMC's are being modified to act as lift barges. These barges will be equipped with a stabilized winch system (if developed), a compressed air system suitable to handle the blow requirements for submarine salvage at depths of 850 feet, and storage facilities for the necessary mooring and salvage equipment.

Stabilized Winch - Study and tests are underway to determine the feasibility of providing a winch with a lifting capacity of 75 tons and with such compensating features as are necessary to ensure that the lifting lines will not encounter a condition of resonance due to the wave forces acting on the lifting ship. If the study indicates development is feasible, the resulting winches are to be installed on the lift barge.

Rigid Pontoons - Rigid pontoons have been the predominant method of lift employed in U.S. NAVY submarine salvage operations. These pontoons were originally designed to be lowered with a minimum of negative buoyancy to a depth corresponding to the limit of the diver. The present rigid pontoons cannot be lowered to depths of 850 feet unless they are modified.

Means of increasing the depth of the existing rigid pontoons with minimum effect upon their lift potential are being developed.

Chemically Generated Gas - Blowing of the pontoons and/or the various tanks and compartments of a submarine is both time-consuming and expensive in terms of space and equipment on the salvage ships. The use of chemically generated gas is being investigated as an alternative to the use of compressed air.

Compressed Air Systems - The increased size of submarines and the increased salvage depth at which the blowing operation may take place have indicated that increased compressed air capacity will be needed by the salvage vessels. A study of total requirements and possibilities of achieving these requirements is being conducted and will result in the installation selected for the ARSD lift barges.

Liquid Air Generations and Storage - As an alternative to compressed air, liquid air systems are being studied to determine their relative cost and merits. If attractive and feasible, such a system may be developed in lieu of either the compressed air or chemical gas generation system.

Collapsible Pontoons - Collapsible pontoons are of interest from the standpoint of storage and transportation. Tests in the 1950's using these pontoons revealed some deficiencies. In recent years the technology of fabricating collapsible containers has improved many features, making their use in salvage more attractive. The capability and desirability of augmenting or replacing rigid pontoons with collapsible pontoons are under study and should it be revealed that these have merit, prototypes will be procured and tested.

Foam - Materials for buoyancy are being studied as a possible means for displacing water from a sunken submarine. The depth range for the use of foam will be from 400 to 600 feet with water temperatures ranging from 29° to 70°F. Under consideration are buoyancy materials composed of hollow or cellular spheres. The major objective of this study is to produce buoyancy materials that will maintain 20 pounds per cubic foot or less in density at depth. The secondary objective is the development of equipment, accessories, logistics and delivery systems for the application of these buoyancy materials to salvage operations.

Synthetic Fiber Rope - Preliminary studies are being conducted to determine if synthetic fiber rope is desirable for deep salvage operations.

The inherent elasticity of such synthetic mooring lines may be a solution to the problems involving the resonance of lifting lines at a depth of 850 feet. The study will consider the use of the synthetic fiber rope in depths exceeding 850 feet since its high strength-to-negative buoyancy ratio is very advantageous in deeper waters.

Air Hose for Pontoon Blowing - At the present time there is no satisfactory air hose available for use at continental shelf depths. The existing hose utilizes wire braid and will be punctured by broken wires if the braid collapses under external pressure. A dacron braid hose is under development and may be available in the future.

8.4. Salvage Operational Control Center

In order to coordinate the various tasks undertaken in the salvage phase, the command function must be considered. A Salvage Operational Control Center is being considered which will permit the Salvage Officer to control and monitor the various salvage tasks. This control center will consist of three key elements: communications system, data processing equipment, and environmental sensors.

8.4.1. Communications System

Rapid, dependable communications between the Salvage Operational Control Center and other components of the salvage force are vital to ensure success of the complicated procedure of raising a submarine. Considerable thought is being directed to this important element. Radio, telephone, and closed-circuit television are features that will be considered for instant communications between the Salvage Officer and other ships, aircraft, submerged capsules, and even the divers themselves.

8.4.2. Data Processing Equipment

To reduce the calculation time for selecting mooring designs, estimation of lift and breakout requirements and buoyancy/moment changes, a small computer is being considered in the design of future salvage systems. The computer may be able to provide immediate information and predictions of changing conditions. This will give the Salvage Officer a distinct advantage in taking corrective measures in less time and it will minimize calculation errors. Computer-assisted diving operations, therefore, may be more efficiently and safely handled.

8.4.3. Environmental Sensors

Instrumentation to relay and record environmental data for the Salvage Officer's evaluation and inputs to the computer are being considered for development. Information on bottom conditions and aerological changes could be displayed for immediate use. Other measurements could inform the Salvage Officer of the extent of flooding in compartments, the amount of lift being exerted, and conditions on the bottom that might determine the breakout force.

8.5. Conclusion

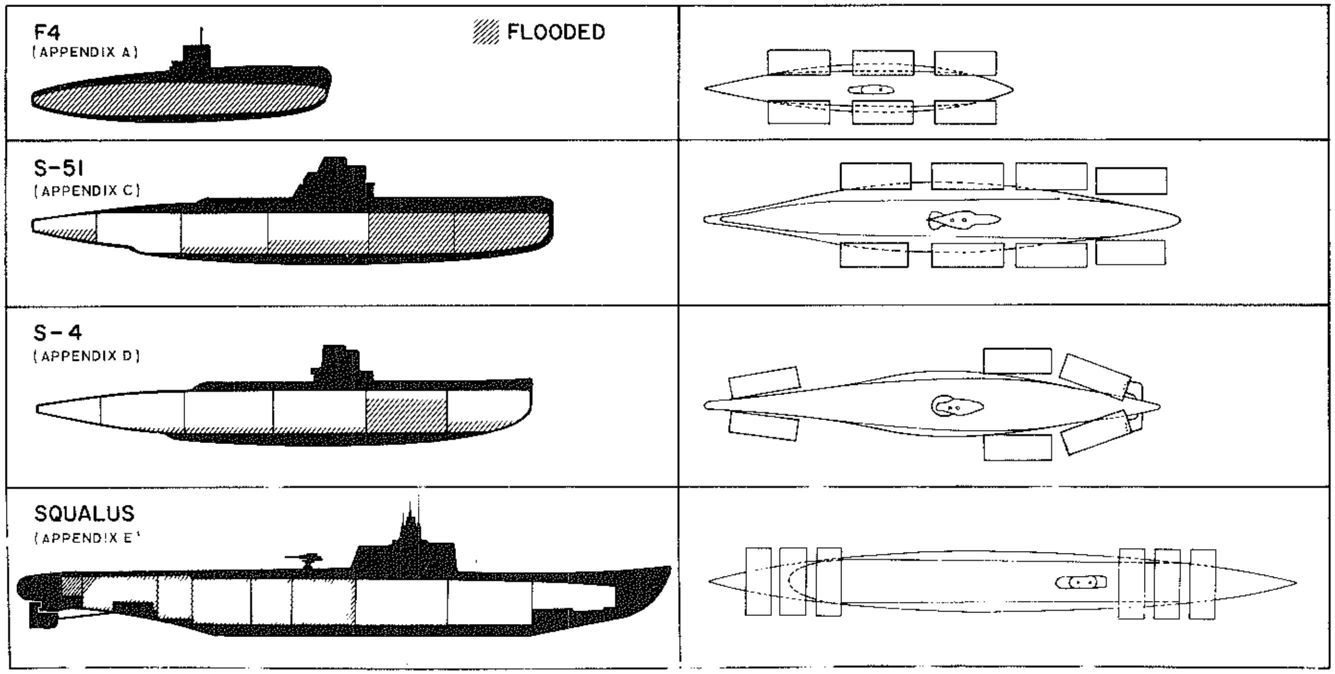
Notable by their absence from the development program are investigations concerned with the problems of submarine salvage under ice and problems associated with the salvage of submarines under conditions which dictate that the submarine cannot be raised by successive lifts and towed to the nearest shore. These are problems which are not high on the list of probabilities, and which would, in all likelihood, be studied and solved when the need arose. A third area not covered by the current development program, but one that is receiving increased attention by both the government deep submergence efforts and industry, is the support of divers from a submersible mobile platform. A device to provide such support will probably be configured such that it is half submarine and half sea lab. Limited investigations are currently underway and the results may reveal that this method of diver support is both feasible and attractive.

Appendices

Introduction

The following appendices are presented to supplement the basic text. The historical record of these salvage operations is of great interest; of greater importance is the opportunity Salvage Officers have been given to study the several phases of each operation. Important lessons and guidelines for future operations can be learned through diligent case study. The basic techniques of past successful salvage operations remain; it is likely that should the necessity of submarine salvage occur again, the Salvage Officer will experience similar problems and have available equipment and logistic considerations of salvors before him

The reader is encouraged to study each of the following salvage operations carefully, and avail himself of the lessons learned from these experiences.



FOUR SUBMARINE SALVAGE OPERATIONS.
RESTORATION OF BUOYANCY AND
SALVAGE PONTOON ARRANGEMENT.
FIGURE APPENDIX I

APPENDIX

A. Salvage of Submarine F-4

A.1. Submarine Missing

On the morning of 15 March 1915, three submarines, F-1, F-3, and F-4, left Honolulu harbor to perform a short submerged run and then return. The Officer of the Deck on the tender, ALERT, became apprehensive when only F-1 and F-3 returned. When a short preliminary search did not locate the missing submarine, an extensive search was launched and a sound watch set.

Air bubbles and an oil slick were located about noon approximately 1-1/4 miles from the harbor entrance. A check of the air bubbles and soundings indicated that F-4 lay in water about 55 fathoms deep. No signs of life could be detected.

A.2. Rescue Attempts

Several divers were placed in the water but were unable to locate the submarine. A sweep was made by two tugs in an attempt to catch and pull the submarine into shallow water. A catch was made about the middle of the next morning, but the submarine could not be moved.

A dredge was used in an attempt to lift the submarine while the tugs pulled it in. One of the lifting wires carried away when subjected to about 100 tons force. It was concluded, at that time, that the submarine was filled with water.

A.3. Salvage Preparations

F-4 lay in water deeper than any diver had ever worked in up to that time. She was full of water and would be a deadweight of 260 tons. It was decided to lift the submarine and haul it into shallow water. Thus, the dredge, GAYLORD, two mud scows of 600 tons capacity, and an anchor barge with derrick, etc., were obtained. The mud scows were converted into pontoons for surface lifting.

During the process of converting the mud scows and devising a means for winding the cable, lifting drums were constructed.

It was determined that by using mechanical advantages with these winch drums a lift of 300 tons could be achieved. With a 300-ton lift the submarine could be raised and taken into shallower water. However, the conversion of the scows was completed so that either method could be used.

A.4. Moving F-4

Four lines (2 to 2-1/2 wires) were swept under the submarine and connected to the drums on the mud scows. This took considerable time and effort. The location of these lines was checked and reported by divers working with air supplied from compressed air flasks. The divers could only stay on the bottom a short time and, therefore, could not be expected to accomplish any work.

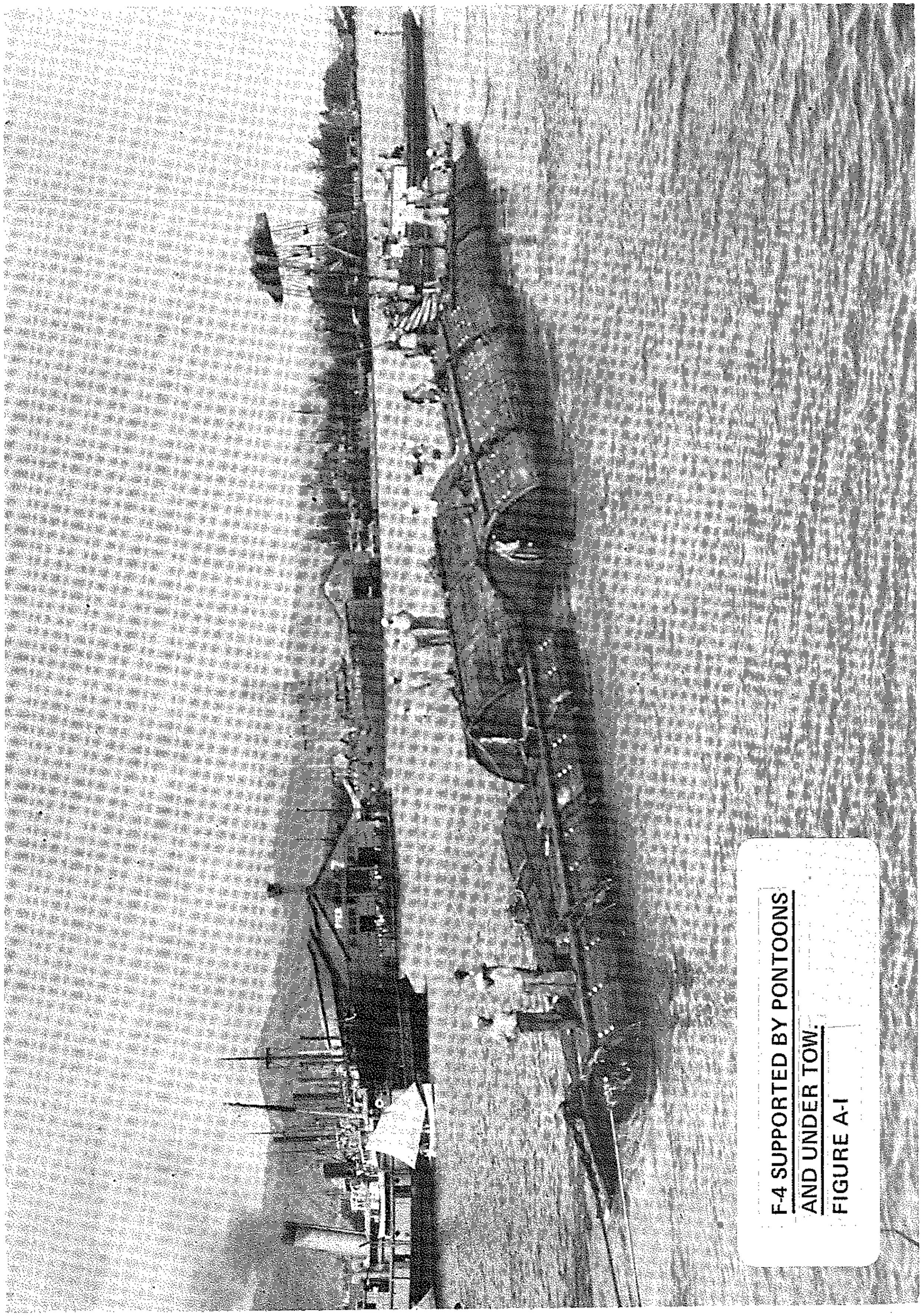
On 19 April, the stern was lifted 12 feet and swung about 45 degrees toward the beach before one of the stern lines parted. With one day lost due to bad weather, the lines were again attached and ready by the morning of the 23rd. F-4 was then lifted another 8 feet and moved 50 feet closer to shore.

The morning of 24 April saw rough weather setting in and all cables carried away one-by-one. On the morning of the 30th, a buoy was dropped to mark the position of F-4 and the salvage force returned to the harbor.

Because of the continuous heavy swells resulting in rapid wear on the wire ropes, it was decided to insert a 15-fathom shot of 2-5/8-inch chain in the center of the hoisting wires where each passed around the submarine.

Between 3 and 19 May, time was consumed in numerous attempts to sweep lines under F-4 and in sitting out unfavorable weather. On 20 May, a lift of 20 feet was made and F-4 was swung broadside to the channel entrance. The scows would hoist the submarine and GAYLORD, connected directly to the submarine and towed by tugs, would move it into shallow water. The submarine was lifted about another 20 feet and moved 100 feet nearer to shore before the drums were filled with wire. Operations were halted while the ends of the wires were cutoff. The new end was then connected to the drum and another lift was made. On 21 May, two lifts of 23 and 32 feet each were made. A single lift of 55 feet was made on the 22nd, one of 26 feet on the 23rd, and another of 26 feet on the 24th.

The morning of the 25th saw F-4 moved into 48 feet of water near the outer black channel buoy. Here the operation was halted to shorten the chains.



F-4 SUPPORTED BY PONTOONS AND UNDER TOW.

FIGURE A-I

While this work was in progress, the weather took a turn for the worse and the lines were let go after the scows and submarine were considerably tossed about.

On 28 May, a diver sent down to inspect F-4 reported that it now was badly damaged and had a large hole in the hull near frame 63. Since another lift might have broken the submarine in two, it was decided to manufacture six salvage pontoons and use them to complete the salvage operation.

A.5. Pontoons

The pontoon cylinders were made 32 feet long and contained two compartments; four pontoons had a diameter of 11 feet and two were 12-1/2 feet. A blow and vent valve for each compartment was installed on the top near the center bulkhead and a 4-inch flood valve was installed on the bottom at each end. Two tons of concrete were placed in the bottom of each cylinder to provide stability. A 12-inch hawsepipe ran through the center (top to bottom) of each compartment. The outside of each cylinder was covered with wooden sheathing 4 inches thick to prevent damage to the shell plating.

A.6. Rigging the Pontoons

The anchor barge was moored over the submarine using a four-point moor. With this as the working platform, six chains were rove under the submarine at frames 17, 27, 41, 51, 71 and 81. Tunnels were washed under F-4 at frames 27 and 41 for the chains installed at these points. Enough clearance was available at the other frames to receive the chains.

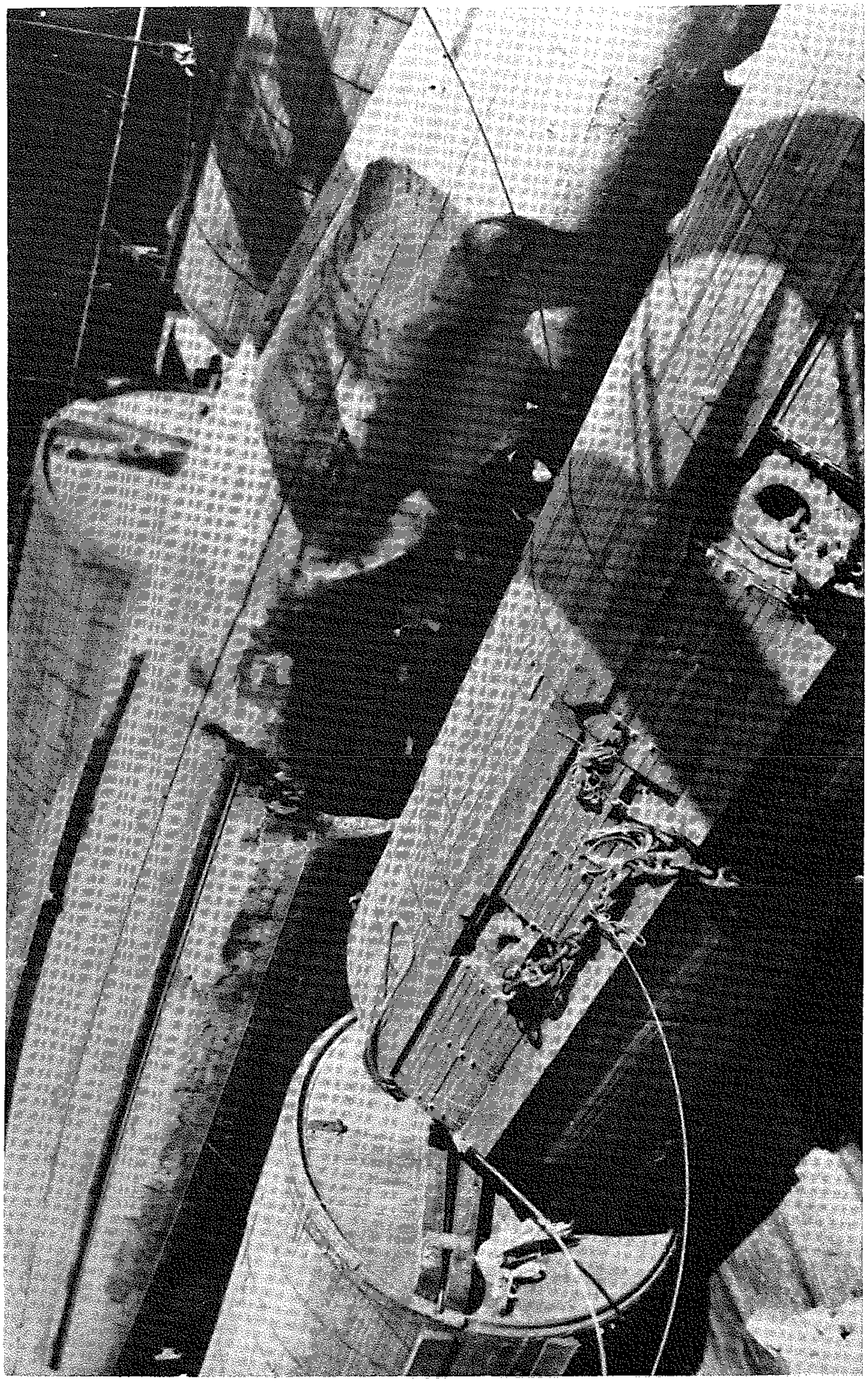
When the chains were in position, the pontoons still in port were flooded, leaving 3 feet of freeboard, and towed out to the barge. Runners were dropped through the hawsepipes to the bottom and shackled to the chains by the divers. The flood valve was left open and a length of hose with a 3/4-inch valve was connected to each vent. When the messenger lines were tending straight up and down, the pontoon vent was opened until the pontoon started sinking. The valve was then shut and the pontoon lowered to the bottom while the ends of the chains were pulled through the hawsepipe. When a pontoon was in the desired position on the bottom, the chains were clamped above the hawsepipes.

A.7. Raising F-4

When all six pontoons were in place, final preparations were made for raising F-4. A bank of twenty-four torpedo air flasks was connected to a volume tank with an air manifold of twelve valves; these were mounted on a coal lighter. The barge was moved and the coal lighter moored about 50 feet from the submarine's position.

On the morning of 29 August, the air hoses from the pontoon vents were connected to the air manifold, the flood valves on the pontoons were opened, and all was ready. The air pressure at the manifold was maintained at 35 psi by manipulating the flask valve and a valve in the line to the expansion chamber.

Divers on the bottom reported conditions as the pontoons became buoyant. Only one pair of pontoons was made buoyant at a time, starting with the after pair. When all pontoons had a strain on their chains and were reasonably horizontal, air was applied to all pontoon compartments and the submarine was raised. After five months on the ocean's bottom, the submarine was towed into Honolulu Harbor and drydocked.



F-4 IN DRYDOCK.
FIGURE A-2

APPENDIX

B. Attempted Salvage of USS S-5

B.1. Rescue

Submarine USS S-5 sank in 165 feet of water 32 miles east of Fenwick Shoal Lightship (Delaware Cape) at 2 P.M. on 1 September 1920. The main induction and hull valves had been left open during an otherwise normal dive. Flooding was stopped after the torpedo room had filled and considerable water was taken into the control and engine rooms.

By blowing the main ballast and fuel oil tanks and pumping some water out, the crew was able to bring the stern to the surface. Bulkhead doors were opened to let water from the engine room run forward to the battery room. This brought the steering gear room above the surface at 8:30 P.M. Some 24 hours after the accident, the ship's force had succeeded in drilling by hand a triangular hole about 6 by 4 inches in the hull. The stern was sighted by SS ALANTHUS at 2:48 P.M. on 2 September, and pumping of air into the submarine through a 1/2-inch hose was started immediately to supplement the diminishing oxygen supply. The SS GEO. W. GOETHALS arrived at 5:30 P.M. These two ships using a ratchet drill, enlarged the hole to about 20 inches in diameter and rescued the crew. The first man was out at 1:25 A.M., and the last at 2:45 A.M. on 3 September.

B.2. Salvage

B.2.1. Situation on 3 September

S-5 was a new submarine of the most recent type on her first trip away from the immediate vicinity of the building yard. She was undamaged except for the hole cut for the escape of personnel and for damage caused by partial flooding. She was therefore deemed to be worth salving, repairing, and recommissioning. She was 231 feet long and her surface displacement was 875 tons. All bulkheads were reported secured and all outboard openings closed, although it was later learned that the bulkheads between the torpedo and battery rooms and between the engine and motor rooms were not tight. The hole which was cut for the escape of the crew was in the boundary of a small compartment of about 10 tons capacity, and this portion of the submarine was still above the surface.

B.2.2. First Phase of Salvage

USS OHIO passed a strap consisting of nine turns of 1-inch wire around the stern of S-5 and shackled a 2-inch towing wire to it. The hole in the steering gear room was not closed. OHIO towed with turns for 11 knots and as soon as S-5 started to move, headed for a five-fathom bank. After 3 hours of towing,the S-5 had moved 3-1/2 miles to a depth of 144 feet. The stern then pulled under and sank and the 1-inch wire strap carried away.

On 4 September, a wreckmaster for a leading salvage company arrived. He felt that submersible pontoons could not be used in the open sea and recommended that the only practicable method of salvage was by compressed air.

Thus ended the first phase of the salvage. The depth of water had been reduced by 20 feet. A 5-inch manila line and buoy had been attached to the stern of the submarine and served as a marker.

B.2.3. Second Phase of Salvage

The wreckmaster's recommendation seems to have been adopted as the salvage plan, and MALLARD, which had been fitted out as a salvage vessel, was assigned to the job. The salvage work actually commenced on 11 October. The plan was to make the top of the ship tight to internal pressure, install spill pipes or spill holes in the bottom, and blow the ship to the surface. It was estimated that one-hundred dives and twenty working days would be needed.

On 19 November, with very little accomplished, work was suspended because of bad weather. It was not until 21 June of the next year that work was resumed using FALCON, which had been fitted out as a salvage vessel during the winter of 1920-21, in place of MALLARD. Nine divers were available. The battery room hatch was cutoff by means of TNT charges and replaced by a wooden plug 12 inches thick, containing a 4-inch spill pipe with foot valve and strainer and two 2-inch air pipes. It was secured by strongbacks and covered by 24 inches of concrete. However, when tested, this arrangement leaked air. It was removed and replaced by a 1-inch steel cover and gasket held by fourteen hook-bolts. The conning tower hatch was cutoff and replaced by a 1-inch plate.

Nine glass ports in the conning tower were blanked. The engine and motor room hatches were each secured in place by a strongback with two hookbolts. The binnacle, which leaked, was removed and the hole blanked.

The control room was opened to the battery room by a TNT charge against the bulkhead. An 8- x 6-inch hole was cut with TNT in the bottom of the torpedo room.

Using TNT, a hole was cut in the bottom of a lube oil sump tank adjacent to the outer hull in the engine room to act as a spill. The main induction valve was sealed with concrete to hold it against internal pressure. When air pressure was applied, the induction valve leaked badly as did the battery room hatch trunk which was found to have a 1/4-inch crack from top to bottom. As of 24 August 1921, the work remaining to be done was as follows:

1. Remove battery room hatch cover, close the crack with pine wedges, and replace the cover.
2. Blank flange the main induction pipes forward and aft under the superstructure.

At this time the status of the salvage was reported to the NAVY Department. Since it was estimated the work would extend into the season of bad weather, instructions from the NAVY were requested. On 29 August, the Secretary of the NAVY directed that salvage be discontinued and that S-5 be stricken from the NAVY list. The Salvage Officer attributed failure of the salvage operation to several factors:

1. Concrete was not successful in holding against internal pressure at main induction and hatch openings already closed, and
2. The battery hatch trunk was damaged.

Four hundred and seventy-seven dives were made and only 10 percent of these resulted in a diver having the bends. This was considered to be a remarkably low percentage.

In reading the weekly reports of the salvage operations, one can hardly avoid reaching the conclusion that the damage to the battery hatch trunk and binnacle stand was caused by the TNT charges being set off inches away (these were to remove the battery room and conning tower hatches).

Mixed in among the reports of the salvage and rescue work is an interesting item:

> "Commander Sub Flot 3 on 11 October 1920 recommended that one Bird-class minesweeper on each coast be fitted out and kept available for submarine rescue. This was approved by CNO and carried out, and was the origin of the ASR's."

APPENDIX

C. Salvage of Submarine S-51

C.1. Collision

The salvage of USS S-51 more than 40 years ago is a prime example of raising a submarine by a combination of self- and external lift. The Salvage Officer was faced with a formidable task since the submarine was completely flooded and the pressure hull open to the sea. Five feet of the hull was buried in mud and clay which meant an additional lift force was needed to break the bottom suction. There were few divers available who had experience in deep salvage work, and there were not enough submersible pontoons for the required external lift. Many of the tools to be used underwater were inadequate, such as cutting torches, underwater lamps, and tunneling nozzles.

This report amply demonstrates the importance of perseverance and ingenuity. These attributes spelled the difference between success and failure in this salvage operation. Also demonstrated are the unexpected and unpredicted problems which plague Salvage Officers. It is of interest to note that the force required to overcome bottom suction was recognized by the Salvage Officer. The account clearly demonstrates how this force can be reduced by ship motion or extending the time the lift force is applied.

The following report of the S-51 operation should be of intense interest to a submarine Salvage Officer and, hence, is treated in greater detail than the other salvage reports in these Appendices.

USS S-51 was sunk by collision with the steamship CITY OF ROME on the night of 25 September 1925. The S-51 was struck just forward of the conning tower on the port beam which opened the pressure hull to the sea with a gash 2-1/2 feet wide by 12 feet high. The submarine sank immediately, completely flooding all compartments. Ten crew members managed to leap from the bridge or get through the conning tower hatch and clear of the ship as she went down. Three of these were rescued by a boat from CITY OF ROME; the other seven were never seen again.

C.2. The Position

The position of S-51 was about 15 miles south of Brenton Reef Lightship and about 14 miles east of Block Island, resting at a depth of 132 feet.

The first divers arrived at the scene the following day aboard a small diving boat from the Newport torpedo station. The first diver down found that the S-51 was lying on a hard level bottom and listing approximately 13 degrees to port. The keel was buried 5 feet deep in the clay bottom.

C.3. Rescue Operations

The diver made a careful inspection along the deck and found air escaping in moderate quantities through all hatches. These hatches were closed, but evidently not set up from inside for the additional air pressure caused by the flooding. The diver hammered on the hatches but got no response; apparently all hands were dead. However, in the absence of conclusive proof rescue operations were attempted. Two floating derricks, one of 150-ton lift capability, the other of 100 tons, were hired from a commercial salvage company. It was assumed that if life existed at all on the submarine it would be because one or more of the after compartments had been isolated by the survivors. With the engine room and motor room free of water, it might be feasible to lift the stern. However, if they were flooded, the cranes would not be able to move the submarine. The latter was the case and further lift from the surface was abandoned.

Had the derricks been able to lift the stern of S-51, they still could not have brought it to the surface. The falls of the cranes were too short and there was no way to hang off the load to get another purchase. With the suspension of rescue operations, the task of salving S-51 was commenced under the direction of Captain E.J. King, Commander, Submarine Base, New London, Connecticut.

C.4. Estimate of the Salvage Situation

The salvage surface force consisted of the diving ship USS FALCON, a minesweeper, converted to an ASR; USS VESTAL, a repair ship; and three tugs used in positioning moors and towing pontoons. In addition, submarine S-50 was used as a model for divers to rehearse procedures they would perform on the wreck.

It was decided to raise S-51 by restoring internal buoyancy and adding external lift by use of submersible pontoons. Computations revealed that the amount of buoyancy required to lift the completely flooded hull was 800 tons.
A reserve buoyancy of another 25 percent was needed for breakout, and as a safety margin, making a total of 1000 tons.

It was hoped that 350 tons of buoyancy could be restored by sealing and blowing various tanks and compartments. This would leave 650 tons of external buoyancy lift to be applied by use of pontoons. To obtain this, eight pontoons with a net lift of 80 tons each were to be employed.

A study of the hatches and piping systems of S-51, especially those of the external ventilation system and its valves, showed that the submarine was not especially suited to the use of compressed air as a means of dewatering compartments. The hatches were all designed to seat with sea pressure and had little provision for holding an internal pressure. A light strongback on each hatch was only capable of holding a maximum three pounds of internal pressure over the ambient sea pressure, about one-third of the amount required to force water out. Under these conditions, it appeared that pumps would be the answer; but here too, there was a problem since the available pumps could only work against a head of 80 feet and the job required a head of 132 feet. In addition, the air compressors on the FALCON could only deliver 150 psi against a back pressure of 60 psi. This, plus the friction in the airlines, would reduce the net effect of compressed air to about 70 psi. It appeared that both pumps and compressed air would have to be used to dewater the compartments unless the hatches could be made to withstand the use of compressed air alone.

Two 80-ton and two 60-ton pontoons, originally built for use in F-4 salvage, were available at Norfolk and were shipped to New York. These pontoons, designed for operation in 45 feet of water, had to be reinforced with extra stiffeners and braces. The New York Navy Yard commenced construction on six more 80-ton pontoons of the same basic design, but of heavier construction to meet the 132-foot operating requirement. These pontoons were strong enough to permit surfacing from 132 feet without rupturing. As an additional safeguard against bursting, 6-inch spring-loaded relief valves were installed at each end. These dump valves were set to lift at a pressure of 5 to 10 psi above ambient pressure.

C.5. Mooring Arrangement

When diving operations were undertaken, FALCON always moored broadside to the wind and seas to form a lee for the divers. When these conditions increased, the repair ship, VESTAL, was moved around to windward and anchored as a breakwater.

To assist in holding FALCON in position, it was customary to anchor two of the assisting tugs about 150 yards off the windward bow and quarter, and run out two mooring hawsers to each ship. In very bad weather, the tugs were anchored in tandem to windward, the first tug holding up the second one, and the second tug holding the line to FALCON. In this manner, it was seldom necessary to secure diving operations due to the weather. As a result of this procedure, diving operations were doubled over ordinary practice and the length of the job correspondingly shortened.

C.6. Commencement of Salvage Operations

Diving operations on S-51 commenced about the middle of October. The first efforts were directed toward cutting away the loop antenna, the submarine clearing lines, and the radio antenna. This was necessary to avoid fouling the divers in the submarine's overhead rigging. The gear was cut with a special cutting hook attached to a line from the surface.

The next step was to get reeving lines in place for the pontoon slings. Dipping a wire line under the submarine's bow and hauling it back and forth in a sawing motion was first suggested. This method was not feasible for several reasons. The depth of the water made the geometry of the sling unfavorable for sawing and might foul the lines. Also, the hard clay bottom did not lend itself to sawing through 60 and 100 feet of the bottom which were the positions for the slings. It was certain that by the sawing action, the sharp bilge keels and the box keel would wear through the cable very quickly. Finally, no diving work could be undertaken while the sawing was taking place. Therefore, it was decided to tunnel under the hull with fire hoses which was difficult, but which would allow other divers to work inside the submarine hull at the same time.

In sealing up the submarine's interior, it was intended to make each main compartment entirely independent of all other compartments, with regard to watertightness. The value of this policy was demonstrated on the final raising day. To accomplish this, however, required additional work, and the sealing problem was especially complicated by the supply and exhaust ventilation mains in the superstructure. The supply main opened into every space except the battery room, and the exhaust main ran from the battery to the engine room. There was no possibility of closing the valves from these mains in the torpedo room or the battery room. Consequently, closing the main air induction valve and the main exhaust valve in the periscope shears would not isolate the compartments.

It was necessary, therefore, to seal each compartment where the induction entered the hull.

Several days were spent in attempting to clear away the obstruction in the engine air induction valve, but without result. As the valve had to be closed, it became necessary to remove the decking over the valve in the superstructure, tear up the steel deck beams over the valve using a 6-inch manila line to FALCON's winch for the purpose, unbolt forty 3/4-inch nuts which held down the valve bonnet, break the joint, and lift off the 300-pound bonnet. All of this work was finished on 2 November. A piece of 1-inch steel pipe, 3 feet long and much corroded, was found to be jammed under the valve disk. This was removed and the valve closed. Evidently this pipe had been left in the vent main during construction and had washed into the valve by the rush of water when S-51 sank.

Near the end of October, the first four pontoons arrived on board the 100-ton derrick UNITED STATES. They were brought directly to the wreck, but about an hour after arrival the weather changed and it was apparent that the derrick was in danger. It was immediately started for Newport, where it arrived not much ahead of a gale that scattered the salvage squadron. It was clearly evident that derricks could not safely be brought out, and thereafter the derrick stayed in harbor where she put the four pontoons overboard and prepared them for towing.

Work on the first tunnel, at frame 46, was started on 22 October. The divers available had done most of their diving prior to the loss of S-51 locating lost torpedoes; consequently, they were experienced in using a washing hose for digging. Tunneling was, therefore, not an entirely new experience for them. A 2-1/2-inch fire hose with a 4-foot pipe and nozzle was first used at a pressure of about 40 psi. The progress for the first day gave reason for optimism, but thereafter, trouble was encountered. Instead of the soft mud in which the divers had ordinarily worked and which washed freely with a hose, it was found that under a thin layer of sand and mud was a bed of hard blue clay mixed with sand. The consistency of the clay was such that a moderate water pressure had no effect on it. It was found impossible to raise the pressure on the 2-1/2-inch hose as the diver was unable to withstand the reaction of the hose, and lost control. After the first day's work, it was necessary to raise the pressure if any clay was to be washed out. To facilitate this, the last length of the fire hose was replaced by a 50-foot length of 1-1/2-inch hose with a pipe nozzle of the same diameter. With this smaller size, the diver was able to hold up to 70 pounds of pressure, which cut the clay when the nozzle was held close.

Another problem was the fact that the clay and sand were so heavy that they would not stay in suspension when cut, but settled again in the tunnel. This feature was aggravated by the small size of the water jet which was unable to set up any appreciable current in the tunnel as it advanced under the boat. As a result, the diver was compelled, after cutting ahead a short way, to turn his nozzle and wash all sediment backwards out of the tunnel. Consequently, only a small portion of the diver's time on the bottom was spent in actual cutting ahead.

The weather conditions in October and November were such that diving was not possible for more than two days in succession, after which two or three days might elapse before diving could be resumed. It was found, on returning after each storm, that the bottom currents had either partly or completely filled the tunnel with heavy hard-packed sand, that had to be washed out before any new cutting was possible.

These factors, complicated by an insufficient force of divers, prevented driving a tunnel through during the autumn operations. Several times success seemed near, with the divers approaching or even toughing the keel, but each time bad weather brought a halt. When tunneling resumed, practically all work had to be redone.

While tunneling was being accomplished outside S-51, divers were at work sealing compartments inside the submarine. To seal off the motor room, two divers entered from the engine room and closed all necessary valves, including the ventilation valve. Later, they closed the motor room door and sledged down the dogs. To discharge the water, the drain valve in the forward bilges of the motor room was opened, there being a non-return check valve on the bilge suction. In the engine room a valve bonnet on the drain line was removed so that water forced from the motor room would discharge into the engine room, but not in the reverse direction. To admit air, a bolt was removed from the top of the motor room and the hole tapped out. A 3/4-inch air connection was inserted for attaching the blowing hose. A strongback was bolted over the motor room hatch to prevent it from blowing open under internal pressure. When air was put in the motor room, considerable water was expelled, then air started to blow out of the ventilation main in the superstructure.

By questioning the survivors, it was learned that the drain valve on the line in the motor room had been defective and could not be properly closed. To remedy this problem, the motor room door was opened, the drain line disconnected, and the valve sealed with a pipe plug.

