Report on Salvage Operations Submarine *S-51*

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Lt. H. Farmer (C.C.) U.S.N.
U.S.S. Holland,
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Calif.

NAVY DEPARTMENT

REPORT ON SALVAGE OPERATIONS
SUBMARINE S-51

BY

EDWARD ELLSBERG
LIEUTENANT COMMANDER, CONSTRUCTION CORPS
UNITED STATES NAVY
SALVAGE OFFICER

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REPORT ON SALVAGE OPERATIONS, "S-51"

The U. S. S. *S-51* was sunk at 10.24 p. m., on the night of September 25, 1925, in collision with the steamship *City of Rome*. The *S-51* was struck at frame 54, at an angle of about 40° abaft the port beam, and a hole about 30 inches wide, extending from the port bilge keel to the superstructure deck, was made. This opening came about midway of the battery room.

At the time of collision, *S-51* was acting as a surface vessel, steering a steady course, of about northwest, at a speed of 11.5 knots. The sea was moderately rough, and all hatches were secured, except the conning-tower hatch. Except for the officers and men on watch, the crew had turned in. The *S-51*, following normal procedure, was ventilating outboard, with main air induction and battery exhaust valves open in superstructure, ventilation valves open in all compartments to external ventilation mains, and all interior doors open for interior circulation. The Diesel engines were drawing air both from the engine air induction valve on the external ventilation main and through the conning tower hatch via the open door between engine room and control room.

As an immediate result of the collision, a large volume of water poured into the battery room, giving the ship a trim by the head and a list to port. The *S-51* appears to have planed under as a consequence of this trim and to have submerged in considerably less than one minute. Under the increasing pressure, water flooded the boat very rapidly and the crew was unable, against the rush of water, to close any of the interior doors. Three men, asleep in the battery room, escaped through the conning tower hatch, and were picked up alive about an hour later. Seven men, two officers and two men forming the bridge watch, and three others who were inside the boat, but managed to get through the conning tower hatch, were washed overboard. These seven were seen swimming, after the *S-51* sank, by the men who were later rescued, but no one of these seven was found when the *City of Rome* finally managed to get a boat overboard. The body of one man in this group was found alongside the hull later; the bodies of the other six were never recovered.

The position of the *S-51*, as reported several hours later by the *City of Rome*, proved to be several miles in error, but no special difficulty occurred in locating the wreck, as a considerable oil slick was soon discovered by the vessels searching, and a moderate stream of air bubbles in this slick gave the exact location. The *S-51* was found in the open sea, about 15 miles south of Brenton Reef Lightship, and about 14 miles east of Block Island, the depth of water being 132 feet.

The torpedo range diving boat from the torpedo station, Newport, brought the first divers. About noon, September 26, 1925, the first diver went down and found the *S-51* heeled over about 13° to port, lying on a hard level bottom, and buried about 5 feet. The diver made a careful inspection along the deck and found air in moderate quantities escaping through all hatch covers, these being closed but evidently not set set up from inside for a full due. The diver hammered on all hatches and listened intently but was unable to hear anything from inside the boat. It was therefore reasonably certain that all hands inside were dead.

In the absence, however, of conclusive proof, rescue operations were attempted under the direction of the forces afloat, the commander, control force, being in charge. Two derricks, the *Monarch* of 150 tons capacity, and the *Century* of 100 tons capacity, being the two largest derricks available, were hired from a commercial salvage company. It was assumed that life inside could exist only if the crew had succeeded in closing off one or more of the after compartments, either the motor room aft, the engine room just forward of it, or perhaps both. If these compartments were buoyant, a 250-ton lift would raise the stern; if they were flooded it could of course have no effect.

The two derricks were towed to the harbor of refuge at Point Judith; their unsuitability for open sea work was immediately demonstrated when they were held inside the harbor of refuge for a number of days awaiting calm weather. Several starts were made from Point Judith in the interim, but no each occasion, after getting several miles to sea, further progress was considered dangerous and the derricks were towed back to harbor.

A calm day finally arrived, the two derricks were towed out and hooked on to wire slings passed around the stern. The derricks took their maximum combined lift, 250 tons, without result except to bend both propeller shafts, the wrecking company's divers having passed their slings outboard, instead of inboard of the shafts. The derricks then cast loose and were hurriedly returned to the harbor of refuge. (See fig. 1.)

For the benefit of those making similar attempts in the future, it should be noted here that the two derricks employed in this operation would have been unable to bring the stern to the surface even had they developed the requisite lift. (Fig. 2.) Neither derrick had sufficient drift on its fall to lift the stern all the way to the surface. Had the stern started, the two derricks would have lifted it about two-thirds of the way and then been unable to do anything except lower away again. No means were at hand for hanging off the load while the derricks shifted purchases; it is further questionable whether the derricks could safely have been kept in the open sea long enough for such an operation even if equipment had been provided.

The raising of the stern having failed, it was deduced that the stern was flooded, and that no life existed inside the boat. To verify this, using an electric arc, the salvage company's divers now melted out the securing studs in two hatches, the torpedo room forward, and the engine room aft. Both compartments were found flooded. No entry was made in the motor room aft.

At this point, the rescue operations were abandoned, and the forces afloat ceased further activities. The wrecking company was discharged from further connection with the work.

The Bureau of Construction and Repair undertook the problem of salvaging the ship. As is usual in such circumstances, the customary number of visionary plans was submitted from all over the country, and a number of offers received from irresponsible individuals and companies. The bureau also received from the wrecking company engaged in the rescue operations an offer to undertake the salvage of the ship. After careful consideration of this offer, the Navy Department and the Bureau of Construction and Repair decided to have the Navy undertake the job itself.

To the commandant of the third naval district, Rear Admiral C. P. Plunkett, United States Navy, was assigned the task. The commander of the submarine base, New London, Conn., Capt. E. J. King, United States Navy, was detailed by the commandant as the officer in charge, salvage operations, and took charge of the salvage squadron. Lieut. Commander E. Ellsberg, Construction Corps, United States Navy, was assigned by the commandant as salvage officer, in charge of technical and diving operations. The following vessels formed regular units of the salvage squadron:

U. S. S. *Falcon*, diving ship, Lieut. H. Hartley, commanding. The *Falcon* was a mine sweeper specially fitted with air compressors and a recompression chamber for diving and salvage work.

U. S. S. *Vestal*, repair ship, Capt. W. V. Tomb, commanding. The *Vestal* furnished repair facilities, boat service, supplies, and berthing for salvage personnel.

U. S. S. *Sagamore*, seagoing tug, Chief Boatswain G. Cregan, commanding. The *Sagamore* acted as a portable mooring; also for towing pontoons.

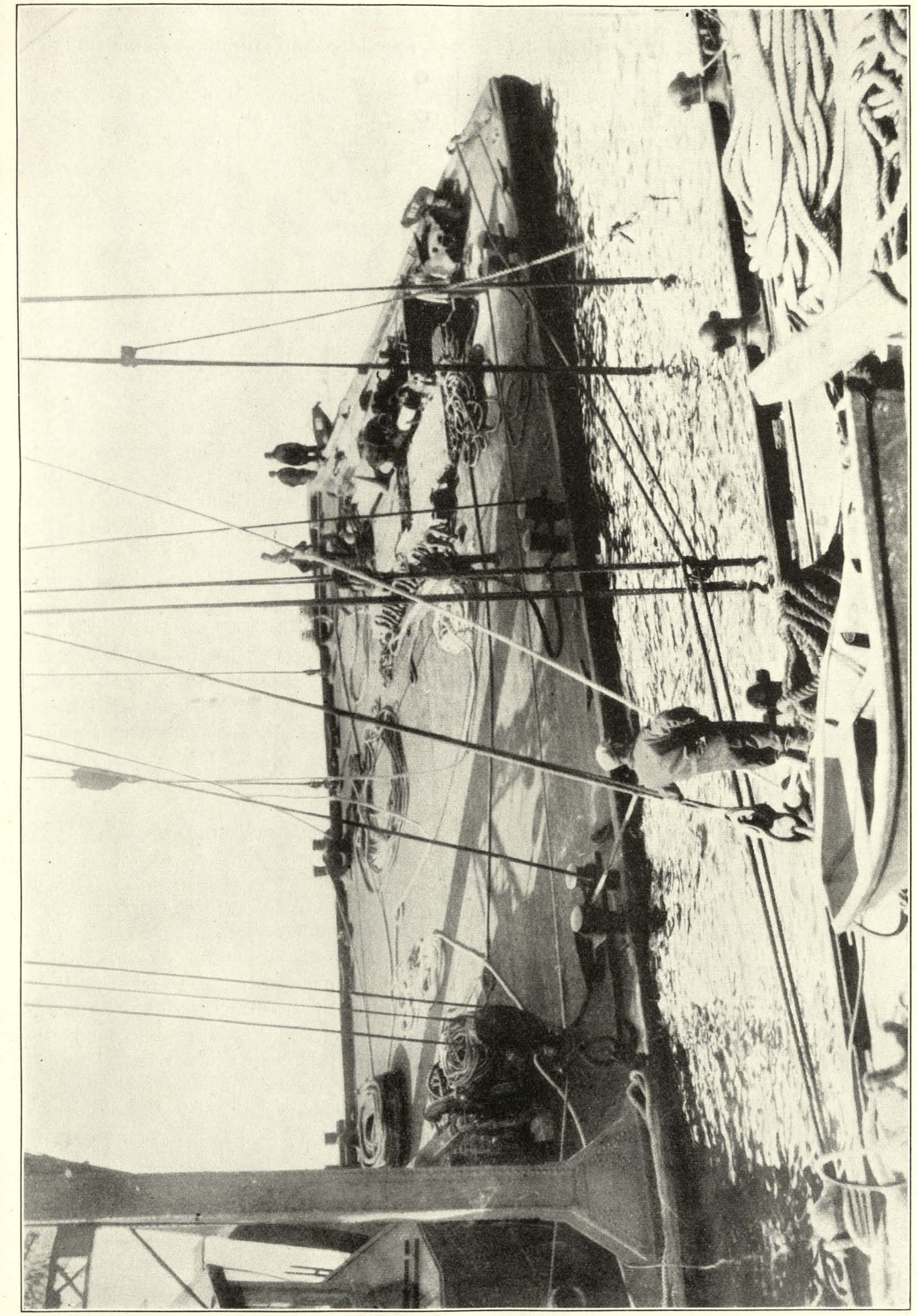

FIG. 1.—DERRICKS ATTEMPTING TO RAISE STERN. (NOTE SLINGS)

Bill Badders. M.C.M.M.-Dr
ON PONTOON UNDER WATER
BETWEEN CRAIN AND TUG.

U. S. S. *Iuka*, seagoing tug, Chief Boatswain Augustine, commanding. Same function as *Sagamore*.

U. S. S. *Bagaduce*, seagoing tug, Chief Boatswain Mangan, Lieutenant Rundquist, Lieutenant Rickertts, commanding at different periods. *Bagaduce* served part time, same function as *Sagamore*.

U. S. S. *Penobscot*, tug, Chief Boatswain's Mate Ashland, commanding. The *Penobscot* acted as dispatch boat, making a daily round trip to New London for mail and supplies.

U. S. S. *S–50*, Lieut. Commander M. Lenney, commanding, submarine. The *S–50*, did duty during the fall operations as a model boat for divers' rehearsals; same service at intervals during spring operations.

In conference with the Bureau of Construction and Repair, it was decided to raise the *S–51* through a combination of restored internal buoyancy, and of external buoyancy to be furnished by pontoons. The *S–51*, as shown by the inclining experiment, had a surface displacement of 1,001 tons and a submerged displacement of 1,230 tons. In the surface condition, liquid weights amounted to about 80 tons. As a submerged wreck, wholly flooded, the buoyancy of the hull structure, engines, lead batteries, sheathing, etc., was assumed to be that of steel, and a deduction of 120 tons was made on that basis. This brought the dead weight to be lifted to 800 tons. This weight was checked against the weight obtained by considering the quantity of water admitted to each compartment, taking account of permeability, and proved to be in reasonable agreement. The weight was probably a little less than 800 tons; but as that figure appeared to be on the safe side, it was thereafter used.

It was further believed from the divers' reports and a study of the plans that it was possible to make buoyant three main compartments—the central operating compartment (C. O. C.), the engine room, and the motor room. In addition, it was believed that main ballast tanks, port and starboard, Nos. 3, 4, and 5, could be blown dry. As possibilities, but not so probable, it was hoped to dry the forward and after groups of oil tanks, the two bow buoyancy tanks, the forward trimming tank, and the water round torpedoes' tank. As bare possibilities, it was considered that main ballast tanks Nos. 2, port and starboard, might be dried, and that No. 1 fuel oil tank and the "A" main ballast tank might also be made dry.

No attempt was to be made to obtain buoyancy, for the reasons given, in the following spaces:

Battery room.—This compartment was the one in which the collision occurred. No reasonable hope existed of sealing up the large and ragged gash extending through inner and outer hulls.

Torpedo room.—On sinking, the *S–51* hit the hard bottom, bow first, with considerable way still on. As a result, the hull had buckled at bulkhead 43, where the structure changed from single to double hull, making a point of discontinuity in strength. At this bulkhead there were two deep circumferential wrinkles showing on the shell plating, these standing out from the shell about 4 to 6 inches along the upper hull and fading out gradually toward the keel. The after bulkhead of the torpedo room was thus badly damaged in its shell connections. In addition, practically every air and drainage line to the torpedo room was severed at the point of collision, making air-tightness hard to obtain.

Port ballast tank No. 1.—Opened to the sea by the collision. Its forward bulkhead was also damaged by the wrinkling at bulkhead 43.

Starboard ballast tank No. 1.—This tank had its forward bulkhead at bulkhead 43 damaged in the wrinkling of the shell, due to buckling.

Port ballast tank No. 2.—This tank was considered a probable loss, as its forward bulkhead at frame 61 was bent in, due to collision damage. An attempt was to be made to use this tank if it proved reasonably tight on trial.

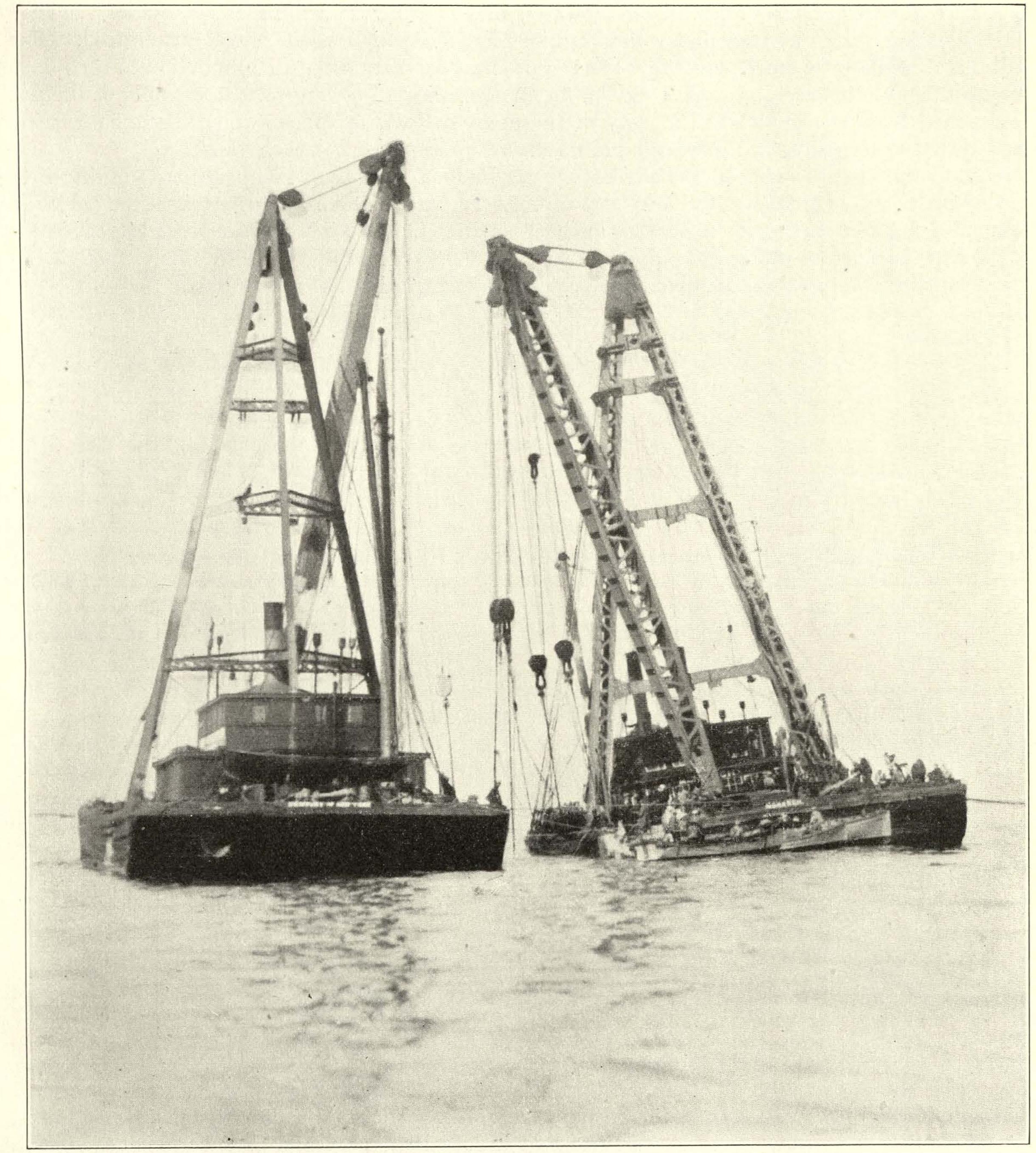

FIG. 2.—DERRICKS ATTEMPTING TO RAISE STERN. (NOTE MAXIMUM LIFT AVAILABLE)

Starboard ballast tank No. 2.—This tank was in good condition and was to be made ready for blowing. However, it was not to be blown down unless its mate, No. 2 port, first turned out to be usable, as otherwise the submarine would be given a bad port list in the raising process.

Miscellaneous variable tanks under the C. O. C.—There were a number of auxiliary ballast and adjusting tanks located under the control room on which nothing was attempted. The individual tanks were small and the work required on each tank out of proportion to the buoyancy obtainable in any one tank. Owing to the double hull structure, these tanks could not be reached from the outer shell in way of the main ballast tanks; underneath the submarine they rested in the clay, and a special tunnel would be required to reach them.

A careful study was made of the attainable buoyancy in each compartment, taking into account a port list of about 13° and the amount of water which could not be expelled even from a sealed compartment on account of irregularities in the tank tops and the impossibility of getting the bottom of the spill pipes to the lowest points in the compartments. (See pl. 1.)

The buoyancies of the compartments which were regarded as certain were:

Compartment	Total buoyancy	Per cent of buoyancy attainable	Net buoyancy
C. O. C.	90	60	54
Engine room	110	80	88
Motor room	130	80	104
Port ballast tanks 3, 4, 5	62	75	46
Starboard ballast tanks 3, 4, 5	62	75	46
			338

buoyancies of the compartments which were regarded as probable were:

Compartment	Total buoyancy	Per cent of buoyancy attainable	Net buoyancy
Forward group oil tanks	43	75	32
After group oil tanks	33	75	25
Bow buoyancy tank No. 1	80	75	6
Bow buoyancy tank No. 2	11	75	8
Forward trim tank	10	75	8
Water round torpedo tank	6	75	4
			83

As improbable, but worth attempting, were the following group:

Compartment	Total buoyancy	Per cent of buoyancy attainable	Net buoyancy
No. 2 port main ballast	19	75	14
No. 2 starboard main ballast	19	75	14
No. 1 fuel oil tank	12	75	9
No. A main ballast	7	75	5
			44

From the above table it appeared that the total internal buoyancy which could be relied on amounted to 350 tons. To raise the submarine, it was required to provide at least 800 tons, together with a margin against accidents and a sufficient reserve to allow the pontoons to float above the surface with an adequate water plane for stability on the long tow to New York. In addition, there existed a powerful but undetermined suction effect between the submarine and its clay bed, and to break it required both excess buoyancy and the ability to manipulate

the submarine before lifting, otherwise the *S-51* could not be torn free. It was believed that a 25 per cent reserve was the minimum for safety, which meant that at least 1,000 tons of buoyancy must be provided. As it was assumed that about 350 tons of internal buoyancy was the most that could be relied on, an external buoyancy of 650 tons was required, and to obtain it 8 pontoons of 80 tons net lift each were required.