After the motor room door was re-secured, another attempt was made to blow the compartment down, evacuating the water through the disconnected drain line. After some minutes of blowing on this occasion,the water began to lower in the compartment. Then, one of the divers reported air escaping through the ventilation valve, which chattered like a relief valve releasing great gusts of air. Nothing further could be done during the autumn operations on this compartment.

Attention was then directed to the control room. To seal this compartment required substitution of two salvage hatches for the regular hatches in the conning tower and the gun access trunk. The original hatches were unable to hold even a nominal internal pressure. In addition, there were many smaller valves that had to be closed and two watertight (WT) doors secured that led to the battery room and engine room.

Handling the salvage hatches presented a problem. Each hatch was made of 1-1/2-inch steel plate and had a heavy strongback with a bolt running through it. A long section of 4-inch suction hose was attached to the hatch for draining the compartment when air pressure was applied. Assembled, the salvage hatch weighed about 700 pounds.

After a rehearsal on S-50, it became evident that the salvage hatches could not be handled from FALCON. The up-and-down surge of the ship would make it dangerous for the divers. It was decided therefore to handle the hatches from underwater on the submarine. For the conning tower hatch,a heavy oak timber provided with an eyebolt was secured over the bridge where it plumbed the hatch opening. The salvage hatch itself was handled by a half-ton chain fall secured to the eyebolt. Using this procedure, the hatch cover was hooked to the chain fall after it had been lowered to the bridge of the submarine. In one dive, two men accomplished this task. For the gun access trunk hatch, another oak beam was placed over the bridge timber in line with the center of the gun access hatch. The salvage hatch was lowered from FALCON and guided down by a line secured to the side of the gun access trunk. As the hatch neared the submarine it was dragged over by the divers who placed the suction hose in the trunk and fed it down until the hatch was landed on the trunk. The divers then hooked into the chain fall and took the weight off the surface line. Considerable difficulty was encountered handling this hatch because of the slope of the hull. However, two divers managed to get it in place and secured in one dive.

When both hatches to the control room had been sealed, the next job was to close and seal-up the internal watertight doors. The most direct means of entrance to the control room was through the gun access hatch. To open the hatch, the following procedure was carefully rehearsed on S-50 and then carried out on S-51. Divers proceeded to the gun access trunk on the starboard side. The glass port was smashed and the latch released by inserting a specially twisted bar into the 4-inch hole. Also holding the hatch was a 1/4-inch wire which was cleared by use of a cutting hook; the hatch then flew open. The divers later entered the trunk and endeavored to squeeze through the small oval hatch at its lower end, but it was too small for a diver to negotiate. This route was abandoned in favor of bulkhead, watertight doors in the adjacent compartments.

Two divers entered the battery room (forward of the control room) and moved aft towards the control room watertight bulkhead door. However, passage was blocked by mattresses and bunks and was too clogged for divers to attempt getting through. Next, the divers attempted to enter the control room through the after bulkhead door from the engine room. Two divers tried this entrance but were unable to squeeze through. A second pair of divers had to quit when their underwater lamps burned out while they were in the submarine. A third attempt by entering through the engine room door was successful. The two men got part way into the control room and cleared away a bunk that had washed into the compartment from the battery room forward. This provided a relatively clear passage through the remainder of the control room. By working forward cautiously to avoid entangling lifelines and lamp cables, the divers managed to reach the forward door. The area was jammed with wreckage which had to be carefully cleared away before the door was finally secured.

On a previous dive, one of the divers noted that one of the air banks in the control room showed about 2000 pounds of air. An attempt was made to open all of the Kingston flood valves in the main ballast tanks in preparation for blowing them down, but without success. When it was found that the air motors would not operate the flood valves, they were opened by hand. By this method it was possible to rig the No. 3 port tank for blowing, as well as the port and starboard tanks for No.'s 4 and 5 main ballast tank group. All other ballast tanks were inaccessible due to wreckage.

After rigging the flood valves open, the air manifold was set up to blow down these three ballast tanks. Another diver was stationed outside the submarine to observe the discharge from the Kingston valves.

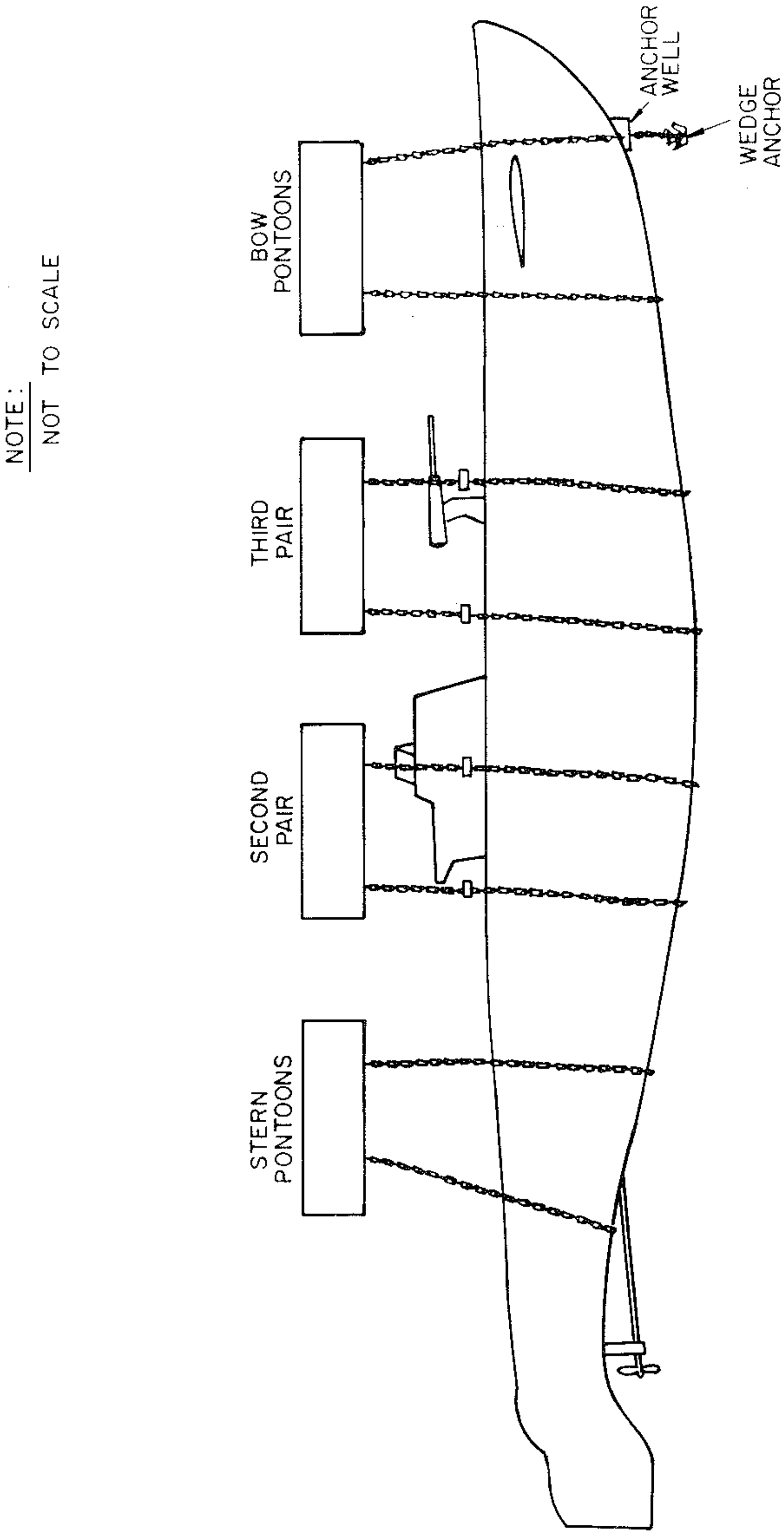
Air was turned on in all three tanks at once, and the gage inside the ship started to drop. The diver outside noted that a stream of muddy water was being discharged from the Kingston flood valve in each one of the three tanks. The tanks were blown for about 30 minutes until the pressure gage inside the submarine dropped so low as to render further blowing inadvisable. All air valves were closed and the diver came out. None of the three ballast tanks had commenced discharging air, so none of them were dry. It was estimated that all of them were from one-half to two-thirds blown down.

A rubber hose was found at the after door of the control room running from a connection in the engine room to the ice machine located under the deck in the control room. As this hose prevented closing the door, it was cut by the divers and gagged on both sides of the cut. The divers then closed the after bulkhead door of the control room and dogged it shut.

A hose for blowing the control room was secured to the connection provided on the salvage hatch already installed and the air was turned on. After building up a pressure of 3 or 4 pounds in excess of the bottom pressure at the point of discharge, air started to blow from the ventilation valve, as in the case of the motor room. Efforts to seal the control room were terminated for the rest of the autumn operations.

About the middle of November, divers worked in the engine room on the fuel oil manifolds, setting the valves and rigging air connections to blow the contents of the tanks. The after group of oil tanks was blown first, the contents being discharged through a hose leading to the surface. It was found that one tank contained water, all of which was blown out until air discharged from the flood valves. The connections were then shifted to blow the forward group, which was completed a few days later. The forward group contained some water in the discharge line before oil was reached.

Prior to the above operations, in late October, an attempt was made to lower the first pontoon. Divers passed messenger lines of 21-thread manila under the stern of S-51 which was clear of the bottom. The manila messenger was used to haul a heavier line which in turn pulled two 1-inch wire lines. The pontoon was to be lowered with a 15-fathom shot of 2-1/2-inch anchor chain hung from each hawsepipe. The chain was stopped off at the top with a heavy bolted clamp. The wire hauling lines were secured to the lower end of each one of the chains.



ARRANGEMENT OF PONTOONS AND SLINGS ON S-51 LIFT.

FIGURE C-1

It was planned to lower the pontoon from the surface using a 6-inch manila line at each end. The pontoon was flooded until nearly awash. In this condition, the pontoon tended to submerge at one end or the other because of the free surface effect. Some time was spent in adjusting with the vent valves and the air connections on each end to make the pontoon submerge evenly.

This effort was unsuccessful and it was decided to let the pontoon flood until it had negative buoyancy and then lower it to the bottom by the 6-inch manila lines. As the pontoon went down the lowering lines parted and it sank to the bottom. FALCON was a short distance from her normal position over S-51 while these experiments were being made in pontoon handling. Consequently, the pontoon missed the submarine on the bottom and landed about 50 feet away. In the meantime, the hauling wires under S-51 had slacked off and had fouled around the submarine. It took several days of work to clear the 1-inch slings and refloat the pontoon. It was evident that the methods previously used in lowering and handling pontoons in shallow water were not applicable in the open sea.

FALCON proceeded to Narragansett Bay where in shallow water, and using another pontoon, an attempt was made to lower it without losing trim. When the pontoon had taken in enough water to submerge, the loss of external water plane and the free surface effect inside the pontoon destroyed all longitudinal stability. The pontoon then upended and dove for the bottom. Two solutions seemed possible; one was to allow the pontoon to flood completely at the surface and provide means of lowering it that could stand the full load of 40 tons. The second was to determine at what point the pontoon had taken in sufficient water to reduce its internal free surface phenomenon, thereby improving stability somewhat. If the pontoon was held reasonably level by the lowering lines, one end would not have a tendency to float up while the other end dropped and took all of the load. It was felt that if such a condition could be found, the pontoon could be completely lowered without losing trim.

After some calculation and considerable experimentation in Narragansett Bay, it appeared that with a negative weight of 10 tons the internal free water plane was sufficiently reduced to make the pontoon fairly stable, provided it was not permitted to exceed a moderate inclination. To handle the weight of 10 tons, a large safety factor was necessary for the dynamic conditions and for the probability of exceeding the designated weight while flooding. It appeared that nothing less than a 12-inch manila line would be satisfactory.

By the time these experiments were completed, it was too late in the season to make an actual attempt to place a pontoon alongside S-51.

After the middle of November the weather became so bad that diving was possible only at infrequent intervals. The water became extremely cold. From 21 November until the end of the month diving was impossible. Finally, on 30 November, diving was attempted again. On this occasion, two of the three divers sent down had to be hauled back up because their air hoses froze from the moisture in the air being pumped down to them. At this time, only four of the original ten divers who had started this work were still in condition to dive. An attempt was made to hire civilian divers to augment the force, but only three men were found who were willing and qualified to work on the job.

Considering the unsuitability of the weather and the fact that only 1 day in 10 or 15 could be counted on as a diving day, it was decided to suspend operations for the winter. The mooring buoys were removed by the Lighthouse Service and two marker buoys were left at the site of the sunken submarine. The pontoons were left moored to the docks at the torpedo station, Newport, Rhode Island.

C.7. Resumption of Salvage Operations

To prepare for salvage operations the following year, a diving school was set up at the New York Navy Yard. Twelve divers were found physically qualified and commenced training in a diving tank. They were required to learn the use of various underwater tools and to perform tasks of working with pipes, cutting out rivets and handling weights. Also, a series of experiments was carried out to develop an underwater cutting torch. The torch, which had been provided by the NAVY when salvage commenced, had failed to work.

The second year of salvage operations on S-51 commenced late in April. Some difficulty was experienced in relocating the wreck because the marker buoys had drifted. The first job undertaken was to land pontoons alongside the port and starboard quarters of the submarine. Considerable difficulty was experienced in this endeavor. Lines carried away and the pontoons sometimes came to rest some distance from their intended position. They were then either hauled into position on the bottom or refloated and sunk again.

The newly developed underwater cutting torch was used for the first time with success. When the chains had been hauled through the hawsepipes of the pontoons a predetermined length, the stud of a link would be burned out, which then permitted a nickel steel toggle bar 40 inches long and 3-3/4 by 3-3/4 inches in section to be slipped through. This was then locked by a bolt on each side of the chain link.

Work was commenced on lowering a pair of pontoons for the bow slings. The reeving line was passed under the bow, but it kept slipping free due to the rise of the forefoot. To remedy this, a diver was sent down to release the anchor on the submarine. The shank of the anchor then functioned as a preventer. The reeving lines pulled the 4-inch manila through the tunnel and then the wire was hauled down. However, the 4-inch manila parted when a strain was taken; it had been cut by the bilge keel. Attempts to locate the 4-inch manila line were unsuccessful. The weather then worsened and the increasing seas caused the pontoon moored alongside FALCON to surge and crash against the sides; finally it had to be cast loose and towed away. When a diver went down the next day, he found the wire reeving line fouled on the bottom and this had to be cleared away.

To replace the 4-inch line that had been cut by the bilge keel, it was necessary for the divers again to work through the tunnel. When all was in readiness to haul in on the wire and thus heave the chain through the tunnel, it was found that the links caught and held on the box keel. In every instance that a strain came on the chain, the first link would be brought hard up against the angle of the box keel which hung about 16 inches below the hull. This heaving by the tug eventually tore the winch loose from the deck and the effort was halted. The pontoon was brought to the surface along with the chains. The hauling wire was carefully checked, then the chains removed from the pontoon. The eye of the hauling wire was shackled in to the chain and a special steel fairing installed to streamline the connection. With this rig the first chain was independently lowered and passed through the tunnel under the keel without difficulty. The first bow pontoon was lowered on the port side until it was about 20 feet clear of the bottom and a pair of divers went down and checked the position. The pontoon was then lowered the rest of the way and the locking bar was inserted.

This method of handling the chains and pontoons was considerably superior to lowering the pontoons with the chain attached. The reason for the original method of rigging resulted from the means of securing the chains in the hawsepipes of the pontoon.

This was a steel clamp made in two halves, weighing about 300 pounds, and secured by four 1-1/2-inch bolts. Such a rig was extremely difficult to handle and probably could not be secured without auxiliary rigging from the surface. In shallow water, where a diver could work all day, such means were feasible. In deep water, however, where divers' time on the bottom was very limited, it was considered best to shorten the work by securing a pair of chains to the first pontoon, making up the clamps on the surface. However, when the use of the cutting torch made possible the removing of studs in the links and insertion of the locking bar at any desired point, it became possible to eliminate the clamps entirely.

Early during the spring operations, work was started to seal off the ventilation main leading to the control room, engine room and motor room. The motor room was attempted first, as the ventilation line leading to this compartment could be most easily reached. The deck of the submarine just forward of the motor room was removed and the deck beams cleared away with the cutting torch. Several days followed while a succession of divers worked on unbolting the induction flange. Several of the bolts were inaccessible because of the close proximity of the engine air induction valve. To remove this piece, a wire was brought down and wrapped around the pipe and a strain put on it from the surface, tearing it clear. The flange was then cleaned off and the blank cover bolted in place. Air was then applied to the motor room to see if it would hold pressure. After blowing for about half an hour, a stream of air bubbles came to the surface over the forward end of the motor room. The leak came from an opening in one of the butts of an upper plating strake on the starboard side. Apparently, a poorly fitted butt joint had been made tight during construction of the vessel by peening the edges of the plates and thus sealing the overlapping seam. The effects of corrosion and an internal pressure had caused the butt edge to give way, creating a bad leak.

Divers were sent down with strings of lead wool and the crack was calked with ordinary wood calking tools. Then an air-driven chipping and calking tool was applied. The work went very slowly as each time the trigger was actuated by the diver air bubbles obscured his view. Most of the work had to be done by feel. When the leaks had been calked, air was again applied and the water driven down a little further. Again, bubbles streamed from the compartment; this time from the stern of the submarine. Upon inspection, a large dent was found about 10 feet from the stern in the tiller room. In this dent one rivet was missing and another nearly pulled through, allowing air to escape freely.

The tiller room was a small compartment aft of the motor room and connected with the latter by a manhole about half-way down the bulkhead. It was evident that this manhole was open and that the air in the motor room, having driven the water down to the level of the top of the manhole, was now escaping through the tiller room rivet holes.

A lead plug was cast to the size of the open hole and fitted with a tapered oak cone driven into its base to act as an expander. When this plug was inserted in the hole, the wood plug was brought up against the frame bar inside and resulted in spreading the lead plug inside when the diver hammered it home from outside.

To seal the partly pulled rivet, the diver drove soft pine plugs into the open parts of the countersink so that the wood was firmly jammed in. The wood was then trimmed to prevent lines or cables chafing across it and possibly starting the leak again.

The reason for the dent in the shell is not definitely known. The location was far removed from all collision damage and could not have been a result of the submarine hitting the bottom. It is believed however, that one of the vessels engaged in the original rescue operations dropped anchor over S-51 and that the anchor had landed on the stern, dented it and bounced clear.

The work of sealing the motor room leaks was completed early in June, and the pressure again applied. No further leaks appeared on the outside of the vessel in the vicinity of the motor room. However, when the water level inside had been forced down to the point where it reached the shaft stuffing boxes in the bulkhead between the engine and the motor rooms, air started to escape in considerable quantity through the stuffing boxes into the engine room. At this point, the motor room was about two-thirds empty. It was only by sending all the air FALCON could supply into the motor room that it was possible to drive the water lower. The moment blowing ceased, the air below the shaft lines would escape and the motor room refill to this level.

Inquiry of the officers on S-50 brought out the information that on all submarines it was impossible to keep interior shaft stuffing boxes tight as the vibration due to the close proximity of the engines quickly wore the packing to a considerable clearance. No attempt was made to tighten up the stuffing boxes since they were practically inaccessible to a diver.

Having sealed up the motor room ventilation valve by blanking it off, consideration was given to the same procedure for the ventilation valves in the engine room and the control room.

The main engine air induction valve, having had its bonnet previously removed in the process of closing the valve, was quickly sealed from the outside by bolting a steel strongback across the valve body and pressing a heavy oak block firmly down on top of the valve disk to hold it on its seat.

The battery exhaust valve, which discharged into the engine room, and the ventilation supply valve, which opened into the control room, presented different problems. Both valves were closed by their internal locking gear, but it was known that this was ineffective. It appeared possible to get at a section of the battery exhaust main in the superstructure and blank it off. The line to the control room was so covered by other pipes and structure as to be practically inaccessible.

It was noted that each one of the compartment ventilation flapper valves had a 1-1/4-inch drain valve screwed into its body just above the flapper disk. In the case of the motor room, such a drain valve had previously caused considerable trouble by leaking and had to be plugged. It now appeared that through these drain valve openings a cement mixture might be injected into the ventilation valve bodies on top of the closed flapper valves, which, on hardening, would permanently seal the valves closed.

To carry out this scheme, a special elbow, to get into a confined space, was made on the repair ship, VESTAL, to suit the drain valve connection in the control room. This was tried on S-50. The door from the engine room to the control room, which had been closed during the fall operations, was undogged and reopened. Three divers were sent down to install the cement connection, but found conditions in S-51 were sufficiently different to prevent installation. After modification, the fitting was finally installed, but with great difficulty, as the water in the control room was black from particles in suspension and vision beyond 6 inches was impossible. The work had to be done by sense of touch in a cramped space. Conditions were so bad that a submarine lamp was invisible unless held within a few inches of the diver's faceplate.

Meanwhile, experiments were being carried out on the VESTAL to determine the best cement mixture. The primary requirement was to obtain a cement that would harden in salt water. The secondary problem was to obtain a cement that would flow freely through 250 feet of 1-1/4-inch diameter hose, pass through a number of valves and fittings and still not be too liquid to set firmly.

Several brands of commercial cement were tried but their hardening qualities in salt water, except in very thick mixtures, were extremely poor. A special bauxite cement was tried and found to be satisfactory. A mixture of two parts by volume of this cement to one part of water was found to be thin enough to permit flow.

For injecting the cement, a steel tank was constructed and tested to 200 psi. The tank had a quick-opening hand-hole on top for filling, test cocks on the side for determining the cement level, and a discharge connection tapering from 3 inches to 1-1/4 inches at the bottom. Using 200 feet of hose leading to the bottom and attached to a piece of 12-inch pipe, a full-scale experiment was carried out on the repair ship to test the apparatus and the mixture. The cement was forced out by an air pressure of 150 psi on the tank. Five hours after the pipe had been injected with the cement, it was found that it already had set moderately hard. It was kept submerged in salt water and by the next day had set solidly.

The hose and the apparatus were taken out to FALCON where the divers ran the hose inside the submarine and connected the last short length to the fitting on the control room ventilation valve. When all connections had been made, the cement was mixed on FALCON and two charges forced through. The divers then uncoupled the hose section near the control room and sent it up. A few days later the divers closed and dogged the door to the control room.

In the engine room a similar connection for injecting cement was fitted to the battery exhaust ventilation valve and a hose connected up for the job. Because this valve was larger than the one in the control room, about 10 cubic feet of cement was used to seal up the valve. The two ventilation valves in the control room and the engine room were thus sealed off with only a fraction of the work that would have been required by any other method. After an hour of blowing the control room with high pressure air, all water was expelled.

Work was started on the tunnel for the last pair of pontoons which were to be placed at frame 74, just even with the conning tower. A new washing nozzle had been designed aboard FALCON. In this nozzle were six jets, one large one ahead, and five smaller ones radially astern. It was found that this jet arrangement compensated for the reaction which previously had made it impossible for the diver to hold a 2-1/2-inch hose with adequate working pressure. Also, the radial jets enlarged the hole cut by the forward jet and shot the material back through the tunnel.

The divers found that with this nozzle they could easily control the hose at all pressures which the pump could supply (200 psi).

As a result of this highly efficient nozzle, a sizable tunnel was dug on the starboard side, so that on the first day the keel was reached in only five dives. The next day, a tunnel was started on the port side. The fourth diver washed his way into the starboard tunnel. He then crawled through the tunnel with the messenger line. By the afternoon, two 2-1/2-inch chains were hauled through ready for attachment to the pontoons. The efficiency of the new nozzle was well proven in 2 short working days; the previous tunneling work had required nearly 8 weeks.

After the last pair of pontoons were lowered and connected to the chains, work was commenced on blowing dry the port ballast tanks. These had been partly blown the previous November using the submarine's air. On this final blow, the air was supplied by a diver inserting an air hose from the outside of the ship through the Kingston valves which had been opened. These valves were buried in the clay on the port side and it was necessary to wash them clear. When blowing started, it was discovered that only a few minutes of operation was required since most of the air in the tanks had been retained from the blowing operations of the previous year.

To blow No. 2 port ballast tank, it was necessary to burn a hole in it near the bottom since the operating gear for the Kingston valves could not be reached from inside the submarine. When air was applied to this tank, it was found to leak through plates damaged when the submarine hit the bottom. Consequently, the No. 2 starboard ballast tank was not used as it would give the submarine a permanent list when raised. It was also decided at this point not to blow the other starboard ballast tanks for the time being. The submarine had a list of 11-1/2 degrees to port which was hoped would be eliminated; at the same time it was hoped the bottom suction would be broken when the submarine rolled to starboard. Having blown dry three portside ballast tanks, the rolling moment available was somewhat over 600 foot-tons. It was believed that when S-51 was further lightened, she would roll to starboard.

Consideration of the conditions governing the forward and the after groups of oil tanks led to the conclusion that the forward group of tanks could not be safely blown dry while on the bottom. This was due to the fact that no adequate vent for this group of tanks could be provided which would relieve the pressure when the vessel rose.

This might result in rupture of the tanks. On the other hand, this group could not be blown dry and then vented before rising because the battery compartment directly above it was open to the sea, and the tank top would collapse if the pressure inside the tank were reduced with the vessel on the bottom. It was therefore decided that the forward group of oil tanks would remain flooded while on the bottom and these would be regarded as reserve buoyancy available when needed.

Having blown the after group of oil tanks, the fuel oil manifold in the engine room was set for blowing the forward group. The ladder in the engine hatch was removed and the floor plates under this hatch were taken out so that the suction pipe from the salvage hatch could reach to the bilge 4 feet below the floor plates. The divers had considerable difficulty in aligning the salvage hatch due to the submarine's port list.

C.8. Initial Lifting Attempt

On 13 June, S-51 was completely sealed up. The motor room was then dewatered as was the engine room, the two being connected through the drain line. In preparation for lifting, all pontoons were supplied with enough positive buoyancy to float above the submarine. It was necessary to level them off with equal amounts of chain scope and to lash the slings. It was essential that the pontoons be level before lifting commenced, otherwise attainable buoyancy would be lost. The lashings were to prevent the chain slings from slipping aft when the stern was lifted on breakout. When this leveling operation was attempted on the first set of pontoons, considerable difficulty was experienced. They tended to upend as when they were lowered from the surface. This was resolved by lightening up one pontoon to the extent that a wire from the surface could lift it to the proper level above S-51's main deck. Then the pontoon on the opposing side was blown until it rose into position and leveled. When the pontoons were in proper trim, air was added to give them a positive buoyancy of about 8 tons.

The lifting wire to the first pontoon was then cast free. Leveling and positioning each set of pontoons was done in the same manner. On three occasions, the lifting wire parted allowing the pontoon to sink and the process had to be repeated. Such operations were confined to relatively calm sea states to prevent cables from parting.

Five days passed after blowing the portside ballast tanks and S-51 had not rolled to starboard.

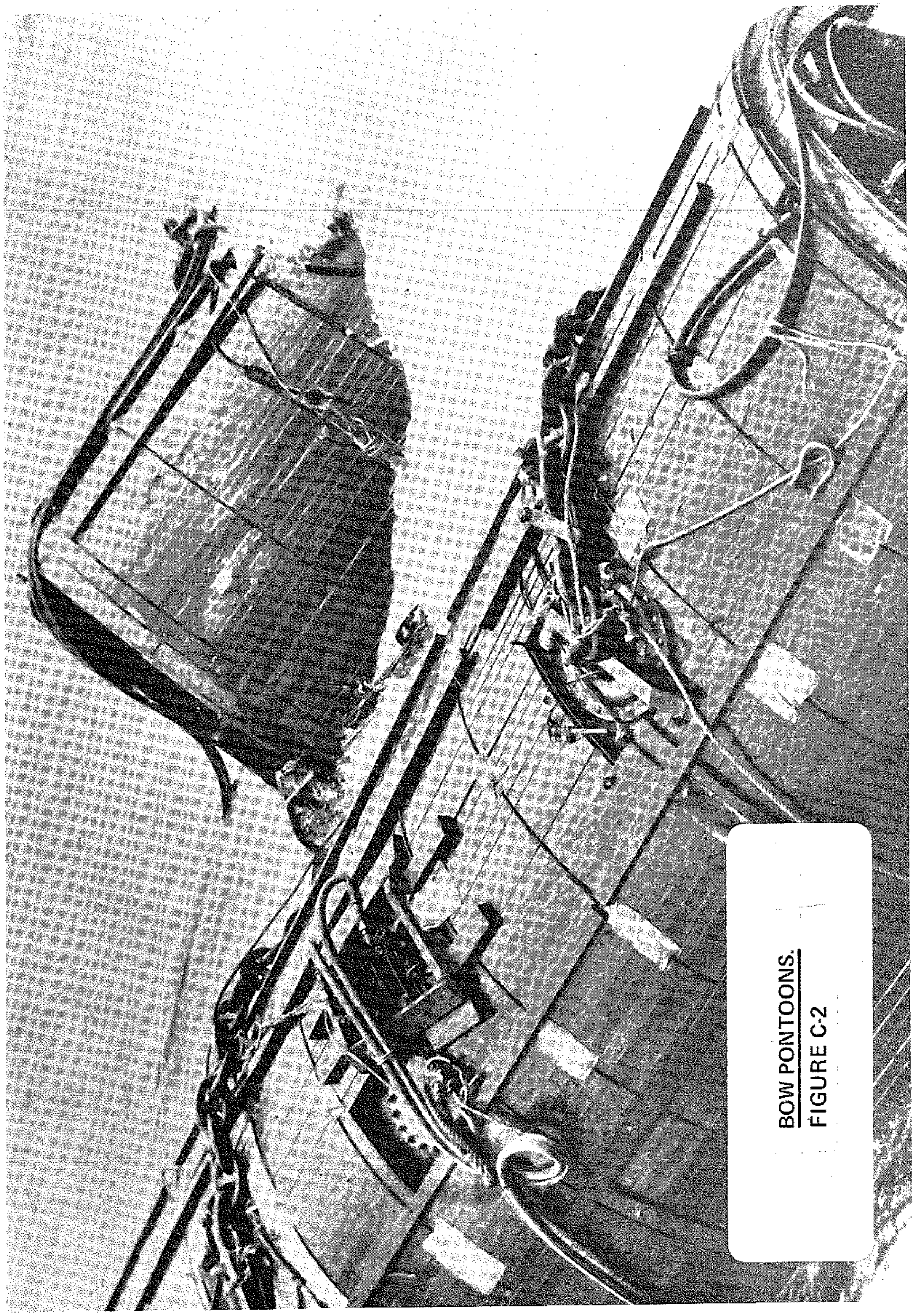


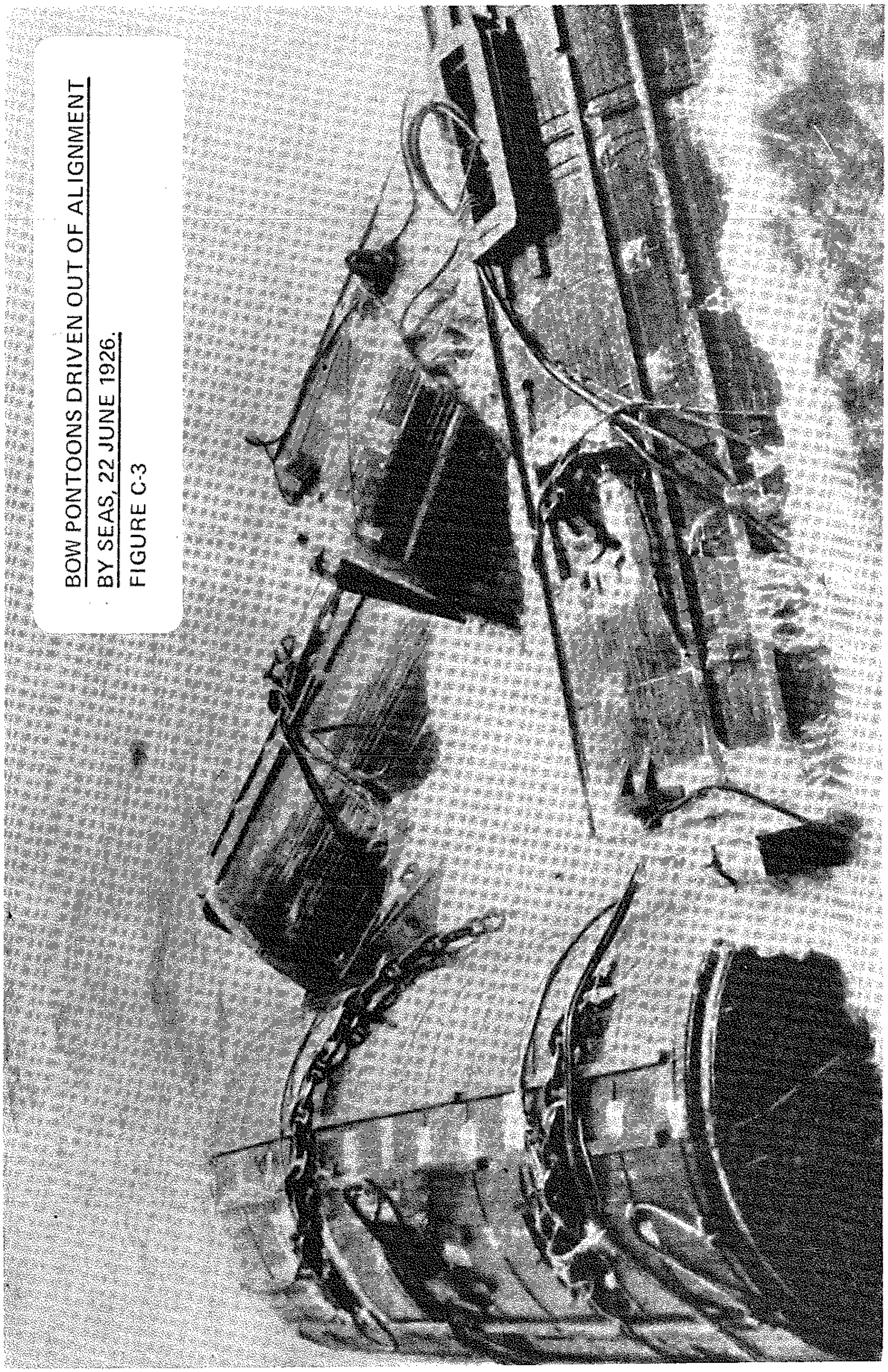
FIGURE C-2
BOW PONTOONS.

During this time the blowing hose to the engine room was severed by one of the pontoons when it was being adjusted, allowing the compartment to refill. The pontoons adjacent to the battery room and control room were blown dry in an attempt to initiate rolling the submarine, but nothing happened. The following day the stern pontoons were made slightly buoyant, and a diver went down to install the lashing clamp. Soon after the diver started his descent, the tenders topside observed air bubbles roiling the sea the entire length of the submarine. When the diver had reported on the bottom, he sent back word that S-51 had shifted and now was nearly 20 degrees to starboard.

This news greatly heartened the Salvage Officer. There could be no doubt that the suction effect was in a large measure broken by the roll. It was also discovered, on further inspection, that the stern of S-51 had lifted about 5 feet, showing that the buoyancy already attained astern was nearly sufficient to start the stern upward without help from the stern pontoons. This checked out well with the buoyancy calculations. These had been revised to reflect that a large portion of the tiller room, all of the motor room, most of the engine room and several fuel oil tanks had been dewatered. The buoyancy calculations are shown in Table C-1.

While the leveling operation was underway, starboard ballast tanks 3, 4 and 5, which had never previously been dewatered, were blown dry. A diver then descended to inspect the location of the starboard after pontoon, which was somewhat close under the counter with the submarine leaning on it. The diver was standing on the bottom just outboard of the pontoon when it rolled gently and then started to float up while the submarine rolled from 20 degrees starboard to 10 degrees port. The diver reported this topside and then, as it appeared that the submarine and pontoons were on their way up and that he was in a dangerous position, he started to run along the bottom to get well clear. Unfortunately, his air hose led across the pontoon chains and was fouled there. The diver then climbed his air hose to the floating pontoon and cleared it. Shortly after this, the pontoon settled again, coiling down the chain under it where the diver's air hose had been snagged.

To prevent any premature rise of the stern, about 60 tons of water were flooded back into the third pair of pontoons, abreast of the conning tower. An inspection made shortly after showed that the stern, which had been up about 5 feet or more, had settled back nearly to its original position. The submarine was now heeled 5 degrees to port.



BOW PONTOONS DRIVEN OUT OF ALIGNMENT BY SEAS, 22 JUNE 1926.

FIGURE C-3

TABLE C-1

BUOYANCY CALCULATIONS

Compartment	Total Buoyancy (tons)	Expected Net Buoyancy (tons)	Actual Net Buoyancy (tons)
Control Room	90	54	60
Engine Room	110	88	96
Motor Room	137	104	137
Port Ballast Tanks, 3, 4 and 5	62	46	50
Starboard Ballast Tanks 3, 4 and 5	62	46	50
After Group Oil Tanks	33	23	33
Forward Trim Tank	10	8	10
Water Round Torpedo Tank	6	4	6
No. 2 Bow Buoyancy Tank	11	8	11
Total	521 Tons	381 Tons	453 Tons

Lashing the pontoons as they leveled off was done partly to hold them against a change of position during the blowing operations, but mainly to prevent them from slipping aft when the stern lifted and before the bow came up. It was essential to ensure that the bow pontoons, in particular, did not slip, otherwise they would lose their lifting moment and allow the stern to broach at a steep angle, possibly tearing out the stern slings. If such an event happened, it would destroy months of work, in addition to being extremely dangerous. Wherever possible, appendages of the submarine were used for lashing preventers. The stern pair of pontoons had the after chain passed inboard of the shafts, just forward of the skeg. The bow pontoons had the forward chain caught in the anchor well under the keel and the after chain rove through the bow plane guards so that movement was impossible (Figure C-1).

To prevent motion aft on the part of the second and third pair of pontoons, a special steel clamp was secured on each chain below the pontoons and just above the point where the chain cleared the hull. A 1-inch wire lashing with an eye in each end was then run generally athwartships just above the deck of the submarine and attached to the special clamps. The entire rig was designed for a breaking strain of about 35 tons on each wire. In this way, each wire tightly cradled the submarine in a continuous loop of chain and wire when the angle of the ship caused the wires to take up a strain. Further, the wires for the third pair of pontoons led across the deck just forward of the gun access trunk (Figure C-1), which thus acted as an effective stopper. As an additional safeguard for this pair, another wire was led around the gun mount somewhat forward of the pontoon.

To keep the second pair of pontoons from sliding forward, a wire lashing was run from the chains aft around the gun mount, in addition to the athwartships pair of wire lashings. It was further evident that under full buoyancy, the bilge keels in way of the chains for the second and third pair of pontoons would buckle up and thus form a niche for these chains which would tend to prevent slippage.

Having secured the lashing clamps around the chains, the divers took measurements of the lengths of lashings needed, using a small manila line stretched between the clamps. With these lines as a guide, FALCON cut the 1-inch wire and spliced in eyes with cable clamps.

During the installation of the lashing wires on the second pair of pontoons, trouble commenced which led indirectly to the rising of the bow a short time later.