Such buoyancy as might be obtained in the "probable" and in the "improbable" groups, amounting to a maximum of 83 tons for the first and 44 tons for the second, would constitute additional reserve.

The suction effect was checked over. At its worst, with the vessel in intimate contact with the clay bottom under an absolute pressure of 73 pounds per square inch, it appeared that to overcome suction by direct lift would require a pull of 8,000 tons. Instances were on record of the suction effect, notably on a submarine which having bottomed in deep water found itself unable to rise even after more than enough water had been expelled from the ballast tanks to give it positive buoyancy. This vessel finally freed itself by sallying back and forth with the propellers, thus allowing water to work under the hull and break the suction. For the *S-51* it was decided to break suction, first, by rolling the ship to starboard and, second (and mainly), by lifting her stern first, thus allowing the water to work forward under the hull.

It was further realized that it would be impossible to control the trim while in the raising process so as to bring the ship up on an even trim; if left to chance either end might come up first. No substantial objection could be found to raising the vessel one end at a time, and as the general arrangement of the ship together with the location of the undamaged compartments favored it, it was determined to lift the *S-51* stern first, and all pontoon locations, sling locations and lashings were selected with this in mind. (See pl. 5.)

Several objections were received from various unofficial sources to raising the vessel one end first; none were based on a clear understanding of conditions. It can be definitely stated that neither by derricks, pontoons, by partial restoration of internal buoyancy, by total restoration of internal buoyancy, or by any combination of these methods could the *S-51* have been brought up both ends together; any attempt to control the rise of either bow or stern by laying out anchors or other weights to check the movement would have been both futile and dangerous.

As the only possible means of control to reduce the angle the boat might take in the raising process, it was first decided to use a pilot pontoon secured at each end, halfway to the surface, the idea being that when the pontoon on the end which rose first broke the surface and lost its lift, the further rise of that end would be checked while the other end was being lifted to the same level; the further blowing of the submarine was to give enough additional buoyancy to bring the boat up the rest of the way, still rising one end first. The theoretical advantage of this method was that the maximum angle of the boat was reduced from 25° to perhaps 10° to 12°. The practical difficulties in connection with its use were that as the set of main pontoons attached to the submarine rose part way to the surface, the air in them would expand, force water out of the pontoons, and make them increasingly lighter as they came up. This might result in a greater gain in buoyancy in the main pontoons than was lost when the pilot broke the surface. If such were the result, that end of the submarine would keep on rising and the pilot would be wholly useless as a check. This probability, together with the large amount of additional work required for attachment and the fact that the pilot pontoons would be obstructions after the *S-51* rose, lead to the abandonment of the idea. The two 60-ton pontoons which happened to be available, ex-*F-4*, and which were first assigned for use as pilots, were kept on hand as a reserve in case it was found impossible to seal up any of the major compartments. They were, however, never used for any purpose.

It was calculated, and subsequent events proved correct, that the *S-51* could safely be handled at the maximum angle, between 25° and 30°. In case of another salvage operation where the ratio of depth of water to length of boat is such that this angle would be much exceeded, it is believed that the best solution is to set the main pontoons at such a height above the submarine as to limit the angle to about 30° when the pontoons first break the surface at one end. With all pontoons afloat, the vessel can then be towed to more shallow water until she bottoms, and all pontoons reset as low as possible.

A study of the structure, hatches, and piping systems of the *S–51*, especially of the external ventilation system and its valves, showed that the vessel was not especially suited to the use of compressed air as a salvage agent. The hatches were all designed to seat with the sea pressure outside holding them in place. Against an internal pressure they had only a light strong back set up on a relatively small central bolt which was inadequate to resist a third of the necessary internal pressure without letting go; in addition the strong back could not be set up hard enough to prevent air leakage under a very small excess internal pressure—2 or 3 pounds.

Under these conditions, pumps at first glance appeared more suitable, as their use would result in a pressure inside less than the outside pressure and would thereby help to seal the hatches and the ventilation valves. But pumps brought in additional difficulties. Steam was out of question as a source of power, owing to the long lead and the cold water which would condense it on the way down. Air was practically ruled out, as the *Falcon's* compressors could deliver only 150 pounds on the surface on no discharge; against a back pressure of 60 pounds, the net pressure was only 90 pounds which would be reduced by friction of hoses to about 70 pounds. If a small pump was used, this pressure could be maintained, but the pump would be a toy in comparison with the job; if a large pump were employed, the *Falcon* would be unable to supply enough air to keep the net pressure up to even 20 pounds and the pump would be ineffective.

Electricity as a source of pump power appeared more satisfactory. Direct-current pumps were undesirable due to the danger of short circuiting the pumps if the casings leaked. There were available a number of special submersible salvage pumps with 4-inch suction and discharge; these required a special motor generator to supply them with alternating current, but there was no danger of the pumps themselves short-circuiting, as the design called for water circulating through the coils. The cable connections to the surface required absolute watertightness, however, or a short circuit would result. These pumps would discharge 100 tons an hour against a maximum head of 80 feet.

As the head of water here was about 132 feet, it was obvious that even the alternating-current pumps were inadequate to the job without making up the difference in head by an internal pressure equal at least to 52 feet of water, or about 23 pounds. There would be required air connections as well as pumping connections to each compartment.

It will be seen that the depth made the use of pumps of any description difficult, and it was consequently decided to use compressed air alone as the first resource. However, as a stand-by, a complete outfit of the alternating-current submersible salvage pumps was taken, the *Falcon* was fitted out with the special motor generator, a special foundation for attaching each pump to the deck of the *S–51* was made and fitted on the *S–50* as a model, all salvage hatches were fitted with connections to which the pumps could attach their suctions, and electric cables made up in 300-foot lengths for the pumps were provided. A duplicate motor generator installation was provided on the *Vestal* in case it turned out that the *Falcon's* regular generators proved inadequate to carry the ship's load and also run the motor generator.

The expedition was thus fitted out to use compressed air alone if the compartments could be made to stand internal pressures; or to use pumps if it was found that they could be sealed only against external pressures. In any case, compressed air alone would have to be used on the pontoons and all ballast and other tanks on the *S–51*.

The pontoon question required immediate attention. Two 80-ton pontoons and two 60-ton pontoons, originally built for use on the *F–4* in Honolulu Harbor, were available at Norfolk, and were shipped to New York. They were known to be unsuitable as they stood, since they were designed for use only in 45 feet of water. On test at 25 pounds internal pressure, the heads bulged 1½ inches, and further pressure appeared dangerous. As the pressure at the bottom of this job was about 58 pounds, the new pontoons were built with heavier heads, heavier bulkhead stiffeners, and internal tie angles, all designed to resist the full pressure. The new pontoons were successfully tested under a hydrostatic pressure of 55 pounds. The *F–4* pontoons were then reinforced in a similar manner by extra stiffeners and internal bracing, so that they also were able to stand the new pressure on test.

The pontoons as thus built or strengthened were able, when blown dry at the bottom, to rise suddenly to the top, where the internal pressure now became an unbalanced bursting pressure, without any danger of being ruptured. This safety feature was not generally known; it avoided a point of failure much stressed by amateur experts who predicted trouble due to bursting of pontoons. As an additional safeguard, each pontoon was provided at the bottom of each end with a simple spring loaded relief valve, 6 inches in diameter. These valves were adjusted to blow at an excess internal pressure of between 5 and 10 pounds. As the pontoons were intended to be used with the 6-inch flood valves also open, this gave four 6-inch openings for blowing off air while rising. Taken in conjunction with the known strength of the pontoons, no fears were ever felt for the safety of the pontoons during the lifting process.

The structural arrangement of the pontoons and their fittings for blowing and venting are shown in Plates 8 and 9.[1] It will be noted that each pontoon is divided into two parts by a central athwartship water-tight bulkhead. A 1-inch blowing connection is fitted near the top center of the pontoon for each half, a ¾-inch vent connection is fitted at the top near each end. A 6-inch flood valve with an extension rod is fitted in the bottom of each head; alongside it is the 6-inch relief valve. A 12-inch hawse pipe extends from top to bottom of each half, with the hawse-pipe castings strongly backed up by internal brackets to take the load.

For transverse stability, each pontoon was given about 2 tons of cement ballast, spread across the bottom. For protection in handling and in towing, each pontoon was sheathed with 3½ inches of yellow pine, laid edgewise, and the valves on the heads were protected by 12-inch timbers. For the protection of divers and others in walking on the pontoons, two longitudinal cleats of 2 by 4 inch planks were secured on each side near the top, and proved of great value. Heavy clips were riveted to the heads for towing and lowering.

The general design of the pontoons followed that of the *F–4* pontoons, except as modified for extra strength. It was shortly discovered that the type of pontoon was generally unsuited for the work in hand, especially in deep water, and should not again be used without numerous changes. At the period, however, there was no time to design new pontoons, and the *F–4* type of pontoon was supposed to be satisfactory. The principal defect was lack of longitudinal stability when submerged (this led to numerous difficulties in handling and a tremendous amount of extra work); the next most important defect was loss of attainable buoyancy in the high end of the pontoon when inclined. This was a serious problem on the day of actual raising, when this lost buoyancy amounted to at least 150 tons.

The navy yard, New York, undertook the immediate construction of six additional 80-ton pontoons. These were finished and delivered in about four weeks.

Each pontoon had a gross lift of 120 tons, a weight of 40 tons, and a net lift of 80 tons.

The next problem was divers. Civilian divers willing to work in deep water were exceedingly scarce, there being no more than 5 or 6 along the Atlantic coast. It was decided to proceed wholly with naval divers, and a check of those available indicated that 30 divers could

[1] Plates 8 and 9 show pontoons as altered after the salvage operations in order to obtain additional longitudinal stability. (See Appendix D)

be obtained from the fleet and from various naval stations. Thirty men whose records indicated that they had qualified as divers were ordered to report for the job; of these about half came from the fleet, then in southern waters. The schedule of operations was made out on the assumption that most of the men could dive; it was shortly discovered that most of them could not dive in deep water, and the number of actual divers qualified to work in deep water was reduced to 10. (See fig. 3.) This was a wholly inadequate number to carry on the work with any hope of completing it in the six weeks' period before winter broke. That the 30 men provided were not deep-sea divers was not made plain until after operations had commenced. It was then too late to do anything except keep on and accomplish as much as was possible with the forces in hand. For the benefit of those undertaking deep-sea salvage jobs in the future, disappointment should be avoided by making sure that the divers provided are qualified for actual deep-water work. Further, unless at least 20 such divers can be obtained, it should be realized that the work (and the expense) will be unduly dragged out. It is probably better not to undertake the job at once, but to organize a diving class, using the available divers as instructors; when the students have reached a suitable stage of diving ability, work may commence. There will be opposition to this policy, as considerable hysteria attends every case of loss of a submarine and there will be pressure for immediate action. However, civilian divers do not exist in sufficient numbers; the Navy will always have to provide its own, and the best results will be obtained by training enough men first rather than by rushing in and wearing out the few real divers at hand trying to cover a deep-water job with an inadequate force. This was promptly demonstrated by the history of the *S–51*.

The *S–51* was sunk on September 25, 1925. Rescue operations by outside wreckers lasted until early in October. The decision to undertake salvage, using the Navy resources, was made about October 7, 1925, and the *Vestal*, then in Cuba, was ordered north immediately. The *Falcon* was sent to New York for fitting out with electric pumping equipment and other material. The *S–50* was sent to New York and placed in dry dock, where she was carefully studied, inside and out, by all divers.

On October 14, 1925, the *Falcon* sailed for Block Island. Arriving at the scene of the wreck, the *Falcon* first planted 6 moorings around the wreck, 1 dead ahead, 1 right astern, and 2 off each beam. These mooring anchors varied from 3,000 to 6,000 pounds each. To each anchor was secured a short length of 1¼-inch chain. To the chain, a mooring line consisting of two parts of ¾-inch steel wire rope 40 fathoms long was attached. A mooring buoy was attached to the wire lines. At first can buoys borrowed from the Lighthouse Service were used, but one of these sank and the others were soon superseded by log buoys obtained from the navy yard. As unmooring especially was usually carried out in bad weather, the type of buoy was important, and spruce logs cut from an old mast were found very satisfactory and were easy for a boat to work alongside. Several of the buoys cut from heavier woods proved unsatisfactory, as they barely watched, and completely disappeared under a strain on the mooring line. Such heavy buoys were replaced by large cylindrical steel buoys of 5-ton buoyancy, originally designed to float submarine nets.

A seventh mooring, with a 10,000-pound anchor, was planted by the derrick *United States* to the southward, about one week later.

The mooring lines from the *Falcon* to the buoys were 7 or 8 inch manila hawsers, each with a pelican hook at the outer end. In mooring, the *Falcon* normally steamed in headed either north or south and brought her bow close aboard the windward mooring. A small boat ran out the first mooring line and secured the pelican hook to the buoy, using a split pin on a lanyard as a toggle pin. Another windward line was run immediately, and the *Falcon* paid out on these while the boat ran out three more lines.

A normal moor called for five lines, two to windward, one ahead, one astern, and one to leeward for centering purposes. While the *Falcon* ordinarily moored parallel to the *S–51*, heading

FIG. 3.—DIVERS ON FALL OPERATIONS

north or south as weather required, there were many occasions on which such headings were impossible and the *Falcon* was then moored athwart the wreck.

Great skill in mooring was exhibited by the *Falcon*, which usually ran the five lines and centered herself in 30 minutes. The best time in mooring was 12 minutes.

Unmooring was a difficult operation, as it always took place either in darkness or in bad weather, and many times in both. To unmoor, a small boat ran along the buoys in succession the lee buoys first, and the bow man tripped the pelican hooks by catching the lanyard on the toggle pin with his boat hook. Hauling the lanyard first pulled the pin out. As the lanyard was attached at its other end to the locking link on the pelican hook, a jerk usually pulled the link clear and tripped the hook. As in heavy weather the boat always plunged up and down, considerable skill in maneuvering was required of the boat in unmooring. A standard Navy 36-foot or 40-foot motor launch was first used, being the only boats available, but these were clumsy and slow for the job. Later a 26-foot motor whaleboat was borrowed from the Coast Guard, and too much praise can not be spent on the performance of this boat in the open sea and its handiness for the mooring and unmooring job. Such a boat is indispensable for future operations and should not be omitted from the equipment of the salvage ship.

The *Falcon* was always moored to form a lee on one side, from which side diving was carried on. In case the wind and sea increased during the day, the *Vestal* was moved around to windward and anchored as a breakwater. To assist in holding the *Falcon* in position, it was customary in bad weather to anchor the *Sagamore* and the *Iuka* about 150 yards off on the windward bow and quarter and run out two additional mooring lines, one to each ship. (Fig. 4.) As a variation, in very bad weather, the *Sagamore* and *Iuka* were often anchored in tandem to windward, the first tug holding up the second one, and the second tug holding the line to the *Falcon*. In this manner, having started diving, it was never broken off due to a change in wind or sea, unless the wind got beyond force 5, when holding the *Falcon* became impossible. As a result of this policy, the number of diving hours, short as they were, was at least doubled over ordinary practice, and the length of the job was correspondingly shortened.

Diving on the salvage operations commenced on October 16. The first efforts were directed toward cutting away the loop antenna, the clearing lines, and the wireless aerials. This was necessary to avoid fouling the divers in the submarine's overhead rigging. This gear was cut with a special sharpened cutting hook attached to a line from the surface. Clearing away took three days, as the hook had to be resecured for each cut; no faster means was available at the time.

Two descending lines of 4-inch manila were secured to the submarine, one to the muzzle of the gun forward, and the other to the railing near the engine room hatch aft. About 20 feet of slack was allowed on each line; three small cork buoys were attached to the surface end of each line to float it. Later as many as four descending lines were used. The descending lines usually lasted two to three weeks, when they chafed away, and at least one line was ordinarily found missing after each storm.

It was now desired to provide the reeving lines for the pontoon slings. Dipping a wire line under the bow and sawing it aft was first suggested. This method did not appear applicable, as the depth of water rendered the leads bad for sawing and would result in fouling lines; the bottom was hard clay, which did not lend itself to sawing; the line would have to be worked 60 feet aft under the deeply embedded hull for the first pair of reeving lines and 100 feet aft for the second pair; it was certain that the box keel or the sharp bilge keels would cut the sawing line in half very quickly, and, finally, no diving work could be undertaken while sawing was under way. It was decided to wash a tunnel under for the reeving lines, which, while difficult, would permit the interior work on the submarine to proceed at the same time.

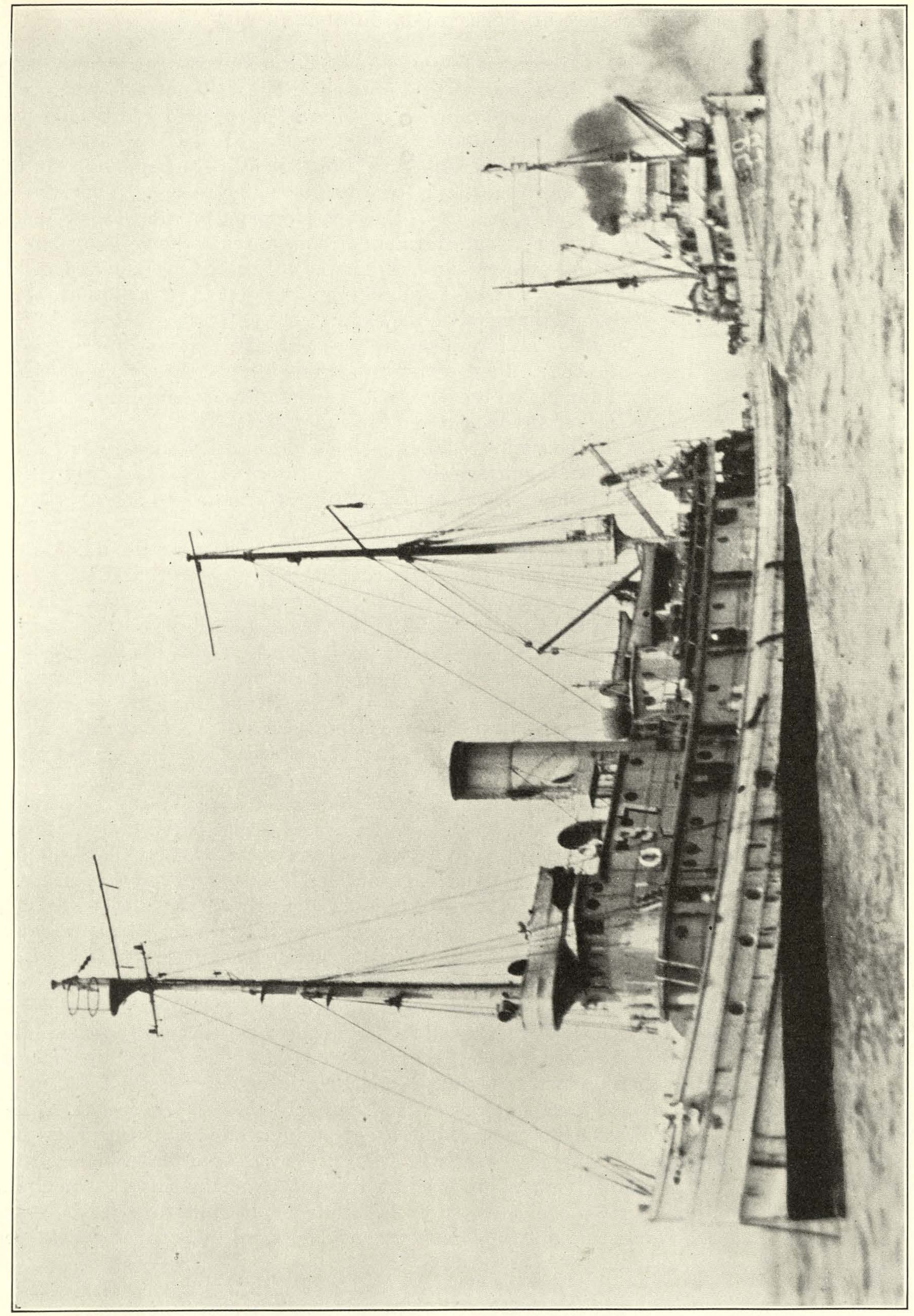

Fig. 4.—"IUKA" HOLDING "FALCON" IN POSITION OVER WRECK

In sealing up the interior, it was intended to make each main compartment entirely independent of all other compartments as regards water-tightness. The value of this policy was demonstrated on the final raising day. To accomplish this, however, required additional work, and the sealing problem wasespecially complicated by the supply and exhaust ventilation mains in the superstructure. As shown by Plate 2, 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 inlet valve and the main exhaust valve in the periscope shears (even if these could be sealed against internal pressure, which was not possible) would do nothing toward sealing up these ventilation mains. It was required therefore that the ventilation valves in each compartment be effectively and separately sealed aft.

Frazer and Smith boarded the *S–50* and were carefully rehearsed on closing the valves in the engine room. They then descended to the *S–51*, where Frazer slipped through the engine-room hatch while Smith remained outside on the deck of the submarine to tend Frazer's lines. This was the usual procedure whenever anyone entered the submarine.

Frazer closed some 20 valves in the engine room as per schedule but the largest valve of all, the 25-inch main engine air induction, a quick-closing lever-operated valve, closed only three-fourths of its travel, and several attempts failed to make it close farther.

The same day tunneling was started at frame 46, Bailey and Michels beginning on the port side. Their progress was fair, using at first a 2½-inch fire hose with moderate pressure.

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 the *Falcon's* winch for the purpose; unbolt forty ¾-inch nuts which held down the valve bonnet; break the joint and lift off the 300-pound bonnet. All of this work. done by Frazer and Smith, was finished on November 2, when we found a piece of 1-inch steel pipe, 3 feet long and much corroded, jammed under the valve disk. This pipe, evidently left in the vent main during building, had been washed into the valve by the rush of water when the *S–51* sank. (See fig. 5.)

Meanwhile work was started on sealing the C. O. C. The most direct means of entrance seemed to be through the gun access hatch, which was fitted as an escape hatch but was found closed. To open this hatch, the following procedure was carefully rehearsed on the *S–50* and then carried through on the *S–51*; Kelley and Anderson smashed the glass port on the starboard side of the gun access trunk. Reaching through this 4-inch hole with a specially twisted bar having some five different bends in it to clear obstructions inside, Kelley hooked the latch holding down the cover and tripped it; then inserting a small cutting hook, he seized the ¼-inch wire secured to the under side of the hatch and cut it. The hatch flew open. The divers found two bodies in this trunk, which they sent up, the two men having been trapped there through inability to operate the escape features of the trunk. The divers later entered the trunk and endeavored to squeeze through the small oval hatch at its lower end. Here Kelley stuck about halfway through, and it was then decided to try the doors instead.

On October 25, 1925, the first four pontoons arrived on board the 100-ton derrick *United States*. They were brought direct 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 which scattered the salvage squadron. It was clearly evident that derricks could not safely be brought out, and the *United States* thereafter stayed in harbor where she put the four pontoons overboard and prepared them for towing out.

FIG. 5.—MAIN INDUCTION VALVE BONNET. (NOTE 1-INCH STEEL PIPE WHICH WAS JAMMED UNDER VALVE DISK)

Work on the first tunnel, at frame 46, was started on October 22. The divers available had all done most of their diving in chasing lost torpedoes and were consequently experienced in using a washing hose for digging out buried torpedoes. Tunneling was therefore the thing they knew most about, and no special difficulty was anticipated. A 2½-inch fire hose with a 4-foot pipe nozzle, at a pressure of about 40 pounds, was first used. The progress for the first day gave reason for optimism, but thereafter continued 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 hard sand and mud, there was a bed of hard blue clay mixed with some sand in which the submarine was buried. 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 2½-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 found imperative to raise the pressure to cut the clay. To permit this, the last length of fire hose was replaced by a 50-foot length of 1½-inch wash deck hose with a pipe nozzle of the same diameter, and with this reduced size the diver was able to hold a pressure up to 70 pounds, which would cut the clay when the nozzle was held close against it. With this nozzle work was continued throughout the fall.

Another unpleasant discovery was the fact that the clay and the sand were so heavy that, unlike mud, they refused to stay in suspension when cut and settled again in the tunnel within a foot or two of the nozzle. 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 of this, the diver was compelled, after cutting ahead a little, 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.

Finally weather conditions through October and November were such that diving was ordinarily impossible 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, which had to be washed out before any new cutting was possible.

The above factors, complicated by an insufficient and a decreasing force of divers, prevented driving a tunnel through during the fall operations. Several times success seemed near, with the divers approaching or even touching the keel, but each time bad weather caused a suspension, and practically all work had to be done over again when tunneling was resumed.

After the first three diving days, sufficient knowledge of the troubles existing in sealing up and in tunneling was gained to make it evident that the 10 experienced deep-sea divers would not be able to finish the job before winter set in. An attempt was made to bolster up the force by using some of the shallow-water men, sending them down in company with more experienced divers. This policy was tried out on October 28, but the results were unfortunate. The first man sent down failed to orient himself and did nothing. The second man apparently was paralyzed with fear, fell off the submarine, and was found wandering on the bottom after having fouled the lines of another diver. This second man contracted a severe case of bends that night from which he nearly died, and which kept him in the hospital for over five months. A third shallow-water diver sent down late that day wasted the dive of his partner, who was compelled to put in his entire dive, keeping his mate from being washed away by the current or fouling his lines, and consequently accomplished nothing himself.

The experience of this day proved conclusively that the diving course at Newport does not fit a man to dive in work of this kind. In confirmation of this fact, it was noted that of some 20 shallow-water divers present, none desired to work on the job, all apparently realizing fully their lack of training. As there was now neither time nor opportunity for training these men, it was felt that time did not exist for the small number of experienced men present to complete

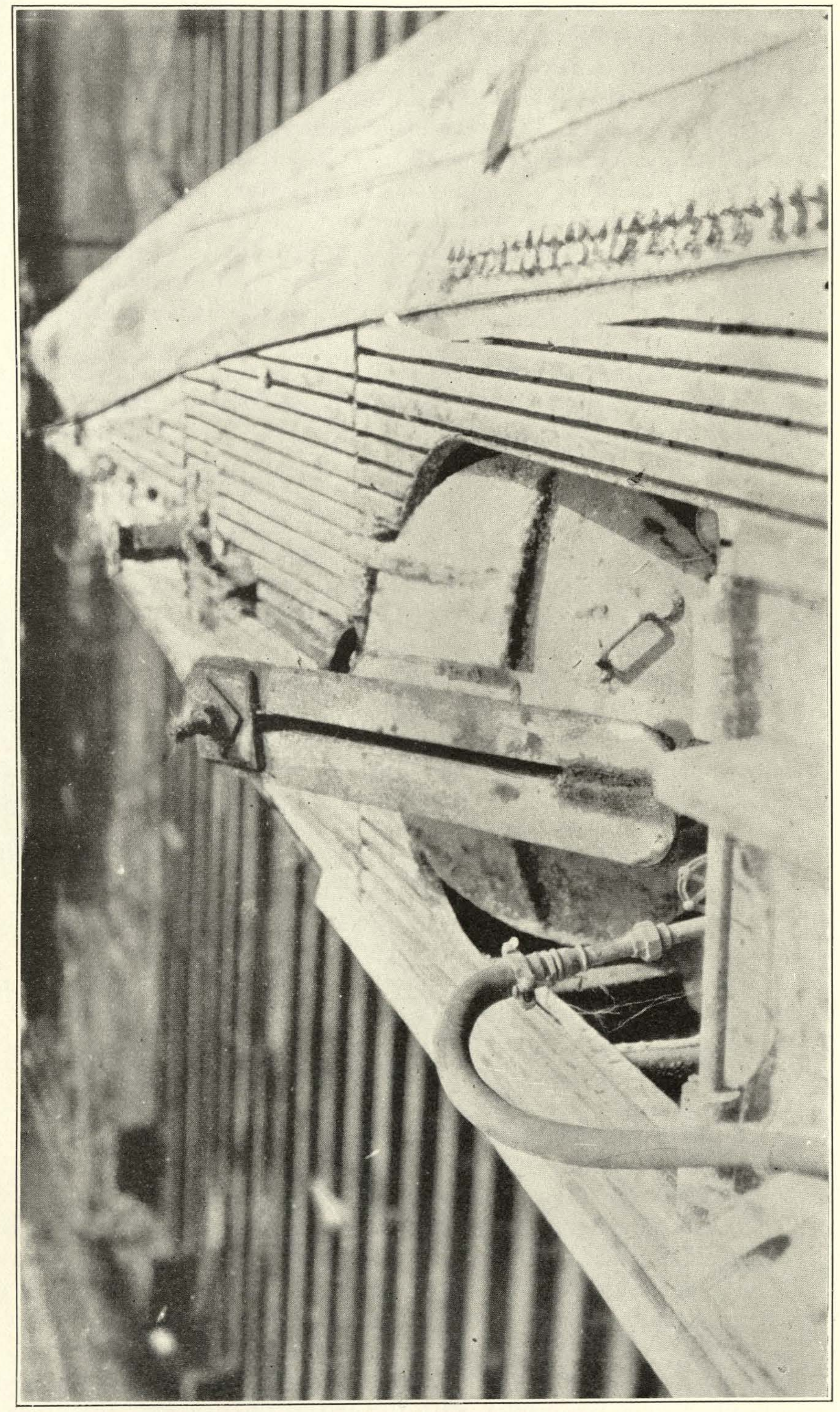

FIG. 6.—CHANNEL STRONG BACK SECURING MOTOR ROOM HATCH

the job; by the middle of November this was seen to be a certainty. However, it was determined to do as much as was possible while the weather permitted.

To seal off the motor room, Eiben and Wilson 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 (pl. 1) of the motor room was opened, there being a nonreturn valve on the bilge suction. In the engine room a valve bonnet on this drain line was removed so that water could be forced from the motor room to the engine room but not in the reverse direction. To admit air, Kelley and Anderson removed a bolt through the top of the motor room, tapped out the bolt hole, and secured a ¾-inch connection for a blowing hose. To prevent blowing open the motor room hatch under internal pressure, an external strong back was made and bolted down over the hatch, as shown in Figure 6.

On November 7, the air was put on the motor room to test it out. Considerable water was expelled, when air started to blow out the ventilation main in the superstructure.

Inquiry of the *S–51* survivors disclosed the fact that the drain valve on this line in the motor room was defective and could not be effectively closed, though they had not previously reported this trouble.

To remedy it, the motor room door was opened, the drain line disconnected, and the valve (1¼ inches) sealed with a pipe plug. The door was resecured after considerable difficulty, on November 15, and on November 18 another attempt was made to blow the motor room. After the water had gone down a few feet, the air started to escape through the ventilation valve, which was reported by the divers to be chattering like a relief valve with the air being released in gusts. This valve was closed and secured by the internal locking gear, but this locking gear, even when set up to the limit, was unable to hold the valve on its seat against a few pounds pressure. Northing further could be done with this compartment during the fall operations.

The second compartment attacked was the C. O. C. To seal this compartment required the substitution of two salvage hatches for the regular hatches in the conning tower and the gun access trunk, as the original hatches were unable to hold an internal pressure. There was further required the closing of numerous valves inside the C. O. C. and the closing of the two doors leading to the battery room and the engine room.

As a preliminary, the hatch on the gun access trunk was opened as previously described. The hatch on the conning tower was open at the time of sinking.

Handling the salvage hatches presented a new problem. Each hatch was made of steel plate 1¼ inches thick, with a heavy strong back and bolt running through it, and with a long length of 4-inch suction hose attached to the underside about as shown in Figure 7. Each hatch weighed around 700 pounds assembled.

why should this be necessary. Orig. design should cover

After a rehearsal on the *S–50* it became evident that the hatches could not be suspended from the surface while the divers endeavored to install them, as the up-and-down motion was too much to allow the divers to work. It consequently became necessary to provide a means on the submarine boat over each hatch for handling it. For the conning-tower hatch a heavy oak timber provided with an eyebolt was secured over the bridge where it plumbed the hatch cover and the hatch itself was handled by a half-ton chain fall secured to the eyebolt in the timber; using this rig the conning-tower hatch was hooked onto the chain fall after it had been lowered in the bridge inclosure and was installed and set up by two divers, Fraser and Smith, in one dive.

Having secured the conning-tower hatch, another long oak plank was attached across the timber already in place over the bridge, with the end of the new timber projecting forward of the bridge enough to plumb the top of the center of the gun access hatch. With this rig in place and the chain fall ready, the hatch was lowered from the surface boat, guided down by

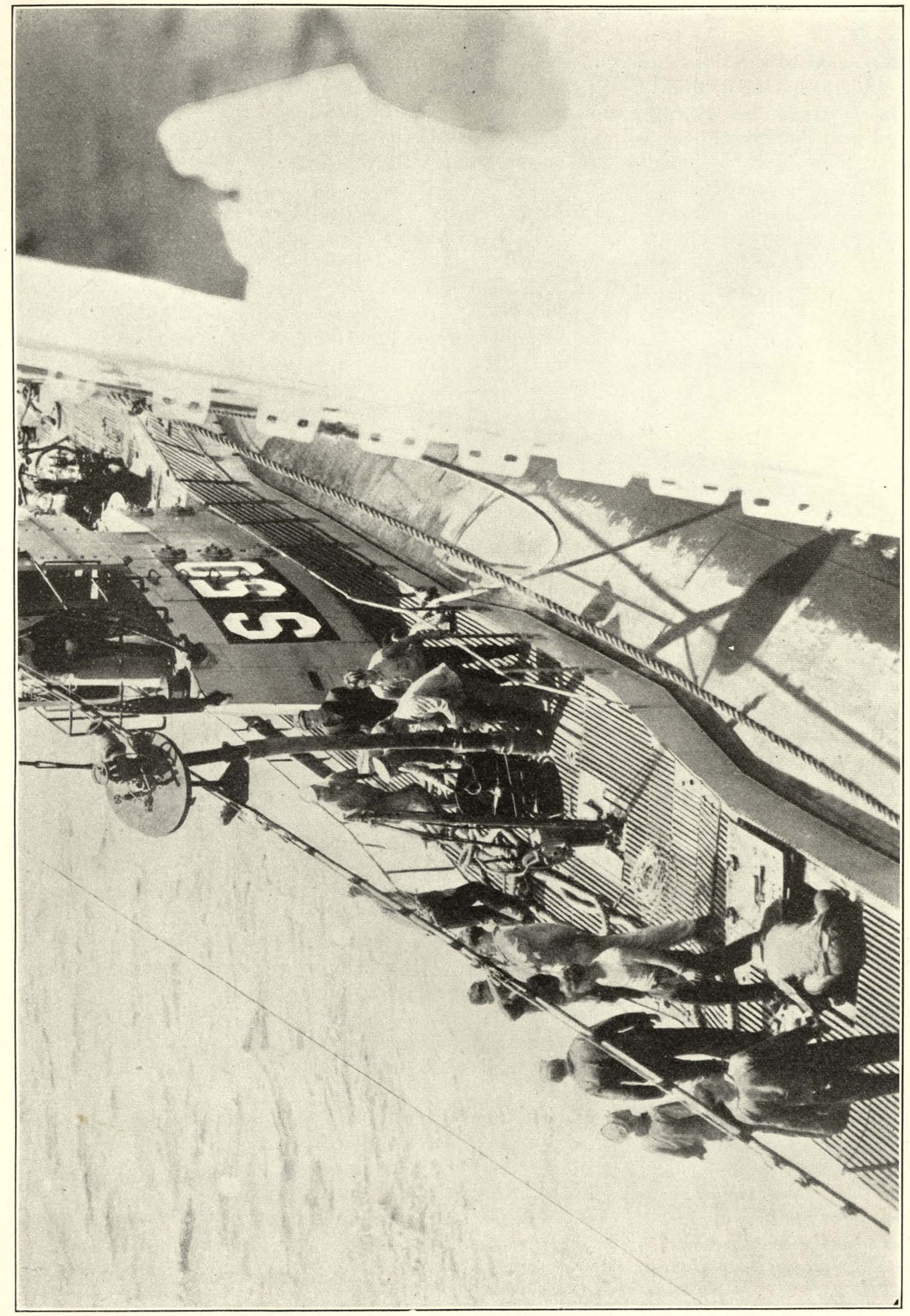

Fig. 7.—Engine room salvage hatch. Practice on "S–50." (Note 4-inch hose)

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 entered the suction hose into the trunk and fed it down until the hatch was landed when the surface line was let go by the divers. The chain fall was then hooked into the strong back bolt and the hatch was thereafter handled from the chain fall by divers. Considerable difficulty was encountered with this hatch in getting it adjusted, on account of the slope of the submarine boat, but this hatch was also successfully installed by Frazer and Smith in one dive. However, it appears that the exertion of handling this heavy weight while plumbing the hatch was such that Frazer strained his heart and it was discovered that further diving by Frazer was out of the question. (Gun access hatch, fig. 8.)

With both hatches in the C. O. C. sealed up, the next attempt was to close the doors. Two divers entered the battery room and went aft along the passage to the crew's quarters toward the forward C. O. C. door and found the passage blocked by mattresses and bunks. An attempt was next made to enter the C. O. C. through the after door from the engine room. The first pair of divers who tried this entrance were unable to squeeze through. The second pair of divers on the same attempt had to quit because four underwater lamps burned out on them during one dive while inside the submarine boat. A third attempt to enter this door, made by Wilson and Eiben proved successful. The two men got part way in the C. O. C., cleared away a bunk which had washed into the C. O. C. from the battery room forward, and then found a clear though congested passage through the remainder of the C. O. C. By working forward they reached the forward C. O. C. door, which was found jammed with wreckage but which was cleared and closed by the divers. The necessary valves to seal up the C. O. C. were next closed by the same pair of divers.

On a previous dive the divers noted that one of the air banks showed about 2,000 pounds of air in the C. O. C. An attempt was consequently made to open all the Kingston valves in the main ballasts, using the master controller in the C. O. C. to operate the air motors at the individual valves. The divers opened the master control, but none of the air motors functioned. As a result of this the Kingston valve for No. 3 port tank was opened by hand from the C. O. C. and the Kingston valves for ballast tanks 4 and 5, port and starboard, which were accessible from the engine room, were opened by hand from the engine room. None of the gear for operating the Kingston valves on the remaining ballast tank were accessible from the inside of the boat, due to wreckage.

Having opened the Kingston valves on port ballast tanks 3, 4, and 5, on the next dive Wilson entered the C. O. C. again and adjusted the valves on the air manifold so as to blow down these three ballast tanks, using the ship's own compressed air. Another diver was stationed outside the submarine to observe the discharge from the Kingstons. Air was turned on all three tanks at once and the gauge inside the boat started to drop in pressure immediately. The diver outside noted that a stream of muddy water was being discharged from the Kingston in each one of the three tanks. The tanks were blown for about 30 minutes, when the air on the gauge inside the ship 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 through the after door of the C. O. C. running from a connection in the engine room to the ice machine located under the deck in the C. O. C. 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 door on the C. O. C. and dogged it down.