When the second pair of pontoons had been leveled off with moderate positive buoyancy, measurements for the lashings were taken. When the lashings were sent down for installation, it was found that they could not be installed because the forward end of the No. 2 starboard pontoon had sunk until it rested on the bow pontoon just ahead of it. The bow pontoon was on the bottom and had not been floated up. Had this bow pontoon not been there, the No. 2 starboard pontoon would have sunk to the bottom, probably standing on end. Inspection revealed that the pontoon had sunk because of many small leaks emanating from seams and rivets. These leaks were probably started by the knocking about that the pontoon received during towing and while alongside FALCON. Every pair of pontoons leaked to some extent except the third pair. The result of this condition was serious. Considerable effort had already been expended in leveling off the pontoons and it was necessary that they be kept leveled off. The starboard pontoon was refloated and thereafter all pontoons were given periodic shots of air to compensate for the leakage.

On 20 June, the bow pontoons were leveled off and the flood valves closed to minimize flooding due to the small leaks. The next day the divers were down measuring for lashings on the stern pontoons when the stern pontoon on the port side suddenly shifted and lifted the stern about 10 feet. Fortunately, the divers escaped injury. The forward end of this pontoon was given some air to replace what had been lost through leakage and an attempt was made to close the flood valves, but only one could be partly closed. Since the submarine was considered to be light, the engine room was flooded to prevent a premature rise. The final lashings were put in place by the end of the day on 21 June.

The next day was stormy and divers could not be used, and raising S-51 was out of the question. Since it was known that air leaked from the pontoons, FALCON moved into her moorings and picked up the air hoses which were buoyed off in the salvage area. The stern pontoons were blown first for one minute, then the third pair of port and starboard pontoons was given a half minute blow. Since the second pair of pontoons had been blown dry previously and their flood valves kept closed, they were not blown at this time.

Problems arose when the hoses to the bow pontoons became fouled in the propeller of FALCON. This required several minutes to clear in the heavy seas. As the hoses were brought aboard to be connected to the air manifold, the Salvage Officer observed a mass of bubbles breaking the surface.

It was thought at first that one of the hoses had carried away below, but the volume increased and became excessive for such an accident. It was sensed that either the bow pontoons had torn loose and were coming up, or the submarine itself was rising. In either case, FALCON was in a dangerous position. The mooring lines to the stern were on the winches and the winch men at the throttles in preparation for unmooring. The port quarter line was cast off and the starboard quarter line heaved in full speed to haul FALCON's stern clear. The ship was barely out of the bubbles when in a cloud of spray the bow pontoons burst through the surface followed quickly by the second pair, with the bow of S-51 visible between them. FALCON let go her port bow mooring lines to be clear of the area where the stern of the submarine would come up. Meanwhile, the four pontoons holding the bow of the S-51 surged in the waves, smashing into one another. It was decided to commence blowing on the stern compartments and pontoons to complete the floating of S-51 and make for sheltered water.

To furnish sufficient air to all spaces in the blowing process required more than 2 hours. An attempt was made to use air from S-50, but the rough weather prevented the submarine from coming alongside. The steep up-angle of S-51 prevented the dewatering suction hoses on the salvage hatches from reaching the water, which was mostly at the after end of the compartment. It was determined that about 130 tons of buoyancy in the control room and engine room were lost because of this. When air bubbles were seen on the surface over the middle of the wreck, it was obvious that the stern was not going to come up.

About noon, a sizable bubble appeared over the stern. At first it was thought the stern was coming up. Then the bubbles increased and the starboard after pontoon broke the surface, followed in a few seconds by the port after pontoon. The 2-1/2-inch chains had parted under the submarine. It was now impossible to raise the stern with the loss of buoyancy of the after group of pontoons. There was immediate danger of the four surfaced bow pontoons sinking as they crashed into each other in the heavy seas. Since all floods and vents on these pontoons were closed, it was necessary for a man to swim to each one and open the valves. When this had been done and S-51 had settled back to the bottom, FALCON unmoored and took refuge from the storm. The pontoons that had broken free from the stern were taken in tow to port.

C.9. Successful Lift Made

The next day two divers were sent down to inspect the results of the accidental raising of the bow. The bow of the submarine was about 30 feet from the original position and the pontoons were scattered on the bottom on their ends, with chains and wires in a tangled mass.

A study was made to determine the cause of what had happened. It was concluded that the bow pontoons must have been more buoyant than estimated. There was no means of knowing the buoyancy condition of a pontoon unless it was completely empty or completely full. It appeared that sufficient buoyancy had accumulated forward when work ceased late on the previous day. Surfacing at that time was probably prevented by the suction effect of the clay bottom. The air put into the tanks just prior to the surfacing was either aft or amidships and would have had negligible effect on the forward lifting moment. The air in the after pontoons would tend to reduce the forward moment by shifting the center of buoyancy aft, and would help hold the bow down.

It is probable that the motion of the sea was sufficient to rock S-51 in her bed on the bottom. Such motion at that depth had been observed previously by divers in the swaying back and forth of the pontoons afloat over the hull. On this occasion the lightened ship was rocked sufficiently to break loose the suction on the bow, which rose with accelerating force. The air in the pontoons expanded as they rose, increasing the buoyancy.

The first job attempted when the divers had returned was to place a pair of reeving lines under the submarine for replacing the second pair of pontoons. The keel was barely touching the bottom and it was essential to get the lines under before it settled. One line was passed through at frame 30 and sawed back to frame 42 by two divers. For the second reeving line, a tunnel had to be washed which took about half an hour using the new nozzle. Messenger lines, then wires, were passed to pull chains into position which were laid out on the bottom until needed.

The next step was to clear away the pontoons at the bow. One pontoon was still afloat and fouled by one of the lashing wires across the deck; it was cut loose. This was done by a diver with the cutting torch. When the pontoon swung back in position, it swept the diver off the submarine, but he miraculously escaped injury.

When all of the pontoons had been freed and surfaced, they were taken into port for repairs. The seams were calked and the wood sheathing replaced.

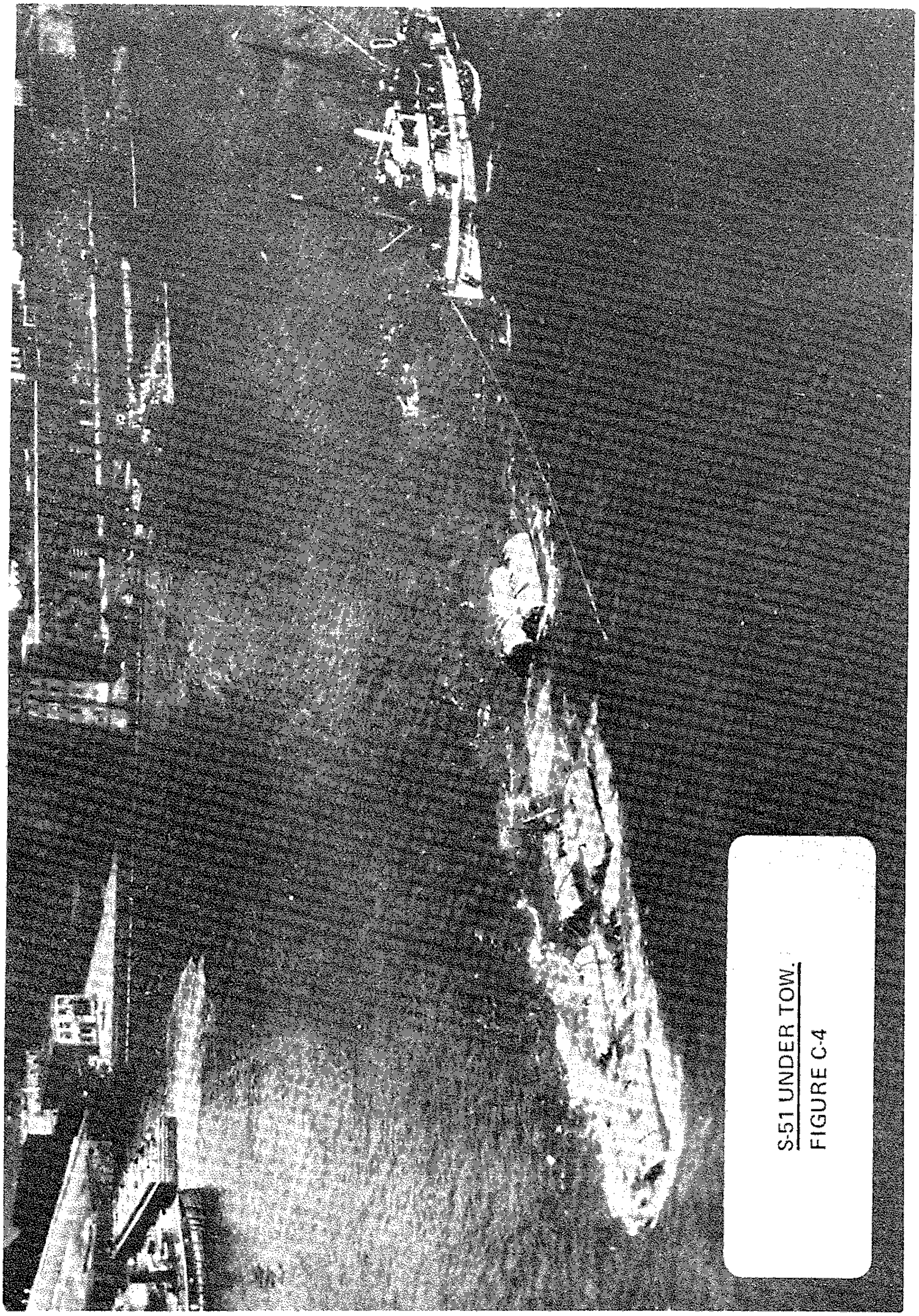
By early July, FALCON was again over S-51 ready to lower pontoons. The same procedures were employed in connecting the sling chains and leveling the pontoons above the main deck of the submarine.

Certain forward tanks, which on 21 June were dry, were on this occasion left flooded. The No. 2 bow buoyancy tank was considered lost as it was dented in and could not hold air pressure. The capacity of the tank was small and did not warrant the extensive work required to repair it. The forward trimming tank and the water-round torpedo tanks had vented themselves down practically to atmospheric pressure while the bow was at the surface. On sinking again, these tanks reflooded under the bottom pressure. Had time permitted, they would have been blown down again, but the weather forecasts for the following day were such that it was considered unsafe to risk further work which would delay the job until a later date. Work on these forward tanks was abandoned with regret.

Another consideration causing some anxiety was that about 150 tons of buoyancy in the six forward pontoons would be unavailable for lifting the bow while the stern was up. This was because the pontoons would assume the angle of the ship, about 25 degrees, and only half of the pontoon could be blown down. It had originally been intended to ensure this buoyancy by blowing the after halves of all six forward pontoons before lifting the stern. However, with the experience of 22 June in mind, this plan was abandoned. No chances could be taken that would permit the bow to come up first again. Confirming the soundness of this calculation, the last two divers up reported that S-51 had changed her list position from 20 degrees starboard to nearly upright or just a few degrees to starboard. It was clear that the submarine was moving with slight or no suction holding her.

The margin of positive buoyancy for starting the bow up after the stern had surfaced was not great, but it was thought to be adequate. The Salvage Officer kept in mind the forward group of oil tanks that could be blown if need be, although there was some risk of rupturing the tanks.

When the last diver had left the bottom, FALCON hauled clear, leaving S-51 about 150 feet away on the port beam and parallel to FALCON. The mooring buoys ahead and astern were dragged clear to afford an approach for the tug, SAGAMORE, which steamed in ahead and picked up both the buoyed-off bow towing lines to S-51. The other tug, IUKA, came in from astern to take the other towing line. The starboard mooring buoy was dragged clear so that the assisting submarine, S-50, could move in to furnish air from her banks.



S-51 UNDER TOW.
FIGURE C-4

Shortly after noon, the compressed air was applied to the engine room and motor rooms. After blowing for an hour, air started discharging at the surface over the engine room hatch. Blowing was maintained for a few minutes longer to ensure that both compartments were dry. The air pressure was then shifted to the control room and almost immediately air was seen escaping at the surface. This was a serious situation. It could only indicate that the control room was losing the air rapidly, or that the hose had carried away. No examination could be made as FALCON was not in diving position over S-51; and, in any case, with S-51 partially buoyant, diving would be too dangerous both to FALCON and to a diver. It had to be assumed that 60 tons of buoyancy were lost through the control room reflooding.

After blowing the stern pontoons for only 11 minutes, a large bubble mass appeared, followed shortly by the stern pontoons containing the stern of S-51 in the chain slings below the surface. All air was immediately sent to the six forward pontoons; blowing was continued on them as a group for about 40 minutes when several air discharges at various spots forward showed that some of the pontoons were dry.

Meanwhile, air was shutoff on all six bow pontoons and then re-applied to them one-at-a-time to test their condition. It was found that both the bow and third pair were venting air from forward and after ends. It was also found that the after ends of both pontoons in the second pair were venting air and were therefore also completely blown down. There remained only the forward ends of the second pair to be blown. All air was now concentrated on the two hoses leading to the forward ends of the second pair of pontoons. The situation was tense, as nearly an hour had gone by since the stern rose. Blowing was continued at a reduced speed and still pressure showed an increase on the second pair, indicating they were still forcing water out. Then the gages showed a pressure drop on the bow pontoons. The surface of the sea became turbulent and within a few minutes all pontoons were riding on the surface. The air was put on the forward group of fuel oil tanks which were blown clear, giving additional buoyancy.

C.10. S-51 Under Tow

Boats went alongside the pontoons and secured the flood valves and cleared the blowing hoses to FALCON. Late in the afternoon the towing operation got underway. IUKA led with a 100-fathom line to S-51. A preventer was secured between the bullnose of S-51 and her gun mount.

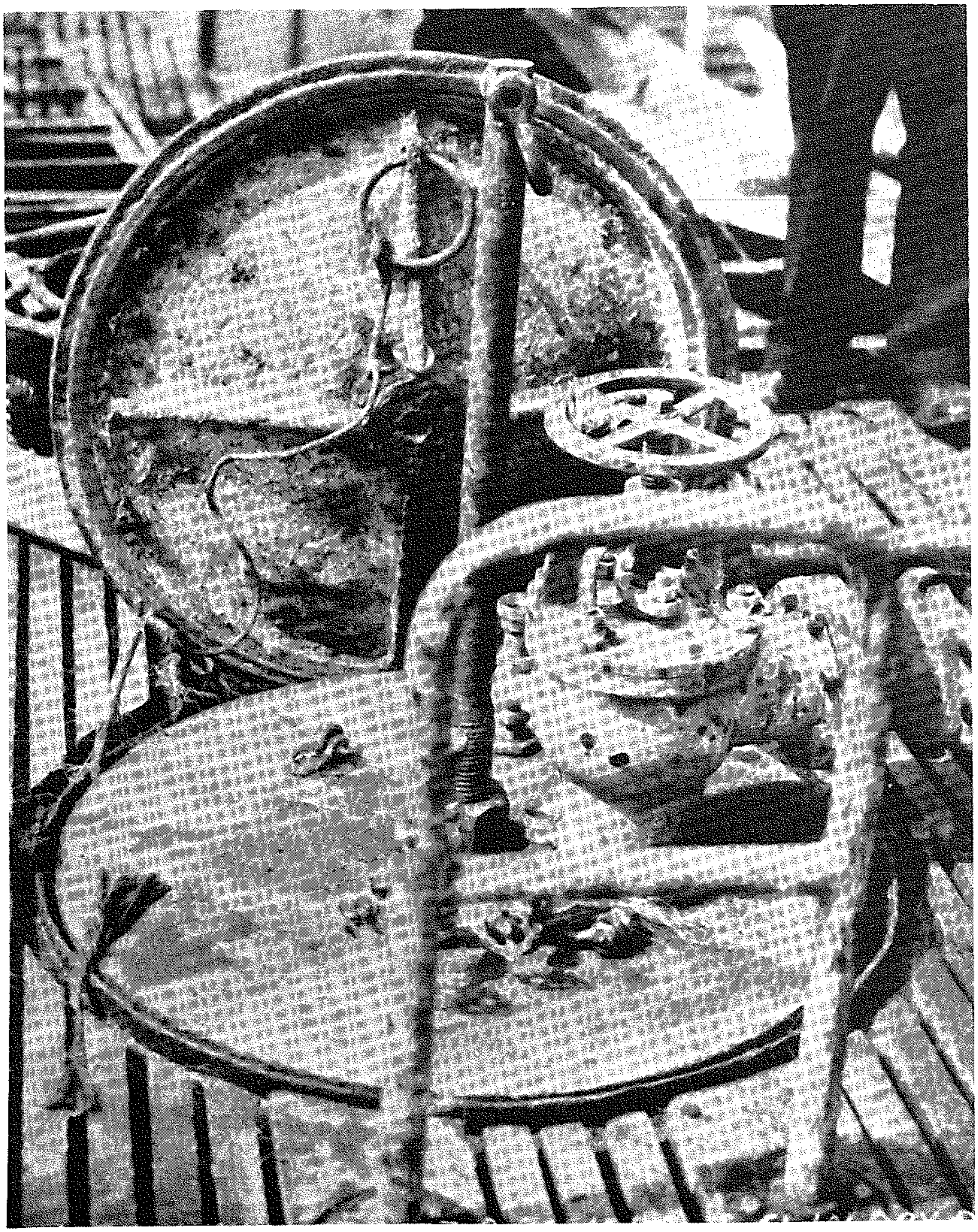
FALCON brought up the rear with her air hoses to the tanks, compartments, and pontoons. A 150-fathom line from the stern of S-51 to FALCON was used to prevent FALCON from dropping too far behind and parting the air hoses. An independent 10-inch manila line was run directly from FALCON's bow to SAGAMORE. FALCON was thus towed and was able to steer S-51 by use of the line to her stern.

The only part of S-51 which was clear of the water was the signal bridge of the conning tower. The periscope shears indicated that she was listing about 10 degrees to starboard. Maximum draft of the submarine was about 33 feet; this allowed a safe margin through all channels encountered and into drydock. It had been anticipated that the minimum draft throughout the tow would be 35 feet.

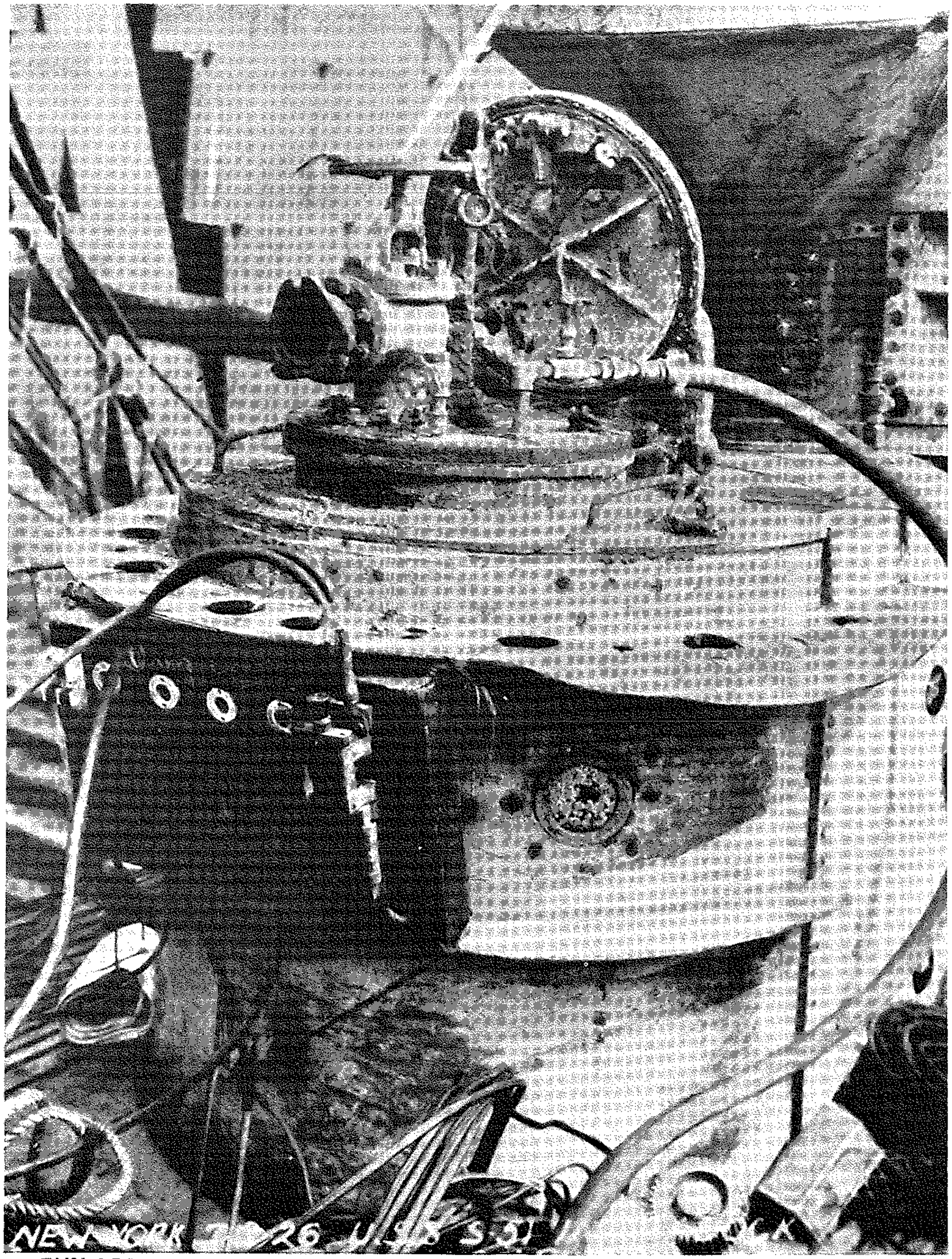
The first stage of the tow was on a course direct for Point Judith to get over shoal water as soon as possible. Towing speed varied between 2 and 3 knots. FALCON maintained air pressure on the hoses to counteract any additional flooding.

The tow proceeded satisfactorily until reaching the East River. Here, after passing Blackwells Island and only about a mile from the Navy Yard in Brooklyn, S-51 grounded on Man-of-War Rock. The second pair of pontoons broke loose as a result, and considerable effort was required in shortening slings on the remaining pontoons in order to refloat the wreck.

On 8 July, S-51 crossed the sill of the drydock in New York, 9-1/2 months after her sinking. The actual salvage time required to raise the submarine and bring her into drydock was 124 days.



ENGINE ROOM SALVAGE HATCH
IN POSITION, S-51.
FIGURE C-5



GUN ACCESS SALVAGE HATCH IN POSITION.
(NOTE AIR FITTINGS)
FIGURE C-6

APPENDIX

D. Salvage of USS S-4

D.1. The Collision

On Saturday, 17 December 1927, at 3:37 P.M., the submarine USS S-4 was making a submerged run on the measured mile off Provincetown, Massachusetts. As the submarine emerged from this run on a southwesterly course, the Coast Guard destroyer PAULDING struck it on the starboard side well forward of the gun at an angle of about 45°. PAULDING at the time was traveling at a high rate of speed (approximately 18 knots). The submarine was rising by the bow but had not emerged sufficiently to bring her hull out of the water. The force of the collision made S-4 roll to port and sink bow first beneath PAULDING.

D.2. The Position

S-4 came to rest at a depth of 102 feet in soft mud on the crest of a shallow ridge running parallel to the southern tip of Cape Cod. The submarine lay almost directly in the path of larger vessels leaving or entering the harbor of Provincetown from the west. However, the traffic during the winter season, aside from fishing crafts, was limited to Coast Guard cutters, small steamers, coastwise schooners, and tows which came into the harbor for shelter during storms. Fishing vessel traffic was well inshore of S-4. All other traffic was required to keep to the south of the wreck. Additionally, the area in which S-4 lay was fairly well sheltered from the seas and swell of the open ocean. Nevertheless, bad weather during the rescue attempt hampered diving operations.

D.3. Estimate of the Salvage Situation

The prospects for a satisfactory continuance of diving to start salvage work were not bright. The best information indicated only 2 or 3 diving days per week could be expected during the winter and spring. The winds were quite variable and their velocities ranged up to 80 miles per hour. The atmospheric air temperature varied from a minimum of 8°F above to a maximum of 43°F. Residents had indicated that 12°F was considered a low temperature, with 0°F temperature being unusual. Icing and freezing were to be expected and proved to be a problem.

The boats were frequently covered with ice and the engine cooling water froze. Working with the heavy hawsers was extremely difficult when they became iced and too stiff to handle on the bitts.

The winter was unusually free from heavy snow and rain, although the relative humidity frequently reached 100 percent. A high moisture content in the diving air caused snow to precipitate and ice to form in the air lines. Placing an air conditioning plant in operation proved satisfactory in controlling the moisture. The temperature of the water was erratic; at the beginning of the operation it varied from 34°F to 51°F. The higher temperature was recorded when the wind and tide carried warm water from the shallow part of Cape Cod toward the operating area. There was a marked difference between surface and bottom temperatures; on 26 December, the surface was at 38°F and the bottom temperature at 50°F. The temperature slowly decreased, reaching a low of 32°F near the first part of March. After 5 January the surface and bottom temperatures remained within 1°F of each other.

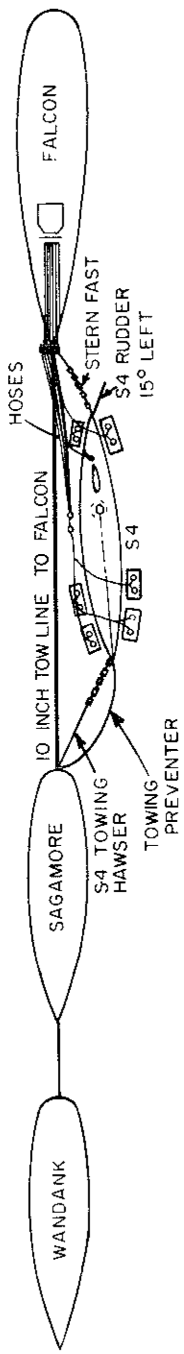
The current swept across the beam of S-4 at a maximum of 1-1/4 knots. This had to be considered in mooring, but did not interfere with the diving.

The ocean bottom at the salvage site had an upper layer of very soft silt or mud not more than 1-foot deep. Underneath this the bottom was more soft than hard; it was of a decidely sandy nature, and mixed with minute shells. The texture of the bottom was sufficiently coarse to permit the passage of water through it when blowing the main ballast tanks. The bottom was firm enough however to hold its position when excavating tunnels underneath the vessel. Due to the permeable character of the bottom, it was estimated that the so-called "suction effect" on the S-4 would be practically nil.

It should be noted that although the salvage operations were carried out during the dead of winter, the season was fairly mild. Even the worst storms were of relatively short duration, and none were so destructive in character as to cause serious damage to vessels of the salvage force, moorings, or buoys. In addition, Provincetown Harbor was within 2 miles and Boston Harbor (and the Navy Yard) were only about 45 miles away.

D.4. Salvage Force

The salvage force was composed of the submarine rescue vessel FALCON, the submarine tender BUSHNELL, tugs WANDANK



SUBMARINE S-4 UNDER TOW.

FIGURE D-1

and SAGAMORE, the submarine S-6, and various Coast Guard craft. Other components were the floating crane, UNITED STATES, and a steel coal barge. Boats and launches were available for transportation between ships of the force and nearby Provincetown.

BUSHNELL was the flagship of the force and acted as a depot for material and personnel, as well as a repair ship. It provided quarters for the extra personnel of the diving force (about forty one), supplied a daily working party to the diving vessel, and manufactured most of the special material.

The salvage and diving vessel, FALCON, was fitted out with air compressors, recompression chamber, and other apparatus essential to work of this character. The duty of the vessel was to provide a working platform from which diving and actual salvage operations could be conducted. When the weather permitted diving, FALCON would moor over the submarine using permanently established mooring buoys.

The tugs WANDANK and SAGAMORE acted as tenders to the diving vessel. When seas or wind picked up during diving operations, the tugs were used to hold FALCON in position by anchoring nearby and running mooring lines to FALCON.

S-6 was a model for S-4 and remained reasonably close so that divers could go aboard for instruction and rehearsal on short notice. In addition, the officers and crew of S-6 were expected to keep themselves cognizant of the progress of the work and offer suggestions and assistance to the salvage party whenever possible. S-6 carried on local maneuvers when she was not needed by the salvage force.

The manner of mooring the salvage vessel followed the method used in the S-51 salvage operation. Two 8-inch manila mooring lines were used forward, run to mooring buoys on the bow. One or two additional 7-and 8-inch manila lines were run forward, as occasion demanded, for preventers or for holding the ship in a fore-and-aft direction if her own anchors were not down.

Two 8-inch manila mooring lines were used aft on each of the two large sweep drums on the towing engine. These two lines ran out of the afterchocks to the quarter moorings, so that by hauling on one and veering on the other, the stern of FALCON could be moved from side-to-side. A 7-inch manila line from the afterchocks to a mooring buoy astern held the ship from going ahead.

The general salvage plan was to provide S-4 with the maximum amount of self-lift by dewatering the compartments and tanks. The additional buoyancy required would be obtained by use of pontoons. Information available indicated that the battery room and the No. 1 main ballast tank were damaged. All other compartments and tanks could probably be used for regaining buoyancy.

The Portsmouth Naval Shipyard supplied the Salvage Officer with information on volumes of compartments which formed the basis for his preliminary estimates of lift requirements. Buoyancy to be gained by the use of pontoons was justified by these estimates and the S-41 salvage experience.

High pressure air was to be used as the means for dewatering tanks and compartments. An air test performed on S-6 indicated that the hatches would stay seated up to about 10 psi of internal air pressure before they lifted, losing air. Each compartment or tank was to be entirely independent of the other spaces and would be sealed and blown down individually.

D.5. Sealing Compartments

Before proceeding with the sealing of compartments, the topside was cleared of lines and antennas. Diver access to the interior of the submarine was through the engine room hatch. After entrance was gained, the first job was to clear the compartment of debris that might foul the diver. Work inside the submarine proceeded very slowly because of the restricted space and poor visibility.

The following techniques were used to seal up compartments:

D.5.1. Torpedo Room

A strongback was placed over the torpedo hatch to hold the internal pressure as it built up in the compartment. The hull penetration for the acoustic listening device was sealed off. A hole was drilled and tapped in the torpedo hatch casing and a 3/4-inch globe valve installed for the blowing connection. A hole was also cut in the pressure hull between frames 33 and 34, and a spill pipe leading to the bottom of the compartment inserted and sealed. All work on the torpedo room was performed from outside the vessel because experiments on S-6 demonstrated that a diver, fully dressed, could not safely work his way into the compartment.

S-4 BREAKING SURFACE,
17 MARCH 1928.
FIGURE D-2

D.5.2. Battery Room

The battery room could not be sealed because of the collision damage. However, some buoyancy was achieved by injecting a 7-foot pipe section into the compartment to blow it down to the opening in the pressure hull.

D.5.3. Control Room and Conning Tower

Salvage efforts in these areas took considerable time because the positions of the large number of valves had to be checked and set. All openings in the bulkheads were closed. A spill pipe with hose and valve was placed in the magazine and connected to the trim manifold. Water was then forced from the magazine by applying air pressure.

There was no way to reinforce the conning tower hatch with a strongback. A collapsible container was fabricated and placed over the hatch. This device was then lined with canvas and filled with lead pigs and cement. The weight of this device held the hatch closed when air pressure was added to the compartment.

The air supply for blowing down the control room was obtained from the external air salvage line. This line was then broken in the control room to permit air to enter that compartment. The main induction valve, which seats with sea pressure (similar to hatches), was sealed shut with cement.

D.5.4. Engine Room

The engine room was to be dewatered by use of a salvage hatch in place of the regular hatch. This was a steel plate with a gasket held in place by a strongback. The plate had a non-collapsible hose with check valve and stop valve mounted on the outside. An exterior air connection was fitted to the hatch for attachment of the blowing hose.

To ensure that the suction hose would not become fouled when the hatch was lowered into place, a trough was secured to the ladder. This guided the spill pipe to the lowest point in the compartment.

D.5.5. Motor Room

The motor room was fitted with a similar salvage hatch to dewater the compartment.

As each compartment was rigged, it was blown to ensure that the units were functioning as they should. After testing, the compartments were reflooded to keep the submarine from shifting until it was ready for raising.

D.5.6. Main Ballast Tanks

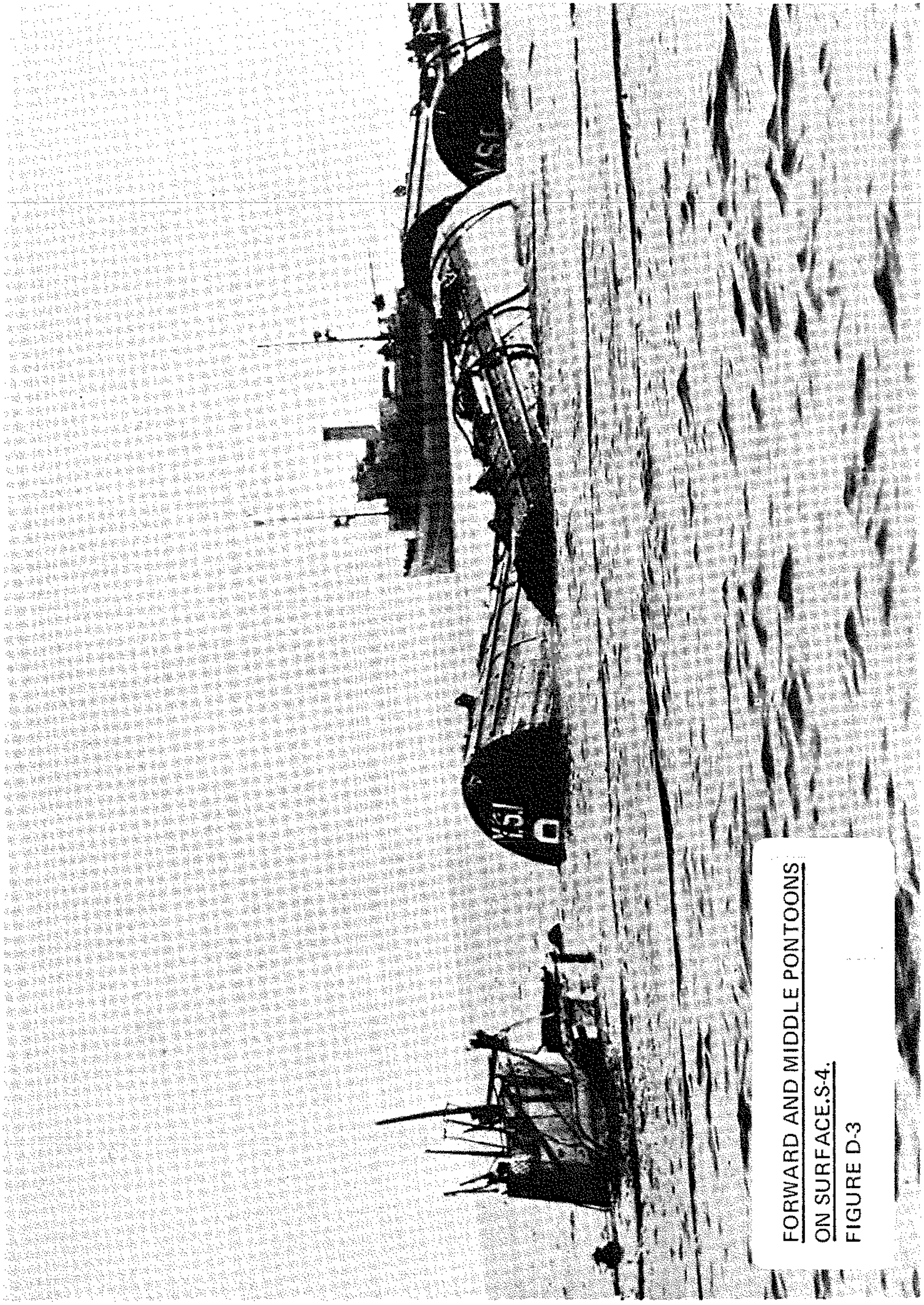
The starboard forward main ballast tank had been damaged and could not be used. The blow valve for No. 1 main ballast was shut at the high pressure manifold and the other main ballast tanks were blown via the external high pressure air connection. When the air was first connected to the ballast tanks, a leak was discovered in the cover of the No. 2 main ballast vent valve. A 1/4-inch iron pipe plug had been eaten away due to galvanic action that had occurred since the sinking. This was quickly replaced and the main ballast and safety tanks dewatered. These were left de-watered because it was feared that if reflooded, sand and mud would enter through the Kingston valves.

D.5.7. Fuel Oil Tanks

The air supply was first connected to a cross connect in the engine room and an attempt made to blow the oil out of the filling connection. When this did not succeed, a hole was cut in the No. 2 fuel tank for the oil and water to escape. When air pressure was applied, no air flow was achieved, indicating some valves that could not be reached were shut. A connection for the air supply was made via one of the screwholes in a manhole cover near the bottom of No. 6 fuel oil tank. The screw was removed and a threaded fitting put in its place and the air hose attached. A check revealed that the fuel tanks could now be blown. It was decided not to use these tanks except in an emergency since the oil would contaminate the salvage area. Because the blowing connection was at the bottom of No. 6 tank, and No. 2 tank at the other end of the series was open to sea, the difference in head forced the oil up the blowing hose when the pressure was vented. This oil was permitted to flow (150 to 200 gallons an hour) into the forward bunkers of FALCON.

D.5.8. Miscellaneous Buoyancy and Work

The bow buoyancy tank was blown by placing a hook pipe on the end of a blowing hose in one of the flooding holes and blowing it. A hole was cut in the bottom of the forward trim tank and it was blown by putting the hooked pipe in this hole also.



FORWARD AND MIDDLE PONTOONS
ON SURFACE.S-4.
FIGURE D-3

An attempt to blow the auxiliary ballast tanks was considered, but it was decided that too many complications were involved. It was also assumed that the auxiliaries were only about half filled, and, thus, not much additional buoyancy could be obtained from them.