A hose for blowing the C. O. C. was secured to the connection provided on the salvage hatch already installed and air was turned on the C. O. C. 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

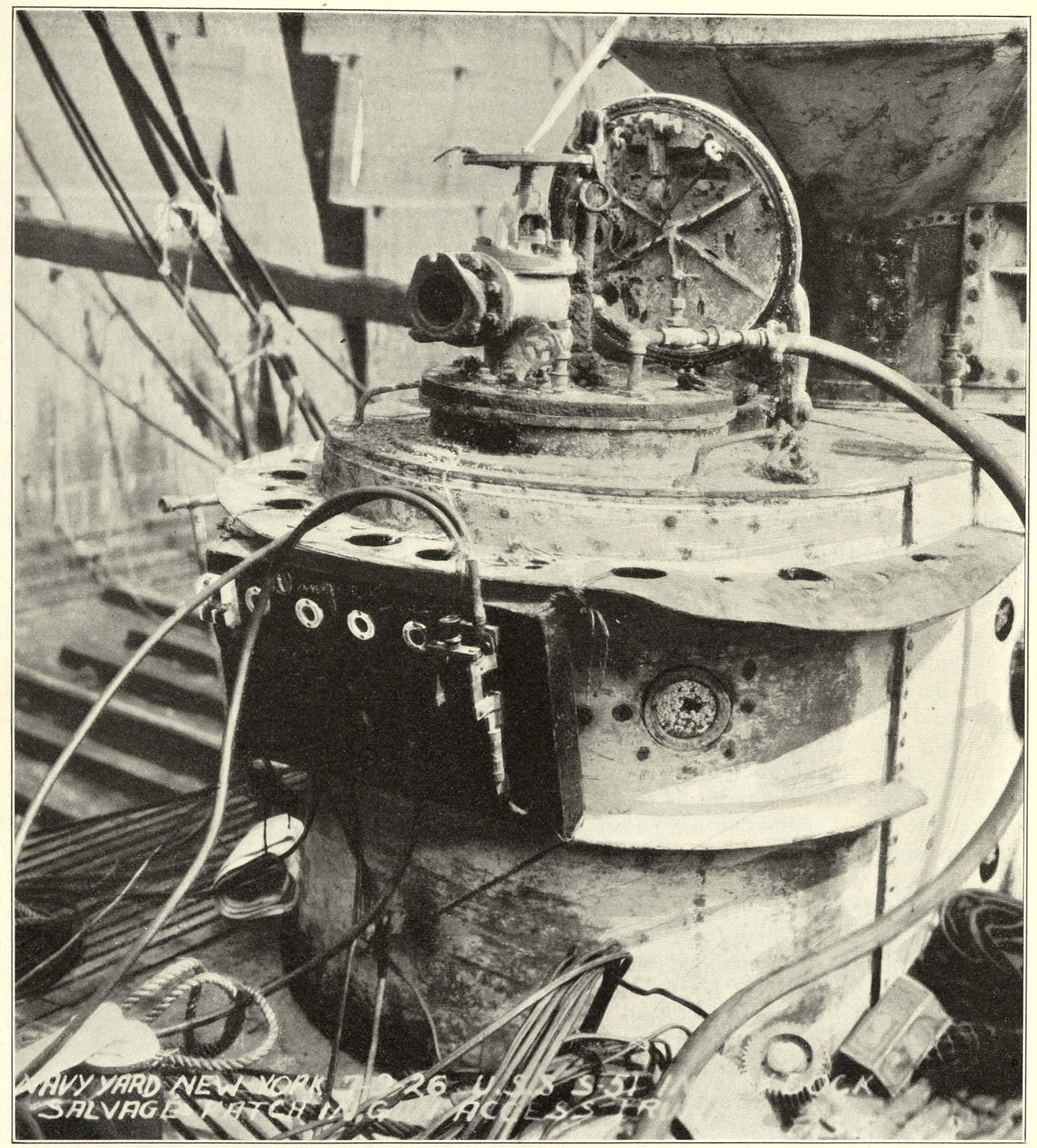

Fig. 8.—Gun access salvage hatch in position. (Note air connections)

in gusts from the C. O. C. It was evident that in spite of being locked from the interior the ventilation valve in this compartment was operating in the same manner as the valve in the motor room. As this occurred at about the same time—that is, late in November—nothing could be done during the remainder of the fall operations.

About the middle of November divers worked in the engine room on the fuel-oil manifolds, setting the valves and rigging air connection to blow the contents of the fuel-oil tanks, of which there were two groups, one forward and one aft. The after group of oil tanks were blown first, the contents being discharged through a hose led to the surface. It was found that the after group contained nothing but water, all of which was blown out until air was discharged. The connections were then shifted to blow the forward group, which was done a few days later. From the forward group of oil tanks there was discharged first water, then oil, and finally water again, until air was discharged.

Late in October an attempt was made to lower the first pontoon. Divers passed reeving lines of 21-thread manila under the stern of the submarine, which was clear of the bottom. On these as guide lines there were hauled heavier manilas and then two 1-inch wire lines. The pontoon was to be lowered with a 15-fathom shot of 2½-inch anchor chain hung from each hawse pipe, each chain being held at the top of the hawse pipe by a heavy bolted clamp similar in design to those used on the *F–4*. The wire hauling lines were secured to the lower end of each one of the chains. The pontoon was to be lowered from the surface, using a 6-inch manila line at each end.

Flooding of the pontoon was started as in previous practice with these pontoons on the *F–4* and the *U–111*. The pontoon sank until it was practically awash, when it tended to submerge one end first. Some time was spent in juggling with the vent valves and the air connections on each end of the pontoon in an endeavor to level the pontoon and make it go down horizontally. This was not successful, as whenever the pontoon was made heavy enough to submerge as a whole one end always dropped first. As no more time was available for holding the pontoon at the surface, the weather getting worse, the pontoon was finally permitted to flood until it had negative buoyancy and was then lowered over the side on the 6-inch lines. As the pontoon went down a few feet it grew heavier and it became quite evident that the 6-inch lines could not hold the weight. To prevent the lines from breaking, an endeavor was made to pay them out fast; but in spite of this, first the line on the after end and then the line on the forward end of the pontoon broke in quick succession; later it was found that the pontoon had descended to a depth of about 50 feet when this happened. The pontoon thereafter fell freely to the bottom. Fortunately the *Falcon* was being held clear on one side of the submarine and the pontoon landed away from the submarine about 50 feet on the starboard quarter. The hauling wires with which it had been expected to guide the pontoon in position against the submarine had slacked off and fouled themselves around the submarine. After some days' work these wires were finally cleared and the pontoon was blown dry and brought to the surface. It was evident that the methods previously used in lowering and handling pontoons in shallow water were not applicable in the open sea.

The *Falcon* proceeded to Narragansett Bay where, in shallow water, using another pontoon, an attempt was made to lower evenly. It was again demonstrated that as soon as the pontoon had taken in enough water to submerge, between the loss of external water plane and the free water surface inside the pontoon (the pontoon at this time being two-thirds full of water), it retained no longitudinal stability, and the slightest inclination toward one end or the other would cause that end to drop and the water on the inside to flow to that end and make the pontoon go down one end first. Two solutions seemed possible; one was to allow the pontoon to flood completely at the surface and provide means of lowering it which could stand the full load of

40 tons. The second was to discover at what point the pontoon had taken in sufficient water to reduce its internal free water somewhat and consequently its lack of stability. If the pontoon were 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 the load. It was felt that if such a condition could be found the pontoon could be flooded to that condition, the flood valves closed with the pontoon slightly submerged, and the pontoon then lowered. After some calculation and considerable experiment in Narragansett Bay, it appeared that with a negative weight of the pontoon of 10 tons the internal free water plane was sufficiently reduced to make the pontoon reasonably stable provided it was not permitted to exceed a moderate inclination. To handle the weight of 10 tons there was required a large factor of safety for 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 this time it was too late in the season, however, to do anything further about lowering pontoons alongside the *S–51*.

Meanwhile the mate to the first pontoon lowered, which had been moored to the buoy near the wreck on the day of lowering the first pontoon, was torn away by a bad storm and washed ashore about 30 miles away on a beach in Buzzards Bay. An independent expedition was sent out on the *Sagamore*, which after some difficulty managed to pull the pontoon down the beach and float it again, where it was taken back to Newport.

After the middle of November the weather became so bad that diving was possible only at infrequent intervals and the water became extremely cold. From the 21st of November until the end of the month diving was impossible altogether until the 30th of November, when an attempt was made to dive. On this occasion, of three divers sent down two had to be hauled up because their air hoses froze up with ice from the moisture in the air being pumped down to them and completely cut off their air supply. At the same time only 4 divers out of 10 who started the job were still in good condition for work. It appeared that operations could not be continued successfully.

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, except those of the wrecking company which had handled the rescue operation originally, and the latter were not employed.

Considering the unsuitability of the weather, the impracticability of being able to work more than 1 day in 10 or 15, and the lack of divers, it was decided, on December 6, to suspend operations for the winter, and all vessels of the salvage squadron proceeded to their usual stations. The mooring buoys were removed by the Lighthouse Service and two marker buoys, one can buoy and one lighted buoy, were left to mark the position of the wreck. The pontoons were left moored to the docks at the torpedo station, Newport.

Before the shallow-water divers who were attached to the *Falcon* temporarily were detached and sent to their permanent stations, all of them, about 20, were put in the recompression chamber on the *Falcon* and the pressure was run up to 80 pounds, being the equivalent of about 180 feet depth of water. As a result of this pressure test, it was found that 12 of the men were capable of standing the pressure and appeared suitable material for deep-sea divers.

The diving personnel on the *Falcon* scattered to their regular stations with the exception of the few men who were kept at New York to overhaul diving equipment during the winter and with the exception of Chief Torpedoman Kelley, who was retained as an instructor for the diving class which was immediately started, using the 12 men just selected.

During the months of December and January these men were given daily work in a diving tank at the navy yard, New York, where they were required to use air tools of every description and do various jobs under water on pipe joints, cutting out rivets, and handling weights, the idea being to make the men thoroughly familiar with tools under water and to get them into the habit of working under water without conscious effort as regards the proper adjustments of their diving rig. In the meanwhile a series of experiments was also carried on looking toward the development of a practicable under-water cutting torch, the torch previously available for use by the Navy having failed to operate on every occasion during the fall operations when it was tried. The torch experiments were carried out under the direction of Lieut. Commander Edward Ellsberg, who at the same time took the diving course with the other shallow-water divers.

Meanwhile considerable attention was given to the method of rigging the *Falcon* for lowering pontoons, and a careful mathematical investigation was made of the stability conditions of a pontoon while being flooded on the surface and while being lowered.

At the end of January the members of the diving class were considered sufficiently trained and were sent to the south to join the *Falcon* again for the purpose of actually diving in deep water. Unfortunately, the operating schedule of the fleet was such that during the first month that these men were aboard the *Falcon* no opportunity whatever arose to permit them to dive. As a result of this condition the men were all returned to the navy yard, New York, about the middle of March, where their training in the tank was resumed, followed shortly by diving in the basin of the navy yard where, on account of the mud bottom and the opacity of the water, diving conditions were somewhat harder than in the tank.

About the middle of April the diving squadron was reassembled at the navy yard, New York, and all equipment which had been landed was taken aboard. All divers were recalled from their permanent stations and rejoined the *Falcon*. The total diving force with which the expedition was equipped at the start of the spring operations was 25 men, of whom 10 were the original divers, 12 were members of the new diving class, 2 were divers from the fleet not previously available, and 1 was the yard diver from the navy yard, Boston.

The *Falcon* sailed from the navy yard, New York, on April 23, 1926, and proceeded to Narragansett Bay, where the next three days were spent practicing on sinking a pontoon in deep water. It was found that the calculations were correct and that a pontoon flooded down to a negative weight of 10 tons could be lowered slowly to the bottom, held at any depth desired, and finally placed in any position required before actually landing. The total time taken in lowering the pontoon could be indefinitely extended, and in practice a pontoon was held for periods of over 30 minutes. By marking the 12-inch lowering lines with distinctive marks, at each fathom of their length, it was possible to maintain the pontoon in a horizontal plane at all times during lowering. To accommodate the wire hauling lines which were required around the submarine, the bulwarks of the *Falcon* were cut away in two places on each side and new steel chocks made on the *Vestal* were installed.

At the same time all members of the new diving class were given an opportunity to dive in 130 feet of water and work on the pontoon as it was landed on the bottom. The new divers all passed this test in deep water satisfactorily with the exception of one man, who had trouble clearing his ears and who was unable to stay on the bottom as a consequence.

The underwater cutting torch was also tested out on the bottom in deep water satisfactorily, a steel bar 3¾ by 3¾ inches in section being rapidly cut.

Having made sure that practicable means of lowering pontoons was available, the *Falcon* sailed on April 26, 1926, from Newport for the scene of the wreck. Arriving at its approximate location it was found that the two marking buoys which one week before had been sighted in proper location and close together were now separated by a distance of over 5 miles. As the weather was hazy at the time, it was not possible to determine by sights of lighthouses on the horizon which buoy was correct, if either of them was. An attempt was made to get radio-compass bearings from stations in the vicinity, but these plotted about 3 miles away from each buoy. Assuming that the more northerly buoy was probably correct, sweeping was started by the *Falcon* in its vicinity, but no results were obtained that day.

The next day the *Vestal* arrived. With clear weather it was possible from the high bridge on the *Vestal* to sight three lighthouses and get an accurate fix of the northerly buoy. Compared with the original fix of the wreck obtained last fall, the wreck appeared to be about one-quarter of a mile west of the position of this buoy. Sweeping was consequently concentrated in this area, using grappling hooks. Late in the afternoon of the second day, one of the grappling hooks made a hard strike and a diver descending the grappling line found himself on the deck of the submarine. The grappling line was immediately cast loose from the grapnel and made fast to the submarine, after which the *Falcon* replanted the moorings in the same locations as during the fall operations. An inspection of the submarine boat showed no change in position from that when last sighted in November. The vessel had not settled any deeper in the bottom nor changed her list or trim, nor had there been any silting up around the hull. There was a slight marine growth over parts of the hull, but no great amount. Diving was prevented by rough weather during the next few days, but on the 30th of April, 1926, the weather was fair and the *Falcon* took position for lowering the first pontoon on the port quarter of the *S–51*. Divers passed two small reeving lines under the stern on which were hauled through heavier manila lines and then a pair of 1-inch wire lines for hauling. These wires were secured to the lower ends of a pair of chains suspended through the pontoon hawse pipes, the chains being held on top of the pontoons by bolted clamps.

Unfortunately, just after the pontoon went awash and before the flood valves had been closed, a splice in the wire strap holding the forward lowering line opened up under no special strain, and as a result of this accident the pontoon tore free and sank to the bottom, end on. As before, the *Falcon* was holding herself a little clear to port, so the pontoon in landing hit the bottom about 30 feet outboard of its designated position. The next day this pontoon was lightened up on the bottom by blowing out some of the water and was then hauled over to its position against the port quarter of the submarine.

The wire hauling lines, having pulled the chain under the submarine, were rove through the hawse pipes of the second pontoon on the surface and this pontoon was then lowered on the two wires as guides. This pontoon was sunk somewhat lighter than intended, with the result that it landed alongside the submarine standing on its end rather than horizontally. As a result, one of the chains unrove through the hawse pipe. The matter was rectified by lightening the pontoon and bringing it to the surface, after which it was resunk. The second time it went down evenly and landed in the horizontal position as intended.

The torch was then used for the first time in actual work on the job. The chains were hauled through the pontoon hawse pipes for a predetermined amount after which a stud in the link just above the hawse pipe was burned out of each chain and a nickel steel toggle bar 40 inches long and 3¾ by 3¾ inches in section was slipped through the chain and locked in position by a long half-inch bolt on each side of the chain link. (See fig. 9.) When this had been completed, the lowering lines were cast loose and the hauling wires were burned free of the chain and taken up.

Meanwhile work was recommended on the forward tunnel at frame 46, using the same size hose and nozzle as during the fall operations.

A special inclinometer was made and taken down by one of the divers to measure the heel of the ship. A measurement was taken just forward of the conning tower and it was found that the *S–51* was listed over exactly 11½° to port.

Work was now commenced on lowering a pair of pontoons on the bow, and reeving lines were passed under that part of the bow which was clear of the bottom. The forward reeving line, however, slipped out three times from under the ship owing to the rise of the forefoot. To remedy the situation Chief Torpedoman Kelley went down with the torch and reaching down 2 feet through a hole in the deck burned in half the wire holding the mushroom anchor. This

Fig. 9.—Bow pontoons. (Note nickel-steel toggle bar through link, locked in position by ½-inch bolt each side)

dropped the anchor from its place under the keel forward until it rested on the bottom, and in this position its shank, which still protruded into the hawse pipe, formed a trap behind which the next reeving line was passed and which prevented any further slipping out of the reeving lines.

A pontoon was then rigged and lowered on the starboard bow in the same manner as those at the stern, and later in the same day another pontoon was lowered on the port bow. This was the first instance in which two pontoons were lowered in one day. These pontoons were secured by the divers in the same manner as those at the stern.

During a storm early in May which came up during the night while the *Falcon* was lying moored over the submarine, one of the tugs, the *Iuka*, drifted down on the *Falcon*, and in getting clear the *Falcon* was compelled to cut most of her mooring lines, while the *Iuka* fouled her anchor in the bow pontoons on the *S–51* and was then forced to slip her cable.

As a result of this, when the storm cleared considerable work was necessary to clear the fouled anchor and chain, to replace the descending lines which had been carried away, and to recover the lost mooring lines.

On May 11, 1926, after the longest dive made, up to that time, 2 hours and 20 minutes, Eadie and Wilson working from opposite sides of the submarine both managed to drive their tunnels down to the keel of the submarine. Eadie pushed his foot under the keel to the other side to which Wilson secured a small line which Eadie hauled back with his foot and the first line was thus passed. A second reeving line was then pulled through, tied to the first line, and the two lines cleared of each other.

On this same day 16 divers made a dive, being the maximum number of divers who went down on one day during the entire operation. On the next good day preparations were made to sink a pontoon on the port side abreast frame 46. Manila lines, 4-inch, were rove through the tunnel as hauling lines for the 1-inch wires. The wires were hauled down and secured to the chain hanging from the pontoons at the surface as usual. However, when all was in readiness and the 4-inch lines were hauled in to pull the wires through, one of the 4-inch manila lines was cut in half by the starboard bilge keel of the submarine when apparently running freely and without strain. The remainder of the day was spent in an endeavor to recover an end of this line but unsuccessfully. Meanwhile the weather changed and in a heavy sea the pontoon alongside became a serious menace and had to be cast loose from all lines and towed away. The next day it was found that one wire reeving line was fouled on the bottom and had to be cleared. To replace the line which had been cut it was necessary for the divers again to work through the tunnel and push a new line through, this time with a small pipe 8 feet long as a lance to carry it through under the keel. After some difficulty this was accomplished and a new 1-inch wire was rendered through. About 7 p. m. work began on sinking a pontoon on the port side. The pontoon was lowered successfully and was held at a point about 30 feet above the bottom, where the chain should have started to render through under the keel; but in spite of the maximum pull that could be given on the hauling wires by the *Falcon*, the chain failed to render. Two heavy manila hawsers, 6-inch and 8-inch, were then secured to the wire hauling lines, and the ends of the hawsers sent over to the *Iuka*, which was anchored about 100 yards broad off the beam, with the idea of getting a flat hauling lead which might make the chains render more easily under the keel of the *S–51*. The *Iuka* heaved on both lines with her quarter-deck winches but without result. A diver was sent down to inspect conditions on the bottom and found the pontoon in its proper position about flush with the deck of the submarine and with the two wires on the opposite side of the submarine leading out flat and taut toward the *Iuka*, but no chain was through under the keel. The diver came up and the *Iuka* then started ahead on her main engines gradually working up to full power, but in spite of this she was unable to haul the chain through.

The *Iuka* then slacked off the 6-inch manila line to get her entire hauling strain on the 8-inch line. After about five minutes under these conditions, the 8-inch line parted, throwing the entire strain suddenly on the 6-inch line, which also parted. As nothing more could then be done, the pontoon was lowered the remainder of the way to the bottom.

During the following two weeks various methods were tried to haul the chains under the keel, including the placing of tapered wood blocks under the keel as fair leaders. Various attempts were made to clear the first link from the keel with crowbars and several more attempts to haul the chain, using the *Iuka* to haul. In every instance whenever 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, and the chain would then bind securely and could not be freed. Owing the the close quarters, a diver having to work in a small tunnel and in an extremely difficult position, the divers were never able to clear the chain. Finally, after the last attempt at hauling had resulted in tearing the quarter deck winch out of the *Iuka*, it was concluded that a different method would have to be used, and the pontoon was brought to the surface, together with the chains. Having done this, the position of the wire hauling lines through the tunnel was carefully checked, after which the chains were removed from the pontoons. The eye of the first wire hauling line was shackled in to the end of one of the chains, using a Boston design detachable link for a shackle. Over the eye of the wire was then fitted a special steel cone which gave a smoothly faired surface from the 1-inch wire around the outer diameter of the first link, with no angles to catch on the box keel. With this rig the first chain was independently lowered and passed through the tunnel under the keel without difficulty, where it was equalized with the same amount of chain on each side of the hull. The second chain was lowered in the same manner. There being no pontoon to contend with at this time, the divers were able to work on the bottom while the chains were being lowered and to guide the chains through the tunnel. Having secured the chains, they were then held up as shown in Plate 3, and a pontoon was lowered on the port side until it was about 20 feet clear of the bottom, in which position a pair of divers went down on the pontoon, checked its location, and then rode the pontoon the rest of the way to the bottom. Here the divers cast off all lines and inserted and secured the locking bars. The mate pontoon, meanwhile, was brought out from Newport and was lowered and secured the same day.

This method of handling the chains and the pontoons was seen to be considerably superior to the manner in which the pontoons had been handled before—that is, with the chains lowered with the first pontoon. The reason for the original rig was that the only means of securing the chains in the hawse pipes of the pontoon was by means of a steel clamp made in two halves, weighing about 300 pounds, and secured by four 1½-inch bolts. Such a rig was extremely difficult to handle and probably could not be secured without auxiliary rigging in the way of chain falls or lines to the surface. In shallow water, where a diver could work all day, such means were available. In deep water, where his time on the bottom was very limited and extreme exertion was likely under the heavy pressure to affect him unfavorably (as actually happened in the case of Frazer), it was considered best to cut this work in half by securing the pair of chains to the first pontoon by making up the clamps on the surface, leaving only the work of clamping the chains to the second pontoon.

However, when the use of the torch made possible the removing of studs and the insertion of a locking bar at any desired point, it became possible to eliminate the clamps. This was first done only in the case of the second pontoon of each pair, but was obviously applicable to both pontoons, and the further use of clamps was wholly discontinued. It might casually have appeared that all studs might have been burned out on the surface originally, but there was considerable danger in such a practice of the chain kinking up if the studs were missing while the chain was being handled under the submarine boat, and as such a kink would insure the parting of the chain in a load, it was considered safer to burn off the studs where wanted, rather than taking a chance on burning out a large number to insure getting an open link on the hawse pipe.

Early in the spring operations, on May 11, 1926, work was started to seal off the ventilation main leading to the C. O. C., the engine room, and the motor room. The motor room was first attempted, as the ventilation main leading to this compartment could be most readily reached of the three compartments. The deck of the submarine just forward of the motor room was removed, and the deck beams covering the ventilation main were then burned clear by Chief Torpedoman Kelley. Work was then started on unbolting both flanges of a section of this 12-inch main for the purpose of blanking it off on the motor room side. After some days all the bolts were removed from the after flange, but several of the bolts in the forward flange were practically inaccessible due to their location close alongside the engine air induction valve. After several attempts by divers to get at these bolts, it was determined, after an inspection by the salvage officer, that there was no need to unbolt both flanges. Consequently, a wire line was tied around the pipe near the unbolted flange and on heaving from the *Falcon* the pipe was torn out of the ship, the forward flange breaking off the pipe while the unbolted flange came clear. The joint left in the ship was then scraped clean by divers and a new blank flange, which was immediately made, was securely bolted on. (See figs. 10, 11, and 12.)

After blanking off the ventilation main to the motor room, air was turned on to blow it dry, and divers reported a good stream of water being discharged through the nonreturn drain line into the engine room. After blowing about half an hour, a stream of air bubbles came to the surface over the forward end of the motor room. A diver's examination showed that a butt in one of the upper strakes of the shell on the starboard side was open over a sixteenth of an inch (the vessel was single hull throughout the motor room) and a steady stream of air was escaping from a length of about 2 feet at the upper portion of the butt.

It was evident that the leak was due to defective workmanship originally, as there was no evidence of damage or strain in that vicinity. Apparently a poorly fitted and wide-open butt had been made tight by splitting the edges of the plates and bringing the feather edges of the two plates together. Between corrosion and an internal pressure part of the feather edge had now given way, causing a bad leak.

To remedy this, Eadie and Eiben were sent down with strings of lead wool made by twisting together lengths of fine lead fuse wire. They calked this lead wool into the open butt until the space between the two plates was completely full, using ordinary hand wood calking tools for the job. Eadie then took a standard air-driven chipping and calking hammer and, using a fuller, proceeded to recalk the plates themselves in the usual manner. This calking job was complicated by the fact that each time the trigger was pulled the stream of air escaping from the hammer set up such a cloud of bubbles in the water that it was no longer possible to see the work clearly and the diver had to be guided by his sense of touch and general skill. When the air pressure was put on the compartment, the part of the butt which had been recalked was found tight, but new leaks had developed over the remaining length of the butt (as is usual even in surface work) and Eadie was compelled to recalk the entire butt with the air hammer. This effectively stopped all leaks in this location.

In this calking job, the surface air pressure was kept at 150 pounds. The net pressure at the hammer was between 80 and 90 pounds, taking account of hose friction. On examination of this job later with the vessel in dry dock, the calking could not be distinguished from the other calking done while the ship was building.

Air was again turned on the motor room and the water driven down a few feet farther, when another stream of air bubbles appeared, this time near the stern of the submarine and aft of the motor room itself. On a diver's examination of this new leak it was found that about

Fig. 10.—Section of 12-inch air supply line to motor room, removed by divers

10 feet from the stern there was a large dent in the top of the boat in way of the tiller room; in this dent one rivet was completely pulled through the shell and the adjoining rivet was partly pulled through. Air was escaping freely from these two places.

The tiller room was a small compartment abaft the motor room, connected with the latter by a manhole about halfway down the bulkhead. It was evident that this manhole was open (which was not known definitely before) 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 via the tiller room leaks.

To seal the leaks, 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 brought up against the frame bar inside, and resulted in spreading the lead plug inside the hole while the lead was being hammered down by the diver outside. The result was a firmly secured flush lead plug which was entirely tight and proof against jarring loose or being torn away by towing lines during later salvage operations.

To seal the partly pulled rivet (the rivet itself was solid and in no way loose) the diver drove soft pine plugs into the open parts of the countersink so that the wood was firmly jammed in; then trimmed the wood off flush to prevent lines from tearing out any of the wood filling. This rivet showed pinhole leaks afterwards through the pine, but they were of no consequence.

The reason for the dent in the shell was never definitely discovered. 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 that one of the vessels engaged in the original rescue operations dropped anchor over the *S–51* and that the anchor landed on the stern, dented it in, 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, but 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 dry. It was only by sending all the air the *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 the *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, as they were practically inaccessible to a diver; further it was considered that when the engine room was sealed up and blown dry, air leakage around the shafts would be of no consequence. If, however, on this job the engine room, instead of the battery room, had been the bilged compartment, this leakage around the shafts would have been a serious matter.

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 C. O. C. 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 strong back 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 C. O. C. presented different problems. Both valves were closed by their internal locking gear, but it was now known that this was ineffective. It appeared possible to get at a section of the battery exhaust main in the superstructure and

FIG. 11.—TWELVE-INCH SUPPLY PIPE TO MOTOR ROOM SEALED BY COVER PLATE INSTALLED BY DIVERS

blank it off, though with more difficulty than in the case of the motor room. The line to the C. O. C., however, was so covered by other pipes and buried inside the structure of the periscope shears as to be practically inaccessible for blanking off from the exterior of the boat.

A start was made, on removing the deck over the engine room, to get at the battery exhaust main at the same time as work was proceeding on unbolting the ventilation main to the motor room. The latter operation, while successful, took so much time that work was suspended on the engine room and a search made for methods requiring less diving.

It was noted that each one of the compartment ventilation flapper valves had a 1¼-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 *Vestal* to suit the drain-valve connection in the C. O. C. This was tried on the *S-50*. The door from the engine room to the C. O. C., which had been closed during the fall operations, was undogged and reopened after some difficulty (the gasket stuck). Eadie, Wilson, and Eiben then proceeded to install the cement connection, but found conditions on the *S-51* sufficiently different to prevent installation, as less clearance existed on the *S-51*. After modification, the fitting was finally installed, but with great difficulty, as the water in the C. O. C. was so black from particles in suspension and from dead water throughout the winter that, even with a submarine lamp, vision was possible not over 6 inches, and the work had to be done by sense of touch in a cramped space. Conditions were so bad that the lamp itself was invisible unless held within 6 inches of the diver's faceplate.

Meanwhile experiments were being carried out on the *Vestal* to determine the best cement mixture. The primary requisite was to obtain a cement that would harden under salt water; the secondary problem was to obtain a cement mixture that would flow freely through 250 feet of 1¼-inch-diameter hose, pass through a number of valves and fittings, and that would still not be too liquid to set firmly.

Several brands of standard Portland cement were experimented with, but their hardening qualities under salt water, except in very thick mixtures, was extremely poor. A special bauxite cement, furnished by the Atlas Lumnite Cement Co., was tried and found to be extremely satisfactory. A neat mixture of two parts of this cement to one part of water by volume was found to be thin enough to insure flow, while its setting properties under salt water were excellent. The use of Lumnite cement in this proportion is strongly recommended for all future salvage jobs where cement is required.

For injecting the cement, the *Vestal* made a steel tank tested to 200 pounds, with a quick-opening handhole on top for filling, test cocks on the side for determining the cement level, and a discharge connection tapering from 3 inches to 1¼ inches at the bottom. Using 200 feet of hose leading to the bottom of the sea into a piece of 12-inch pipe, a full-scale experiment was carried out on the *Vestal* to test the apparatus and the mixture, the cement being forced out by 150 pounds of air pressure on the tank. About five hours after injection, the pipe was hauled up and the cement was found already to have 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 to the *Falcon*, where the divers ran the hose inside the submarine and connected the last short length to the fitting on the C. O. C. ventilation valve. When all connections had been made, the cement was mixed on the *Falcon* and two charges forced through, being about four times as much cement as was required to fill the valve body. The divers then uncoupled the hose section near the C. O. C., sent up the remainder of the hose, and a few days later closed and dogged down the door to the C. O. C.

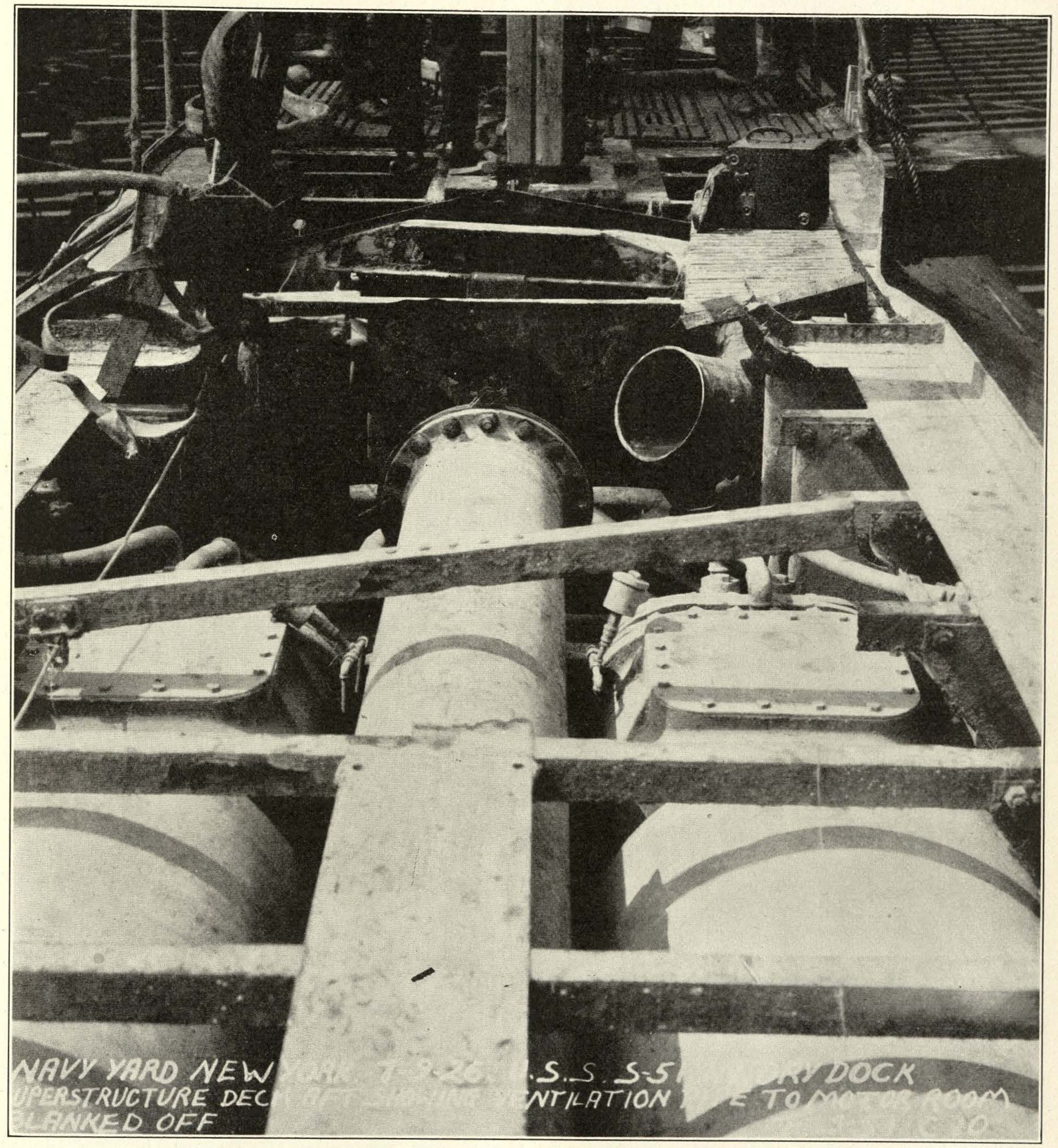

FIG. 12—SUPERSTRUCTURE DECK REMOVED BY DIVERS IN WAY OF MAIN AIR INDUCTION VALVE. (NOTE STRONG BACK ON THIS VALVE)

In the engine room a similar connection for injecting cement was fitted to the battery exhaust ventilation valve and a hose coupled up for the job. As this valve was larger than the one in the C. O. C., the cement tank on the *Falcon* was increased in size by lengthening it until it held 7 cubic feet. About 10 cubic feet of the cement mixture was forced through without difficulty, after which the hose was removed and the rig dismantled.

The two ventilation valves in the C. O. C. and the engine room were thus sealed off with only a fraction of the work that would have been required by any other method.

Air was soon put on the C. O. C., and in a little over an hour it was cleared of water.

At this point, the end of May, work was started on the tunnel for the last pair of pontoons, abreast frame 74. There was first used on this tunnel a new nozzle designed and made by Machinist's Mate (Second Class) Waldern, attached to the *Falcon*. In this nozzle there were 6 jets, 1 large one ahead and 5 smaller ones radially astern. It was found that the jet arrangement abolished the reaction which previously had made it impossible for the diver to hold a 2½-inch hose with any special pressure; further, the radial jets enlarged the hole cut by the forward jet and shot the material cut loose astern at considerable speed. The divers found that with this nozzle they could easily hold all the pressure that the *Falcon's* wrecking pump could supply through a 2½-inch fire hose—200 pounds—and even at this pressure they called for more, but the *Falcon* was unable to supply it. (See fig. 13.)

As a result of this highly efficient nozzle, a sizable tunnel was run 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 to meet the one on the starboard side. The first diver made excellent progress, but while the second diver was down the cylinder head blew off the *Falcon's* wrecking pump, the cast-iron head being too weak to stand the 200-pound pressure. Tunneling had to cease while the *Vestal* made a new head out of 1-inch boiler plate, which was installed late that day.

The next day tunneling was resumed, working on the port side. The fourth diver down, Carr, washed his way through into the starboard tunnel and crawled through under the boat to the starboard side, dragging the hose through with him for a reeving line. Two regular reeving lines were quickly passed through, and the same day, in spite of very rough weather in the afternoon, a pair of 2½-inch chains were dragged through the tunnel and equalized.

It was estimated that the new nozzle was at least 10 times as efficient in cutting as the standard nozzle, for in two short working days a longer tunnel had been run through at frame 74 than the one at frame 46 on which six weeks' work was spent in the fall and two weeks' work in the spring before success was achieved.

On June 5 the fourth and last pair of pontoons was lowered abreast the conning tower and secured to the chains already rove through the tunnel at frame 74.

The same day work was commenced on blowing dry the port-side ballast tanks Nos. 3, 4, and 5, which had been partly blown out the previous November, using the submarine's own air. On this final blow the air was supplied by a diver inserting an air hose from the outside of the boat through the Kingston valves, which had previously been opened. These Kingstons, however, were buried in the clay on the port side and it was necessary to wash this clear first. It was discovered that these tanks had retained practically all the air forced into them months before, as it required only a few minutes blow on each one to dry it completely.

To blow No. 2 port ballast tank it was necessary to burn a hole in it near the bottom, and the same process was required for starboard tanks Nos. 2 and 3, as the operating gear for the Kingstons for these tanks could not be reached from the inside. Having burned through No. 2 port ballast tank, an air hose was inserted, but all the air immediately escaped from the top. This trouble had been considered likely from the beginning, as the forward bulkhead of this tank was somewhat damaged in the collision; the use of this tank was abandoned and with it there was also abandoned No. 2 starboard tank, which, while intact, could not be used without giving the ship a permanent list when raised.

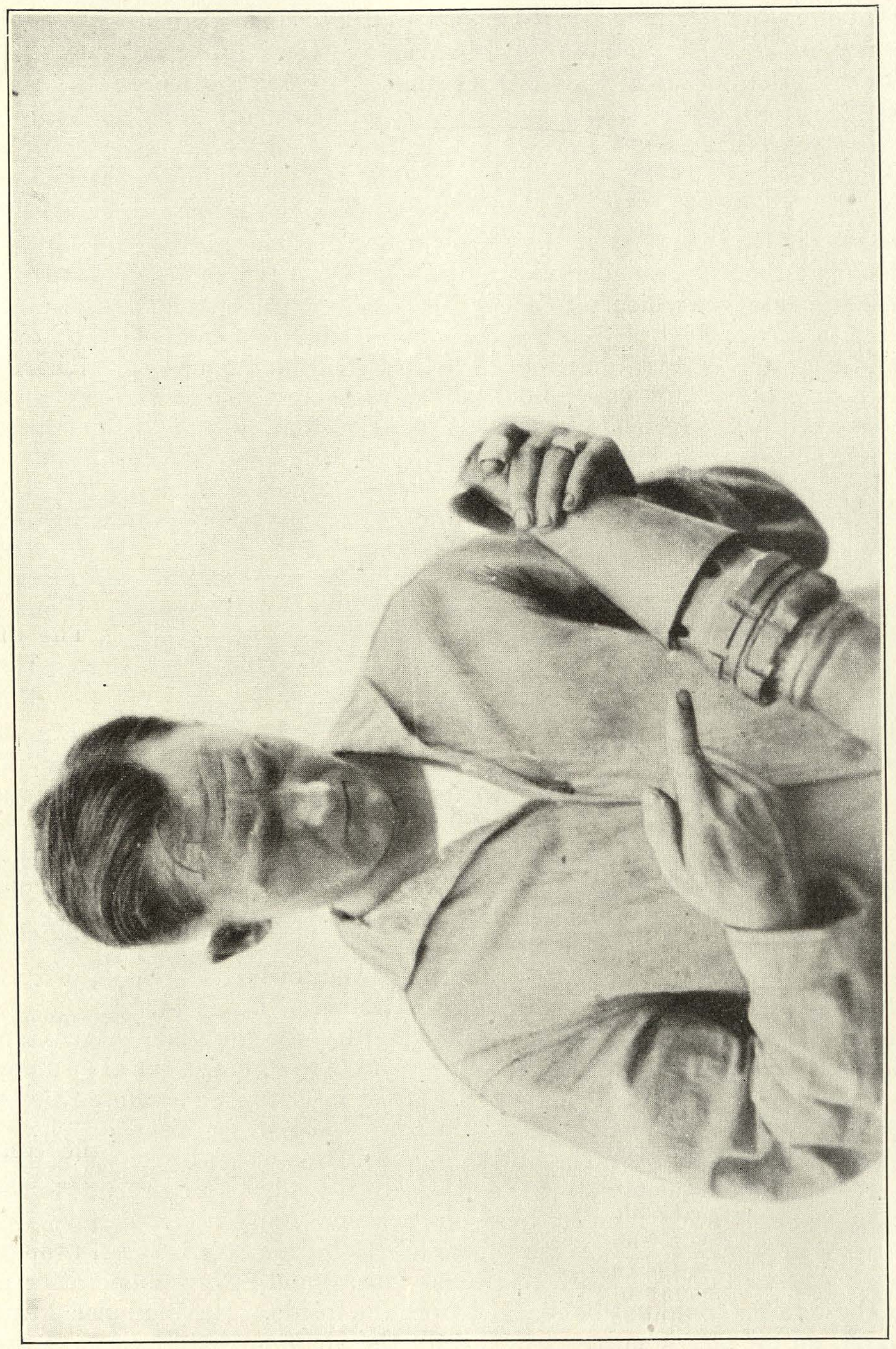

FIG. 13.—WALDREN'S SPECIAL BALANCED HOSE NOZZLE

It was decided at this time not to blow the other starboard side ballast tanks for the time being. The submarine had a list of 11½° to port, which it was hoped could be eliminated and at the same time the bottom suction could be broken by rolling the ship to starboard. Having dried out three port side ballast tanks, the rolling moment available was somewhat over 600 foot-tons; it was believed that as the vessel was lightened she would roll and thus break the bottom suction, which constituted an unknown but powerful force, considerably greater than the dead weight.