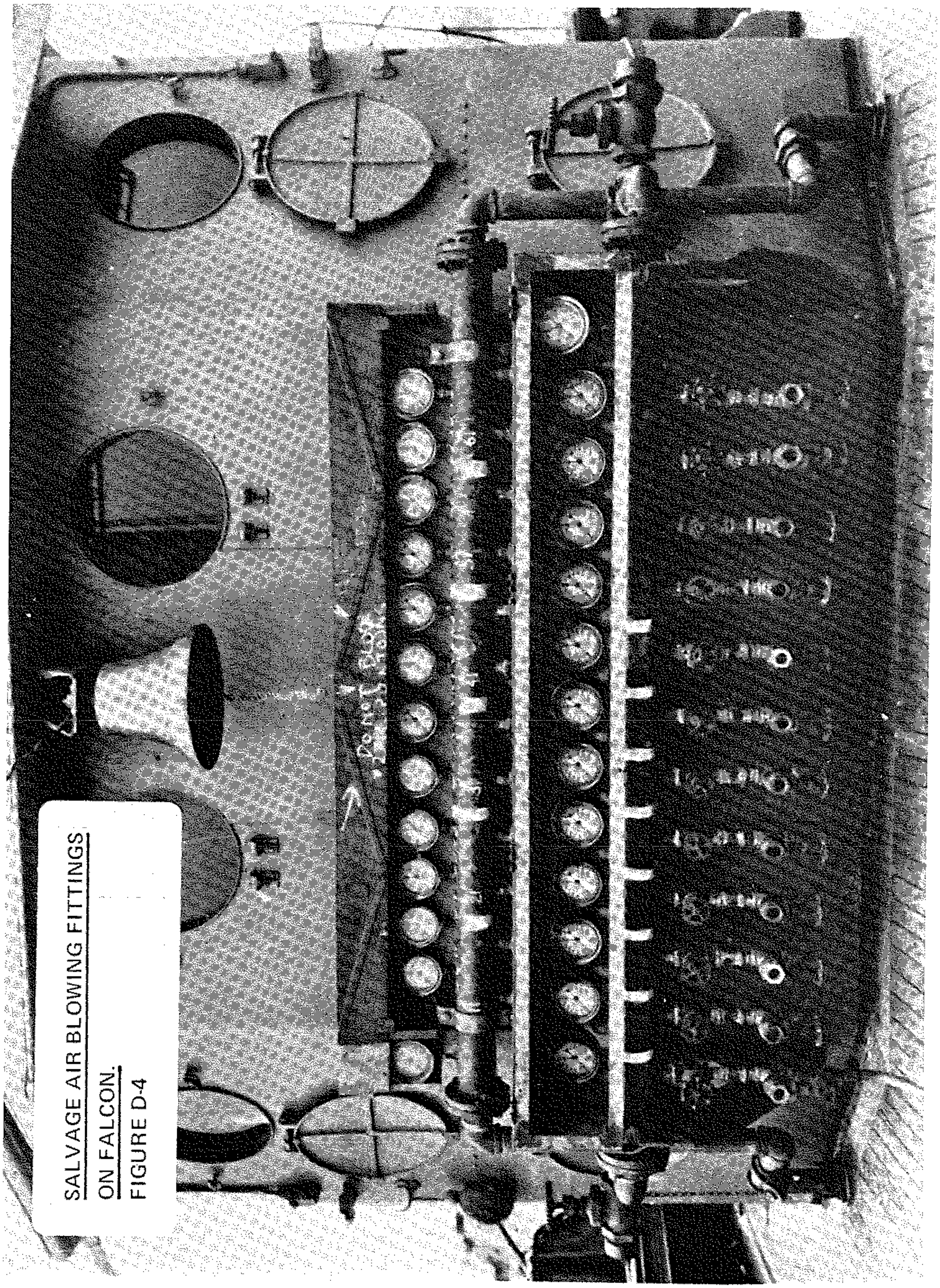
The outboard ventilation line started to leak air when the control room was blown. It was discovered that air was coming from a ruptured section up forward. A flange was broken forward and aft of the control room and the section over the control room blanked off.

D.6. Preparation of Pontoons

Six pontoons and equipment for handling and attaching to S-4 were prepared. Type II pontoons were used. The center compartment had sufficient buoyancy to support the major weight portion of the pontoon. With the two end compartments fully flooded, the pontoon has a slight negative buoyancy (3 to 4 tons) and sinks. When the end compartments are blown to the bottom of the drop pipes, there is sufficient buoyancy (8 tons) to hold the chains and keep tension on them. When the full lift of 80 tons is desired, the end compartments are completely blown.

To prepare for reeving the slings, tunnels were washed at each point where chains were to pass under the hull (frames 19, 46 and the stern). A 1-1/2-inch line was passed under the vessel from a diver on one side to a diver on the other. By hauling on the 1-1/2-inch line, a 2-1/2-inch line was passed which in turn pulled a 6-inch manila line under the submarine. The 6-inch line then hauled the 1-inch reeving wire under the hull. This 1-inch wire was used to pull the 2-1/2-inch chain sling. As the slings were rigged, the wire was buoyed off on the surface until the pontoons were ready to be lowered. A messenger wire was run through the hawsepipe in the pontoon and connected to the reeving wire. Then the pontoon was flooded and lowered. As it went down, the reeving wire and then the chain were pulled through the hawsepipe. Two chains were used for each set of pontoons. A diver counted the links as the chain came through the hawsepipe and placed a toggle bar in the correct link which was painted. When the toggle bar was inserted and the locking bolt secured, the reeving line on the chain was cast off. When both pontoons of a pair were in place, they were blown down to the bottom of the drop pipe. This kept the chain taut and prevented it from sinking.

Bow plane guards were fabricated and installed to prevent the forward pontoon chain slings from fouling between the planes and the hull.



SALVAGE AIR BLOWING FITTINGS ON FALCON.
FIGURE D-4

For the middle pontoons, a wire preventer was secured to the gun mount and connected to both ends of the after chain to prevent them from slipping forward.

The work of making preparations to attach pontoons and to seal up compartments went on simultaneously.

D.7. Towing Bridle and Arrangement

A towing bridle was rigged before S-4 was raised and the towing hawser on the submarine was used as a preventer. Since the rudder on S-4 was 15° left, it was expected the submarine under tow would veer to port.

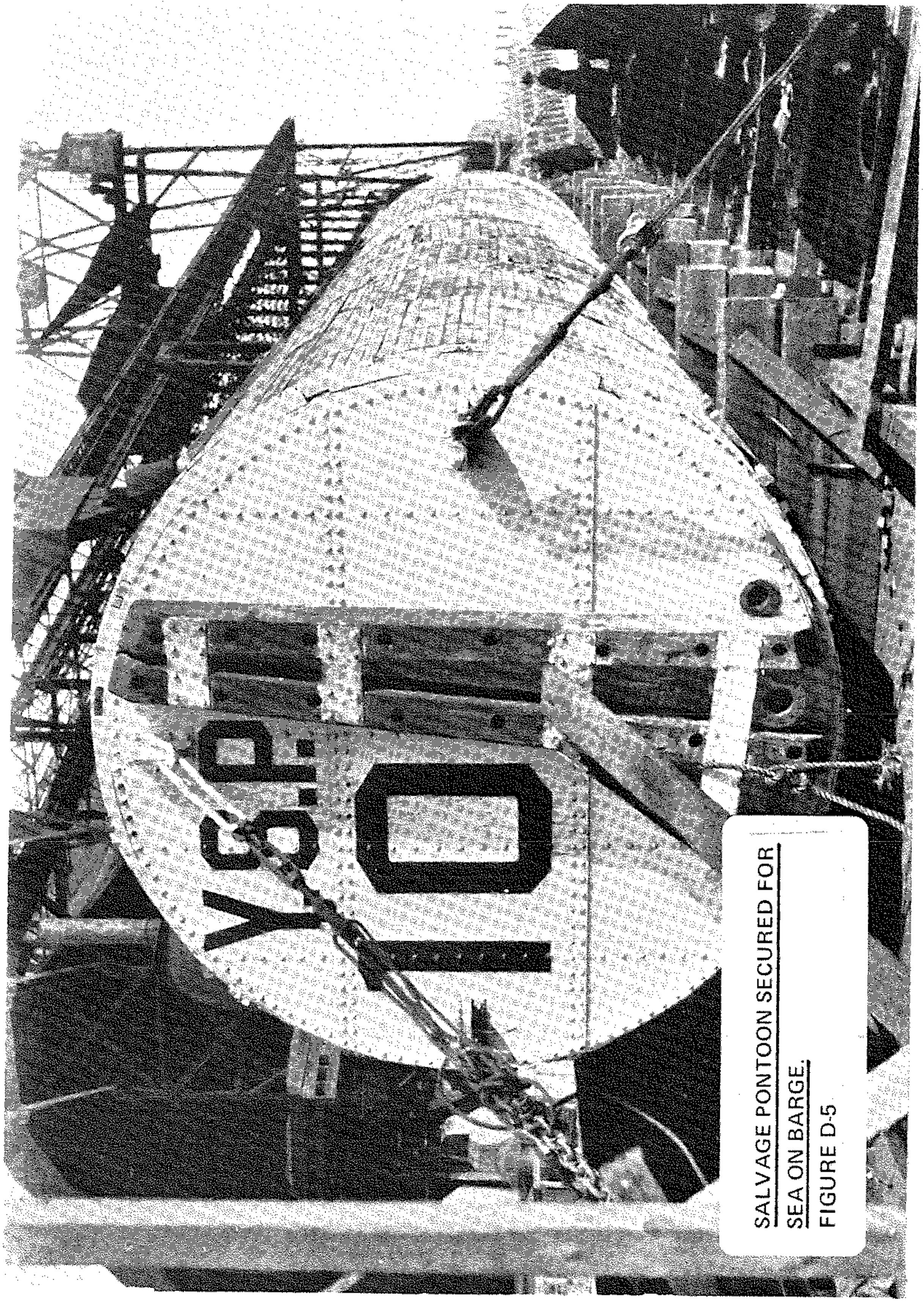
D.8. Raising S-4

The sources for air during the final blowing of compartments and tanks on S-4 were as follows:

FALCON had two salvage compressors rated at 150 cubic feet per minute at 150 psi and three smaller compressors with a capacity of 33 cubic feet per minute at 80 psi. The two diving compressors (150 cubic feet per minute at 150 psi), were put on the line for the lift operation. The air banks had a capacity of 103 cubic feet at full charge of 2,500 psi. Submarine S-6 supplied air from her banks via a fire hose. Pressure on this line was maintained at 125 psi to the air manifold of FALCON.

(Figure D-1 illustrates the positions taken by the various ships assisting in the operation.) It had been decided to blow the compartments before blowing the pontoons. The main ballast tanks were already blown and it had been previously decided not to blow the fuel tanks unless necessary.

As the blowing operation progressed, it was decided to leave some water in the engine room and the torpedo room. Compartment blowing ceased and they were vented to about 35 psi. The blowing of pontoons started when pressure was applied to the stern pontoons. This was to lift the stern first and permit the chains of the forward pontoons to obtain a better grip. When the stern pontoons appeared on the surface, the forward and center pontoons were blown. Shortly after the hoses started rising to the surface, the periscope fairwater of S-4 appeared in the midst of a seething mass of foam.



SALVAGE PONTOON SECURED FOR SEA ON BARGE.
FIGURE D-5

At first the bridge rail was barely awash, but as the pontoons and the compartments blew themselves dry with the excess air pressure inside, S-4 rose until about half of the bridge was out of the water.

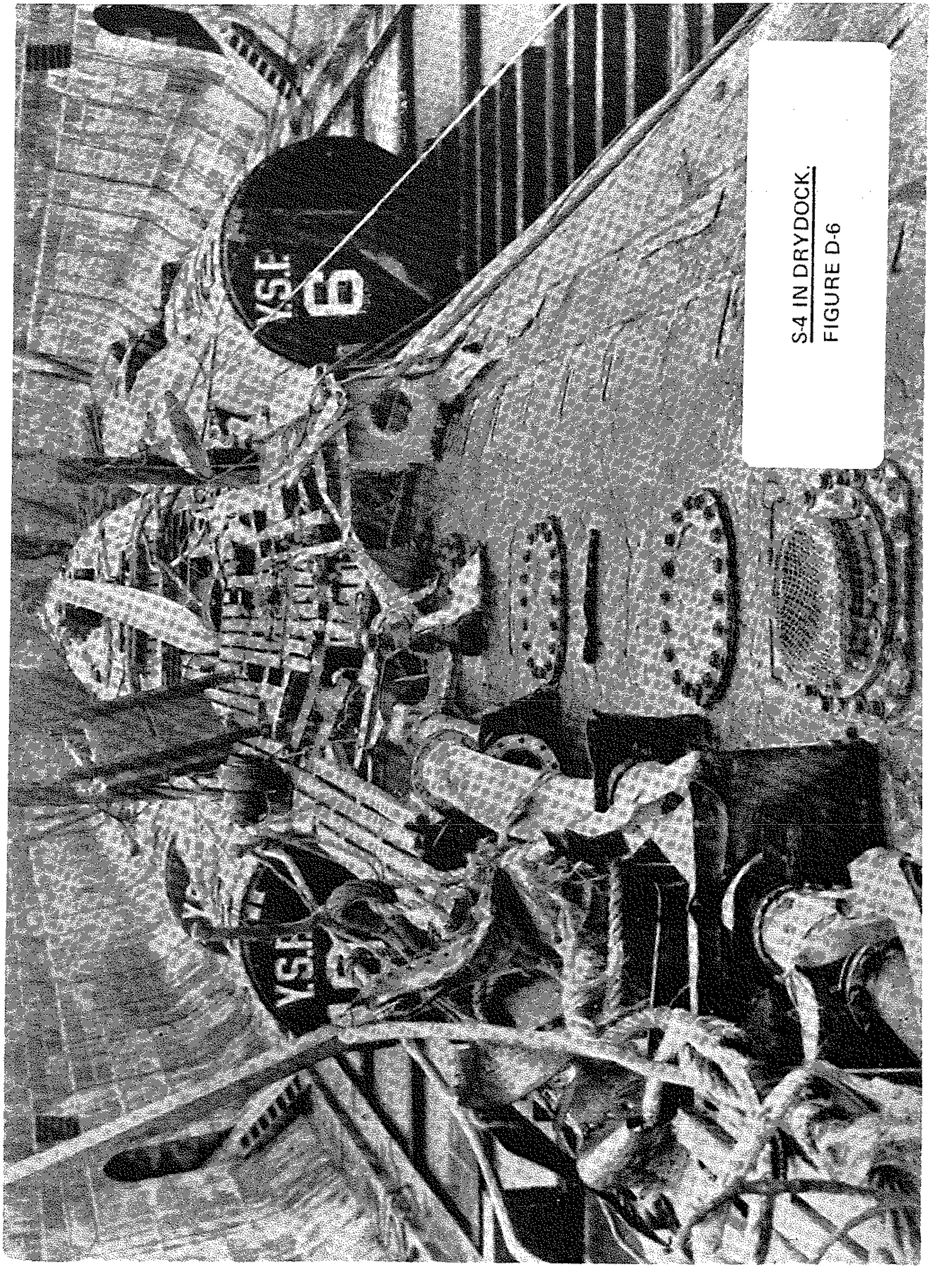
D.9. Towing S-4

As soon as S-4 reached the surface, the following steps were taken in preparation for the tow (Figure D-1):

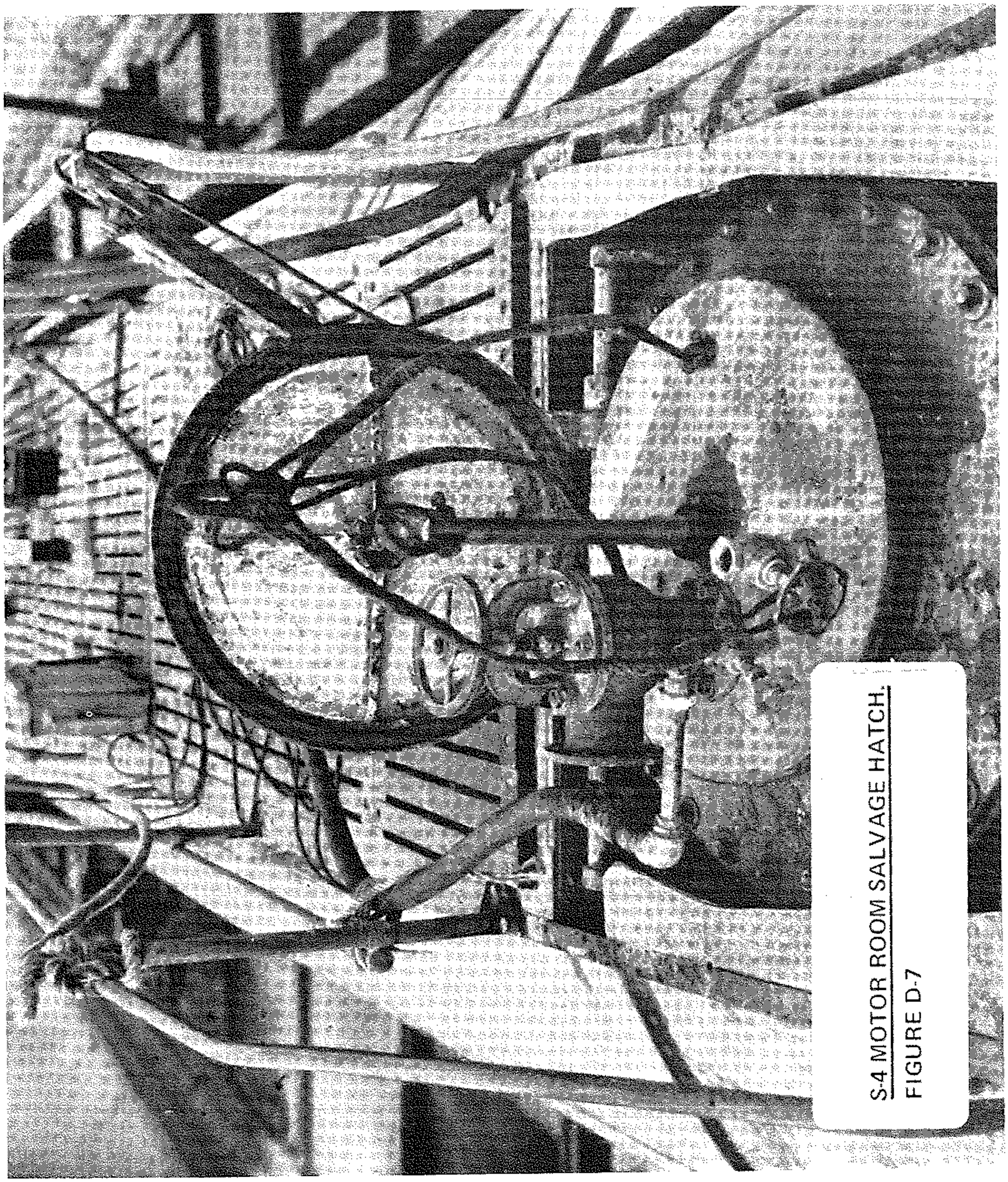
1. Hoses were lashed to the pontoons.
2. Sluice and flood valves were closed.
3. Blowing hoses to FALCON were shortened.
4. Anchors and buoys were cleared from the area.

SAGAMORE started westward to Boston with the tow while WANDANK was taking her station. Speed was increased slowly to 5 knots at which, in the smooth sea, the tow rode very well. However, it was feared that this speed would bring unnecessary loads on the towing and pontoon gear, and the speed was reduced to 3.7 knots.

The following day, the salvage fleet entered port with wind and sea building up to storm proportions. Had the ships delayed more than 2 or 3 hours in getting underway, the operations might have ended disasterously.



S-4 IN DRYDOCK.
FIGURE D-6



S-4 MOTOR ROOM SALVAGE HATCH.
FIGURE D-7

APPENDIX

E. Salvage of USS SQUALUS

E.1. Submarine Sunk

On 23 May 1939, USS SQUALUS was on training operations near Portsmouth, New Hampshire. While making a quick dive at 16 knots, water suddenly entered the engine room and after battery compartment through the air induction line. The submarine settled stern first and came to rest on the bottom in 240 feet of water. The watertight door between the control room and the after battery room was closed after an estimated 50 tons of water had entered the control room.

SQUALUS had an up angle of about 6 degrees and no list. The after battery room was known to be flooded, but the condition of the two engine rooms and the after torpedo room was unknown. Thirty-three men were in the three forward compartments. No response could be obtained from the twenty-six men in the after part of the ship. Main ballast tanks were blown, but the submarine could not regain positive buoyancy. During the next 40 hours, thirty-three survivors in SQUALUS were rescued by the McCann rescue chamber. The operation then became one of salvage.

E.2. Salvage Plan

E.2.1. Submarine Condition

Upon completion of the rescue operation, it was apparent that all of the four after compartments were flooded and open to the sea. Survivors reported that the main ballast flood valves and emergency vents were open, the main vents were closed, all hatches and other hull openings forward were secured, and from the after battery compartment forward, there was watertight integrity. It was also reported that flooding appeared to have taken place through the main induction valve. (See Figure E-1 for the arrangement of compartments and tanks.)

While the divers were attaching the rescue chamber's downhaul cable to the after torpedo room hatch during the rescue operations, they reported that the superstructure deck at the hatch was only about 2-feet above the bottom. This meant that the base line of the submarine at this point was about 20-feet deep in the clay bottom.

It was later ascertained that the keel of the ship was clear of the bottom for about 70 feet at the forward end.

E.2.2. Salvage Factors

In devising a salvage plan, the following factors were considered:

1. Except in an emergency involving human life, the maximum time allowed for a diver on the bottom or on the submarine at the 240-foot depth was to be 20 minutes. This precluded sending divers inside the submarine.

2. Only one diver would be allowed on the bottom at one time, except in an emergency.

3. Heavy physical labor could not be performed by divers in such depths, which ruled out any efforts to close the main induction valve before the first lift.

4. The ship was provided with high and low salvage air connections for all compartments and with salvage air connections to the tops of all main ballast and fuel oil tanks.

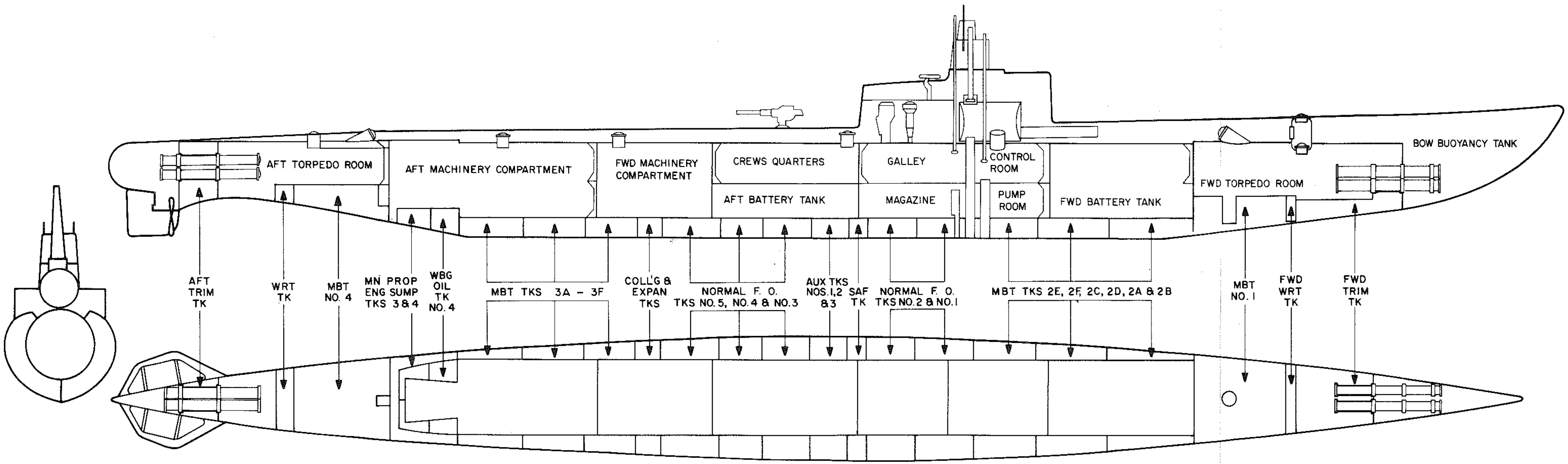
5. Except for the open induction valve, the ship was in normal condition for submerged operation.

6. The weight of water inside the ship could be estimated with a fair degree of accuracy.

7. Two 60-ton and seven 80-ton submersible pontoons were available.

8. It was known that a cable clamp had been designed by Portsmouth for use with wire rope slings and tested satisfactorily on S-4.

9. With the emergency vents open, the three main ballast tanks on each side of No. 2 and No. 3 group would each act as a single tank about 45 feet long, with flood valves distributed throughout its entire length. Because of this flood valve distribution, the amount of water which could be blown from these tanks decreased as the trim angle of the ship increased. At 20 degrees, about three-quarters, and at 30 degrees, about one-half of the buoyant capacity of these tanks could be recovered after one end had been lifted. About 90 percent of the main ballast tank buoyancy could be recovered during breakout.



SQUALUS COMPARTMENT AND BALLAST TANK ARRANGEMENT.

FIGURE E-1

10. More than 90 percent of the buoyant capacity of the fuel oil tanks could be recovered.

E.2.3. Salvage Method

In order to reduce the possibility of slow flooding of dry compartments, hoses were attached and the internal pressure was built up to equal sea pressure. So far as could be ascertained, no further flooding took place. Consideration of the above factors led to the following salvage method:

1. Employ the buoyancy of all main ballast and fuel oil tanks.

2. Lift the ship in three stages of about 80 feet each. For this lift, the trim angle would not exceed a maximum of 20 degrees. At this angle, slippage of the slings was considered improbable and preventers would not be required.

3. Do not dewater the after compartments or the variable ballast tanks while the submarine is in deep water.

4. Provide external lift needed to supplement the self-lift of the ballast tanks using two groups of pontoons, one group forward where slings could be swept under the ship, and one group aft. With this arrangement, only one tunnel was needed for the after slings.

5. Wash the sling tunnel at frame 180 where the depth of the keel was about 15 feet below the mud. The shape of the keel at this point was such as to limit the amount the sling could slip along the bottom. It was estimated that a lift in excess of 500 tons could be applied at this location without damage to the submarine, provided the slings were placed between the hull and the propeller shafts.

6. Lift the stern first because more self-lift could be maintained by the main ballast tanks while the ship was on the bottom than could be maintained if either the bow or stern were lifted. The amount of this additional lift was about 80 tons and it would be a valuable asset while breaking out the stern, but would not be needed after the stern had been broken out.

7. Limit the height of the lift of each end to the desired 80 feet by placing control pontoons 80 feet below the surface. When the control pontoons reached the surface, the submarine would stop and be suspended in the slings 80 feet off the bottom.

8. Use wire rope slings, with a 15-fathom shot of chain in way of the hull to take the chafing. This arrangement involves less weight than chain slings and requires less work by divers in setting the pontoons.

9. Place pontoons athwartships for the first two lifts. This simplifies setting the pontoons by permitting the two ends of a single sling to be placed through the two hawsepipes of a single pontoon. The placing of each pontoon can then be completed independently of any other pontoon. This can be accomplished only if the ship is to be lifted part way to the surface. If she is to be completely lifted to the surface at a draft that will permit her to enter a harbor, the pontoons must be placed parallel to the axis of the ship and set simultaneously as they must share a pair of slings.

10. Arrange the slings and pontoons as shown in Figure E-2 for the first lift. Calculations indicated that the stern could be lifted first with a reasonable margin of lift for bottom breakout and the bow could be lifted in the next operation.

11. Tow the ship toward shallow water after the first lift and ground her in a favorable spot. The control pontoons would then be lowered 80 feet below the surface and a second lift made in the same manner as the first. The ship would again be towed toward shallow water and grounded again, this time at about the 80-foot depth.

12. Bring the submarine to a draft of less than 40 feet in the third lift so she could be towed to the Portsmouth Navy Yard for drydocking. For this lift, the induction valve would be closed by divers by means of the external gagging gear. The water in all flooded compartments would be pumped out by the salvage pump on the rescue vessel through the low salvage air connection. Pumping required only that hoses be connected to the compartment low salvage air connections and that air be fed to the flooded compartments through the high connection at a pressure equal to sea pressure. By pumping rather than blowing, the work of making the compartments capable of holding an internal pressure higher than sea pressure could be avoided. Pontoons placed parallel to the axis and close to the ship would be used to make up any additional lift required.

E.3. Salvage Force

A large number of vessels are required to support a salvage operation and SQUALUS salvage was no exception.

The following vessels were made available:

1. USS FALCON - salvage vessel - used as a diving platform, and actual salvage work was performed from it.

2. USS WANDANK - tender for FALCON - assisted FALCON when mooring, and helped to maintain her position when seas and wind threatened the security of the moorings.

3. USS SAGAMORE - tender for FALCON.

4. USS SACRAMENTO - flag ship - provided quarters for divers and salvage force and stored material until required by FALCON.

5. CG 409 & 410 - dispatch boats - made regularly scheduled trips between Portsmouth Navy Yard and the salvage area.

6. CG 991 - work boat - towed pontoons, placed anchors, etc.

7. USS SCULPIN - a sister ship from the same building yard - practice ship for divers and model to check position of valves and other equipment, as well as to rehearse operations to be performed underwater.

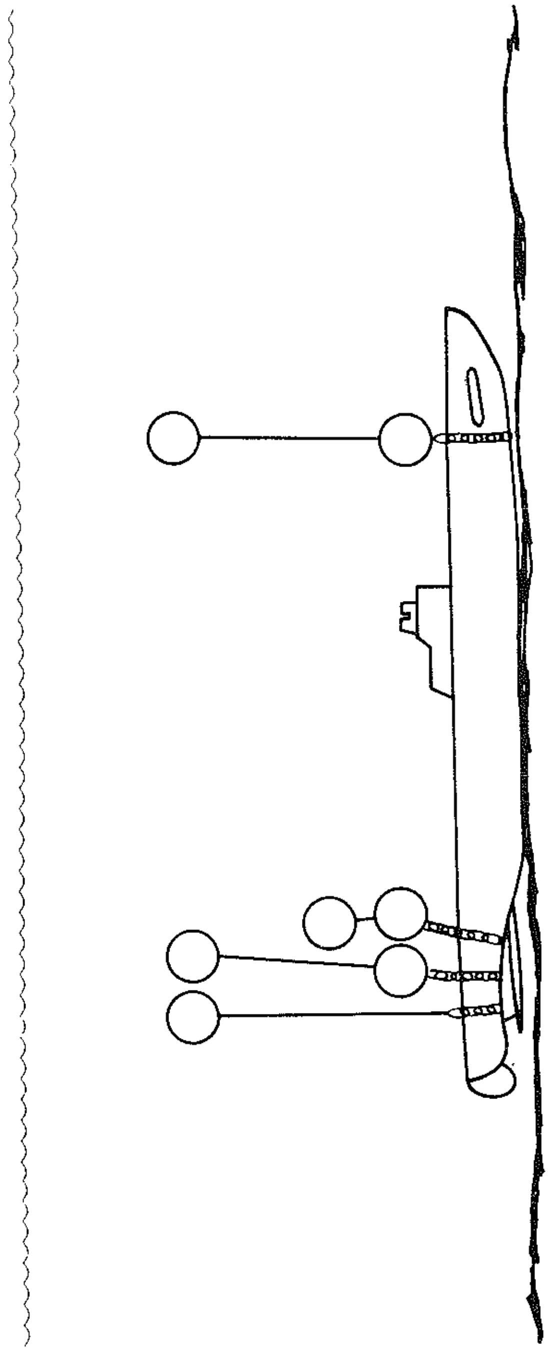
8. PENECOOK - harbor tug.

E.4. Diving Gases

When diving operations on SQUALUS began, difficulties were encountered. The divers were experiencing nitrogen narcosis while diving to the depth of 240 feet. It was decided to employ the helium-oxygen breathing mixture that was under research at the experimental diving unit. Although the research work had not been completed, the equipment necessary to dive with this helium-oxygen mixture was available, and tests had already demonstrated that such a gas mixture was definitely better than air at deep depths. (Refer to Paragraph 2.2.) The use of these gases required the divers to wear special electrically heated underwear since the gas mixture was a better heat conductor than air.

E.5. Pipe Lance

A sectional pipe lance bent into the arc of a circle and of the correct diameter to pass around the hull inboard of the shafts was used to get a messenger line under the stern.



SEVEN-PONTOON ARRANGEMENT ON SQUALUS FOR UNSUCCESSFUL FIRST LIFT.

FIGURE E-2

The end of the lance was equipped with a self-propelled nozzle similar to the one used in washing out tunnels. A series of reaction jets were added along the lance to assist in forcing it through the mud.

A water hose was attached to one end of the lance and a diver guided it in the desired direction. When it was believed that the lance had come up to the surface of the mud on the opposite side of the submarine, air was forced through the lance. A diver then located the nozzle by following the stream of bubbles emitting from it. Once the lance was passed under the submarine, a steel snake was run through it and used to pull a messenger line through. The messenger line was then used to pull a larger line for the sling under the submarine. This, in turn, was used to pull out the lance and to haul under the submarine a 1-inch wire reeving line.

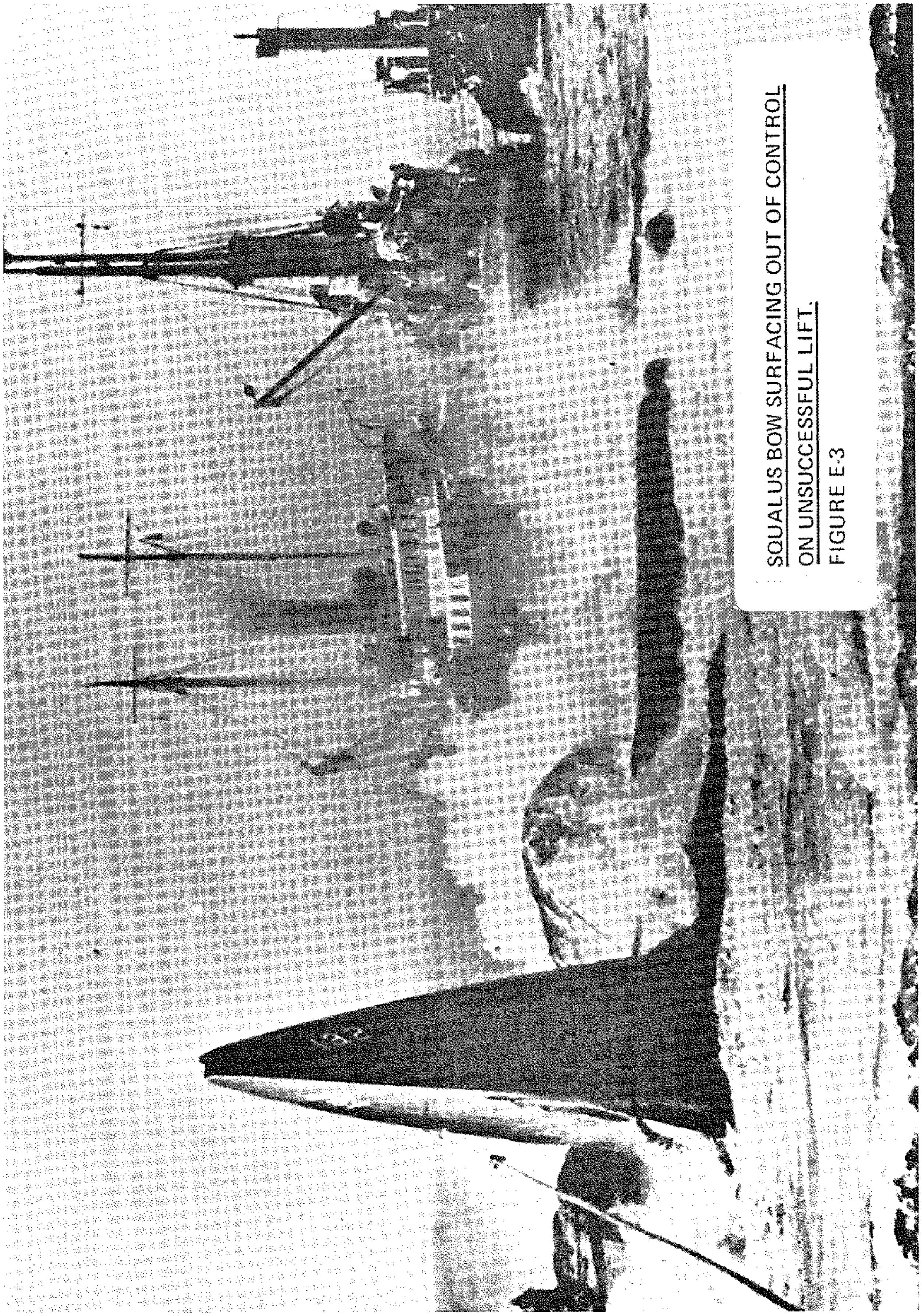
E.6. First Lift Attempt - 13 July 1939

The pontoon arrangement for the first lift attempt involved seven pontoons (Figure E-2). At the stern were three lift pontoons and two control pontoons. The bow had one lift and one control pontoon.

The control pontoons and fuel oil tanks No.'s 3, 4 and 5 were blown in preparation for the first lift. The remainder of the stern pontoons were blown next. Then, starting aft and working forward, the main ballast tanks and remaining fuel oil tanks were blown in succession.

As No. 1 fuel oil tank was being blown, the stern started rising. The two control pontoons came to the surface and their slings went slack. Momentum of the submarine had made it continue to rise after the lift of the upper pontoons was lost, but it soon settled back on the slings and the control pontoons supported some of the load with the stern 80 feet above the bottom.

With the stern lifted, main ballast tanks 1 and 2 were blown in that order. While blowing No. 2 main ballast tank, the bow started rising. The control pontoon reached the surface and about 30 seconds later the lower lift pontoon rose up beneath it, followed by the bow of SQUALUS (Figure E-3). At this time the large up angle caused the stern slings to slip forward along the keel and the sling with the two lowest pontoons parted, probably due to the dynamic loading when the sling was stopped by the after stern tube bearing.



SQUALUS BOW SURFACING OUT OF CONTROL
ON UNSUCCESSFUL LIFT.
FIGURE E-3

The loss of buoyancy at the stern permitted the stern to sink and the submarine slipped back out of the forward sling which was now slack. The large up angle which was exceeded (45 degrees) caused air to spill from main ballast tank No. 2. This, together with the loss of the bow pontoons, permitted the bow to sink also. The attitude of the ship when she reached the bottom was nearly identical to its original attitude.

There was some damage to the pontoons that had collided with one another, and damage and entanglement of many hoses. It was decided to remove the remaining stern slings for careful inspection. An attempt was made to disentangle the hoses, but this proved too difficult. The original hoses were cut away and new hoses rigged. All hoses to the ship were replaced.

The failure of this attempt was caused by a lack of sufficient control at the bow. The margin of control over that dictated by the static calculations proved to be inadequate. When the ship had been raised and a post salvage inspection made, a small leak was discovered between No. 3 main ballast tank and the flooded compartments. This apparently caused partial dewatering of the after torpedo room, while the stern was up and the No. 3 main ballast tank was blown. When the bow rose, free surface caused the bow to become too light. Whether or not the single bow control pontoon would have been adequate had this leak not existed, is not known, but the delay caused by this unsuccessful attempt was much greater than was anticipated when the risks had been considered prior to the first lift attempt.

E.7. Revised Salvage Plan

The salvage plan was modified to provide additional pontoons for lift control. At the stern, six pontoons would be used: three control pontoons at the 80-foot depth, one lift pontoon at 160 feet depth, and two lift pontoons at 200 feet depth. Four pontoons would be used at the bow: three control pontoons at 74 feet and one lift pontoon at 194 feet (see Figure E-4). The additional pontoons near the surface were considered sufficient to control each end after the desired 80-foot lift. The low pontoon at the bow was placed near the ship so that in case the slings started to slip aft, it would strike the bridge and thus limit the distance the sling could slip. The bow slings were placed aft of the bow planes and a preventer lashed the slings close to the sides of the ship so as to prevent them from sliding forward since the bow planes were in the rigged out position.

E.8. Successful First Lift - 11 August 1939

After one month the ship was ready to be lifted in accordance with the revised salvage plan. The preliminary step consisted of blowing two of the upper pontoons at the bow, and the three upper pontoons at the stern. This was followed by blowing the third upper pontoon at the bow and No. 3 main ballast tank. The remaining three pontoons at the stern were then blown in succession. As the last pontoon at the stern was being blown,the stern started to rise. The three upper stern pontoons broke the surface and settled down barely awash. Fuel tank No. 5 was then blown to provide additional buoyancy.