No change in the heel of the boat was noticed for several days after the port-side tanks had been dried out.

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 safely be 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, with the result that the light tank tops would bulge upward and perhaps rupture. On the other hand, this group could not be blown dry and then vented down before rising, for the compartment over it, the battery room, was open to the sea and the tank top would collapse if the pressure inside the tank were dropped with the vessel at the bottom. It was therefore decided that the forward group of oil tanks would be left flooded while at the bottom and regarded as reserve buoyancy to be obtained after raising, or to be used in case of emergency if necessary to bring up the bow, and the blowing connections were so set.

Conditions in the after group of oil tanks were different, as this group was below the engine room, which was to be blown dry. Here it was possible to equalize the pressures on the tank tops by providing a vent from the fuel-oil tanks to the engine room. After blowing the after group of oil tanks dry, this was done by one of the divers by smashing the glass on the Thomas fuel-oil gauge to the aftermost tank. This allowed the oil tanks to vent to the engine room, but did not permit water to flow from the still flooded engine room into the tanks as long as the air pressure stayed in the oil tanks.

Having blown the after group of oil tanks, the fuel-oil manifold in the engine room was set for blowing the forward group, and all was then in readiness for sealing the engine room. The ladder in the engine hatch was removed and the floor plates under this hatch were removed so that the spill pipe from the salvage hatch could reach some 4 feet below the floor plates down to the tank top in the bilges.

To handle this hatch, the *Vestal* built a small davit similar in size to the torpedo crane used on submarines; this was sent down and set up on the submarine by the divers to plumb the engine room hatch. The engine room hatch differed from the gun access and conning tower hatches in being larger and in having a trunk 30 inches long from engine room to deck. This placed the strong back for the engine room hatch much farther below the cover than in the cases of the covers fitted over the conning tower and the gun access hatches.

Divers Smith and Carr were rehearsed on the installation of the hatch on the *S-50* under conditions approximating those on the *S-51*. They then descended to the *S-51* and the hatch assembly was lowered down to the *S-51's* deck where the divers hooked it with a chain fall from the davit and attempted to install it. The attempt failed due to inability to get the strong back centered at the bottom of the deep trunk, a difficulty caused by the heel of the *S-51* to port which resulted in the heavy hatch and its strong back sliding off repeatedly to the low side. After a struggle lasting 3 hours and 20 minutes, the two divers, against their will, were told to cease and come up. On this, the longest dive ever made on the *S-51* job, the divers were given a decompression of nine hours and, while very weak afterwards, showed no signs of the "bends."

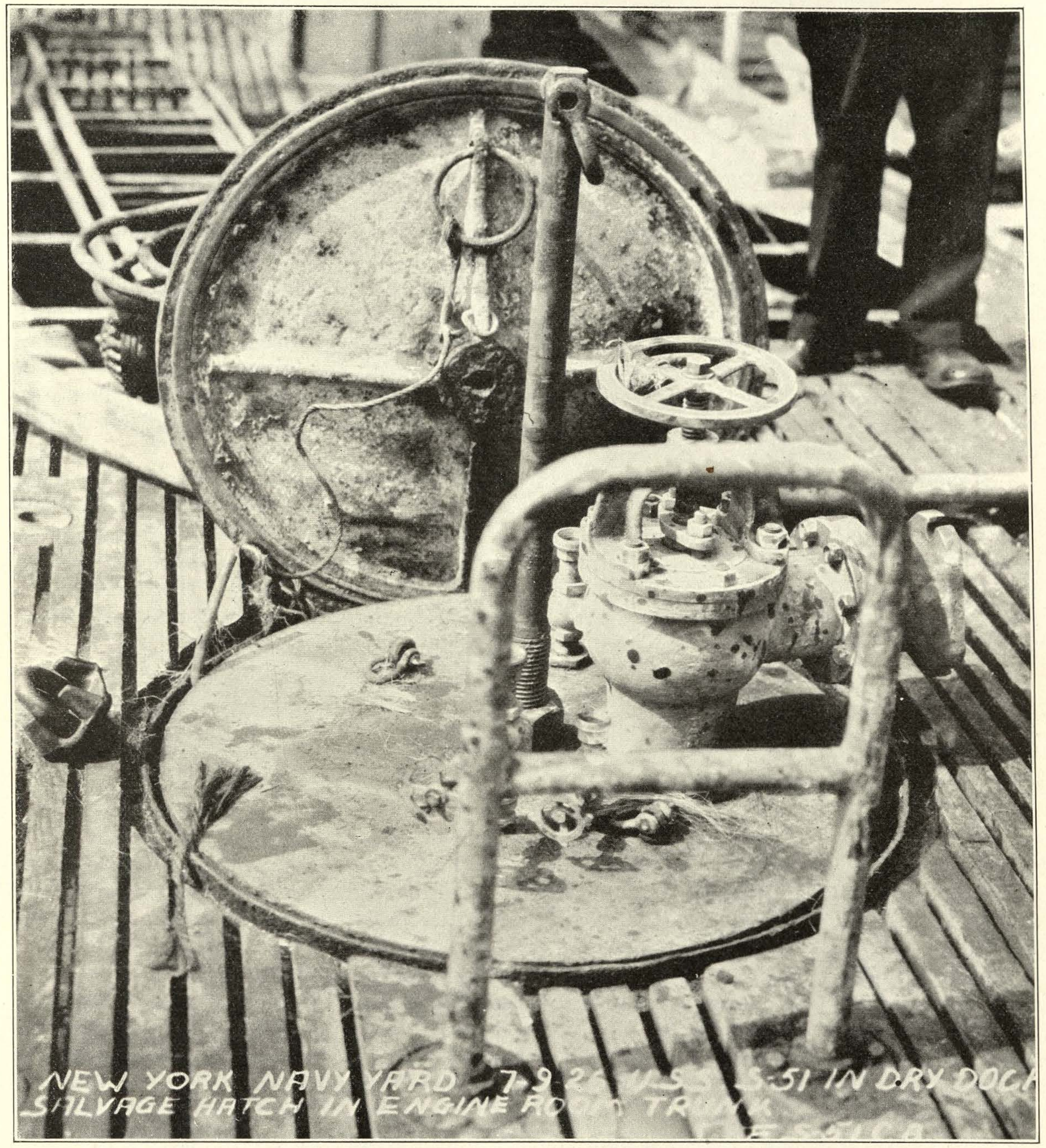

FIG. 14.—ENGINE ROOM SALVAGE HATCH IN POSITION. (NOTE THREE AIR CONNECTIONS)

After a second pair of divers had tried to adjust the hatch and failed, the hatch and strong back assembly was sent back up to the *Falcon*, where the rig was redesigned for installation in two parts, the strong back to be installed separately and held in place, centered, by a light auxiliary strong back near the top of the trunk, after which the hatch cover was to be lowered in place. This design was tried on the *S-50*, found satisfactory, and the divers rehearsed in its use. (See fig. 7.)

Another attempt was then made to install the hatch and strong back on the *S-51*, but various mishaps caused failure, and it was only at the end of four days' work on the hatch that Smith and Carr, who started the job, finally succeeded in lining up the hatch and bolting it down. (See fig. 14.)

It could be noted from the results on this hatch that the divers were beginning to play out; that their physique and their power of coordination was falling off though their morale was excellent, as it seemed evident to all hands that the end of the job was in sight. The number of divers available had decreased from the 24 men who started the job in April to 15 men by the middle of June. Of these, 3 were able to work only on short dives; practically all of the remainder were in poor condition, and minor cases of the "bends" were becoming frequent. To help as much as possible, all divers were taken to Newport on bad weather days for recreation and a change of scene.

The interior of the *S-51* was, on June 13, completely sealed up. Air was put on the motor room, shortly blowing it dry, and then drying out the engine room, as the motor room blew through a nonreturn valve into the engine room. After two hours blowing through the motor room, air began to escape from the discharge valve on the engine room salvage hatch, showing the engine room dry down to the bottom of the spill pipe. A few minor leaks were found around the hatch cover; the securing nut was sledged up tightly and these ceased.

Attention was now devoted toward drying out minor tanks forward. Chief Torpedoman Kelley, with the torch, burned holes in the bottom of the forward trimming tanks and the water round torpedoes tank and blew them both dry. On a later dive an air hose was inserted through existing openings in the bottom of No. 2 bow bouyancy tank and it was blown dry. An attempt to blow No. 1 bow bouyancy failed when a bad leak showed up in the deck forming the top of this tank. On account of the small size of the tank, the work required to seal the leak did not appear warranted.

An effort was made to get to No. A main ballast tank, under the torpedo room, with the torch and burn a hole in it near the keel, but the tank was buried in the clay, and it was found that the diver could not get low enough without digging a tunnel under it. The same condition was found as regards No. 1 fuel-oil tank, which was also under the torpedo room. As neither tank was very large and the need for the bouyancy did not appear great, no attempt was made to tunnel under; further, the condition of the divers now made it necessary to eliminate everything but essential work on the bottom.

On June 11, 1926, all pontoons having been lowered and secured, a start was made on leveling off the pontoons above the submarine with slight positive buoyancy, preparatory to lashing them. On account of the long tow, 150 miles, to New York, it was necessary to keep the pontoons clear of the hull of the *S–51* or they would batter themselves and the *S–51*, especially in the early stages of the tow through the open sea. The lengths of the cradle chains were so adjusted as to leave a clearance of several feet between the pontoons and the *S–51's* deck; at the same time they were short enough so that the maximum draft afloat would be about 32 feet, which would clear all channels and allow the submarine to enter dry dock without the necessity of shortening up the slings. (Pls. 5 and 6.)

It was essential that the pontoons should be level before lifting commenced, otherwise attainable buoyancy would be lost. It was further necessary that the pontoons be lashed against slipping aft when the stern was lifted, and these lashings could be put on only after the pontoons were in position above the submarine.

Sufficient knowledge of the cranky nature of the pontoons as provided had already accumulated to make it evident that difficulty would be encountered.[1] To equalize conditions the pontoons abreast the conning tower, which were selected as the first pair to be leveled off, were vented down at both ends until they were known to be completely filled with water. All four ends were then blown together in an attempt to maintain an equality of buoyancy, but owing to variations in hose friction the pontoons rose one end at a time, their lack of longitudinal stability being just as marked here as when first attempts were being made to lower them. Unfortunately the end of a pontoon which rose first would drag all the slack chain through under the boat from its mate pontoon on the other side. The result was a pair of cockbilled pontoons, one of which was very much too high above the submarine, and the other, inclined in the opposite manner, had one end held to the ground. A number of attempts were made to rectify this condition during the remainder of the day, but the pontoons merely seesawed the cockbilling from one end to the other as buoyancy changes were tried, and it was found impossible to get the pontoons level and both at the same height.

To overcome this difficulty an inversion of the lowering process was tried next day. The pontoons abreast the conning tower were flooded again and sunk to the bottom. Here divers descended and fastened a 1-inch wire cable, marked off in fathoms, to the lifting pad at each end of the starboard pontoon only, using a pelican hook to shackle up the wires. These wires were led to the surface where they passed through the bitts, one to the forward winch and one to the aftercapstan. A moderate strain was put on the wires.

Both ends of the starboard pontoon were then blown together for one minute. When blowing ceased both winches took a pull, but the weight to be lifted was still too great. Blowing was resumed for periods of one minute at a time, alternating with attempts to lift. When the negative weight had been reduced so that it came within the safe capacity of the gear, about a 5-ton pull on each wire, the pontoon was slowly lifted from the bottom, still with negative weight, and hoisted up until the marks on the wires showed that it was at its proper height above the submarine. In this process the pontoon lightened up somewhat as the internal expansion of air under decreasing pressure forced out some of the contained water; on the other hand, the pontoon had added to it the weight of the chain cables, which it lifted off the bottom as it rose. The gain and the loss approximately balanced and no pontoon lightened enough to become positively buoyant and float up higher than the point to which it was hoisted. (See pl. 4.)

Having reached a proper height, the starboard pontoon was left suspended from the wires and blowing was started on both ends of the port pontoon. The gauges were carefully watched during this process, blowing being frequently stopped to check the pressures in the pontoon. As soon as one end showed by a drop of pressure that it was rising, blowing on that end ceased, but the air was kept on the other end until it also floated up.

The motion of each end of the port pontoon was limited, as it was bound to stop when it took up all the slack in the chain leading to the other side. This resulted in the port pontoon finally floating level at a height which placed it abreast of the suspended starboard pontoon. Having reached this position, both ends of the suspended pontoon were gradually blown until the pontoon showed positive buoyancy, as indicated by lack of strain when the suspension wires were slightly slacked off. Both pontoons were then blown together for about two minutes, giving each of them a positive buoyancy of about 6 to 8 tons, when a diver was sent down and cast loose the wires to the suspended pontoon, leaving both pontoons floating properly in position.

The leveling method just described was followed on all other pontoons. It was quick and reliable, the only drawback being the danger of breaking the suspension gear due to the rolling and pitching of the *Falcon*. Owing to its large size and total immersion, the pontoon suspended did not follow the rolling motion of the *Falcon* from which it was hung; in addition it was restrained against such motion, after its mate pontoon had been floated up, by the tension in

[1] See Appendix D.

the chain cables attached to both pontoons. On three different occasions the motion of the *Falcon* under these circumstances parted a pelican hook to the suspended pontoon allowing it to drop and requiring the leveling job to be done over again. Consequently, leveling could be attempted only in moderately good weather; better weather in fact than was required for lowering pontoons.

On June 13, 1926, a second pair of pontoons, being the pontoons abreast the battery room, was leveled off in the same manner.

About five days had now gone by since the port side ballast tanks had been dried out and the *S-51* showed no signs of rolling to starboard, although the engine room and the motor room were now blown dry. On the other hand, the C. O. C., which had previously been dried out, had had its blowing hose carried away while the pontoon in its vicinity were being leveled off, allowing the air to escape and the C. O. C. to refill.

To expedite matters as regards rolling the ship and breaking the suction, the two pairs of pontoons already leveled off, being No. 2 pair and the No. 3 pair, over the battery room and the C. O. C., respectively, were now blown completely dry. Nothing happened.

The following day, June 14, a new blowing connection was attached to the C. O. C., and measurements were taken for the lashings for the pontoons already afloat. Following this, an attempt was made to line up the stern pair of pontoons, in the course of which the port pontoon of the pair was given slight buoyancy.

With matters in this state Carr started down to install clamps for lashing the pontoon chains together. While he was still descending, a series of large air bubbles broke the surface for practically the entire length of the submarine, the disturbance lasting about half a minute. It was evident that something unusual had happened on the bottom. Carr reached the submarine a few seconds later and, after some minutes spent in orienting himself, finally announced that the submarine had rolled and was then inclined about 20° to starboard.

This report was received on the *Falcon* with considerable rejoicing, as it was the first positive evidence received of any movement on the part of the *S-51* since her sinking. There could be no doubt now that the suction effect was in a large measure already broken by the roll; the last lingering doubts as to the possibility of being able to lift the ship were finally removed, as the suction had been the one factor which could not be definitely figured on and which had to be outmaneuvered rather than overcome by direct buoyancy, of which sufficient could not possibly ever be brought to bear.

It was also discovered on further inspection that the stern of the *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 pair of pontoons. This checked with the buoyancy calculations, which had previously been revised to take account of the fact that a large portion of the tiller-room buoyancy, all of the motor-room buoyancy, most of the engine-room buoyancy, and a large fraction of the buoyancy of the after group of oil tanks had been attained. The buoyancy tables had been changed as shown below, on the basis of what was then definitely known to be available:

Compartment	Total buoyancy	Per cent of buoyancy attainable	Net buoyancy available
Tiller room	15	80	12
Motor room	137	100	137
Engine room	110	87	96
Port ballast tanks, 3, 4, 5	62	81	50
Starboard ballast tanks, 3, 4, 5	62	81	50
C. O. C	90	67	60
After-group oil tanks	33	100	33
Forward trim tank	10	100	10
Water round torpedo tank	6	100	6
No. 2 bow buoyancy tank	11	100	11
Total			465

To prevent the possibility of damaging the stern pair of pontoons, the stub mainmast, which came in their vicinity, was burned away with the torch. Several attempts to level off the stern pair of pontoons failed, due to breaking of pelican hooks on the suspension wires.

While the leveling operation was under way, the starboard ballast tanks Nos. 3, 4, and 5, which had never previously been touched, were blown dry by Michels, using an air hose inserted in the hole burned in No. 3 tank and in the open Kingston valves of the other two tanks.

Wickwire, who shortly afterwards went down to inspect the location of the starboard after pontoon, which was somewhat close under the counter with the submarine leaning on it, was standing on the bottom just outboard of the pontoon when the pontoon first rolled gently and then started to float up while the submarine rolled from 20° starboard to 10° port before his astonished eyes. Wickwire reported the first part of this performance over his telephone as it occurred; then as it appeared that both submarine and pontoon were on their way up and 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 fouled there; the pontoon was now so high that Wickwire on the bottom could not see it, but finding himself foul (which was also discovered on the top side) he climbed his air hose to the under side of the pontoon, cleared it of the chain and then slipped down and climbed aboard the stern of the submarine. This prompt action in clearing himself proved exceedingly fortunate, for immediately afterward the pontoon sank again to the bottom, coiling down and resting on the chain where but a short period before his air hose had been fouled. Wickwire checked the new position of the pontoon, noted the angle of heel of the submarine, and came up.

To prevent any premature rise of the stern, about 60 tons of water was flooded back into the third pair of pontoons, abreast 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 and that the submarine was heeled only about 5° to port. It was evident that with both starboard and port ballast tanks blown, buoyancy was now symmetrical and so far as the bottom conditions permitted the ship was floating upright.

Lashing of the pontoons as they were leveled off was installed, partly to hold them against change of position from inequality of buoyancy in the blowing operations but mainly to prevent them from slipping aft when the stern had lifted and before the bow came up. It was essential to prevent such change of the pontoons at the bow during this stage, as slipping aft would reduce their lifting moment; it was further essential that by no possibility should the pontoon chains be permitted to slip out from under the hull while the ship was at an angle with the stern up. To attain this, pontoon sling locations were chosen, taking advantage of such natural stops as the ship's structure presented. The stern pair of pontoons had the after chain passed inboard of the shafts and just forward of the skeg; this wholly prevented these pontoons from slipping aft. The bow pair of pontoons had its forward chain caught in the anchor well under the keel and the after chain rove through the bow plane guards so that movement either astern or ahead was impossible. The third pair of pontoons and the second pair of pontoons, however, were naturally restrained from sliding aft only by the fact that the hull widened out aft in their location, though this widening was not marked in the case of the third pair, abreast the conning tower.

The possibility of the pontoons slipping forward in the raising operations was considered and taken care of to some extent, though it was regarded as remote if the raising plan was carried through of bringing up the boat stern first.

To prevent motion aft on the part of the second and third pairs of pontoons, a special steel clamp was secured by the divers on each pontoon chain below the pontoon and just above the point where the chain cleared the hull. As shown on Plate 6, a 1-inch wire lashing with an eye in each end was then run generally athwartship just above the deck of the submarine, the wire eyes being secured at each end to the chain 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 boat caused the wires to take up. Further, the wires for the third pair of pontoons led across the deck just forward of the gun access trunk, which thus acted as an effective stopper against slipping aft. As an additional safeguard on 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 athwartship 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 slipping.

Calculations showed that at a 30° angle , the force tending to make the pontoons slip was equal to half the lift of the pontoons—a very considerable force—but there was provided by the lashings, by the bilge keels, and by friction of chains against the hull an antislipping force which afforded a fair margin against slipping aft. It may be stated that this proved correct, as the pontoons on the final raising retained their designated positions without evidence of slipping.

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, the *Falcon* cut the 1-inch wire and spliced in the eyes. It was shortly seen that splicing caused too much delay; eyes were thereafter made with clips, using four wire clips for each eye. This proved a quick method and turned out satisfactorily; no clipped eye ever gave way.

Handling the 1-inch wire lashings on the insecure footings over the side of the submarine caused the divers trouble, but they were all installed as desired.

It was during the installation of the lashing wires on the second pair of pontoons that trouble commenced which led indirectly to the rising of the bow a short while later. The second pair of pontoons having been leveled off with moderate positive buoyancy and properly adjusted, the measurements for the lashings were taken. When the lashings were sent down for installation, it was found that they could not be installed, as the forward end of the starboard pontoon had sunk until it rested on the bow pontoon just ahead of it which it overlapped, the bow pontoon itself being on the bottom, not yet having been floated up. Had this bow pontoon not been there, the No. 2 starboard pontoon would have sunk to the ground, probably standing on its end.

This trouble was obviously due to air leakage from the pontoon, which reduced the buoyancy in the forward end until it sank. The same leakage, to a varying extent, was discovered on every pontoon on the job except the No. 3 pair. The leaks were of two kinds—one due to springing of rivets or seams from the banging received by the pontoons either on the tow from Newport to the wreck or while alongside the *Falcon* plunging up and down in the sea during the lowering process; the second type of leak was in the vicinity of the hawse pipes, where some of the calking around the castings, which was probably tight under no load, opened somewhat when a load was applied via the chains and started leaks.

The results were serious. Considerable trouble had already been expended in leveling off the pontoons and it was necessary that they be kept leveled off. The pontoon which had sunk was leveled again. After that all pontoons afloat were inspected and they were thereafter given a brief daily blow to compensate for such leakage as was evident In addition, after blowing the No. 2 pair down completely for the purpose of helping to roll the submarine, its flood valves were temporarily closed, so that the admission of water would be minimized even though air leaked out.

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On June 20 the bow pair of pontoons was leveled off, the process being complicated by the breaking of one pelican hook on a surge, and the untoggling of the other one, which resulted in standing one of the pontoons on end for a while. Both pontoons were finally fairly well leveled off above the submarine, but as leaks showed on both of them, the flood valves were temporarily closed to minimize leakage.

On June 21 the stern pair of pontoons were leveled off above the submarine. The divers measured off for lashings, but while they were being installed the port pontoon of the pair suddenly shifted position under the eyes of the divers, the stern going up about 10 feet and the bow dropping considerably. Fortunately neither of the divers was injured. The forward end of this pontoon was given more air to compensate for leakage and an attempt made to close the flood valves, but one failed to close at all and another was doubtful.

It had been expected to tow the *S-51*, when raised, with her own towing pennant, which was normally secured in place to a towing rig forward with the pennant stopped along the deck edge. A diver's examination of the boat showed the pennant missing. (It was later found on the dock at New London.) It therefore became necessary to supply another towing pennant, and for this purpose a bridle made of 1½-inch chain cable was rove under the keel, through the bow plane guards, port and starboard, and then shackled together in front of the bow, with 150 feet of 1½-inch wire leading forward for the tow line.

As a line for towing astern, should it be necessary, or for steering the boat in any case, another 1½-inch chain bridle was passed around the stern inboard of the propeller shafts, shackled together under the hull, and a 1⅜-inch wire, 150 feet long, led aft from the top of the bridle for the stern line.

Both the bow and stern lines were laid out on the bottom and buoyed to the surface for picking up when the *S-51* rose.

The submarine being known now to be light, the engine room was flooded to prevent a premature rise. The final lashings were put on the bow and stern pairs of pontoons, which work was finished late at night on June 21, and everything was in readiness for raising the submarine on June 22.

The buoyancy conditions when work ceased on June 21, were as follows:

	Buoyancy (tons)
No. 1 pair pontoons (bow pair) just buoyant	20
No. 2 pair pontoons (over battery room) completely dry	160
No. 3 pair pontoons (abreast C. O. C.) partly blown	100
No. 4 pair pontoons (stern pair) just buoyant	10
No. 2 bow buoyancy tank, dry	11
For'd. trim tank, dry	10
Water round torpedo tank, dry	6
Port ballast tanks 3, 4, 5, dry	50
Starboard ballast tanks 3, 4, 5, dry	50
C. O. C., flooded	5
Engine room, flooded	0
Motor room, dry above shaft lines	110
Tiller room, partly dry	12
After group oil tanks, dry	33
Total	577

The moment against rising by the bow, based on the above tabulation, was 11,643 foot-tons. The moment against rising by the stern was 15,117 foot-tons. For complete buoyancy, to float the ship as a whole, there was still required about 243 tons.

The only factors in the above table which were uncertain were the buoyancies in the first, third, and fourth pairs of pontoons. The first and fourth pairs of pontoons were supposed to have just enough buoyancy to float themselves with a moderate margin; they were all leaking and had their valves closed to minimize this leakage. The third pair of pontoons, the only pair which showed no leaks, had once been completely dried and had since had 60 tons of water flooded back in them (estimated).

The *S-51* was practically upright, with a slight port list (less than 5°), but with her stern a foot or two higher and her bow the same amount lower than when first sunk.

Diving work ceased at 10.30 p. m. on the night of June 21, 1926, everything being ready, but it was then too late to undertake the work of raising, in addition to which both divers and deck force were completely worn out, both from long-continued exertion and from the special strains of the last three days drive to level off pontoons and complete the work.

There is no doubt, however, that with conditions as they were on June 22, had the weather been satisfactory, that the *S-51* would quickly have been raised stern first as planned, shortly after blowing commenced on the stern pontoons and the reflooded engine room. Considering the buoyancy then known to be available forward, the bow would have followed with the addition of no great amount of air forward.

The 22d of June dawned in a storm, which grew worse as the morning advanced. Diving was out of the question and raising the ship in such weather was not to be thought of.

Had it not been for the known leaking condition of the pontoons, the delay caused by the storm would have been welcomed as giving the worn-out salvage crew a chance to recuperate before proceeding with the work and strain involved in raising. But with the experience of four different pontoons sinking after being leveled off, and with the leakage from a number of pontoons then visible at the surface, the enforced delay was an added aggrevation.

There was nothing to do, however, but to attempt to hold the situation as it was. With that in view, the *Falcon*, headed south into the storm and opposite to the heading of the *S-51*, succeeded in mooring over the wreck after considerable difficulty for the purpose of giving the leaking pontoons a brief blow, estimated at 2 tons of buoyancy per pontoon. It was intended immediately after this to unmoor and run inside the breakwater at Point Judith for shelter from the southwest storm.

The *Falcon* first picked up the hoses to the stern pontoons and blew through them for one minute. The hoses for the after pair of pontoons were then buoyed off and put overboard, after which the group of hoses for the No. 3 pair of pontoons was brought aboard and given a half minute blow. These hoses were also then buoyed off. Nothing was done to the No. 2 pair of pontoons, as they had been previously blown completely dry and had had their flood valves closed for several days. On a trial the night before they showed as having made but little water and it was felt that they could be safely left another day.

Some delay ensued before the set of hoses to the bow pair of pontoons (No. 1 pair) could be brought aboard. The hoses of this set were swept under the *Falcon's* stern and caught in one of the propeller blades. It was necessary to clear these hoses, as the bow pontoons would sink if the hoses parted. As no divers could be put overboard in the storm, the work was attempted from a surfboat. Clearing the hoses was to some extent aided by the storm, as in the trough of the sea the fouled propeller blade could be reached with a boat hook. Working in this manner, the hoses were gradually dragged clear, though on one occasion, the salvage officer who was handling the boat hook barely escaped being crushed when a wave caught the surfboat under the counter of the *Falcon* and dashed it against the ship.

The hoses, having been freed, were taken aboard and were being hooked to the manifold, preparatory to turning on the air. About 40 minutes had elapsed since the No. 3 pair of pontoons had been disconnected and its hoses put overboard. The salvage officer had just stepped aboard from the surfboat to direct the blowing, when a huge mass of bubbles started to break the surface under the *Falcon's* port quarter. At first glance, it was thought that after all the hoses had carried away from the bow pontoons, but the volume of air was excessive for such an accident. It was immediately sensed that either the bow pontoons had torn loose and were coming up, or the submarine itself was rising. In either case the *Falcon* was in a precarious position and speed was essential. The mooring lines to the stern were on the winches and the winch men at the throttles, preparatory to unmooring. The port quarter line was cast off and the starboard quarter line heaved in full speed to haul the *Falcon's* stern to starboard. The stern was barely clear 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 the submarine visible between them.

The *Falcon* sounded her whistle as an emergency signal to the other vessels present, and let go her port bow lines to keep clear in case the stern of the *S–51* came up. The sea promptly carried the *Falcon* to leeward, but her commanding officer quickly worked her back in position about 40 feet from the *S–51's* port side. The handling of the *Falcon* in this emergency was magnificient; it unquestionably saved her stern from serious injury, and probably saved the ship herself from becoming a total loss.

Meanwhile the four pontoons at the surface were plunging heavily against each other as the seas swept over them and action was required.

A hasty estimate of the situation resulted in the decision that the best course of action was to raise the stern and attempt as speedily as possible to get to a lee to the northward of Block Island about 15 miles away, the storm being from the southward. The danger faced was that the pontoons might be so badly battered against each other as to cause the ship to sink again on the way; it was also possible that the dynamic strains might part the cradle chains with the same result. Still, on a northerly course, the sea would be astern and the pontoons might ride more freely; finally as such a course led to more shallow water about 8 miles away and passed over no deeper spots, it was at least hoped that if the ship sank in the course of the tow that it would occur in water of a lesser depth than that in which she then lay.

Accordingly all the reserve blowing hose being held on the *Vestal* was sent for and coupled up to the buoyed ends of the hoses afloat at the surface and leading down to the pontoons and the compartments on the submarine. Air was turned on each compartment as soon as it was coupled up; the *Falcon's* compressors were all called into action, but were unable to keep up much excess pressure under the large demand.

To help out, the *S–50* was worked into position close aboard the *Falcon* by her commanding officer and an air line run between the ships, but the *S–50's* anchors failed to hold against the storm, she was unable to maintain her station, and the *Falcon's* air plant was compelled to carry the whole load.

To furnish enough air in this manner required over two hours, but there was no help for it. To make the situation worse, it was realized that hardly one-half of the expected buoyancy of the C. O. C. and not over one-third of the expected buoyancy of the engine room now could be obtained. This followed from the fact that these two compartments which had once been dry had been reflooded—the C. O. C. accidentally and the engine room purposely, with the object of preventing a premature rise. It so happened that the spill pipes in the O. C. C. and engine room hatches and the discharge line from the motor room all were located in the forward ends of their respective compartments. With the ship up by the stern, this would permit discharging water until the compartments were wholly dry (which was one of the reasons the plan called for raising the *S–51* stern first); but with the bow up, as was the case actually, the ends of the spill pipes became exposed for the escape of air long before the compartments became dry and no more buoyancy could be realized from them.

This resulted in a loss of attainable buoyancy in these three main compartments of about 130 tons. However, practically all of the buoyancy of the stern pair of pontoons was reserve

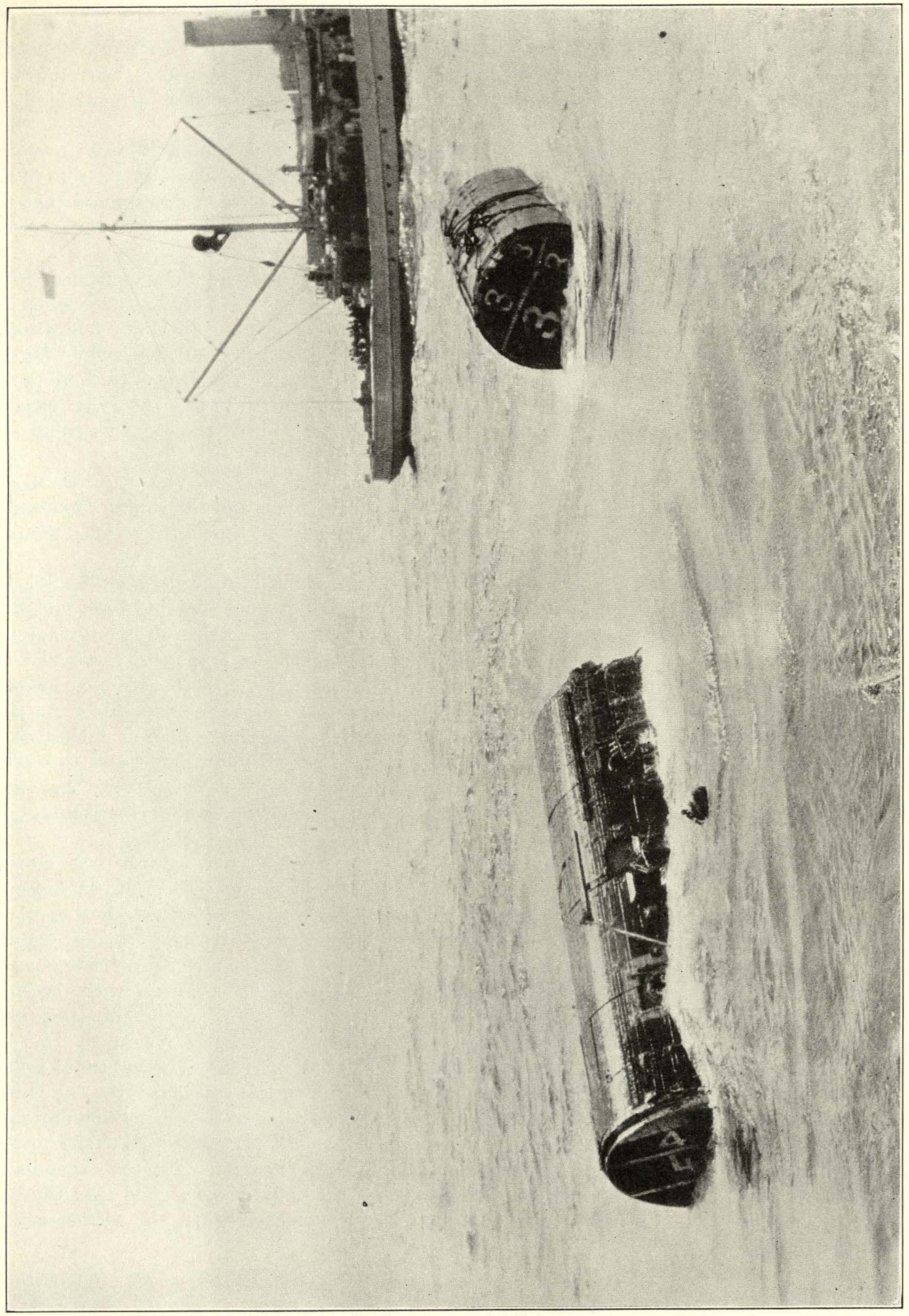


FIG. 15.—STERN PONTOONS WHICH BROKE FREE FROM SUBMARINE, JUNE 22, 1926

for contingencies and towing and was not normally required for lifting; it therefore appeared that the stern could be brought up, but with only a slight margin. On the surface, when the stern leveled off, all the residual water could then be blown out of the after compartments and the ship would float with the reserve buoyancy called for in the plan.

About one hour after blowing commenced, a steady stream of bubbles showed over the middle of the ship. It was evident that in the C. O. C. the air had reached the bottom of the spill pipe and no more buoyancy would be obtained there. It was soon determined that the No. 3 pair of pontoons was also dry, leaving only the motor and engine rooms and the No. 4 pair of pontoons on which blowing continued.

About noon, a sizable bubble which appeared over the stern, and then increased, for a moment made it seem that the stern was rising, but that hope was dissipated at once when the starboard after pontoon broke through the surface alone, to be followed in about five seconds by the port after pontoon, when both pontoons drifted to leeward (fig. 15), meanwhile fouling the remaining hoses to the *S–51*. These were cleared, allowing both pontoons to float to the northward, where they were picked up and towed to Point Judith. It was observed that the 2½-inch chains had parted under the submarine; the broken ends of these chains could still be seen dangling in the hawse pipes of the pontoons.

Deprived of the No. 4 pair of pontoons, it was mathematically certain that the stern would not rise, but as a forlorn hope, the air was kept on the motor room and the engine room until, shortly after, a discharge of air at the surface over them showed that the limit had been reached in their buoyancy. The stern did not rise.

The situation of the *S–51* was now desperate. By no possibility could her stern be floated. In the three hours that had gone by since the bow rose, the four pontoons had been violently pounding each other. The wood sheathing on the forward pair was coming off in large patches and floating away. The pontoons no longer held their fore and aft alignment but had been driven by the sea into a huddled group at the stern where the No. 2 starboard pontoon was riding on top of the pontoon just forward of it, and the two pontoons on the port side were lying at a considerable angle to the *S–51*. As the pontoons swayed and plunged, their chains, especially where they passed under the keel, were subjected to severe punishment and to terrific shocks. It did not seem possible that they could stand such strain; it was certain that they would not hold out until the storm moderated and the lost pontoons could be replaced under the stern. (See fig. 16.)

A canvass of possibilities was made. Towing was suggested; one towline was already round the bow; more could possibly be attached. This proposal was ruled out, as the boat had a negative weight of considerably over 100 tons and it was questionable whether under smooth conditions such a weight could be dragged over the bottom with the propellers digging in as anchors; worse still all the buoyancy of the *S–51*, to gain which so many desperate chances had been taken by the divers, was in the stern compartments. A 15-mile tow with the stern on the ground would irretrievably ruin the water-tightness of this half of the ship and make her final raising perhaps impossible. The suggestion to tow was promptly overruled.

This left as the only course of action the sinking of the bow, which was bound to take place soon in one way or another. There was reason to believe that if left to themselves the chains would soon break. (This was afterwards confirmed by the condition of the chains when brought up for inspection.) When the chains broke, the heavy bow would have a free fall to the bottom with resulting damage that would complicate an already bad situation. On the other hand, if the pontoons were allowed to flood and sink gradually, the chances were good that the bow would go down slowly and the *S–51* would as a ship be no worse off when she settled on the bottom than before she rose.

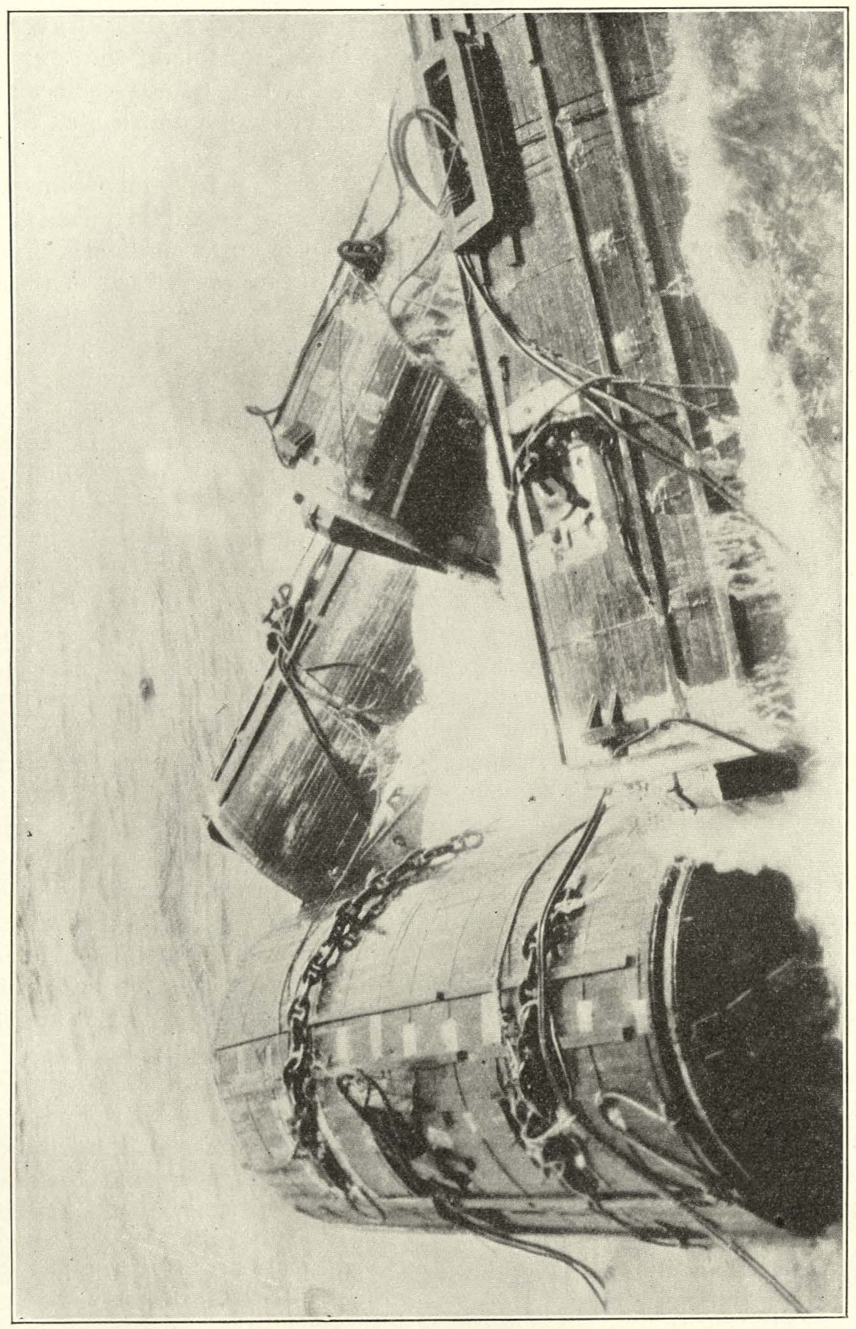


FIG. 16.—BOW PONTOONS DRIVEN OUT OF ALIGNMENT BY THE SEA, JUNE 22, 1926

This decision was the proper one under the conditions, but carrying it out was dangerous. All flood and vent valves on the four pontoons at the bow were closed. The motion of the pontoons was violent and erratic; seas swept over them steadily.