The lower bow pontoon and fuel oil tank No. 1 were blown and the bow started up. By not using the main ballast tanks forward, the gain in buoyancy as the bow rose was limited to the capacity of the fuel tank being blown when the submarine started rising. Because of the small pipe size through which the water was expelled from the tank, the gain in buoyancy was not rapid. The three upper pontoons came to the surface and settled down awash. To gain additional buoyancy, forward fuel oil tank No. 1, main ballast tank No. 1, and part of fuel oil tank No. 2 were blown.

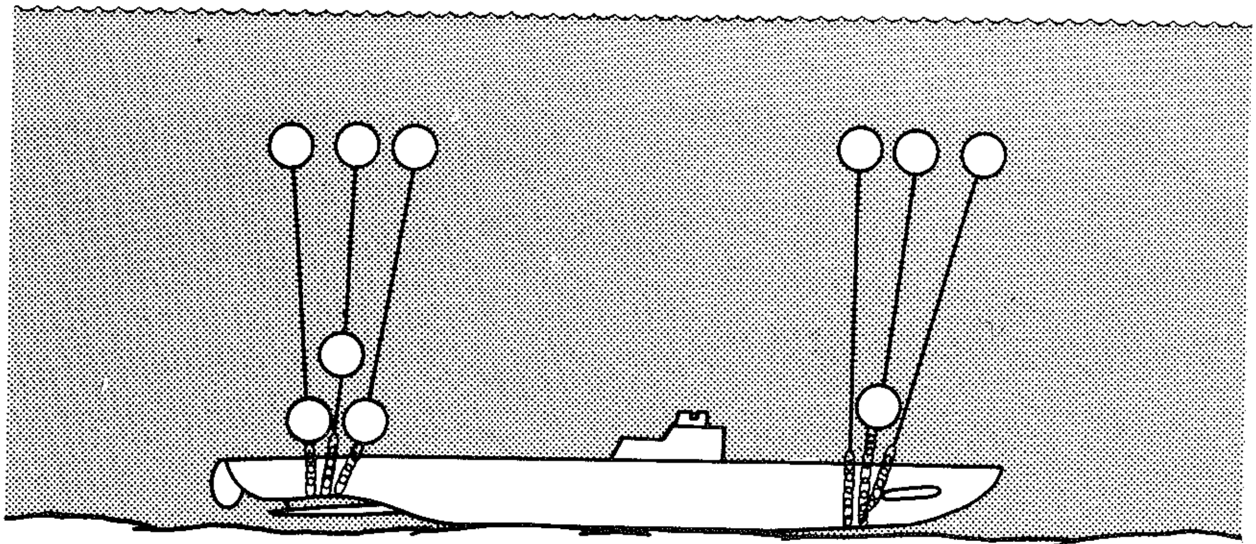
E.9. The Tow

WANDANK picked up the stern towing line and got underway assisted by the tug PENACOOK and a Coast Guard dispatch boat. FALCON slipped her moorings and took the bow line of SQUALUS. This was to assist FALCON in maintaining position and prevent parting of air hoses.

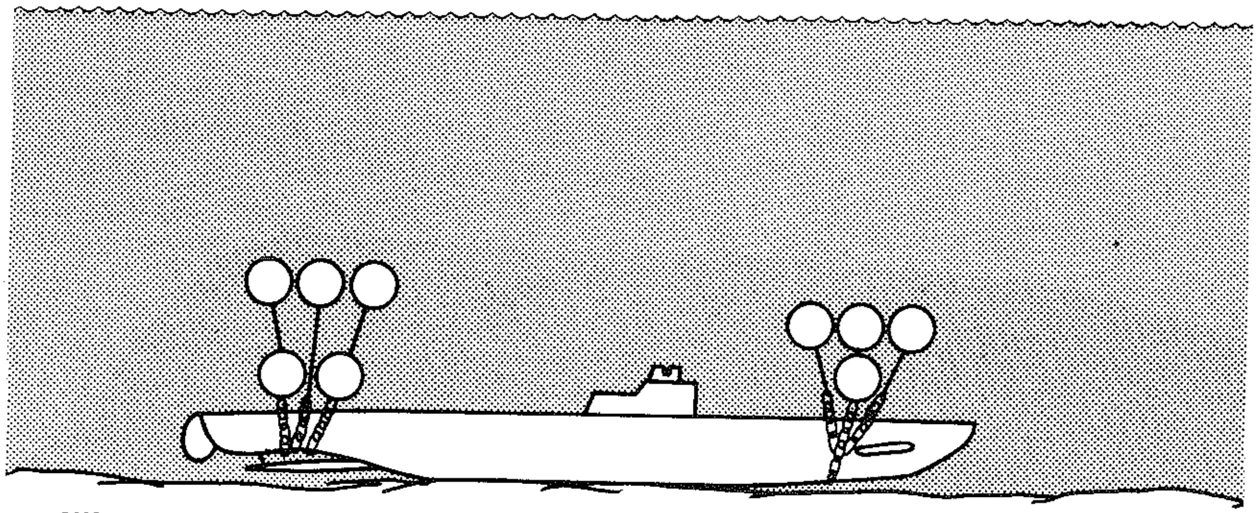
SQUALUS grounded on a bank about 3-1/2 miles south of White Island Light. The pontoons and tanks were then flooded to set her on the bottom. The three upper stern pontoons remained on the surface, but the upper bow pontoons went down about 20 feet, indicating SQUALUS was resting on a sloping bottom. Five temporary moorings were planted for FALCON, three at the stern (windward) and two at the bow.

E.10. Resetting the Pontoons

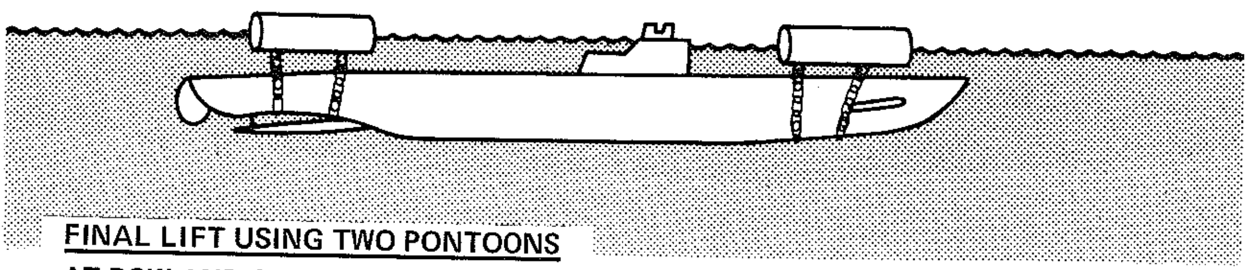
The three upper pontoons forward were reset to a depth of 105 feet. Two of the upper pontoons at the stern were lowered to 80 feet. This put them level with the one that was at 160 feet on the second lift. Since there was no large breakout requirement, the other pontoon at the stern was removed, leaving five pontoons connected to the stern (see Figure E-5).



TEN-PONTOON ARRANGEMENT FOR SUCCESSFUL FIRST LIFT.
FIGURE E-4



NINE-PONTOON ARRANGEMENT USED ON SECOND LIFT.
FIGURE E-5



FINAL LIFT USING TWO PONTOONS AT BOW AND STERN.
FIGURE E-6

E.11. Second Successful Lift - 17 August 1939

The pontoons were set and preliminary blowing for the second lift was completed by evening of 16 August 1939. Two of the upper pontoons at the stern, fuel tanks 5, 4 and 3, and two of the upper forward pontoons were blown in that order.

The following morning, the third upper after pontoon was blown. Main ballast tank No. 3 was then blown. A lower pontoon at the stern was being blown when the stern lifted. The last stern pontoon was blown to ensure sufficient buoyancy.

As soon as the stern pontoons were secured, the remaining two pontoons forward were blown, followed by fuel tanks No.'s 1 and 2. Main ballast tank No. 1 was blown, but when the bow did not lift, it was reflooded, and main ballast No. 2 was blown. The bow rose while main ballast No. 2 was being blown. While the blowing was in progress to lift the bow, it was noted that the stern pontoons were being unloaded gradually. Main ballast tank No. 3 was partially flooded to keep the stern pontoons at about half buoyancy.

It was later discovered that the bow slings had slipped aft until the lower bow pontoon struck the bridge. Later analysis revealed that because of the sloping bottom, the angle of the ship while the stern was up was about 29 degrees and the slope of the keel forward about 22 degrees.

E.12. Second Tow

Shortly after the tow got underway, the bow line from SQUALUS to FALCON parted. An 8-inch manila hawser connected to one of the bow pontoons prevented FALCON from drifting too far away from SQUALUS. A second hawser was connected to the other end of the pontoon to place an equal strain on each end and prevent pulling it out of position.

SQUALUS grounded in 92 feet of water in the location previously selected, bearing 282 degrees true, distance 1.6 miles from White Island Light. Tanks and pontoons were flooded to set the submarine on the bottom, the stern pontoons submerging about 10 feet.

E.13. Preparation for Final Lift

In the shallower depth, the divers could perform more work, and it was decided to remove all hoses and to clear the top-side of SQUALUS from all entanglements remaining from the first unsuccessful lift.

All pontoons, hoses, and slings were removed since the pontoon arrangement which had been in use was not suitable for the final lift. For this final lift and tow into drydock, the pontoons were rigged with the axis fore and aft in line with the submarine.

A preliminary blow of the after compartments revealed that they would not hold air pressure above ambient sea pressure. Suction hoses were then attached to the low salvage connections on these compartments and an air pressure applied to equalize with sea pressure. The salvage pumps on FALCON then pumped the compartments.

Water which had accumulated in the control room and forward battery room was also pumped out through the low salvage air connections in these compartments. Two slings were placed under the stern and two pontoons were set parallel to the axis of the submarine (Figure E-6).

E.14. Unsuccessful Attempt at Final Lift 27 August 1939

The first attempt to bring SQUALUS up with pontoons rigged only at the stern was unsuccessful. To save time, only the stern pontoons were used since it had been calculated that adequate buoyancy could be restored in the forward compartments and tanks. The lift was planned so that the bow would be raised first because, with the stern on the surface, air would spill from the forward ballast tanks before they were completely blown. As the bow of SQUALUS came up, it was noted that she was statically unstable. The submarine rolled to port, thus losing considerable air, causing the ballast tanks to reflood. The submarine sank, landing on the bottom with a large port list. Gages had been rigged to the port and starboard ballast tanks so that the Salvage Officer could determine the submarine's list. By flooding and blowing the ballast tanks, the submarine was righted.

On the next attempt, the stern was brought up first, but the angle was too steep and not enough air could be put into the forward ballast tanks to start the bow up. The stern was reflooded and allowed to settle on the bottom. Then two pontoons were rigged forward with their axes parallel to the submarine (see Figure E-6).

E.15. Additional Preparations

The setting of the two bow pontoons was delayed due to bad weather. Two of FALCON's moorings had broken their anchors and these were replaced during this period.

Rough weather also made one of the stern pontoons wash against the after torpedo room hatch. The pontoon hit the handwheel and caused the hatch to open, subsequently damaging the open hatch.

E.16. Successful Final Lift - 12 September 1939

After the hatch had been replaced and the additional pontoons set, the final lift was again attempted. The blowing sequence was from aft forward. While fuel oil tank No. 2 was being blown, the stern rose a short distance and then sank. This was due to spillage of air and partial reflooding of No. 3 main ballast tank. The remaining bubble was left in No. 3 main ballast, and while blowing of the fuel oil tanks was continued, the stern rose to the surface. The bow pontoons were blown, then No. 1 and No. 2 main ballast tanks. The bow rose after a small amount of water had been blown from No. 2 main ballast tank. The augmented buoyancy due to the expansion of air in the tank was enough to unload the forward pontoons and the ship again became statically unstable. The SQUALUS assumed a list to starboard, spilled air from her ballast tanks, thus causing the stern to sink.

The bow was lowered to the bottom and the list was again removed. Next the stern was raised as before. No. 1 main ballast tank was left full so that No. 2 would be nearly empty when the bow started up and the gain in buoyancy as the bow rose would be decreased. The bow started up with No. 2 main ballast tank almost empty; the pontoons remained well loaded and provided the desired righting moment, and the ship remained upright on the surface.

It is interesting to note that such a simple thing as a change in the sequence in which tanks were blown could change an unsuccessful attempt into a successful lift.

E.17. The Docking

The strong tidal currents around Henderson's Point made it necessary to arrive at the Navy Yard within a short time before or after slack tide.

The time consumed by the sinking and second raising of the submarine made it too late to reach the Navy Yard at high tide. Therefore, the speed was adjusted to reach the Navy Yard at low slack water.

The draft of SQUALUS was 40 feet, as planned, so there would be no serious trouble in case the ship were caught in a falling tide. The depth of the channel at mean low water was also 40 feet. Although SQUALUS touched the bottom several times during this tow, no damage was inflicted and she was freed each time without delay.

Upon arrival at the Navy Yard, SQUALUS was placed beneath the 100-ton sheer leg crane and a wire strap was attached to the periscope fairwater. This held the submarine in an upright position as she was pumped out. The forward deck was raised above the water by blowing all tanks. The forward pontoons then were removed and the forward hatch was opened and all compartments were dewatered. This brought the submarine to a draft shallow enough to permit docking.

APPENDIX

F. Salvage of HMS THETIS

F.1. Position of HMS THETIS

THETIS sank on the afternoon of 1 June 1939 in Liverpool Bay, England, 17 miles northeast of the Isle of Anglesay. The depth of water was 155 feet at mean low water. The average rise and fall of tide was 22 feet with a velocity of 4 knots at the surface. The period of slack water varied from 0 to 30 minutes. The bottom was of hard clay covered with a thin layer of sand. The cause of the sinking was the flooding of the two forward compartments through the lower starboard torpedo tube, the breech door having been opened while the muzzle door was open. The forward portion of the keel was about 2 feet clear of the bottom and the propeller shafts were well clear of the bottom. The maximum sinkage into the bottom was about 4-1/2 feet near the after end of the keel.

During the night of 1-2 June, the crew was able to raise the stern to the surface by blowing main ballast tanks and pumping out fuel and fresh water tanks. Four men escaped through the after escape hatch. An attempt to bring the escape hatch above the surface by towing the stern forward failed when the towing wire parted and the stern sank. Attempts to rescue the crew were discontinued on the afternoon of 3 June, and the operation thereafter was one of salvage only.

The position of THETIS was exposed from all quarters, and the worst sea conditions could be expected with prevailing winds southwest through west to northwest. Sea conditions were subject to very rapid change.

F.2. Salvage Plan

Two lift barges, each 100 feet long, and designed to lift by utilizing tidal action were used in the first attempt to lift THETIS and bring her in to shallow water in a more protected area. During the first attempt at making a lift, a swell suddenly came up after the slings had been secured at low water. Three of the six slings carried away before they could be released. It was then decided to lift with a larger improvised lift ship which would be less vulnerable to unfavorable sea conditions.

ZELO, a merchant ship, 308 feet long, with a beam of 43 feet and a deadweight capacity of 3,350 tons, was selected as the best suited for the purpose. The submerged weight of the submarine, if fully flooded, was approximated at 1000 tons. At the drafts expected during a lift, ZELO would experience 35 tons displacement per inch immersion, so that there would be little loss in lift due to sinkage.

ZELO was fitted out with eight wooden lifting beams supported by under-deck shores carried to the double bottom. Each lifting beam consisted of four pitch pine timbers of size ranging from 12 inches square to 16 inches square and extended over the side about 3 feet. The overside extension was built up to 42 inches diameter with greenheart. Each end of sling was to be secured to one end of a lifting beam by three round turns, then led to a fall on ZELO's deck.

F.3. First Salvage Attempt

Eight wire slings were placed under the submarine: two under the keel forward of the conning tower, two forward of the keel, two under the keel aft of the conning tower and two aft of the keel.

The forward slings were rigged by sweeping a messenger wire rope under the bow and using this messenger to haul the slings into place. At the stern, where the rudder and propellers prevented use of this method, a light manila messenger was passed by divers under the stern where it was clear of the bottom. This manila line was used to haul a wire rope reeving line into place which in turn was used to haul the sling under the bottom. The stern was lifted by means of the No. 1 and No. 2 slings in order to place the last two slings (No.'s 3 and 4) in the desired fore and aft position below the mud line.

When a lift was attempted on 21 July, No. 8 wire at the bow freed itself entirely, and No. 5 wire became slack and apparently slipped out of its desired position. Thus, No.'s 6 and 7 wires became overloaded and the No.'s 6 and 7 lifting beams failed.

ZELO was withdrawn and modified by fitting steel lifting beams with built-in bollards and cast-steel bolsters on the outboard ends. This work required five weeks. A completed bollard was tested to a pull of 180 tons.

ZELO was ballasted with 1000 tons of fresh water, the tanks being completely filled to avoid any free surface.

An inclining experiment performed after completion of this work showed that with the load of the submarine slung from the beams, there would be a positive, although small, metacentric height in the upright condition. This was considered acceptable since a small list would increase the metacentric height.

F.4. Lifting Phase

On 24 August, ZELO returned to the wreck. Slings were again rigged and at 6:30 A.M. on 28 August, the wire slings were secured and clamped tight (pinned down) at low water.

The submarine was lifted and moved inshore on that tide and on each of the five succeeding tides until she lay 2 miles from Moelfre Island in 78 feet of water. Here, the operation was halted to remove the No. 1 periscope so as to permit the submarine to be lifted to a lesser depth without interference between ZELO and the periscopes. The No. 2 periscope was found to be bent over and not to extend above the conning tower.

THETIS was then lifted and moved inshore three more times. On the evening of 3 September 1939, she lay in 37 feet of water (at low water), about 4/5 of a mile from Moelfre Island. At this point, ZELO slacked all the slings and allowed the tide to carry her clear of the submarine. The clearance between ZELO and the submarine was now about 3 feet at high water, and at low water the conning tower would be 6 feet below the surface.

F.5. Slings

Slings were of 2-7/8 diameter 6-61 galvanized wire rope, having a nominal breaking strength of 240 tons. The 6-61 construction was selected because of the need for flexibility to permit securing to bitts of reasonable size. A piece of the wire was tested to a breaking load of 265 tons. This gave a safety factor in excess of four, assuming the load to be equalized among the slings. The only equalization of loads on the slings, other than that provided by the elongation of the wire under load, rested with judgment of the master salvor who eased back on those slings which appeared to be carrying more than the average load. Once equalization appeared to be satisfactory, the slings were painted where they passed over the side of ZELO. This assisted in taking up the slack for the succeeding lift. None of the slings were broken while ZELO was acting as the lift ship.

The weather was good during the period of 28 to 30 August, and although it deteriorated during the three lifts in early September, THETIS was no longer in such an exposed position and the lifting continued.

The weight being lifted could be determined from the draft marks of ZELO. It was noted that the weight decreased as the depth of THETIS decreased. This was attributed to the expansion of entrapped air within the submarine.

The large rise and fall of the tide and the tidal current caused the slings to foul each other and to move along the bottom of THETIS. This was a source of constant annoyance, and although it never caused a tide to be missed, it did require some of the lifts to be made without using one of the slings.

F.6. Towing

Before the first lift, a track was selected and surveyed which would have a gradually shelving bottom and would lead to a sheltered area near and southeast of Moelfre Island. Because of the tidal current, the slow speed of the tow, and poor visibility, it was not always possible to keep on the desired track. This caused some unexpected groundings but no serious difficulty. At the end of each lift, an attempt was made to ground THETIS with ZELO heading into the flood tide. This was not always successful, but when it did succeed, the holding of ZELO in place over THETIS while preparing for the next lift was greatly simplified.

Although ZELO's engines were ready for use, they were never needed. She was towed by two tugs and a third was available for use when needed and for planting new moorings at the end of the lift.

F.7. Final Lift to Surface

The final phase of the salvage plan called for bringing THETIS to the surface stern first by self-lift alone. She had been brought to a place which was well sheltered from the prevailing southwest and west winds with the expectation that the work of preparing the ship for dewatering would proceed expeditiously. However, there were persistent northerly and northeasterly winds accompanied by heavy swells and frequent rough seas during about two-thirds of the seven weeks actually required for this phase of the work.

The engine room hatch cover was replaced by a salvage hatch bolted to the top of the hatch trunk and containing a 6-inch spill pipe leading to the platform deck, a 2-inch flexible pipe leading to the bottom of the compartment near the forward bulkhead, and three connections. Other hatches were secured by strongbacks to prevent their being unseated by pressure inside the submarine.

For the two forward compartments, buoyancy was to be restored by blowing through a valve to be fitted in the torpedo loading hatch cover, the water escaping through the open torpedo tube. External main ballast tanks No.'s 2, 3, 4, 5, and 6 were to be blown down through their flood holes by air introduced into each tank, port and starboard, through valves to be fitted in the top of each tank. Main ballast tank No. 1 was to be blown by a hose secured in its flooding hole.

The doors in all bulkheads aft of frame 40 (the limit of the original flooding) were opened to permit the blowing air to reach all of the after compartments from the connection in the salvage hatch, and to permit water to flow to the spill pipes in the salvage hatch. While the divers were working in the control room, it was discovered that their air was escaping through the stuffing box of the periscope which had been bent over and later broken off during the lifting. The remainder of the periscope was removed and a wooden plug inserted in the hole. This plug did not stop the leak and it was replaced by an expandable wooden plug which was successful.

An attempt to dewater the ship on 11 October was unsuccessful when the port exhaust valve failed to hold the internal pressure. This was plugged and a further attempt made on 13 October, but this also failed because of leakage through the starboard exhaust valve. The salvage hatch was removed and a diver sent into the engine room. He found that both exhaust valve operating gears had not been turned to the fully closed position. They were fully closed and the salvage hatch replaced.

On 21 October, blowing was again started and continued throughout the day. On 22 October, blowing was resumed, and shortly after noon the bow came to the surface but sank again. Blowing continued and the bow again came to the surface and remained there. Since the salvage plan had called for the stern to be raised first, the spill holes were in the forward ends of the two parts of the ship. With the bow up first, not enough water could be removed from the stern and the bow was lowered to the bottom by venting some of the forward main ballast tanks.

When the stern still could not be raised, divers drilled a hole through the lower part of the pressure hull in the after crews' quarters to permit removal of the water trapped below the level of the door to the engine room.

Blowing was resumed on 23 October and a diver reported a good flow of water through this hole, but a large air leak was discovered through a 6-inch sea connection. This hole was plugged and at 2:00 P.M., the stern came to the surface. Blowing was shifted to the forward tanks and at 2:30 P.M. the bow also came up. THETIS was beached in a position where the open torpedo tube was above the surface at low water. The ship was now made tight, pumped out, floated clear of the beach at high water, and towed to Holyhead for drydocking. On 18 November, she was returned to the building yard at Birkenhead where she was repaired and commissioned as the HMS THUNDERBOLT.

APPENDIX

G. Salvage of HMS TRUCULENT

G.1. Collision

On the evening of 12 January 1950, the Swedish tanker DIVINA collided with HMS TRUCULENT in the Thames Estuary, England. The submarine sank in 66 feet of water with a 15-degree starboard list. The "T" class submarine lay athwart the Oaze Deep with her stern clear of the bottom.

A 12-foot long gash, 4 feet wide at the top and narrowing to a point about 6 feet above the keel, was made in the starboard side just aft of the bow planes. The water rushing into this opening had prevented the water-tight doors forward of the control room from being closed. Doors between the compartments aft of the control room were closed, but these spaces had been flooded during escape operations.

G.2. Salvage Method

Since the submarine lay in an exposed position and was a hazard to navigation, it was decided to move it to a suitable beaching ground and dewater it there. Two former German lift ships, AUSDAUER and ENERGIE, were selected because they each had a stern lift capability of 600 tons. This permitted the ships to lay stern to the tide and together lift 1200 tons. The salvage weight of TRUCULENT was estimated at 950 tons.

Four slings of wire were to be positioned under the submarine for the lift. Messenger wires were swept under the stern and sawed forward to the selected position. This work was hampered by bad weather and it took more than a month to get all four messengers in the desired positions.

A decision was made to reduce the weight of the submarine by blowing the No.'s 1, 3, 4, and 5 main ballast tanks. This would reduce the estimated salvage weight from 950 tons to 800 tons and provide a larger margin for error.

G.3. Salvage Preparation

Divers installed air fittings in the top of the main ballast tanks with the Cox power velocity gun.

Air hoses were connected to these fittings and flood holes were cut in the bottom of ballast tanks No.'s 3 and 5, since these were fitted with Kingston valves.

ENERGIE and AUSDAUER were towed out and moored over TRUCULENT on 9 March. Reeving of the lifting slings was accomplished by having a tug pull the end of the main lifting wire under the submarine. The wire end was then passed through the roller shackle of the gantry and pulled back under the submarine to the lifting craft. The two ends were connected to the moving block of the deck tackle. The four lifting wires were in place by 14 March and all was ready for the lift.

The after ballast tanks of both lifting craft were flooded about 90 minutes before low tide. Slack in the lifting wires was taken in as the tide decreased.

G.4 The Lift

A few minutes before low tide, the ballast on the lift craft was shifted from the after to the forward tanks, and at the same time, No.'s 1, 3, 4 and 5 main ballast tanks on the submarine were blown. This had the effect of initially lifting TRUCULENT off the bottom.

When the transfer of ballast on the lift ships was completed, hoisting of the submarine was begun. TRUCULENT started coming up stern first and ENERGIE, at the stern, permitted the AUSDAUER to lift the bow until the submarine assumed an even keel. Then both ships hove together until the submarine deck broke surface. It required about 2 hours to accomplish this lift.

G.5. Salvage Completed

In darkness, the two lift ships and TRUCULENT were towed to the beaching ground some 4-1/2 miles away at a speed of 3 knots. The submarine was lowered temporarily to the bottom on Cheney Spit at high tide. Thirty-six hours later, TRUCULENT was moved and beached again in 9 feet of water at low tide.

Water in the after part of the submarine was pumped out and the cleaning process began. The collision damage was patched and the forward part of the submarine drained. The submarine's anchor and cable, DIVINA's anchor, the torpedo derrick, the gun, and all wires and loose equipment in the superstructure were removed.

TRUCULENT was patched and lightened considerably by removal of heavy equipment. On 22 March, she was closed up and refloated. The afternoon of 23 March 1950, TRUCULENT was towed to Sheerness and drydocked.

H. Submarine Salvage Exercise of ex-USS HAKE (AGSS-256)

H.1. Exercise

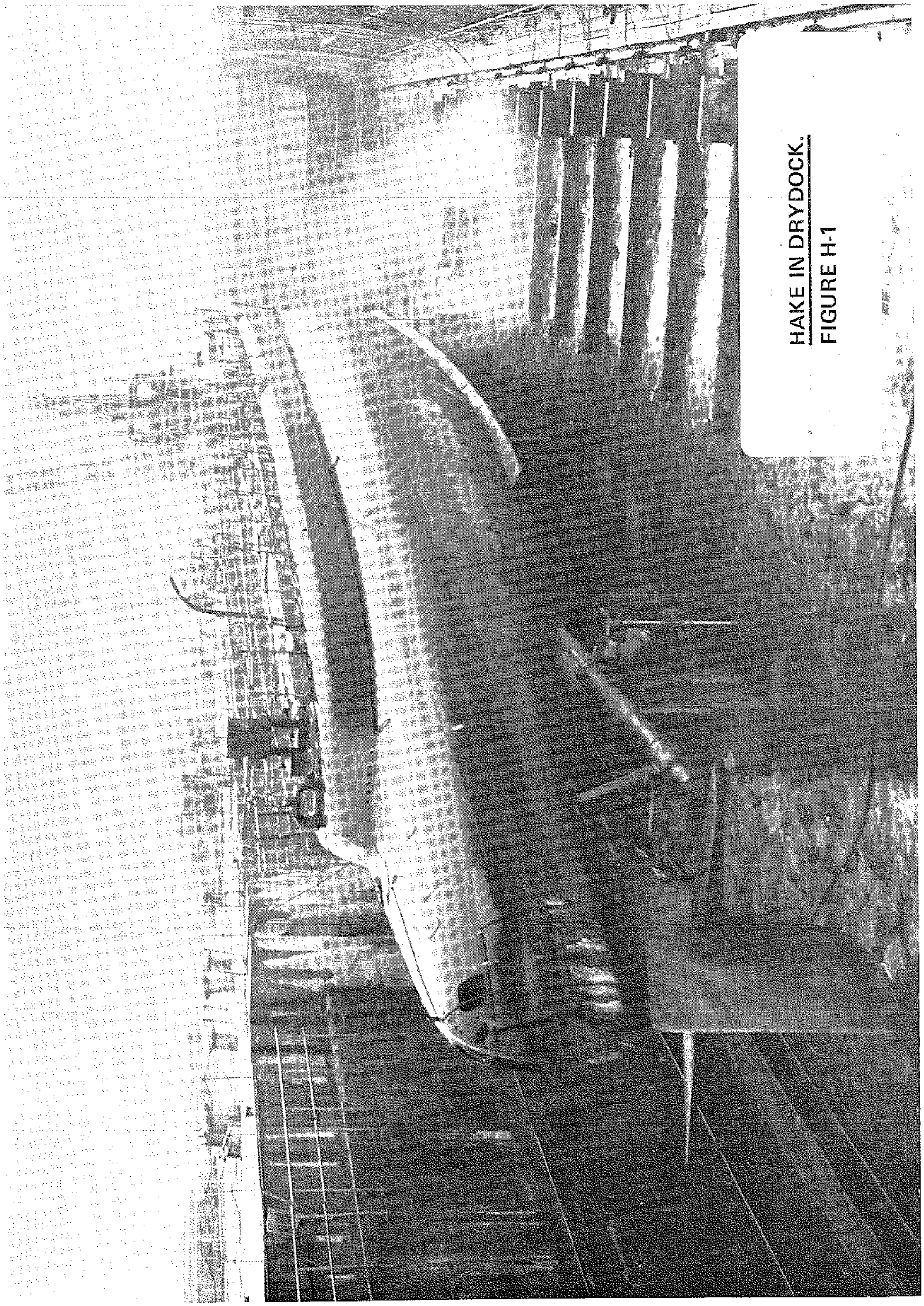
The ex-USS HAKE (AGSS-256) was deliberately sunk to offer submarine salvage experience and capability evaluation to the US NAVY. The planned exercise required the preparation of the submarine, its sinking, and salvage; SUBSALVEX-69 was conducted in the Plantation Flats area of Chesapeake Bay during the period of 5 - 23 May 1969. When the ex-HAKE was raised with submarine salvage pontoons from 108 feet of water the first operational use of the submarine salvage pontoons since the USS SQUALUS salvage in 1939 was accomplished.

H.2. Preparation and Sinking

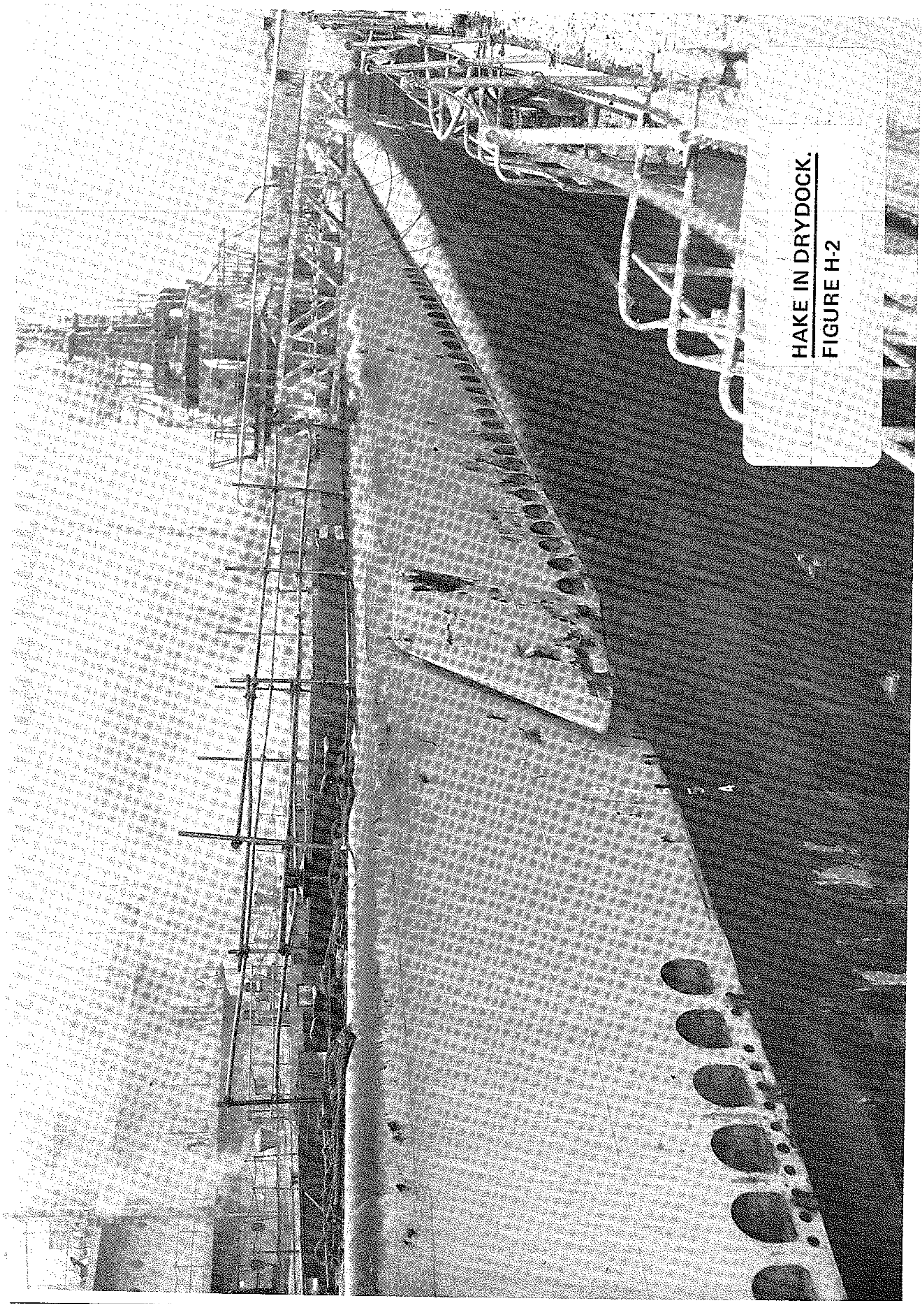
Preliminary planning for the exercise commenced in the spring of 1968; in the fall, after ex-HAKE was made available for training by CNO, detailed operational plans were prepared.

Ex-HAKE was drydocked in December of 1968, at the Norfolk Naval Shipyard, to accomplish certain modifications and inspection necessary for the exercise. The blanks on all flood ports for all main and fuel ballast tanks were removed. Main Ballast Tanks #1 and #7 were fitted with a valve, inserted into the low pressure blow line, to permit venting and venting control from topside. The remaining pairs of main and fuel ballast tanks were fitted with a single valve tied into the low pressure blow lines. These fittings allowed simultaneous venting and venting control of both tanks from topside. Note the submarine in drydock in Figures H-1 and H-2.

After undocking, all variable ballast tanks and other internal tanks were filled with sea water; normal fuel oil tanks were also filled with salt water. Even with the main and fuel, ballast tanks flooded ex-HAKE was too light to submerge since it was not intended to flood any internal compartments for the exercise. To add the necessary weight concrete was placed in the forward and after battery wells, reefer and magazine storage areas, the pump room, and after torpedo room. With this additional weight, ex-HAKE's surface displacement increased to 2074.4 tons. This displacement, plus the combined capacity of all main and fuel ballast tanks (592.3 tons) resulted in a total submerged weight of 2666.7 tons. The normal displacement of ex-HAKE is 2428 tons which results in a net negative weight of 238.7 tons, which was considered optimum for a four pontoon (YSP) lift of 330 tons.



HAKE IN DRYDOCK.
FIGURE H-1



HAKE IN DRYDOCK.
FIGURE H-2

After ballasting and the addition of concrete, ex-HAKE was inclined and found to have adequate transverse stability.

All internal compartments were air tested and all leaks corrected. For a test the submarine was submerged in Norfolk, alongside the South Wall on the NAVY Base, in approximately 30 feet of water. Blow hoses were led from each of the submarine's nine topside vent valves to a control manifold. Any main or fuel ballast tank pair could be selectively vented or blown and positive control maintained. Trim and moment of transition from positive to negative buoyancy could be finally controlled. After remaining at 30 feet for two and a half hours, the ex-HAKE was surfaced; there were no leaks. The submarine was bottomed a second and third time with the conning tower hatch accessible from the surface, making internal inspection possible. Minor leaks around hatches, packing glands, valves, and other sources were found and corrected. The submarine was surfaced; final checks were performed to ensure that the compensating water system was properly lined up with one normal fuel oil tank on service and that all other valves were secured.

With the preparation of the ex-HAKE complete, necessary equipment was prepared and required evolutions accomplished. Following is a brief on these preparations.

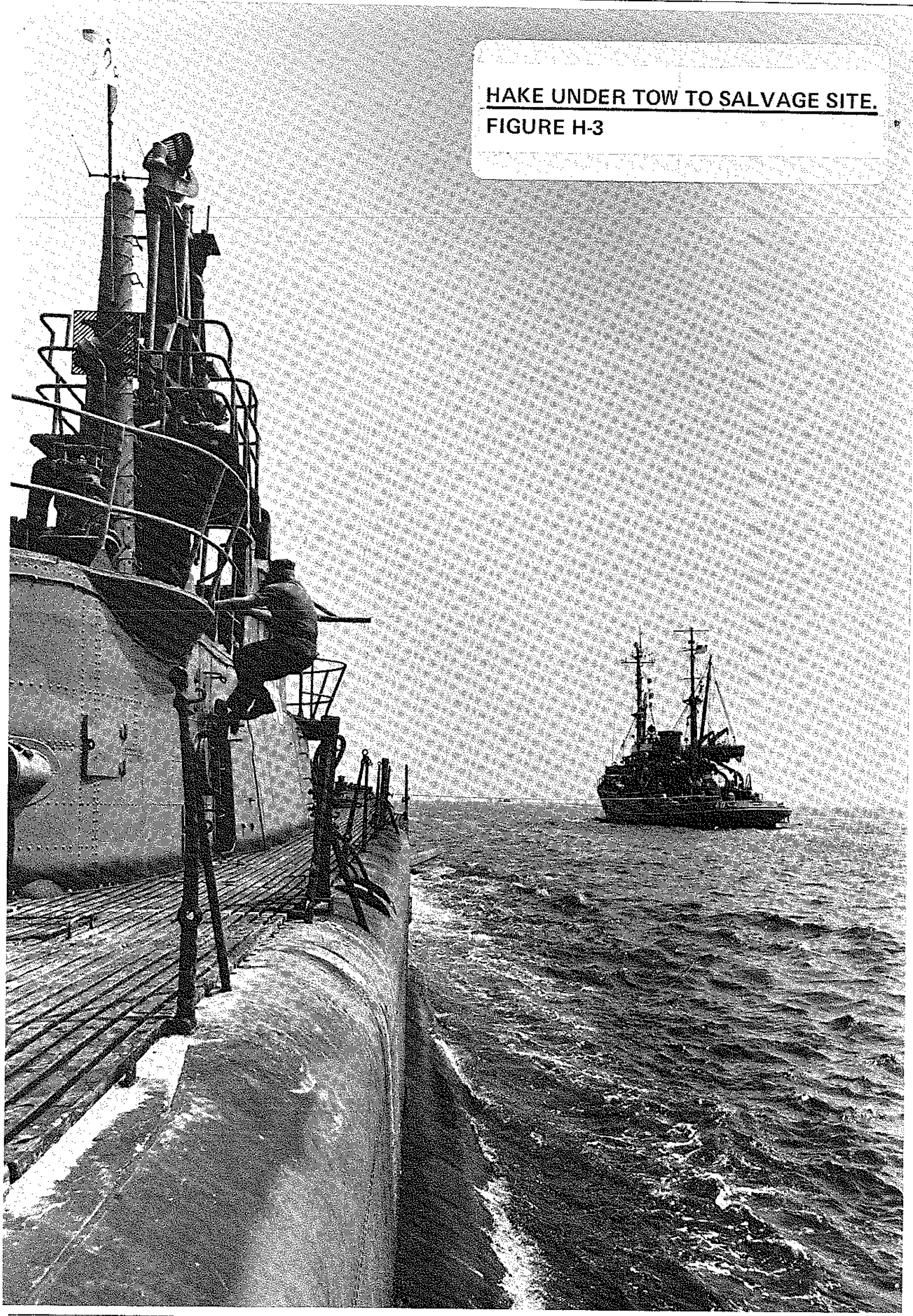
- The submarine Salvage Pool, Boston Naval Shipyard, provided 6 submarine salvage pontoons (YSP) loaded with associated equipment on board two barges (YC).

- Supplementary air for blowing the salvage pontoons was to be provided by two air compressors rated at 450 cubic feet at 500 psi, loaded on an open YC.

- Certain preparations and pre-disposition of expected requirements were possible because the operation was an exercise. Some of these were:

    1. The amount and distribution of weight in the submarine was accurately known; under actual salvage conditions much of this information would have to be interpolated from known data.

    2. All special hardware and rigging known to be required was fabricated beforehand; much time and logistic complexity was spared.



HAKE UNDER TOW TO SALVAGE SITE.
FIGURE H-3

3. Water depth (108 feet) and geographical location were accurately predetermined. Advantageous bottom conditions were experienced however, preparation for appreciable bottom mud suction had been made.

4. The location was not sheltered. Winds reached a steady 30 knots, with gusts up to 35 knots. Seas ran as high as six feet and currents in excess of 2 knots were experienced.

On 5 May, the USS HOIST (ARS-40), with the submarine in tow, arrived at the exercise site. Within several hours after anchoring, the ex-HAKE was bottomed in 108 feet of water and the first phase of the exercise commenced.

H.3. Submarine Rescue

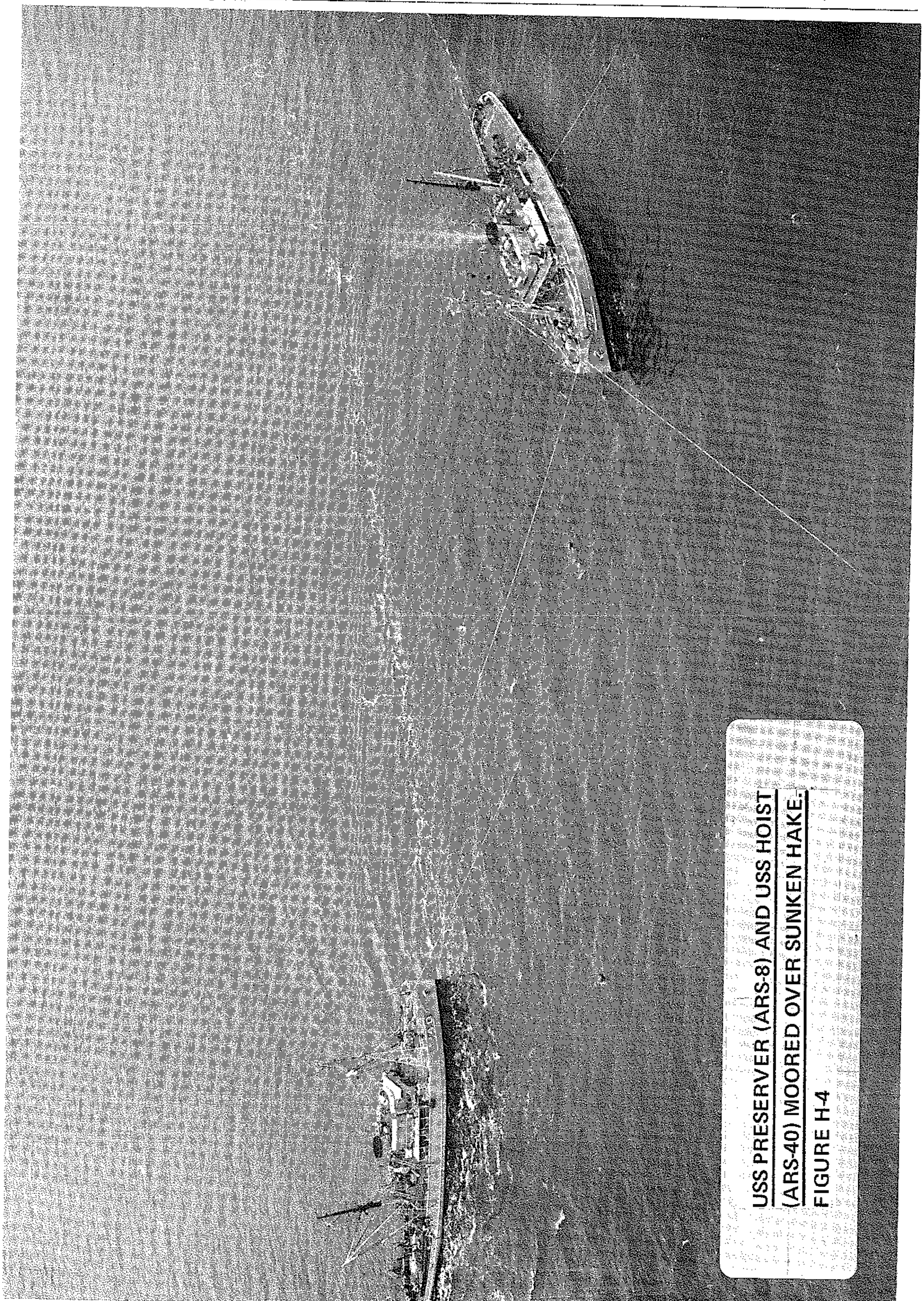
In the morning of 6 May the USS PETREL (ASR 14) commenced laying a four point moor preparatory to making McCann Rescue Chamber runs on the bottomed submarine. Bell runs were made fore and aft during the day. Internal inspection of the submarine revealed a minor leak (4 gal./day), slight port list, and slight up angle. Submarine rescue exercises were secured, and the PETREL recovered her moor and departed on 7 May.

H.4. Submarine Salvage: First Phase

On 7 May the HOIST AND PRESERVER (ARS 8) commenced laying a three point moor over the bottomed submarine. Each ship moored and retained the maneuvering option over the bottom by slacking or taking in the moor legs. Note the two ships in the moor in Figure H-4. Support ships and barges arrived on the salvage site; YRST-2, with HCU-2 embarked, arrived and anchored in the area, USS KIOWA (ATF-72), assigned in support, arrived with two barges (YC) loaded with submarine salvage pontoons in tow. A supporting YTM, with one YC loaded with air compressors and allied equipment arrived on the site and anchored. All elements of the salvage task force were on the site.

H.5. Submarine Salvage: Inspection and Preparation

With PRESERVER and HOIST in the moor, diving operations were commenced. The preliminary survey by divers revealed the submarine to be immersed in two feet of mud with bow and stern clear of the bottom. On 8 May PRESERVER, working in the moor, passed a 2 inch manila messenger, followed by a 1 inch wire, between the propeller shafts and the hull.



USS PRESERVER (ARS-8) AND USS HOIST (ARS-40) MOORED OVER SUNKEN HAKE.

FIGURE H-4

Lifting slings could now be passed around the stern. HOIST passed a messenger wire under the bow, aft of the bow planes.

Two submarine salvage pontoons were launched (YSP 31 and 32), inspected, and prepared for positioning.

On 9 May adverse weather forced PRESERVER and HOIST to buoy off the messengers passed around the submarine and back away from each other in the moor. Reference Figure H-4 and H-5 for the configuration and makeup of the moor.

H.6. Reeving the Lifting Slings

Weather improved considerably on 10 May; HOIST and PRESERVER returned to their working positions in the moor. Rigged and ready for passing, the slings were stowed on the PRESERVER's fantail. The two lifting slings were passed under the submarine's stern. HOIST, rigging on her bow, attempted to pass lifting slings under the submarine's bow, but these became fouled on the diving planes and could not be passed.

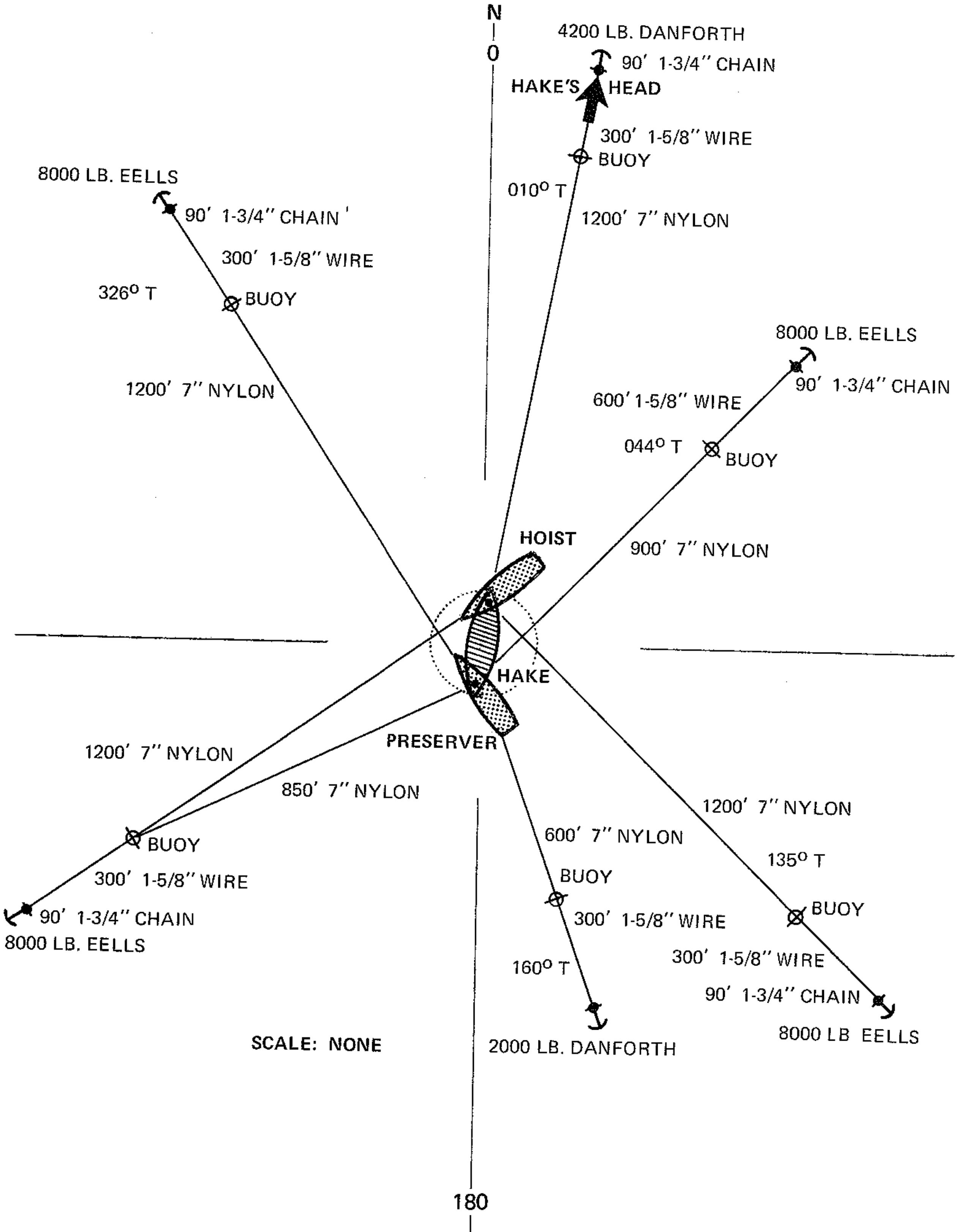
Deteriorating weather on the following day caused further delay. HOIST buoyed off the messenger and shifted back in the moor. PRESERVER fouled one sling in the opening between her port quarter horizontal roller and bulwark; and chafing parted the wire.

H.7. Continued Reeving of Slings and Setting Pontoons

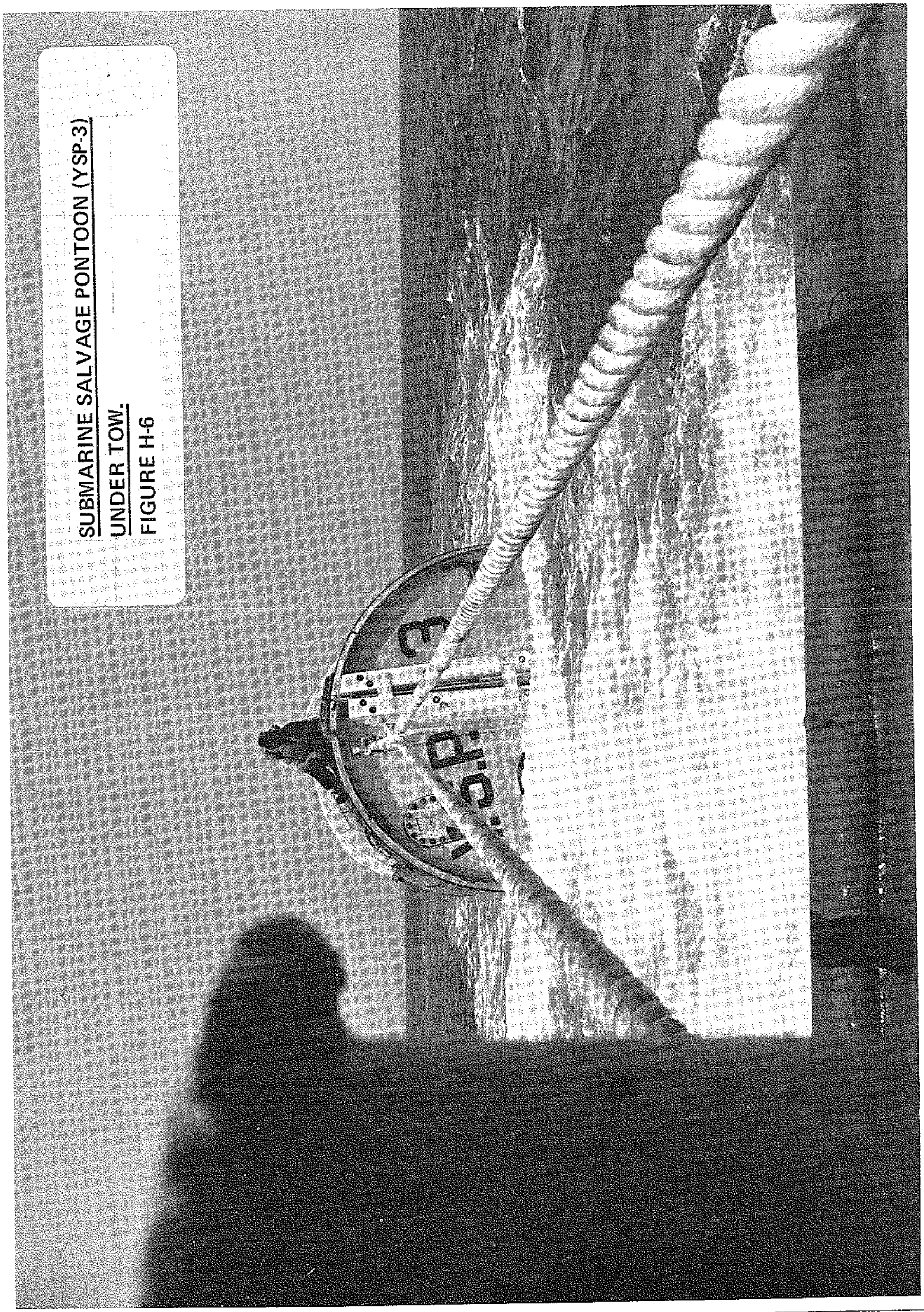
On 11 May the first submarine salvage pontoon (YSP-31) was set athwartships on ex-HAKE's main deck aft and blown to positive buoyancy. It had become difficult to work both ships at the same time and HOIST remained clear of PRESERVER while she buoyed off lifting slings and blow hoses for YSP-31. The first pontoon was in position.

The following day PRESERVER positioned YSP-32 athwartships on the submarine's stern at 40 feet top depth. The pontoon was blown to positive buoyancy, slings and blow hoses buoyed off. PRESERVER backed in the moor allowing HOIST to move into a working position over the submarine. With HOIST in position, PRESERVER tripped out of the moor and returned to Little Creek, Virginia for logistic support.

After several unsuccessful attempts to pass the lifting slings, HOIST concluded the slings and reeving wires were hopelessly fouled in the bow planes. By taking a full strain, the 1 inch messenger and reeving wire were parted. All gear was then recovered and preparations for rerigging made.



WORKING MOOR FOR THE FIRST LIFT. HOIST AND PRESERVER MOORED OVER EX-HAKE.
FIGURE H-5



SUBMARINE SALVAGE PONTOON (YSP-3) UNDER TOW.
FIGURE H-6

HCU-2 launched YSP Numbers 3 and 9 from the YC. Even with valves removed and piping capped, damage was sustained to the valve piping on both pontoons during launch. Repairs were made and both pontoons anchored, ready for use.

On 14 May HOIST succeeded in passing both lifting slings under the submarine's bow.

H.8. Positioning Pontoons

HOIST positioned YSP-9 athwartships on the submarine main deck forward, the pontoon was set on positive buoyancy and all lines and hoses buoyed off. YSP-3 was next to be rigged and positioning this control pontoon proved difficult. It was difficult to pass the wire stoppers (flower pots) because of the short 1 inch wire rope tail, taper spliced to the 2¼ inch lifting wires. Both flower pots were finally rigged and YSP-3 was ready for positioning.

The USS KIOWA (ATF 72), harbor tugs (YTM), and LCM craft were at various times used for logistic and operational support; their value was considerable aiding the operation appreciably.

With reference to Figure H-7 note YSP-9, alongside HOIST to starboard, with connecting pendants and air lines positioned.

By 16 May HOIST positioned the bow control pontoon on positive buoyancy, buoyed off the lifting slings and blow lines, and tripped out of the moor.

With all pontoons in place PRESERVER was anchored 85 yards ahead of the submarine ready to take it in tow. In preparation for the first lift the air barge was anchored 100 yards abeam to starboard of ex-HAKE. All blow hoses were connected to the air barge and all blow and flood valves opened on the forward primary lift and control pontoons. After repairing broken connections and valves, all was ready for the blow; on 16 May, with darkness quickly approaching, the first blow was commenced. Because of unfamiliarity with pontoons, their operational characteristics, and a fear of overpressurizing the compartments, air pressure unloaders were set at 250 psi. Blowing was altered between primary lift and control pontoons forward without result. In total darkness and freshening weather, the blow was secured.

A complete inspection of all rigging,pontoons, and blow hoses was conducted the next day -- 17 May. On inspection several discrepancies became apparent:

- The forward primary lift pontoon was badly tilted; a differential of 25 feet in elevation existed between the two ends. One hose was pinched by a chain sling and had to be replaced.

- The after control pontoon was badly tilted with a differential of 24 feet between ends. Hoses were badly fou ed and pinched; these were replaced.

- One blow hose was defective on the after primary lift pontoon and was replaced.

H.9. First Lift

With the necessary repairs completed, blowing was commenced. The forward control pontoon was the first to be blown dry; shortly thereafter the primary lift pontoon forward was blown. The bow control pontoon failed to surface. Potentially the mud suction was not overcome and was restraining the submarine from breaking bottom.

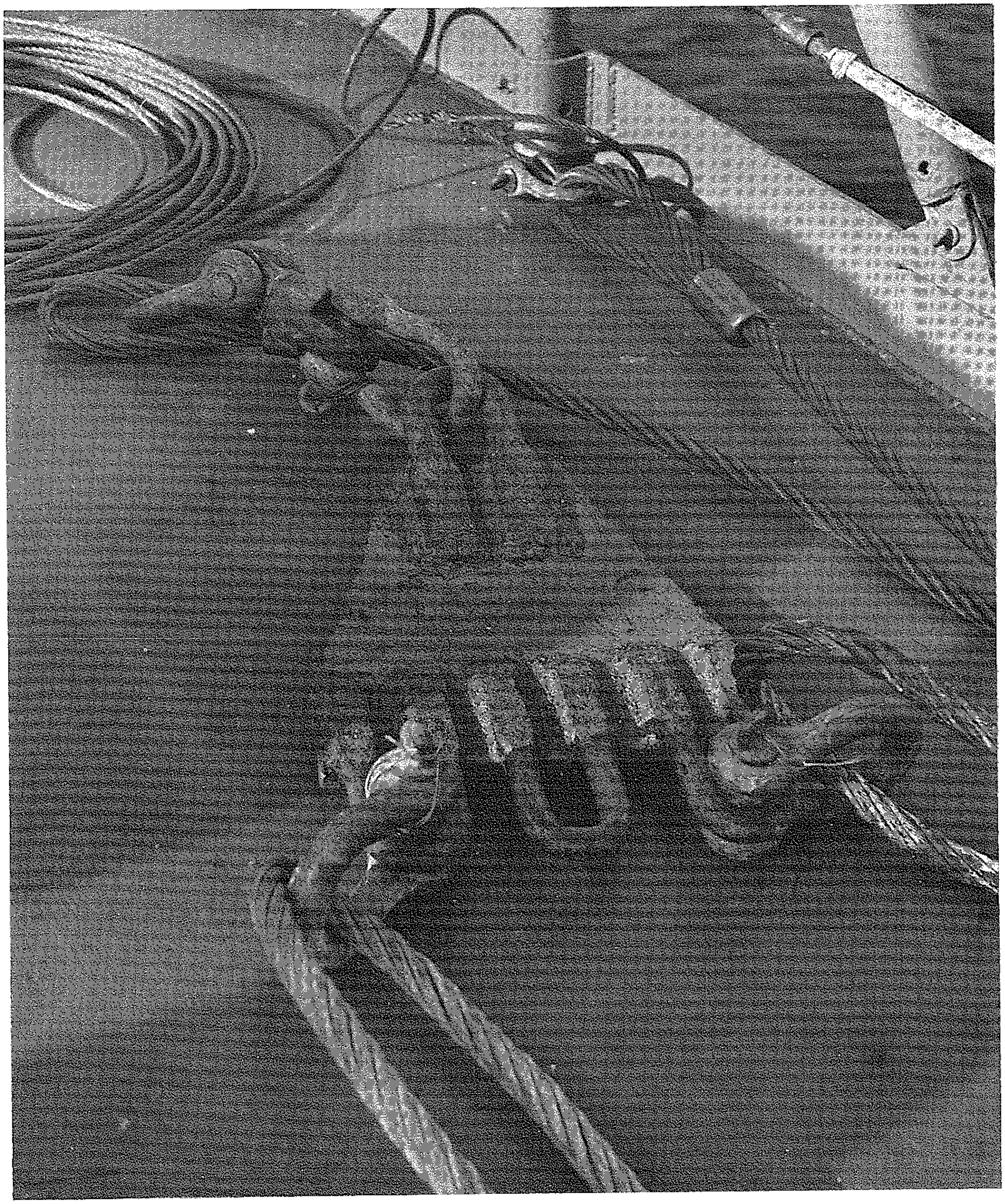
The bow lift was calculated to be heavier than the stern lift; therefore, an attempt was made to blow the stern control pontoon. With a strain on the PRESERVER's towline which was connected to the submarine, and with all pontoons blown dry, the control pontoons surfaced and promptly sank again. Blowing was continued and the after control pontoon surfaced and shortly afterwards the forward control pontoon surfaced and the submarine was off the bottom. Two major factors are believed to have caused the first lift difficulties:

- The submarine salvage pontoons are almost impossible to blow evenly. One end will become more buoyant and cause the pontoon to flip buoyant side high. It is probable that the after primary lift pontoon was uneven.

- The effective mud suction was possibly underestimated. An estimate of the mud suction had to be made, and it was possible for this force to run more than 25% of the total buoyant force required by the lift. Since the mud suction provided a real force and restricting moment it is important to apply all the force required to break mud suction at the end being lifted first. Force required to overcome mud suction can be time critical; several hours under constant strain may be required to overcome mud suction.

With the submarine off the bottom and supported by the pontoons, PRESERVER commenced the tow for bottoming the submarine and ex-

SALVAGE PONTOON ALONGSIDE TO STARBOARD OF ARS READY FOR POSITIONING ON HAKE.
FIGURE H-7



REEVING PLATE RIGGED FOR PASSING.
FIGURE H-8

HAKE was bottomed a short distance from the first lift site and preparations commenced for the second lift.

H.10. Final Lift Preparations

With the submarine bottomed, PRESERVER positioned ex-HAKE's anchor and entered a working moor for the second lift. Note Figure H-12 for the position of the submarine, PRESERVER, and HOIST in the second working moor.

Divers found the submarine on an even keel in approximately 74 feet of water depth aft and 62 feet forward. Mud conditions were similar to the first site; the submarine was immersed in the mud two feet.

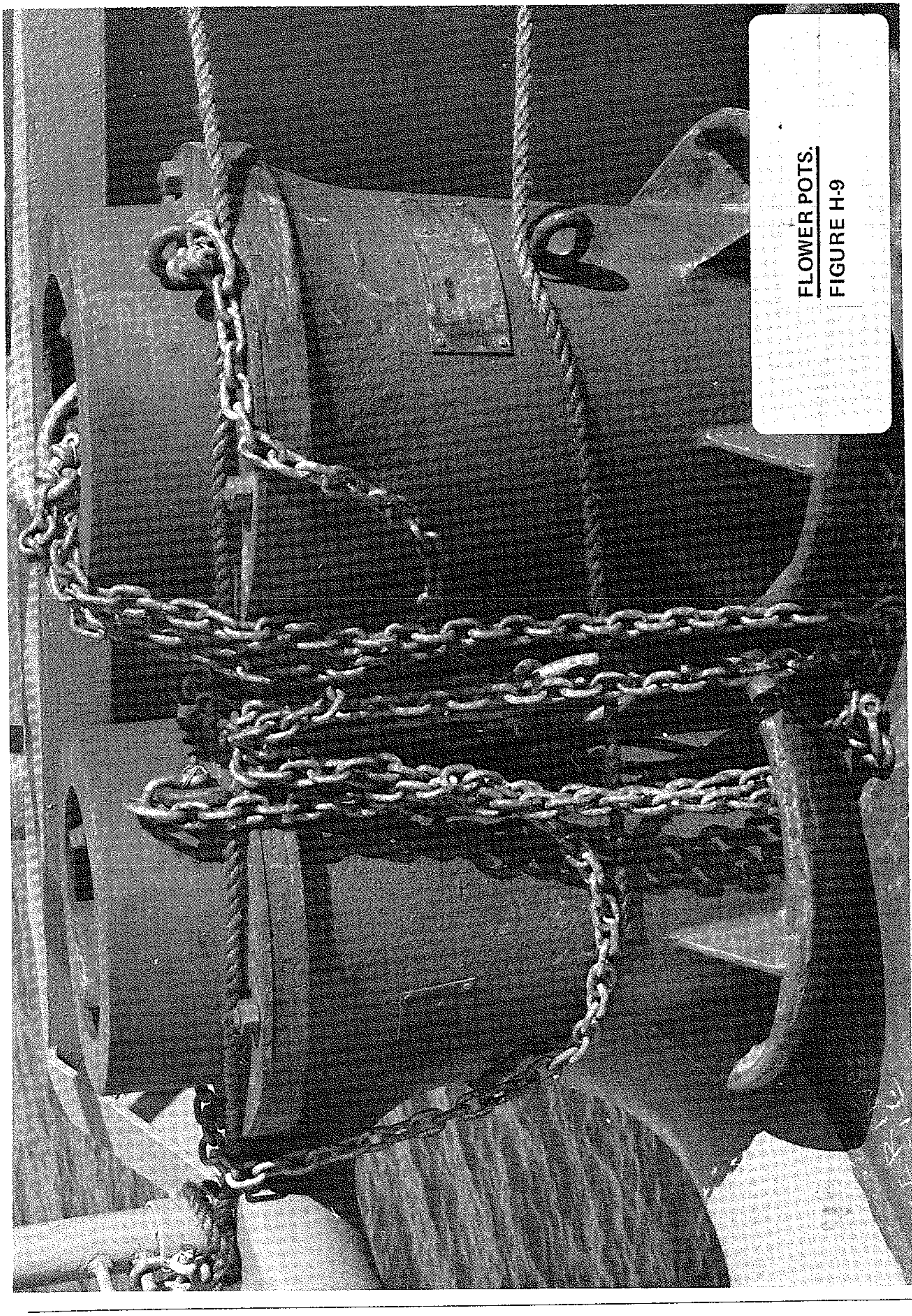
PRESERVER commenced rigging for the second lift by picking up the buoyed slings, surfacing and inspecting both pontoons aft, and clearing some fouled lines and air hose. The following day, 19 May, HOIST entered the working moor (Figure H-12), recovered and cleared the bow lifting slings. On 20 May HOIST continued working on the pontoons by surfacing them and rigging for the second lift. With all lines clear and clamps set, the pontoons were flooded down and secured for the night. In preparation for the lift, MBT #7 was blown dry.

HOIST continued to have fouling difficulties on the following day; lifting bridles for the bow pontoons became fouled on the bow planes. Late on 21 May these were cleared and both forward pontoons were placed on positive buoyancy. The submarine's MBT #1 was blown dry.

H.11. Final Lift

On 22 May all preparations for the final lift were completed. HOIST moored ahead of the submarine and connected a nylon towing hawser to the bow in preparation for the tow. The air compressor barge (YC) was towed into the area and positioned with difficulty; seas with a 2 - 3 foot swell and 15 - 18 knot winds caused problems.

In passing and connecting the pontoon blow hoses, a damaged blow valve was discovered on the forward starboard pontoon; the valve was repaired and all was ready for blowing by noon. With the compressors on board the YC on the line, blowing commenced shortly thereafter; the submarine's bow surfaced with a 15 degree up angle by 1330. Blow of the after pontoons was commenced causing the submarine to surface twenty minutes later. All pontoons were moderately loaded and ex-HAKE was stable on the surface.



FLOWER POTS.

FIGURE H-9

H.12. On the Surface

The boarding party and riding crew came on board at 1400 and made the first surface inspection. The submarine appeared stable, with the waterline located approximately at the mid point of the conning tower, the forward main deck was dry, the after main deck was at wading depth. Internal inspection revealed about 2 feet of water in the forward torpedo room bilges; all other compartments were essentially dry.

Main ballast tanks and fuel tanks were blown dry. This caused an increase in the waterplane and movement of the waterline aft. After slipping the forward pontoons and the stern anchor ex-HAKE was under tow by HOIST for Norfolk, Virginia.

For the tow, the bow pontoons had been disconnected and towed away by HCU-2; the two stern pontoons had been flooded down past mid-diameter for the tow. Sea painters were connected to each pontoon for better control. PRESERVER, KIOWA, and HCU-2 were assigned the recovery of the moor and the unrigging of all gear.

On 23 May HOIST completed the tow to Norfolk, Virginia without incident and delivered ex-HAKE to the South Wall, Destroyer and Submarine Piers, US Naval Station. The SUBSALVEX-69 was successfully completed with many lessons learned and much experience gained for the assigned personnel.

NOTE: The submarine's main ballast tanks, Numbers 1 and 7 were blown for the final lift; a comment on that is appropriate. The mud suction force was greater than originally estimated. Because of the predicted lift angle of 13.7 degrees it was important to lift the bow first. If the stern had lifted first it is almost certain that the bow pontoons' slings would have slid aft along the submarine's hull until they came up against the bilge keel or a greater hull diameter; it was important to avoid this sling movement. In retrospect, it seems apparent that all the estimated mud suction force must be provided by excess lifting force at the end to be lifted first. For this reason MBT #1 with a capacity of 47.66 tons and MBT #7 with a capacity of 43.11 tons were blown dry prior to the lift; the additional buoyancy provided a safety margin against the mud suction on the hull.

POSITIONING FLOWER POT.
FIGURE H-10

H.13. Lessons and Conclusions

On completion of SUBSALVEX-69 a critique was held and the following brief prepared.

SUBSALVEX-69 was conducted by personnel with surface ship salvage experience but with no prior experience in submarine salvage. The experience and knowledge acquired during SUBSALVEX-69 by the participants is considered to have been invaluable. In order to share this experience with other salvage personnel the following Lessons Learned and Conclusions Drawn are submitted as food for thought:

Lessons Learned

- Never splice a short 1" wire working or reeving pendant into a heavy lifting wire. Make it at least 100 feet long - THE EXCESS CAN ALWAYS BE CUT OFF!

- Lifting sling reeving wires must be bar tight when handling pontoons. If the slings are taut while pontoons are being positioned, the submarine salvage pontoons (YSP) are as docile as kittens. If the slings are loose a YSP becomes as big, cumbersome, and heavy as it looks.

- The die-lock chain stopper (toggle bar) works equally well with stud link chain and is much easier to handle than the toggle bar intended for use with stud link chain.

- A reeving plate will always put two round turns in the reeving wires after it has passed under the submarine and started back up.

- Mud suction is a real and tangible force and can amount to 25% or more of the total buoyancy required to overcome the submarine's negative buoyancy. With the approximate magnitude and center of gravity of the mud suction force determined the lifting force necessary to overcome the effective weight and moment of the mud suction force should be computed with respect to the line of action of the buoyant force being applied at the end being lifted first. Additional excess buoyancy equal to approximately 25% of the TOTAL lift required at each end by ALL forces should be available to preclude failure resulting from the inability to blow one or more pontoons

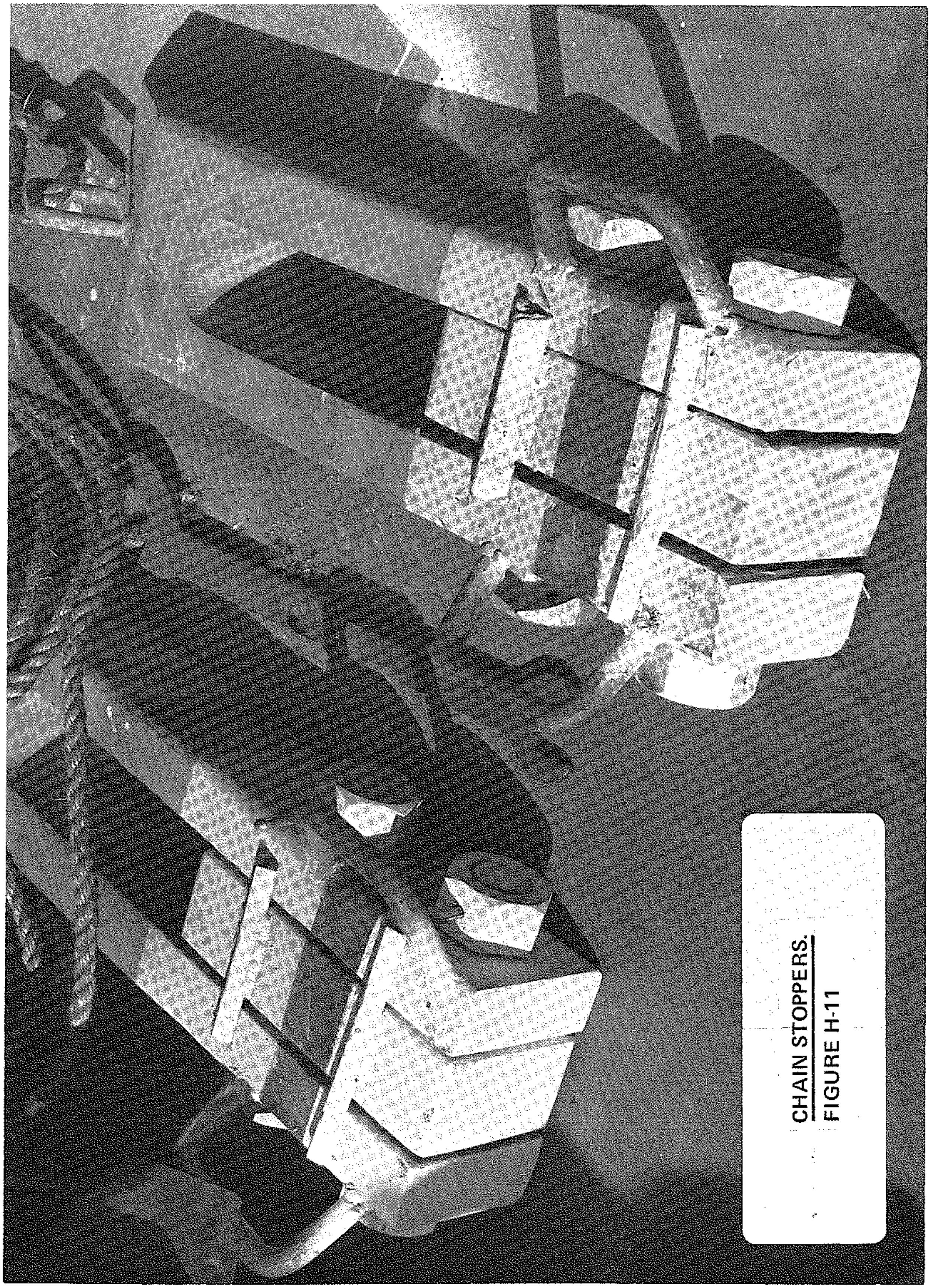
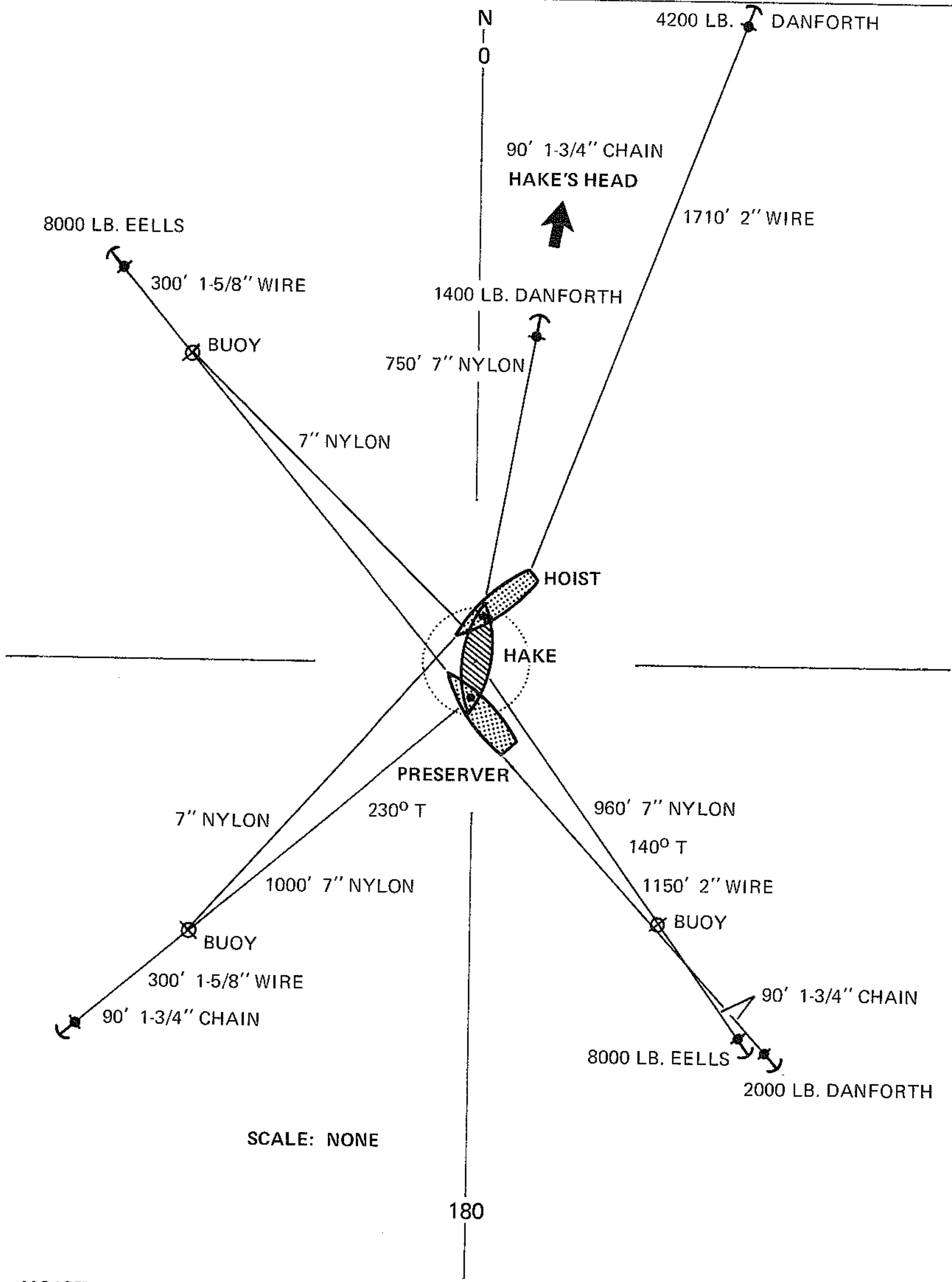


FIGURE H-11
CHAIN STOPPERS.



HOIST AND PRESERVER IN THE SECOND LIFT WORKING MOOR.

FIGURE H-12

completely dry. The presence of considerable excess buoyancy, particularly at the end to be lifted first, makes the use of control pontoons essential.

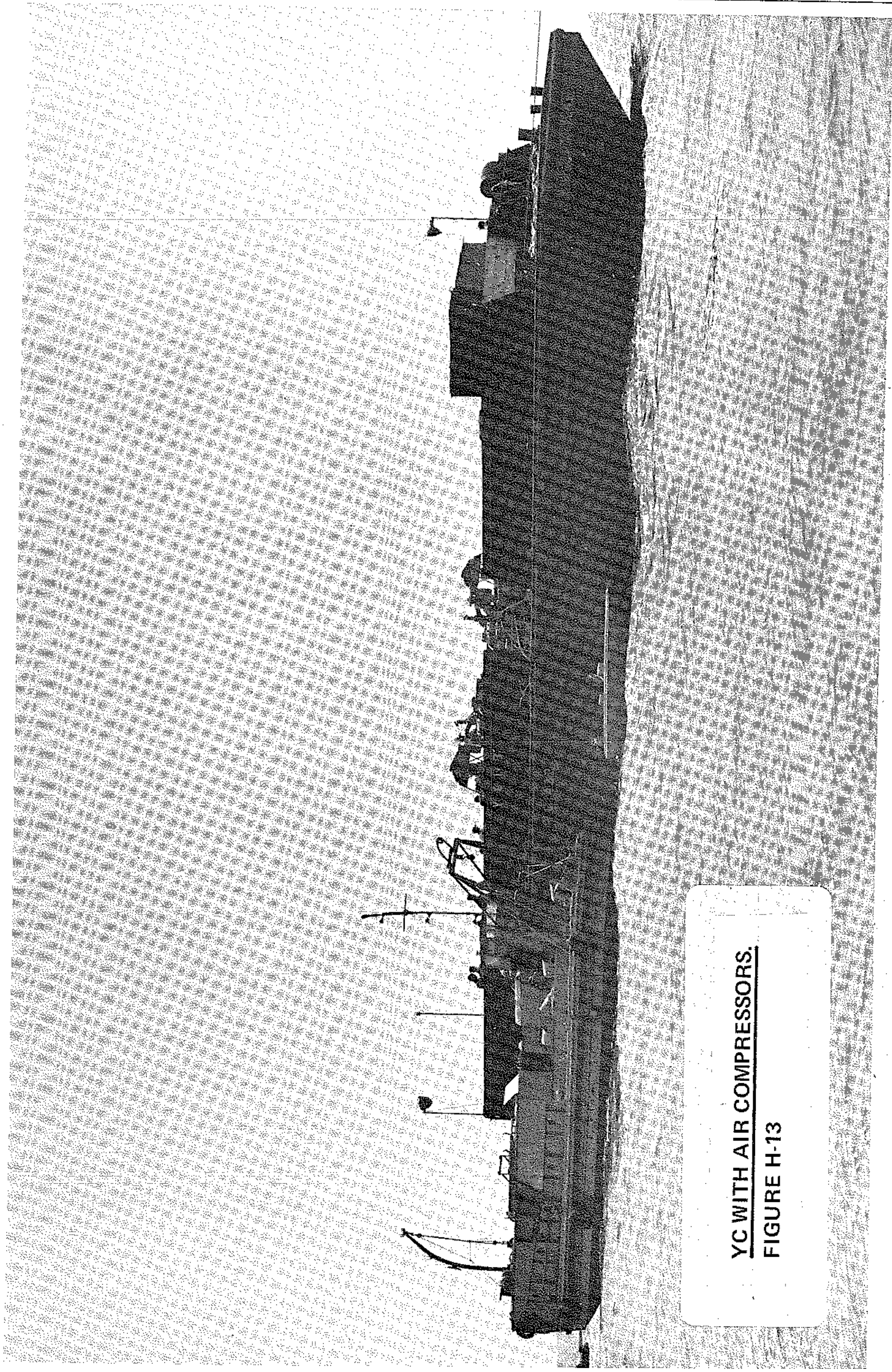
- A pontoon rigged athwartships on a single sling is almost impossible to blow evenly. One end overtakes the other, renders the sling and the more buoyant end flips high. By blowing the low end, which can be blown essentially dry, the positions of the two ends can sometimes be reversed. However, if the sling will not render, the water in the high end is going to stay there and that buoyancy has been irretrievably lost. Hence, the recommendation concerning the amount of excess buoyancy required in the preceding paragraph, above.

- With pontoon valves installed as they presently are knocking off at least one valve per pontoon during launch from a YC has a mathematical certainty of 100%. Even with valves removed, and piping capped off the mathematical certainty of damaging at least one valve's piping during launch from a YC is 100%.

- Again, because of the exposed nature of the pontoon valving, the probability that you will knock off at least one valve with a lifting sling while setting a pair of pontoons is 100%. Changing a valve on a pontoon underwater in poor visibility is a very difficult and time consuming job.

- Pontoons rigged in pairs parallel to the fore and aft axis of the submarine show little tendency to render.

- Never buoy off a reeving wire and a blow hose together. For SUBSALVEX-69, 100' and 150' lengths of blow hose were fabricated to use in setting the pontoons on positive buoyancy. After the primary lift and control pontoons were set for the first lift the short blow hoses and reeving wires were buoyed off together. The premise was that hook up of the blow hoses to the air compressors could quickly and easily be effected on the surface. Nothing could have been further from the truth. Most of the short hoses became unusable through fouling with the reeving wires which necessitated an underwater disconnect and connection. The reeving wires also fouled themselves with the short blow hoses to the extent that clearing the fouled wires and hoses required additional hours



YC WITH AIR COMPRESSORS.
FIGURE H-13

of hard work.

- In consonance with the preceding, never buoy off anything unless it is absolutely necessary. Clean everything off and reconnect it under water if necessary. Considerable time and effort will be saved in the long run.

- Make chain slings as short as possible for two very good reasons:

  1. Excess chain is very heavy and requires the expenditure of buoyant force.

  2. The chain protruding through the pontoon hawse is impossible to keep clear of the pontoon valves and will invariably knock one or more of them off. Cutting torches were created to help solve this kind of problem and detachable links were created to help you out if you should cut the chain too <u>short</u>. Do not hesitate to use either!

- Lowering lines serve two useful purposes:

  1. To permit lowering the pontoon <u>EVENLY</u> down the slings.

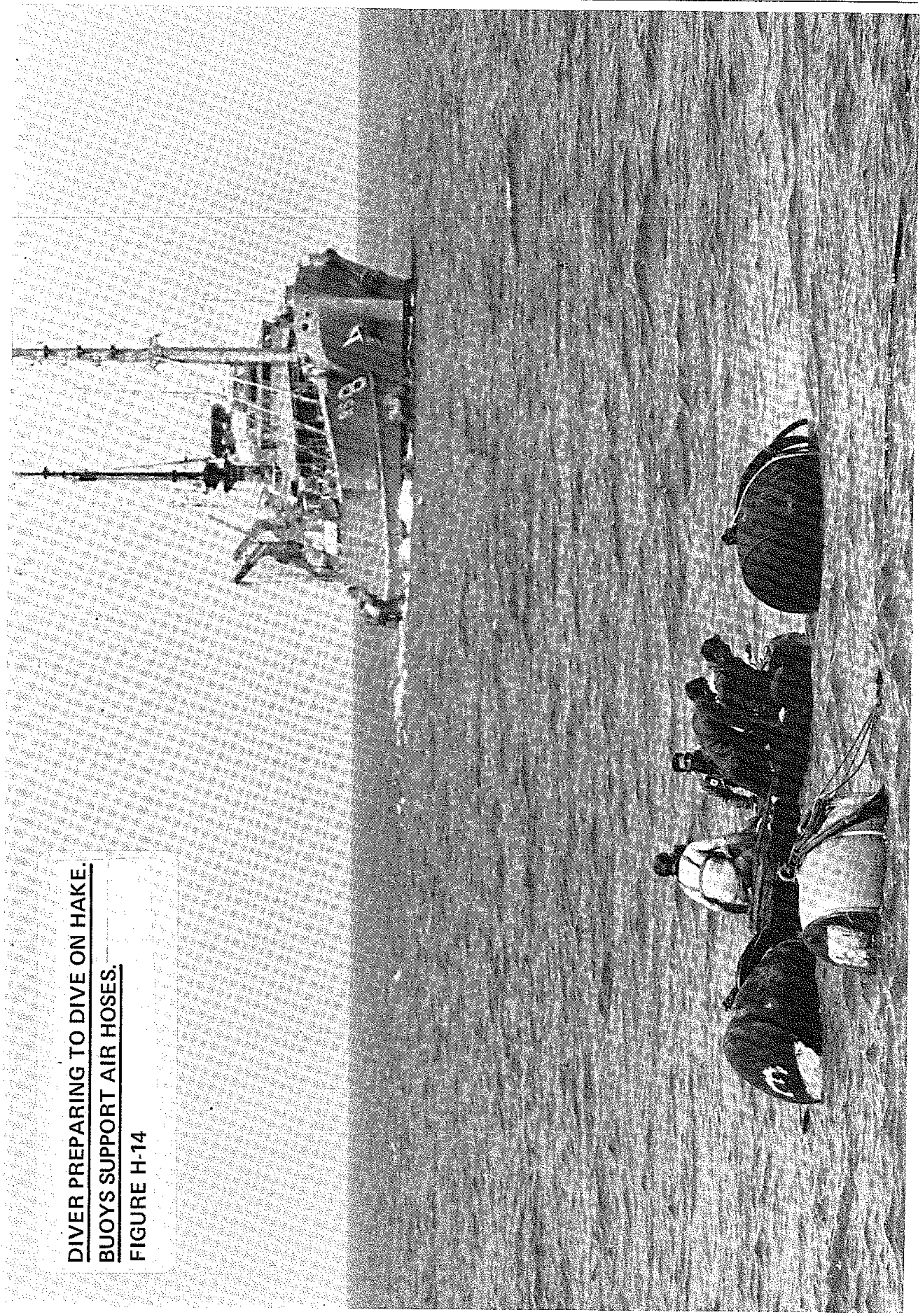
  2. To permit positioning the pontoon where it should be with respect to the submarine, note 2. above is very important and should not be overlooked. The random position the pontoon will naturally take will not be the position desired. Pontoon position relative to the submarine must be positively controlled by the lowering lines.

- Pontoons handle much more easily when flooded down past mid-diameter.

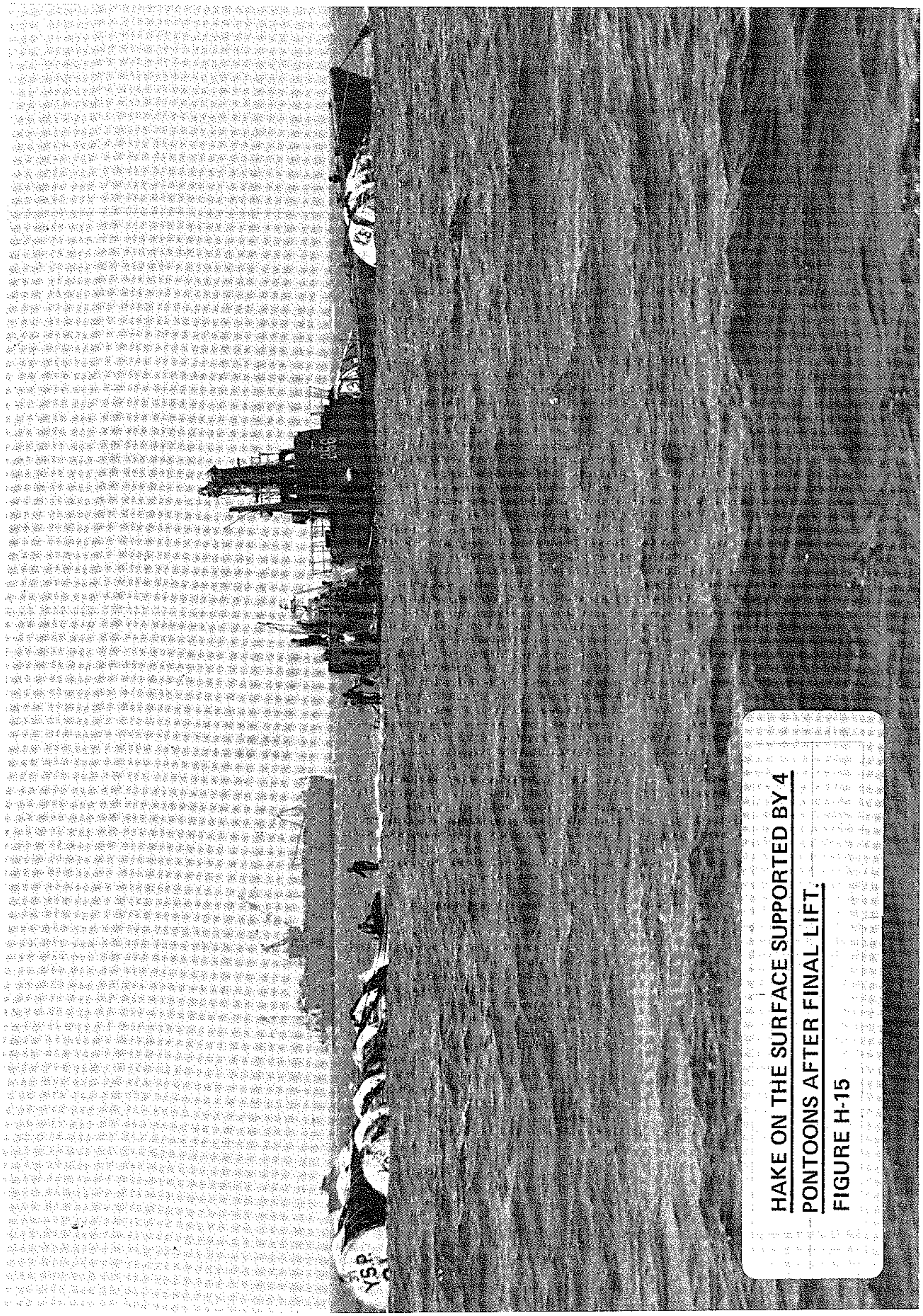
- Pontoons are easily destabilized by excess chain draped around/over the pontoon.

- Divers have difficulty identifying pontoon valves underwater in reduced visibility.

- When making a lift using pontoons, blow the shallowest pontoon first; proceeding sequentially



DIVER PREPARING TO DIVE ON HAKE.
BUOYS SUPPORT AIR HOSES.
FIGURE H-14



HAKE ON THE SURFACE SUPPORTED BY 4 PONTOONS AFTER FINAL LIFT.

FIGURE H-15

downward until lift off is achieved. Regardless of the capacity of the compressed air system available this procedure provides for the most efficient utilization of that air.

- Working two salvage ships over the submarine at the same time limits the flexibility of each in prosecuting their work. Additionally, whenever the weather deteriorates, it becomes necessary for one or both ships to shift position in the moor.

Conclusions Drawn

- Based on the results of SUBSALVEX-69 the salvage by US NAVY Salvage Forces of any sunken submarine which can be reached by divers can, in general, be considered feasible.

- The Submarine Salvage Pontoons (YSP) are a source of large quantities of buoyancy and should be seriously considered for use in surface salvage operations where large amounts of buoyancy are required and working conditions will permit their use.

- The use of Submarine Salvage Pontoons (YSP) is still a valid submarine salvage technique. These pontoons should be modernized to increase their effectiveness and ease of use.

- In future exercises of this type, high capacity air compressors should be installed on the YRST-2 vice a YC type barge. The advantages are many, i.e. convenience for personnel, mooring capability, shop facilities and readily available salvage material and spare parts. Additionally, it may prove highly advantageous to moor the YRST in the immediate vicinity of the submarine and salvage ship in order to assist in passing messengers, reeving wires and lifting slings.

I. Salvage of the USS GUITARRO (SSN 665)

I.1. Brief

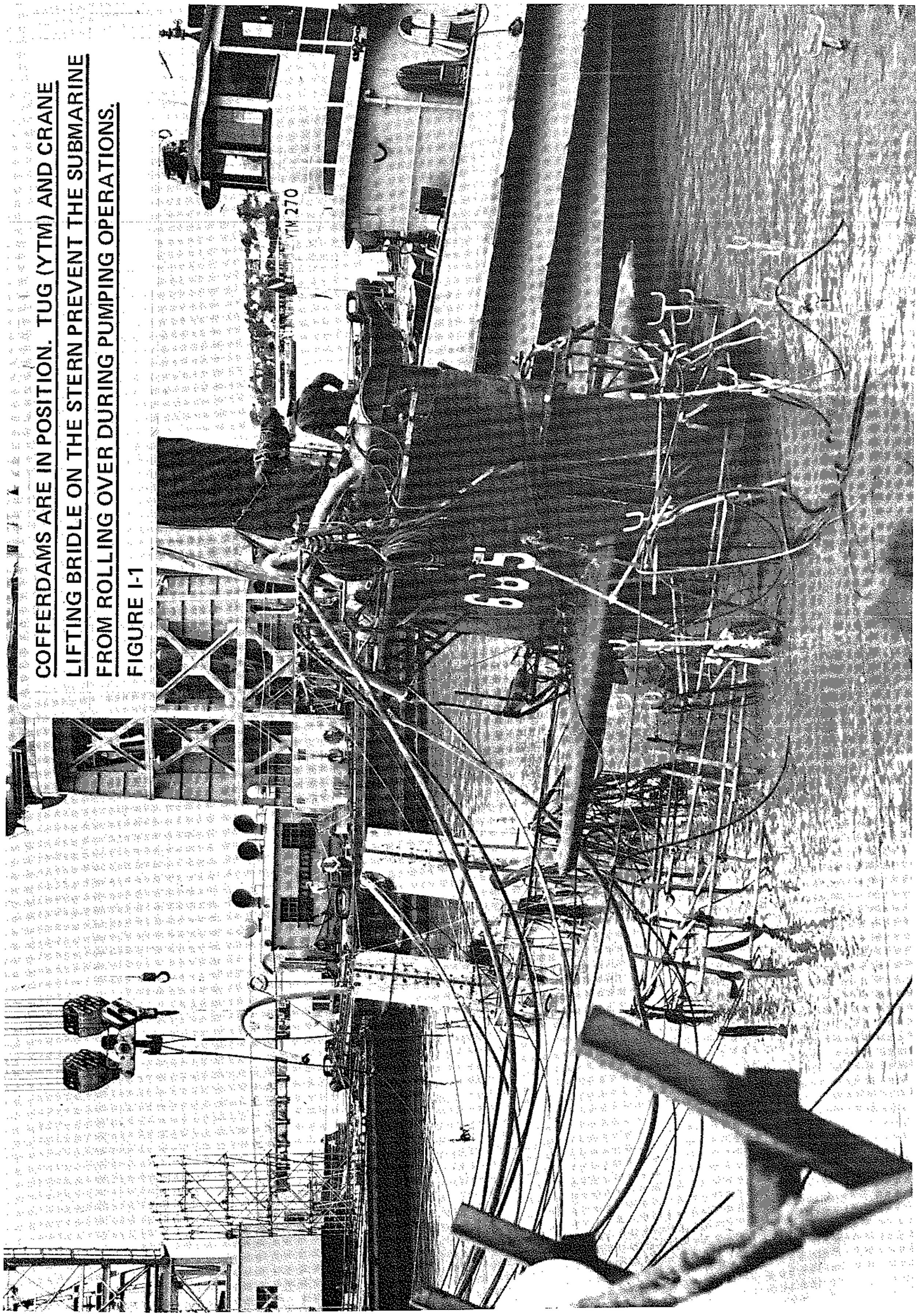
USS GUITARRO (SSN 665) was in an advanced state of construction at the San Francisco Bay Naval Shipyard (Mare Island Division). On the evening of 15 May 1969 uncontrolled flooding caused the GUITARRO to sink. Salvage operations were conducted by the Supervisor of Salvage.

The submarine was refloated at 1119 on 18 May 1969 by dewatering with pumps through cofferdams which had been constructed for that purpose. Though the initial salvage plan envisioned expelling water by means of compressed air through the salvage air fittings, this plan was abandoned in favor of pumping when it became obvious that pumping would be much faster.

After the submarine was surfaced, residual water was removed from GUITARRO until a condition satisfactory for drydocking was reached. Salvage operations were completed when GUITARRO was docked at San Francisco Bay Naval Shipyard on the evening of 18 May 1969. The salvage operation, from beginning of mobilization through successful recovery, was particularly short; only 3 days passed between the date of sinking and drydocking of GUITARRO. The shipyard industrial assistance and complete availability of all services, especially cranes, made the salvage of GUITARRO possible in such a short time. A similar submarine sinking, far removed from the industrial plant capacity available at the San Francisco Bay Naval Shipyard, would present a much more complex problem and probably require much more time and effort for recovery.

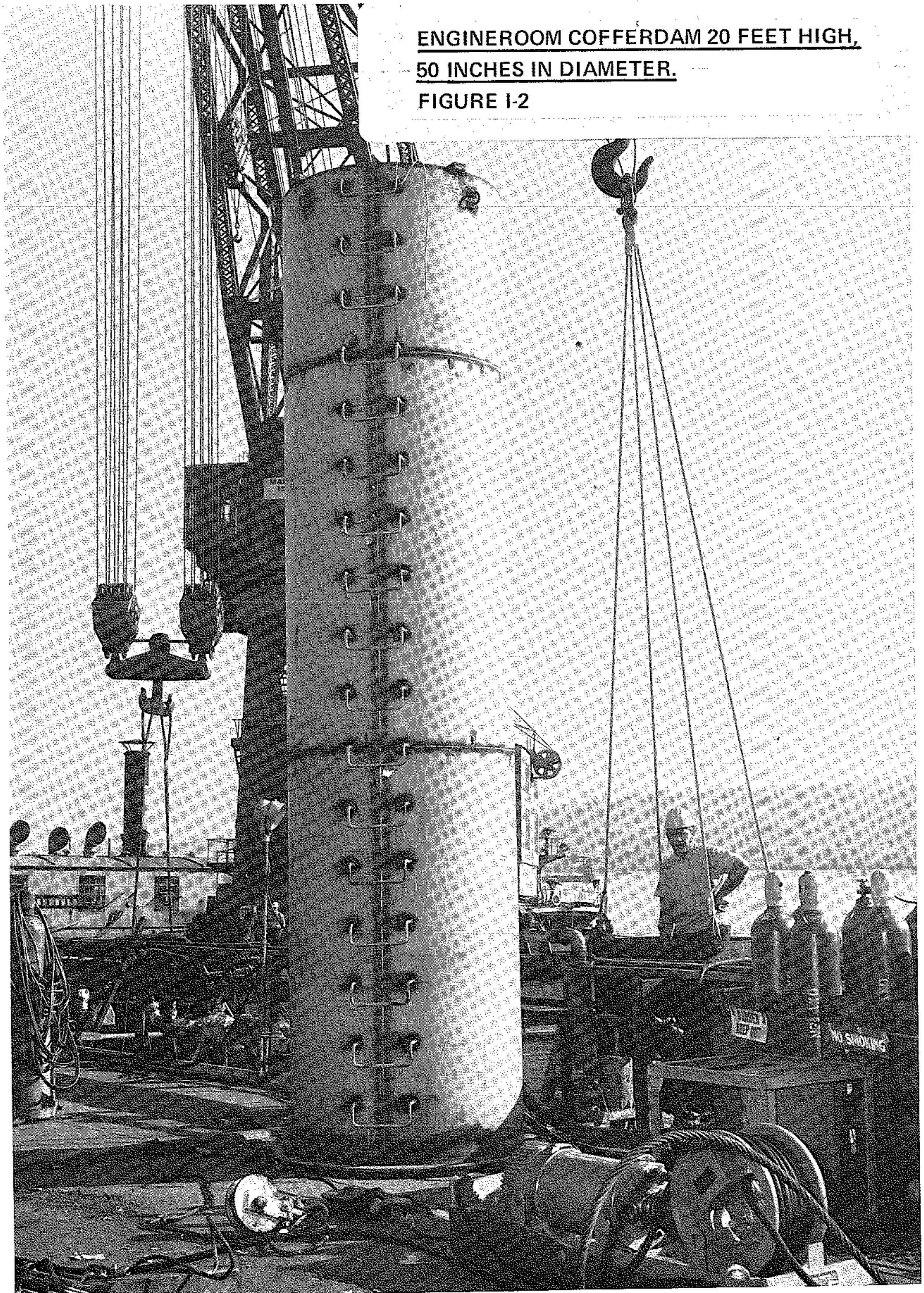
I.2. Narrative

On the evening of 15 May 1969, at approximately 2130 local time, USS GUITARRO (SSN 665) sank alongside the pier at Mare Island Naval Shipyard, Vallejo, California. The ship sank due to uncontrolled flooding which originated in the forward part of the ship. After sinking, the ship came to rest with approximately a 6^{o} port list; the fairwater above the sail planes remained above water, as did the conning tower access trunk. At the time of sinking no fissionable material was aboard. The ship was in an advanced state of construction. With the exception of the reactor, essentially all equipment was aboard. Ballast tank flood ports were temporarily welded closed and temporary covers were installed on ballast tank vents. The forward and after access trunks were open for normal personnel access. The following temporary openings existed:



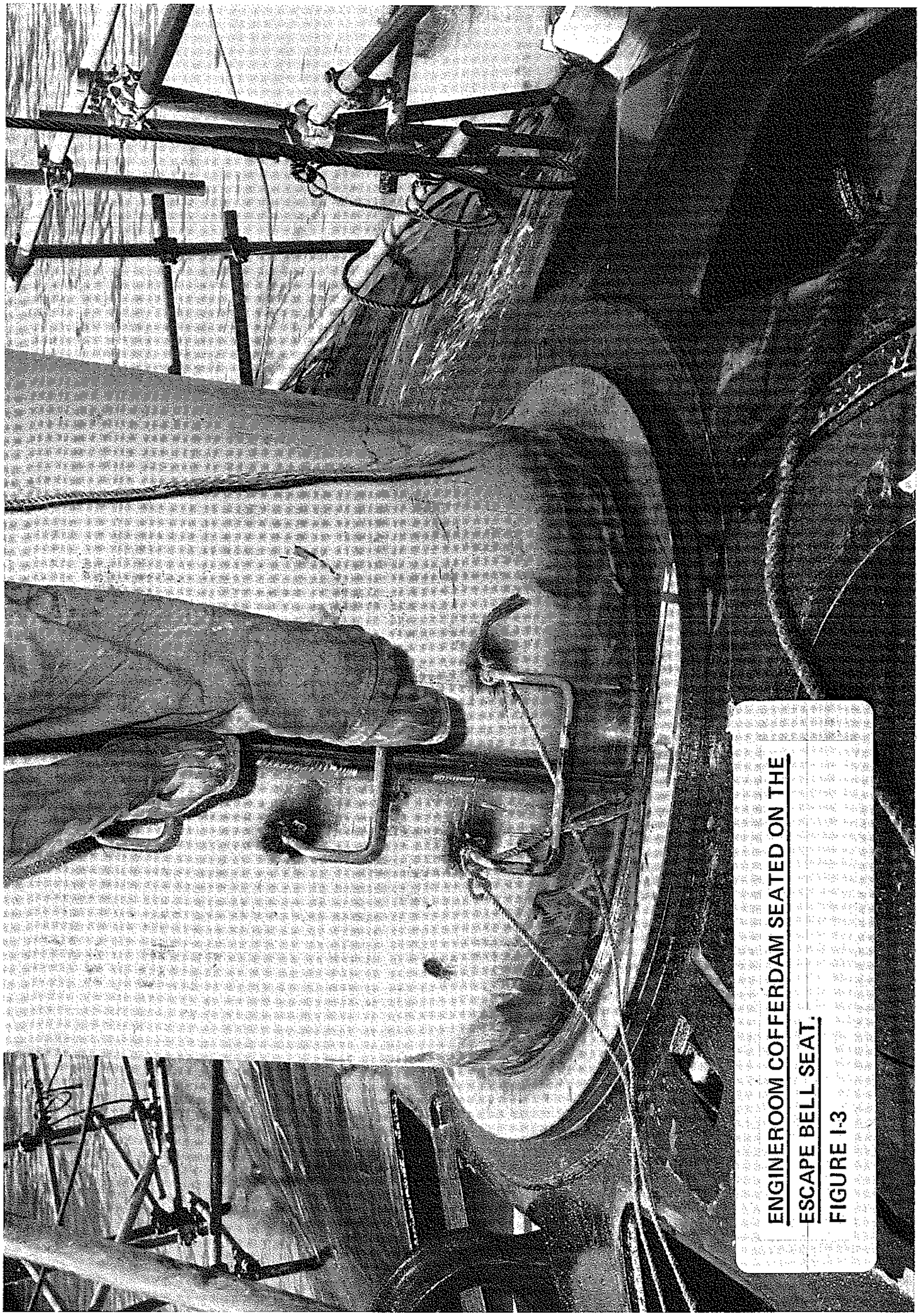
COFFERDAMS ARE IN POSITION. TUG (YTM) AND CRANE LIFTING BRIDLE ON THE STERN PREVENT THE SUBMARINE FROM ROLLING OVER DURING PUMPING OPERATIONS.

FIGURE I-1



ENGINEROOM COFFERDAM 20 FEET HIGH, 50 INCHES IN DIAMETER.

FIGURE I-2



ENGINEROOM COFFERDAM SEATED ON THE ESCAPE BELL SEAT.

FIGURE I-3

- Sonar space. On the top side of the hull were two openings. A bolted access cover had been removed. A temporary access about 22 inches square had been cut. Two normally tight cable ways into the sonar space at FR.11 were not watertight due to work in progress.

- Reactor compartment. A temporary access (approximately 12 feet square) existed in the top of the hull for installing reactor components.

- Auxiliary Machinery Room Two (AMR-2). A temporary services opening existed in the top of the hull for power and ventilation. A temporary services trunk was welded to this opening, but was non-tight at the top where cables and ventilation ducts entered.

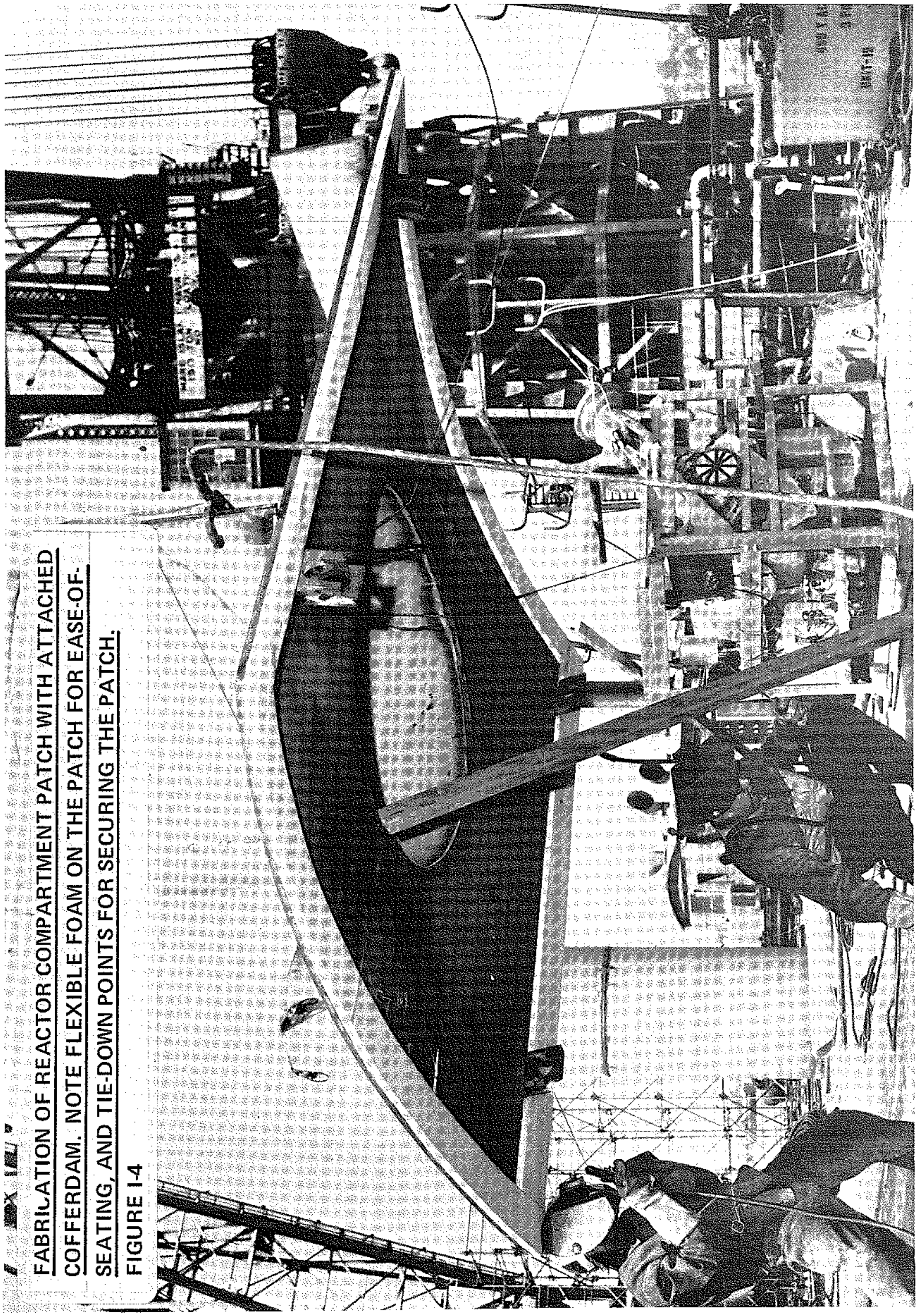
- Hole for missing engineroom high salvage air fitting.

Initial efforts through the night and early morning of 15 - 16 May were concerned with closing internal watertight doors and hatches, clearing some of the maze of temporary service wires that cluttered the topside of the submarine, and closing or patching temporary access openings. Air hoses were rigged to the salvage air fittings in the forward two spaces (crew's living and operations spaces). Pressure was applied and these spaces were found to be watertight.

At 0830 on 16 May, after a review of the situation, it was determined that essentially all of the flood water must be removed from the submarine. Since approximately one-third of the hull was sunk into the mud, it was anticipated that some positive buoyancy would be required to overcome the effect of mud suction. The basic salvage plan was to make the hull watertight, then remove the flood water. Two basic means were available:

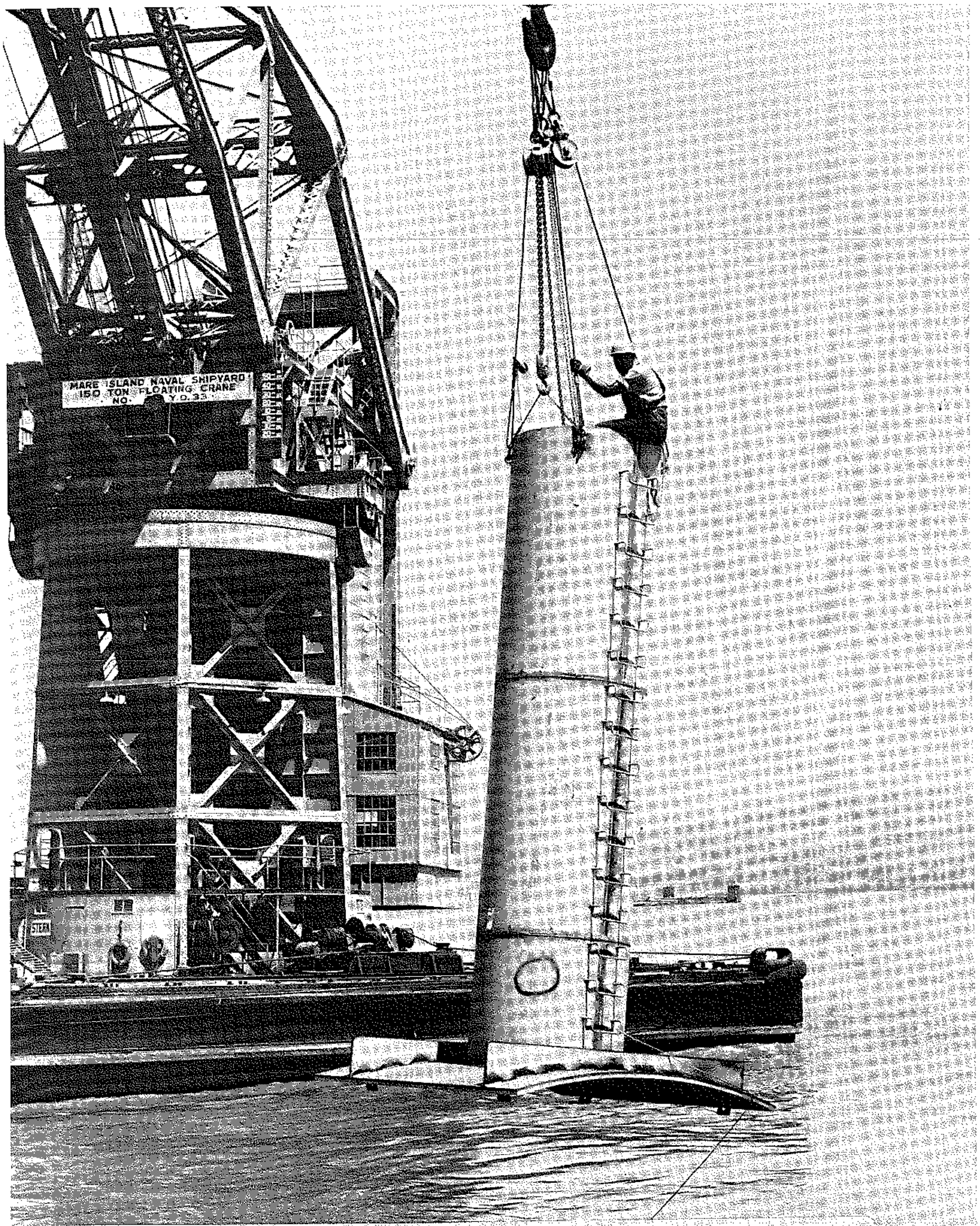
- Air Blow - The preferred way to raise a sunken submarine is by expelling flood water with air through the salvage air system.

- Erect Cofferdams - Since the conning tower access hatch was above water and the after access hatch and reactor compartments were only about 15 feet below the surface, it was feasible to pump water out through cofferdams.

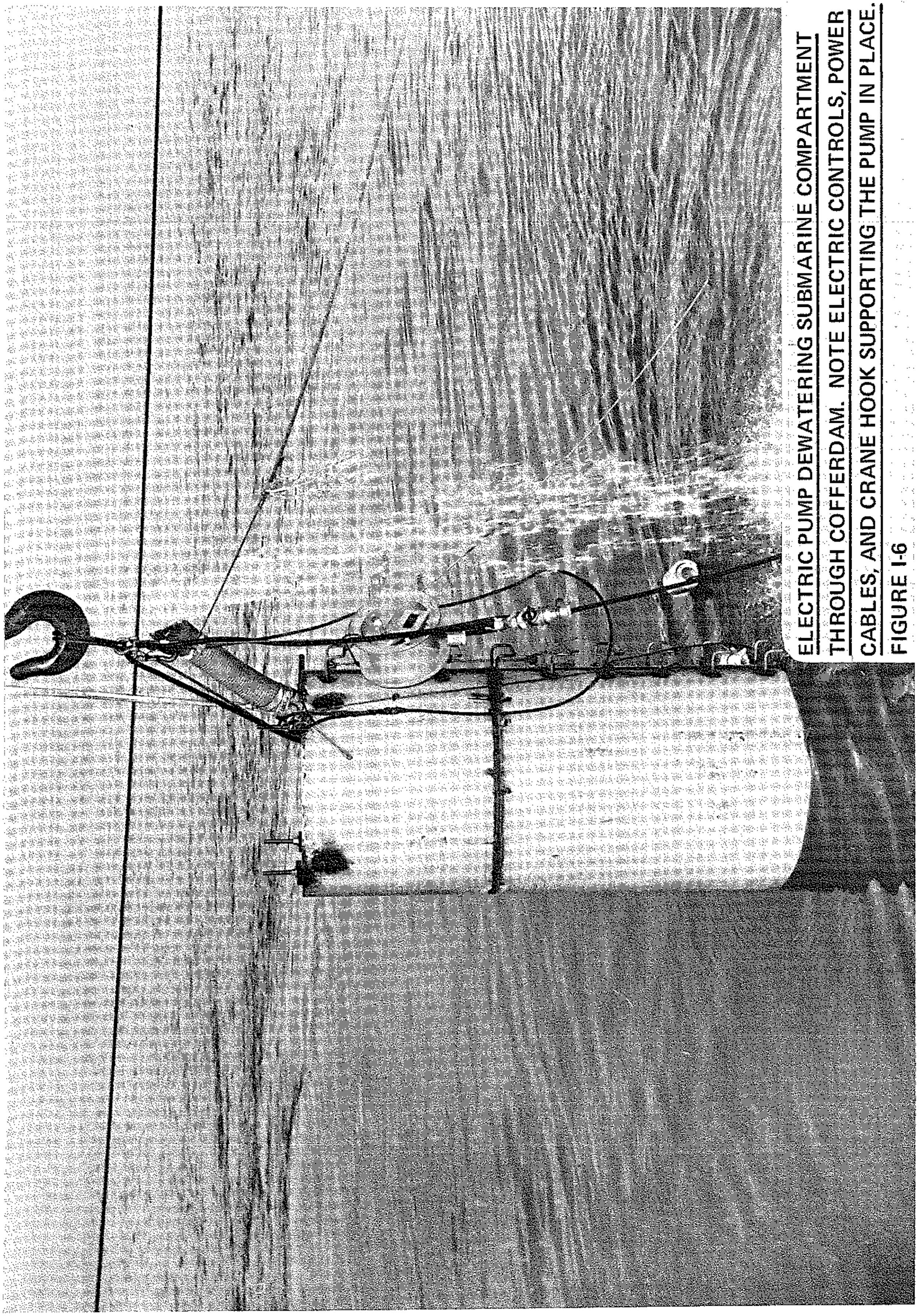


FABRICATION OF REACTOR COMPARTMENT PATCH WITH ATTACHED COFFERDAM. NOTE FLEXIBLE FOAM ON THE PATCH FOR EASE-OF-SEATING, AND TIE-DOWN POINTS FOR SECURING THE PATCH.

FIGURE I-4



CRANE LIFTING REACTOR COMPARTMENT PATCH AND COFFERDAM INTO POSITION. THE COFFERDAM IS FABRICATED FROM 25 POUND PLATE, IS 20 FEET HIGH, AND IS 50 INCHES IN DIAMETER.
FIGURE I-5



ELECTRIC PUMP DEWATERING SUBMARINE COMPARTMENT THROUGH COFFERDAM. NOTE ELECTRIC CONTROLS, POWER CABLES, AND CRANE HOOK SUPPORTING THE PUMP IN PLACE.

FIGURE I-6

The salvage plan actually used both methods. The forward two spaces were blown for about eight hours. When it became obvious that pumping would be much faster than blowing, the blow was secured and pumping became the primary means for dewatering. Pumping had two additional advantages:

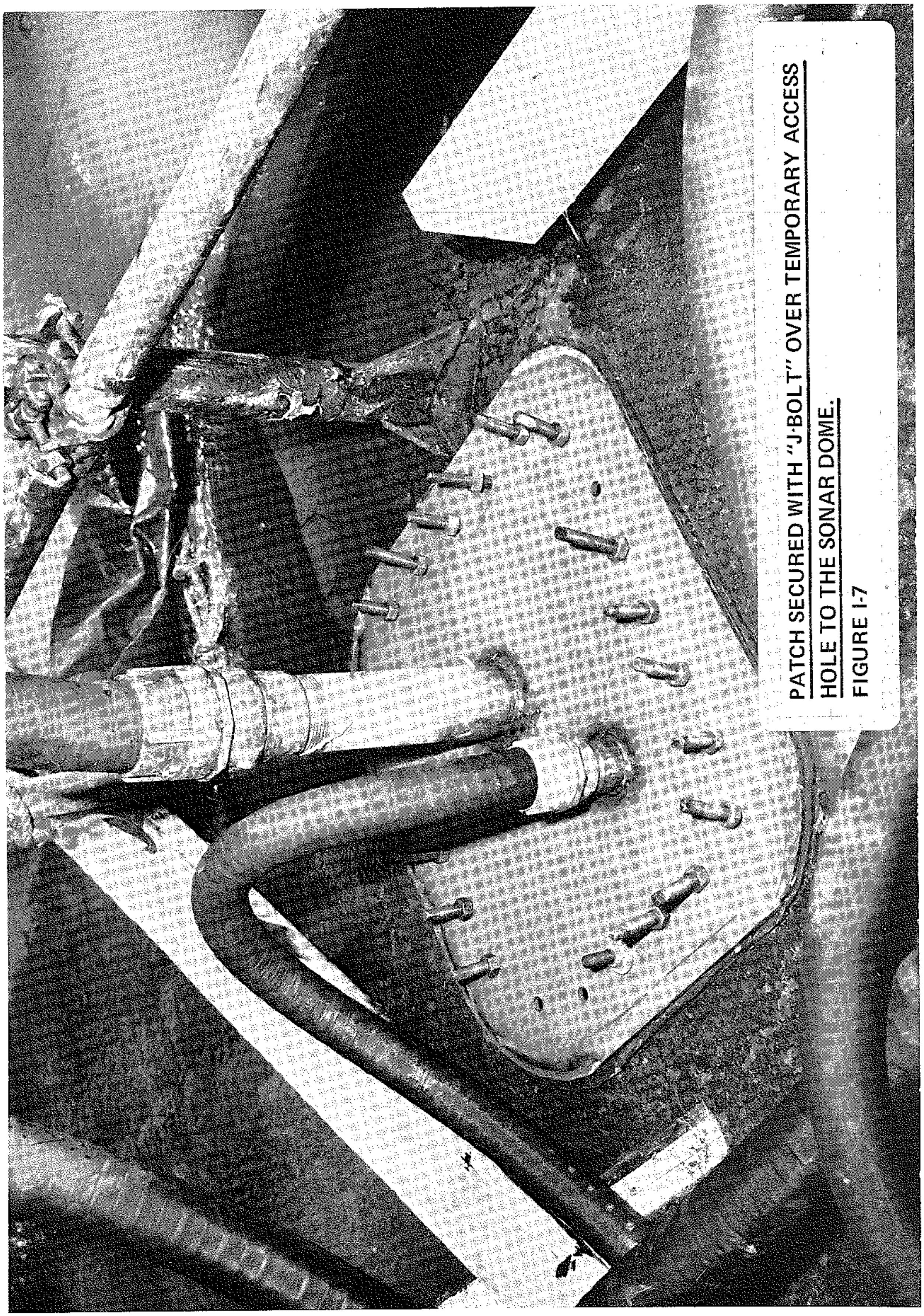
- Since the submarine could be entered during pumping operations, the exact status of buoyancy was known at all times. This permitted the final refloating to be a controlled operation.

- Pumping permitted the removal of residual water that could not be expelled by blowing. Low reserve buoyancy made the removal of this water essential.

Calculations indicated that the ship was in a stable condition, though righting arms were quite low due to the flooding water. As flooding water was removed stability continually improved because of the lowering of the center of gravity. The only concern was the possibility of developing an upsetting moment caused by a free surface effect on the watertight deck of the torpedo room. This was avoided by stripping this space of all water prior to the refloating effort.

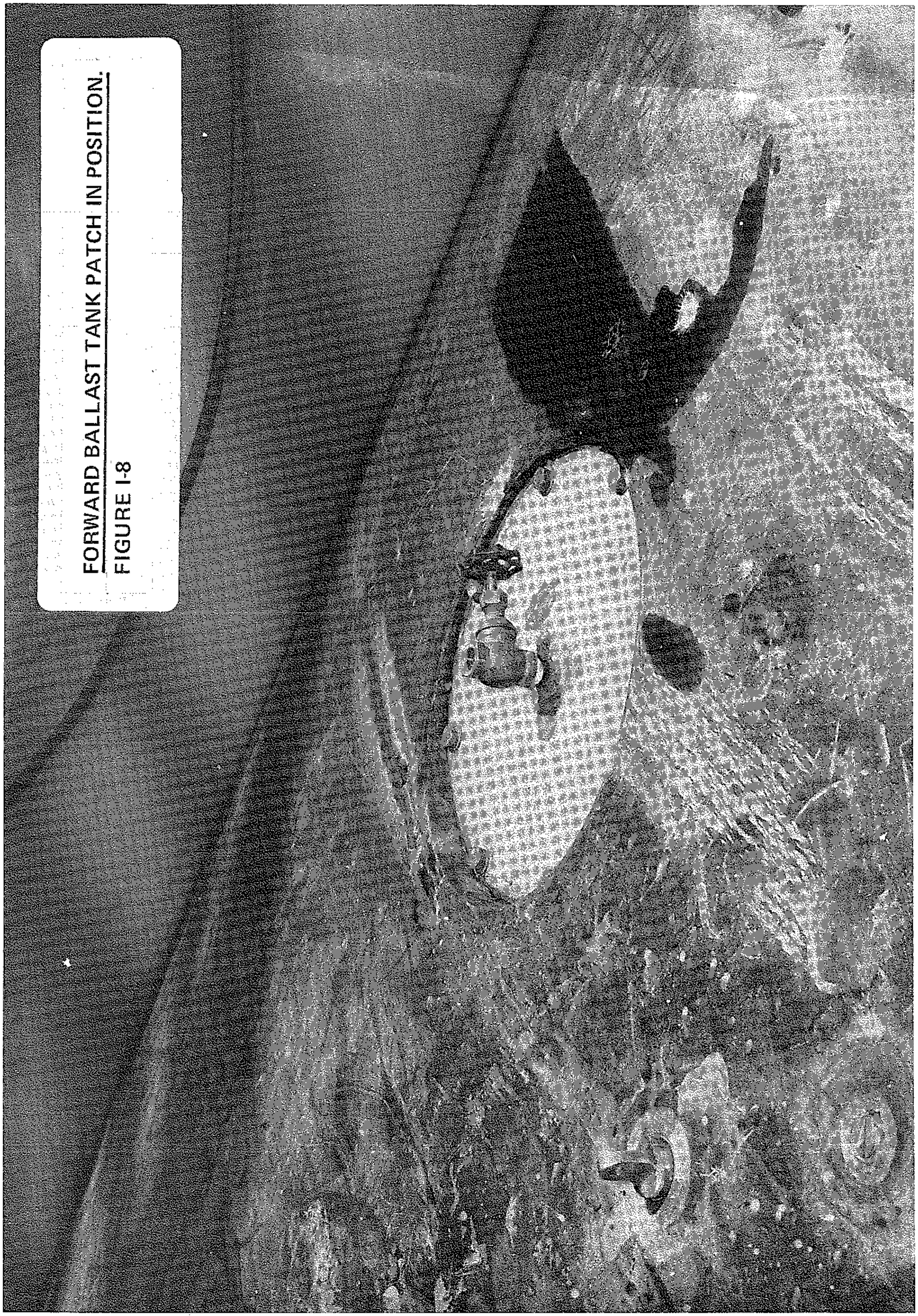
The daylight hours of 16 May were spent in clearing an access through the maze of temporary service lines by divers so that all hull openings could be identified, templated, and made ready for patches. Cofferdams had been designed and were being constructed by shipyard personnel. The 150 ton crane was connected to GUITARRO aft to provide additional stability. During the evening of 16 May preparations were made to blow the main ballast tanks forward. Temporary protective plates over the vent valves were removed by divers. Since three vent valves were closed hydraulically, it was necessary for divers to remove the entire vent valve mechanism. This job was completed with the assistance of a dockside crane on 17 May.

On 17 May all patching was completed. Cofferdams were installed on the after access hatch and on the patch for the reactor compartment. Blow fittings were installed on main ballast tanks forward, and a fitting to pump the sonar dome underwater was installed. At 0500 the forward two spaces were pressurized and water expulsion commenced. This blow continued until 1240, when it was decided to shift to pumping. These spaces were vented, and at 1825 the conning tower access hatch was opened. Salvage crews entered the submarine and found the water level forced down to about three feet below the upper level. Prior to the entry of personnel into the submarine, careful checks were made for chlorine and hydrogen gas; none was found.

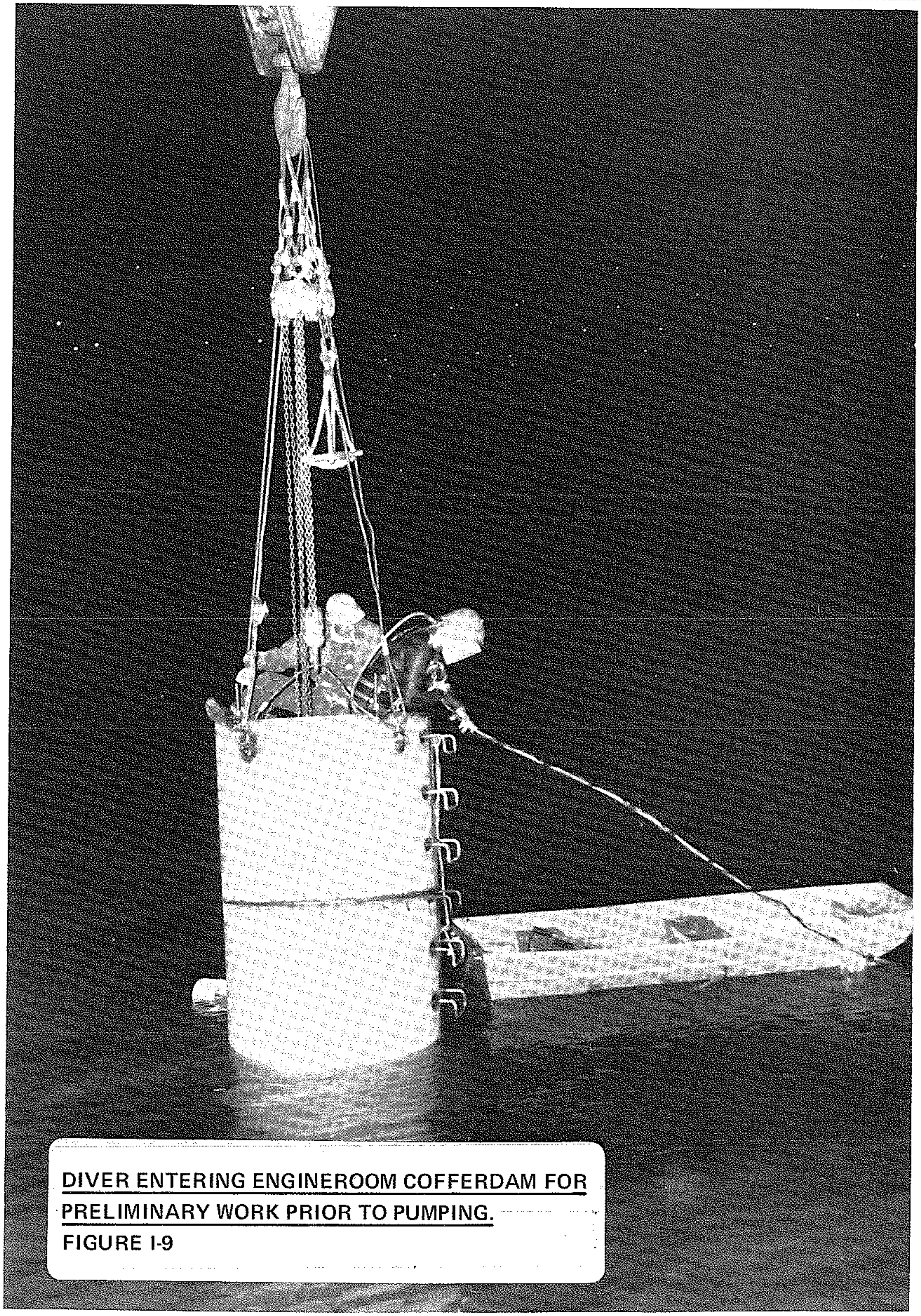


PATCH SECURED WITH "J-BOLT" OVER TEMPORARY ACCESS HOLE TO THE SONAR DOME.

FIGURE I-7



FORWARD BALLAST TANK PATCH IN POSITION.
FIGURE I-8



DIVER ENTERING ENGINEROOM COFFERDAM FOR PRELIMINARY WORK PRIOR TO PUMPING.
FIGURE I-9

At 1700 pumping commenced through the reactor compartment cofferdam and at 2355 pumping commenced through the engineroom cofferdam. The recommended dewatering sequence was followed as a guide, but when it became apparent stability would not be a problem, the sequence was modified. It was decided to completely dewater the submarine with the exception of AMR-2. This flood water was used as ballast to prevent the submarine from surfacing until all preparations had been made.

Pumping and stripping operations continued through the early morning of 18 May. By about 1030 pumping and stripping operations had been completed with the exception of AMR-2. All was now in readiness for the first refloating effort. At 1057 pumps were started on AMR-2 and a 20 ton strain was taken on the floating crane shackled to the stern. At 1119 the submarine rose to the surface. On surfacing the submarine trimmed by the stern, with the top of the rudder below water. The after trim was probably caused by water from AMR-2 moving aft into the engineroom as the submarine surfaced. Salvage crews then entered the submarine for the final stripping effort. At about 1700 stripping operations were complete and the submarine was sufficiently buoyant to enter drydock.

On the evening of 18 May USS GUITARRO entered Drydock #3, Mare Island Naval Shipyard, and salvage operations were terminated.

I.3. Detail Discussion of Weight, Buoyancy, Stability, and Recommended Sequence of Actions to Float GUITARRO (SSN 665)

Buoyancy - Weight Factors (A)

Available evidence indicates that the submarine was floating at the top of the boot topping (which is 6" above normal diving trim draft). This indicates the displacement, prior to start of accidental flooding, was 4266 tons.

At the time Main Ballast 1, 2A, and 2B were full, Main Ballast 3A and 3B contained 30 tons, the forward sonar tank was dry.

Estimating the initial condition on the basis of the condition A weight of the SSN 662, on the assumption that SSN 662 and SSN 665 are both very close to calculated (which was the case in 662), gives:

NOTE : Reference Submarine Guidance Plan, Figure I-15 for compartmentation details.

Condition A	4002	Tons - Including Sonar Tank
	- 143	- Sonar Tank
	3859	
	+ 273	Main Ballast Tank 1, 2A & 2B, Partial Main Ballast Tank 3A & 3B and Variable Ballast
	4132	
	- 49	Internal Tanks
	4083	Tons

Therefore, initial condition range was between 4083 tons and 4226 tons.

The flooded weight on the bottom is based on design dimensions minus permeability factor times density of water (measured). Variable ballast tanks are also considered on the basis of the reported initial condition which is calculated to be 80.18 tons. Minimum weight calculation assumes no further flooding occurred. Maximum weight calculation assumes complete flooding of remaining volume which would be about 78 tons. Main Ballast Tank 3A and 3B flooded an additional 58 tons. Forward sonar dome flooded 143 tons.

Based on the recommended sequence of actions in the following section, <u>Recommended Sequence</u>, the estimated minimum and maximum weights are shown in Table I. The net weight holding the ship on the bottom is shown in Table II.

<u>Stability (B)</u>

Condition on bottom with all internal compartments flooded, Bow Sonar Tanks and Main Ballast Tanks 1, 2, & 3 flooded, Main Ballast Tanks 4, 5, and 6 dry, and assuming that all internal tanks are dry, which would be the worst case, positive stability (BG) equals about 0.17A.

Dewater Operations Compartment, Forward Room, and Sonar sphere .... BG = 0.53 ft.

Dewater Engine Room .... BG = 0.82 ft.

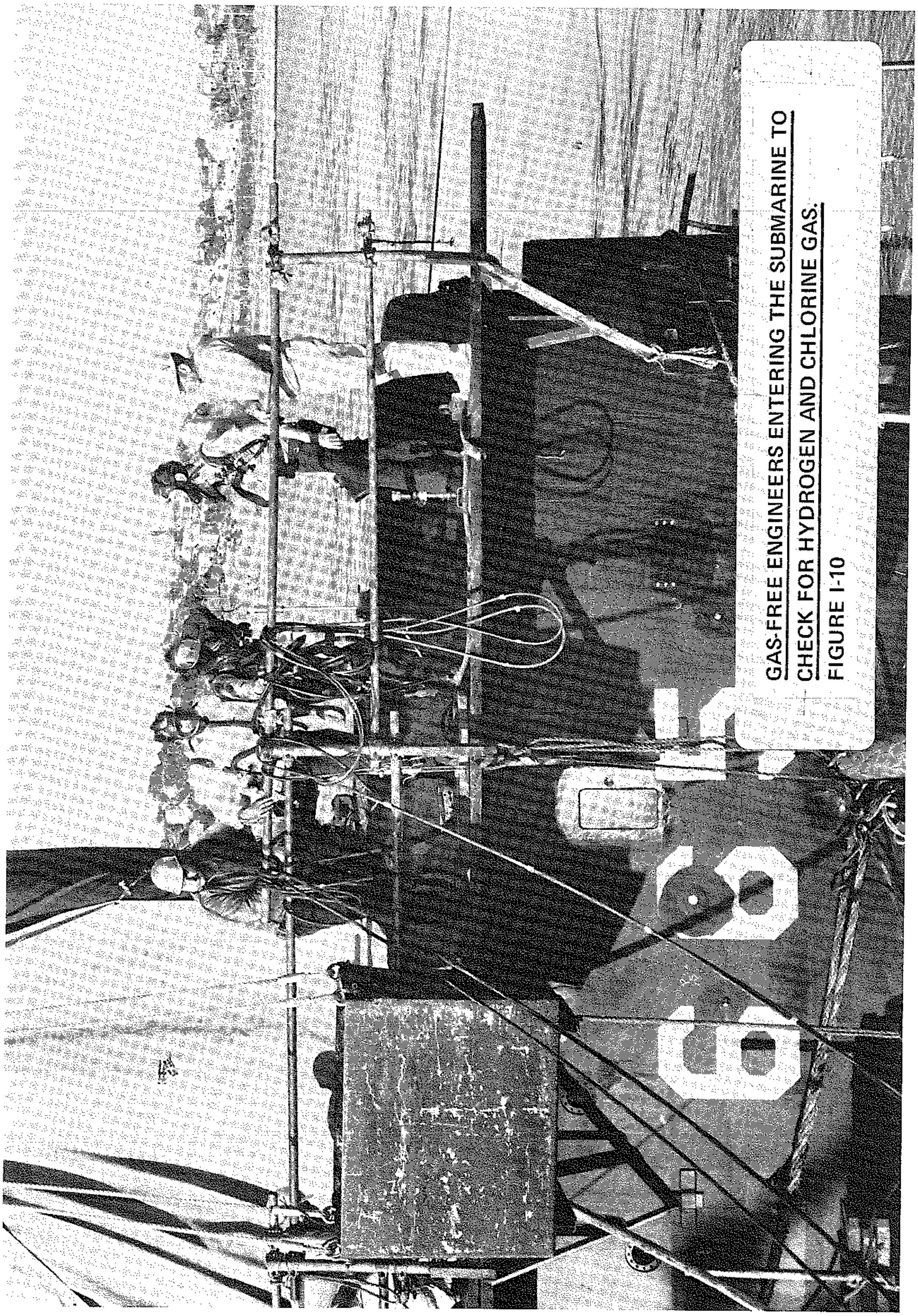
Fill Main Ballast Tanks 4 and 5 .... BG = 0.80 ft.

Dewater Auxiliary Machinery Room .... BG = 0.82 ft.

Blow Main Ballast Tank as recommended ... BG = will increase

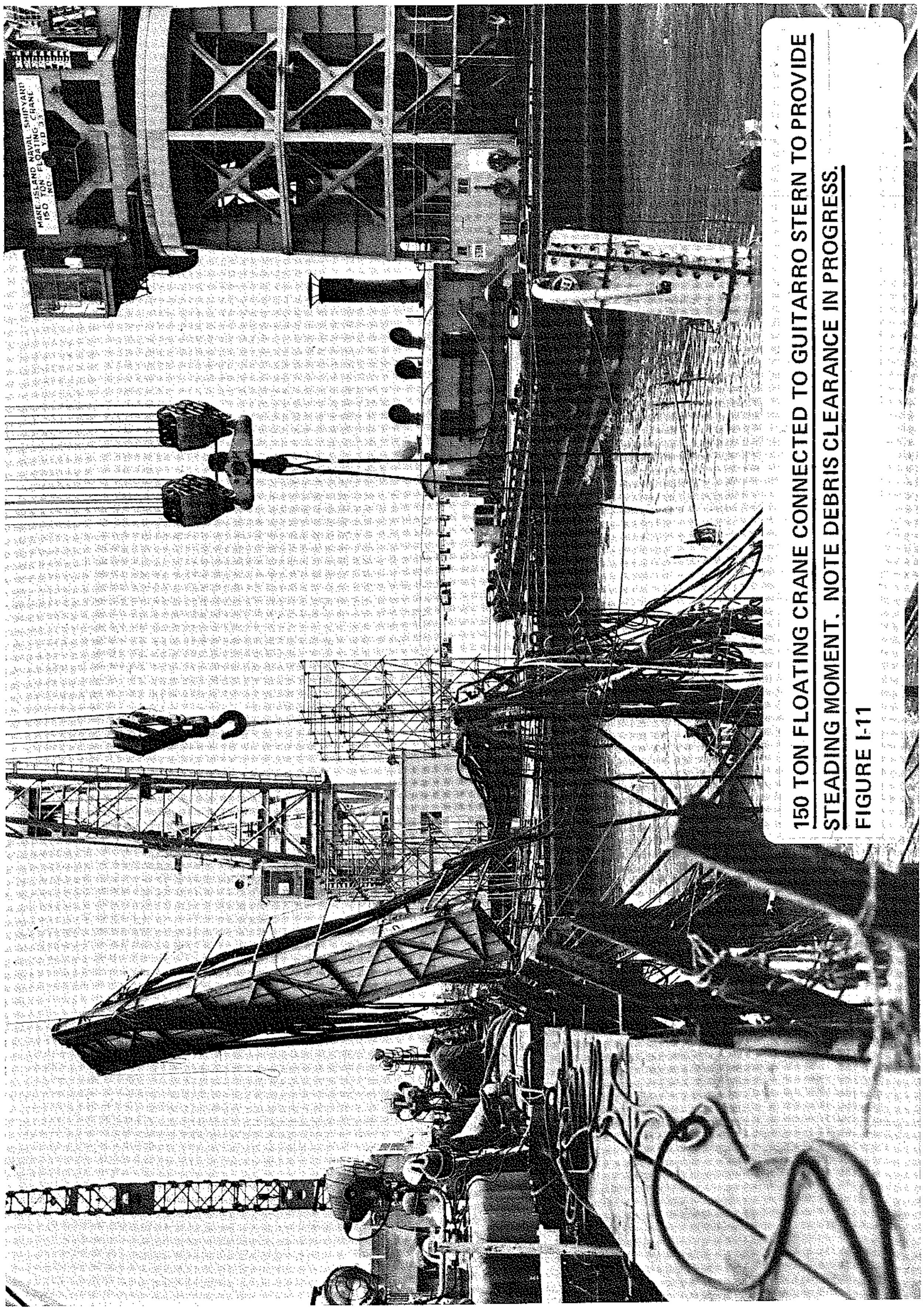
<u>Recommended Sequence (C)</u>

The submarine should remain on the bottom until a <u>controlled</u> effort to raise it is ready.



GAS-FREE ENGINEERS ENTERING THE SUBMARINE TO CHECK FOR HYDROGEN AND CHLORINE GAS.

FIGURE I-10



150 TON FLOATING CRANE CONNECTED TO GUITARRO STERN TO PROVIDE STEADING MOMENT. NOTE DEBRIS CLEARANCE IN PROGRESS.

FIGURE I-11

Precise weights and conditions are not achievable; a bandwith of possible error, on both sides of the best estimate, is required to insure control. The potential error quantities are:

- condition of variable tanks
- amount of residual water ramaining
- lack of precise knowledge of initial weight of the ship before the casualty

An excessive trim circumstance is undesirable during the transitory conditions.

The following sequence is proposed:

- Dewater Operations Compartment and Forward Room and strip to lower flat (deck).
- Dewater Engine Room and strip to bottom of bilges.
- Fill aft Main Ballast Tank group Tanks 5A and 5B.
- Dewater Auxiliary Machinery Room.
- Do not dewater Reactor Compartment or Forward Sonar Tank.
- Blow Main Ballast Tanks in following sequence:

  1. 5A, 5B, and 1
  2. 3A and 3B
  3. 4A and 4B and 2A and 2B

  Ship should rise (See Table II)

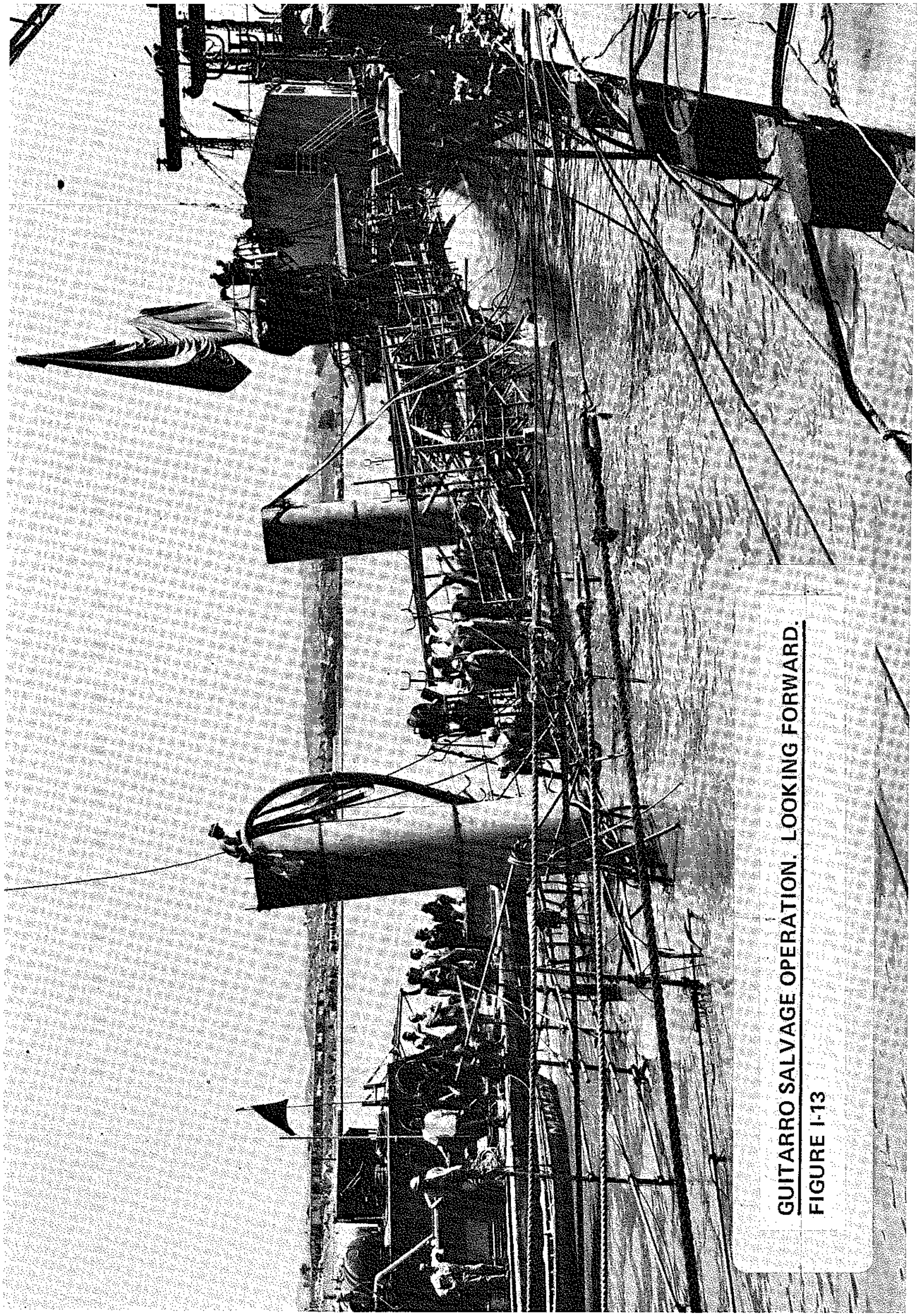
- If ship does not break free, refill main ballast tanks and pump down Reactor Compartment.
- Blow forward and aft main ballast tanks per prior sequence.

I.4. Bottom Breakout Forces

When GUITARRO sank approximately one-third of the hull settled into a very soft mud. In view of the anticipated difficulty in completely dewatering GUITARRO, it was feared that bottom breakout forces due to mud suction might become important.

Preparations were made to overcome the mud suction effect if required. These included (1) hydraulic lances connected to a jetting pump for washout of mud, (2) the use of tugs to rock GUITARRO, and (3) the use of a 150 ton crane to provide additional lift. GUITARRO surfaced before any of these actions were required. The initial surfacing displacement of GUITARRO was about 80 tons. This force is estimated to be approximately the bottom breakout force.

FORWARD BALLAST TANK BLOW FITTINGS CONNECTED FOR BLOWING WITH AIR.
FIGURE I-12



GUITARRO SALVAGE OPERATION. LOOKING FORWARD.

FIGURE I-13

GUITARRO SALVAGE OPERATION. LOOKING AFT.
FIGURE I-14

TABLE I

ESTIMATED MINIMUM AND MAXIMUM WEIGHT FOR VARIOUS CONDITIONS		ESTIMATED WEIGHT	
		Minimum	Maximum
Original Condition (Calculated Displacement)		4083	4226
Flooded Condition	All Compartments	2752	2752
	Sonar Dome	143	143
	Internal Tanks and Partial Main Ballast Tank 3	0	136
		6978	7257
Dewater Operations Compartment (-1103)		5875	6154
Dewater Forward Compartment (-262)		5613	5892
Dewater Engine Room (-804)		4809	5088
Fill Main Ballast Tank 5A and B (+137)		4946	5225
Dewater Auxiliary Machinery Room (-281)		4665	4944
Retain Reactor Compartment Water and Sonar Tank (301 and 143)		4665	4944

ESTIMATED MINIMUM AND MAXIMUM WEIGHT FOR VARIOUS CONDITIONS.

TABLE I-1

TABLE II

WEIGHT, DISPLACEMENT, AND NET WEIGHT HOLDING SHIP ON BOTTOM, ASSUMING REACTOR COMPARTMENT FLOODED			
	MINIMUM WITHOUT RESIDUAL	MAXIMUM WITHOUT RESIDUAL	MAXIMUM WITH 150 TONS RESIDUAL
Weight Submerged	4665	4944	5094
Submarine Displacement	4684	4684	4684
Net Weight Holding Ship to Bottom	-19	260	410
Blow Main Ballast Tanks 5A and B Plus Main Ballast Tank 1.	-221	58	208
Blow Main Ballast Tanks 3A and B	-309	-30	120
Blow Main Ballast Tanks 2A and B	-391	-112	38

WEIGHT, DISPLACEMENT, AND NET WEIGHT HOLDING SHIP ON BOTTOM, ASSUMING REACTOR COMPARTMENT FLOODED.

TABLE I-2

I.5. US NAVY Submarines

The US NAVY operates several classes of submarines. For complete specifications, booklet of general plans, stability information or other information necessary for submarine salvage, contact:

Supervisor of Salvage
(Ships OOC)
Naval Ship Systems Command
Department of the Navy
Washington, D.C. 20360

APPENDIX

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J. Alphabetical Index

Alphabetical Index (Cont'd)

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