The order to open the valves and sink the pontoons was given to Boatswain Hawes and the surfboat crew (see figs. 17 and 18); three men, Badders, Wickwire, and Weaver, volunteered to carry it out. One at a time they boarded the pontoons and fought the sea; pounded into a state of collapse they were successively hauled back to the surfboat each with the valves on his pontoon open; with his men all gone Boatswain Hawes himself leaped aboard the last pontoon and swung open its valves.

The pontoons flooded quickly and settled evenly; No. 1 port pontoon showed slightly for about 10 seconds after the others had completely disappeared and then vanished; the *S–51* sank the rest of the way with no disturbance visible at the surface. The *Falcon* buoyed off all hoses, let go the moorings at about 2 p. m., and with all other vessels of the salvage fleet ran for shelter at Point Judith.

The two pontoons which had gone adrift were soon brought in behind the breakwater by the *Sagamore* and the *Wandank*. In the late afternoon the broken chains were removed by the *Falcon*, and the *Vestal* repair party immediately started to recondition the pontoons. A 100-ton floating derrick, the *United States*, had a week before been towed from the New York Navy Yard to Point Judith to be handy for contingencies even though she could not safely be taken out to sea; a crew for the derrick was mustered from the personnel of ships present, and with the repair ship *Vestal* and this derrick a miniature navy yard was at once put in commission, which shortly did remarkable work.

While the events were still fresh, a study was made to determine the causes of what had happened. It was concluded that the bow pair of pontoons must have been more buoyant than estimated; this was evidently the case with the No. 3 pair also. In the case of the bow pontoons the leakage after the valves were closed must have been much less than what the bubbles at the surface indicated. No means, unfortunately, existed of knowing the buoyancy condition inside a pontoon, unless it happened to be completely empty or completely full; other than in these two conditions its buoyancy could only be estimated with the flow of air in through a long hose and the leakage of air out through the battered shell as two highly uncertain factors governing it.

It appeared that sufficient buoyancy had accumulated forward when work ceased late on June 21 to give a slight positive lifting moment at the bow. Motion, however, was prevented by the suction effect. The air put in during the morning was either aft or amidships and could have had but a negligible effect on the forward lifting moment; actually the air put in the stern pontoons would tend to reduce the forward moment by shifting the center of buoyancy aft and would help to hold the bow down.

It is probable that the motion of the sea was sufficient to rock the *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 as the expanding air forced water out of the bow pontoons on the way up and increased the buoyancy.

By the afternoon of the following day, the sea had subsided enough for diving and the *Falcon* returned for an examination of conditions.

The *S–51* was found with a strong starboard list, about 20°, and with the bow clear of the bottom back to frame 40; the stern was on the bottom. There was no evidence either forward or aft of damage to the *S–51* due to the events of the previous day, except some dents in the bow buoyancy tanks where the pontoons had rubbed. The midship pair of pontoons

Fig. 17.—Wickwire boarding bow pontoons, June 22, 1926

(No. 3 pair) was afloat in proper position abreast the conning tower, but both the No. 1 and the No. 2 pairs of pontoons were in a huddled group at the bow. Three of these pontoons were standing vertically on end alongside the submarine; the fourth one was floating horizontally about 5 feet above the submarine's deck. All four of these pontoons were battered and out of position; it was clear they would have to be cast loose and brought up for repairs.

The bow of the submarine was found about 15 feet to starboard of its former location, the boat evidently having swung somewhat with the storm.

Except for the work required to remove and replace the four bow pontoons and to replace the two pontoons carried away at the stern, the condition of the job did not look worse than two days before. The condition of the divers, however, was critical. They were much worn from their previous exertions, especially during the last two weeks, and they were in no condition to undertake another strenuous diving operation. To some of them the job looked hopeless and their spirits were at low ebb. It was with some difficulty that the surface and diving crews were made to see that an immediate continuance of work was imperative; when convinced that success was possible the divers turned to again with an enthusiasm and a vigor that far surpassed their efforts of the preceding month.

The first operation attempted was to run through a pair of reeving lines for replacing the No. 2 pair of pontoons. The keel here 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 the divers sawed it back to frame 42, its designated location. For the second reeving line, this could not be done, and Eadie had to wash through a new tunnel at frame 50, which he was able to complete in about one hour, this speed being due to the new nozzle. The first line through the tunnel was cut in half by the bilge keel and another had to be run. On the reeving lines, wire lines and then a pair of 2½-inch chains were run through; the wires and the chains were laid out on the bottom until wanted.

The next step was to clear away the pontoons at the bow. The pontoon still afloat was secured across the submarine by the lashing wires and these had to be cast loose. One of the wires lay across the deck where it was easily reached by Chief Torpedoman Kelley and cut with the torch; the other wire ran about 6 feet clear of the side and was out of reach from the deck; furthermore it was under a strain from the floating pontoon. To cut this wire, Kelley lashed the torch to the end of a squilgee handle, reached out toward the wire with the torch already lighted and the cutting trigger pulled, and speedily burned the wire in half. Freed of this strain, the pontoon swung across the deck toward the divers, who started to run; it caught one of them and knocked him off the boat; the pontoon then rose about 10 feet until it took up on both chains. Kelley managed to haul his partner back aboard, fortunately not injured, and both divers came up safely but badly shaken.

Before proceeding further, it was necessary to sink this pontoon, the flood valves of which had not been touched while it was on the surface, as they were inaccessible then. The next divers down on the job found this pontoon still afloat but almost vertical, and reaching the valves was difficult; the next day this was accomplished and the pontoon sank, still standing on end. This completed a trying situation, all four of the bow pontoons being vertical which was their worst position for work.

An attempt was made to capsize the port No. 2 pontoon by attaching a 6-inch manila line to the high end and hauling on it with the *Falcon*; after some heaving the line broke but the pontoon stayed as it was.

In view of this failure, it was determined to attempt the release of the toggle bars holding the chains to the pontoons; even though the diver would have to work on a vertical surface, Grube, one of the newly trained divers, went down on this job and hanging by his life line (which was tended from the top of the pontoon by another diver) managed to remove the locking pins

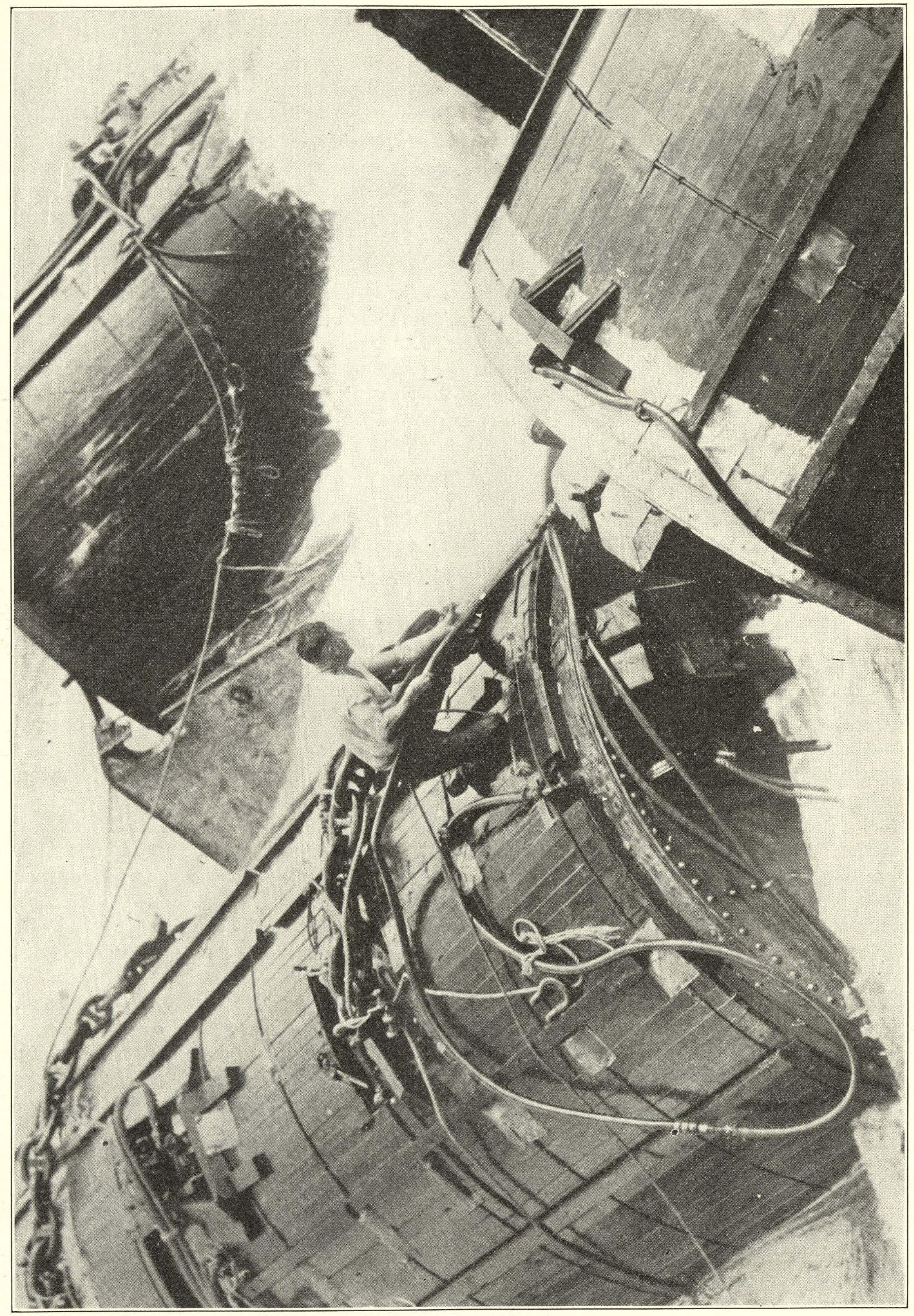


FIG. 18.—WICKWIRE CLEARING AIR HOSE, JUNE 22, 1926

and haul the 130-pound toggle bars out of the chain links, thus freeing the chains. When the divers were clear, the air was turned on and this pontoon soon floated up; the mate pontoon of this pair was then blown clear of water and came up, bringing the pontoon chains with it. Both pontoons were dispatched to Point Judith in tow of tugs for repairs.

The bow pair of pontoons took two days to cast loose and bring up, due to the tangled condition of the chains and the hoses. When finally raised, the port bow pontoon was found to have several large holes punched in its side; both bow pontoons were well battered and were sent to Point Judith for overhaul.

The bow towing bridle previously installed was found useless, as it had torn free of the port bow plane guard through which it passed; Kelley burned the bridle in half and sent it up. A new towing pennant of chain and wire was sent down and shackled into the bullnose; this pennant was the one actually used later for towing. As a preventer, another towline was secured around the gun mount with a length of 1½-inch chain and held in position near the bow by a 1½-inch chain bridle passing completely around the ship; from this point a towing wire led forward. Both the above towlines were laid out on the bottom ahead of the *S–51* and buoyed off.

On the evening of June 30 the divers had completed all work on the towlines and in clearing away damage; the *S–51* was again ready to attach pontoons.

Meanwhile at Point Judith the damaged pontoons had been hauled out of water by the derrick *United States* and landed on her deck. The derrick was secured alongside the *Vestal* (fig. 19) and the repair forces of the *Vestal* worked night and day to repair and calk the battered steel cylinders and replace the missing wood sheathing. New valves and sheathing were hurriedly shipped from New York.

By the end of June the first pair of pontoons was ready—the other two pairs were well advanced. The presence of the *Vestal* avoided a delay of two weeks which would have been required to send the pontoons to the nearest industrial plant for repairs.

On July 1 the *Falcon* was ready to lower pontoons, and the first pair was towed out from Point Judith. The weather was rather bad for lowering pontoons, but the lowering operation was successfully carried through without mishap, the pontoons being lowered and secured to the chains which had some days before been run through and laid out for the No. 2 pair of pontoons. An attempt was made to combine the leveling-off operation with the lowering of the second pontoon of this pair by holding the pontoon over the submarine with the 12-inch lowering lines while the first pontoon was floated off the bottom into position. On account of the violent motion of the suspended pontoon, the divers were unable to stay on the ends of the second pontoon long enough to open the flood valves, and came up seasick from the motion. As the pontoon could not be made buoyant without first opening the flood valves, nothing could be done except to sink the first pontoon again and lower the second one to the bottom, where the 12-inch lowering lines were cast off. The manila lowering lines were so stretched and reduced in diameter by the strains on this day that they had to be discarded and a new pair provided for the remaining pontoons. Fortunately a spare set of 12-inch lines was available on the *Vestal*.

On July 2 a pair of reeving lines was run under the stern of the submarine, the wires hauled round, and a pair of 2⅝-inch chains rove through and equalized. A pair of pontoons was lowered and secured, but as the weather was as bad as on the previous day, no effort was made to level them off.

On July 3 the last pair of reeving lines was run under the bow. To keep them from slipping up the rising forefoot and getting clear, the divers first secured a piece of 2-inch pipe from the mushroom anchor hawse pipe in the keel down to the bottom, into which the pipe was driven about 1 foot. The reeving lines were run through abaft the pipe and followed up with the wires and the 2⅝-inch chains; the after chain was passed through the starboard and port bow plane guards; the forward chain came in way of the anchor well in the keel.

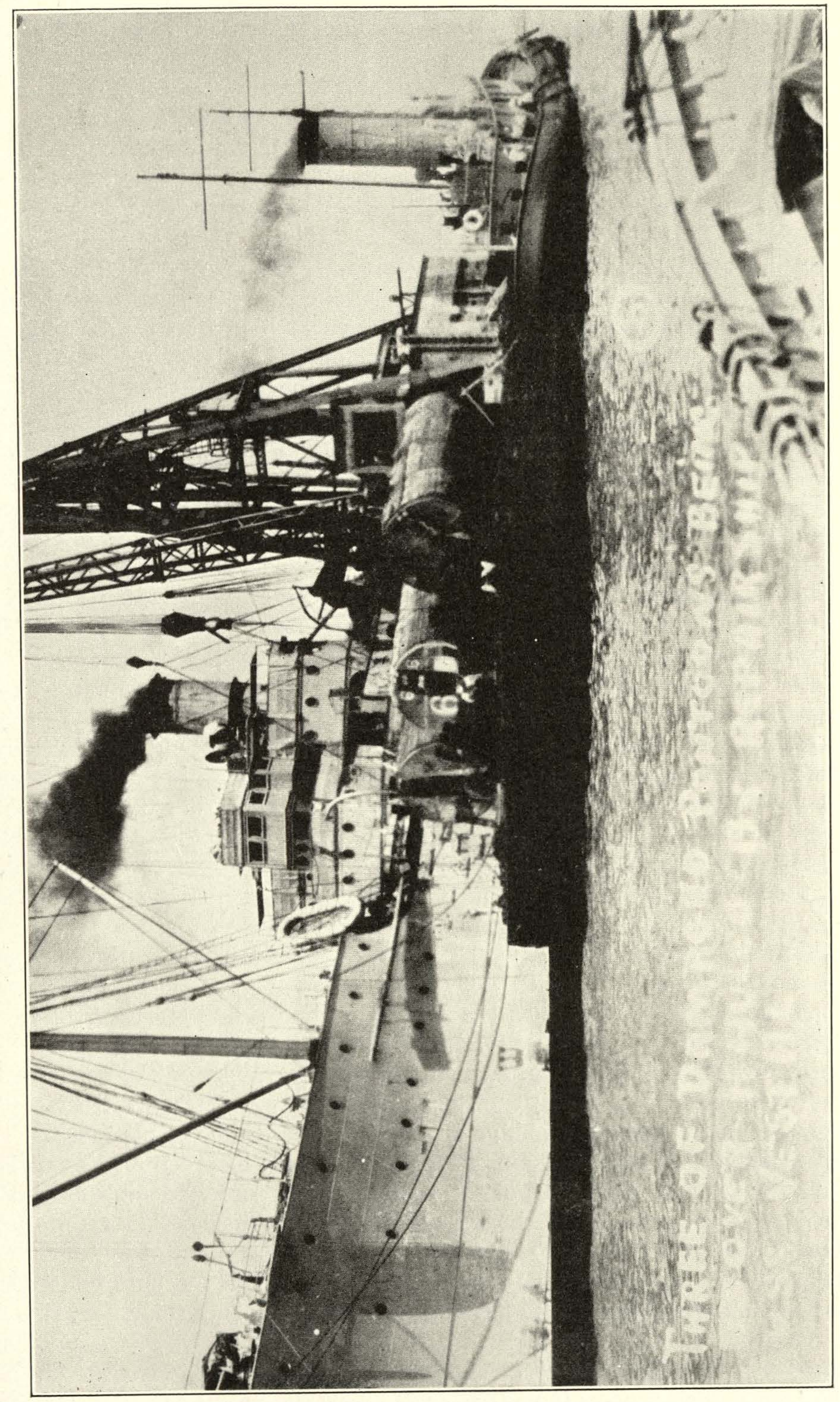


FIG. 19.—DAMAGED PONTOONS ABOARD DERRICK "UNITED STATES" AT POINT JUDITH

The port pontoon of this pair was successfully lowered and secured. In submerging the starboard pontoon of the pair, preparatory to lowering, the forward lowering line, which was wet, slipped on the bitts while the flood valves were being closed and the pontoon went down at this end enough to carry the extension wrench about 4 feet under water, the flood valve being still open. Badders, who was trying to close the valve, jumped into the water, and by several dives got the valve nearly closed, when the extension wrench hit the side of the *Falcon* on a surge and carried away.

As the pontoon could not safely be lowered with a partly open flood valve, some air was blown into that end of the pontoon to lighten it somewhat; by that time Eadie was ready in a diving rig and was put overboard in it to close the valve, which he did about 8 feet under water.

The pontoon was then lowered to its position over the submarine, where it was held while the divers inserted the toggle bars. The mate pontoon was blown off the bottom and floated up into position over the submarine. When this was done, the divers opened the flood valves on the suspended pontoon and it was blown until it became buoyant, as indicated by loss of strain on the lowering lines. When this was attained, the lowering lines and wires to chains were cast off and the bow pair of pontoons was leveled off in final position. The flood valves were immediately closed to minimize leakage.

This pair of pontoons was the only pair that the salvage party was able to lower, secure, and level off afloat in one continuous operation. Its success was due to the moderate weather which prevailed that day, better weather being needed for leveling than for lowering.

Three pairs of pontoons having been lowered and secured in three successive days, the morale of the salvage force was considerably bolstered up, and the men were driving hard again to clean up the job and get away.

On July 4 the *Falcon* rigged for leveling pontoons, with only a moderate swell. The standard method was used. Commencing with the No. 2 pair of pontoons, a 1-inch wire was secured to each end of the starboard pontoon. This was gradually lightened by blowing until the *Falcon* winches were able to lift it when it was hoisted into position above the submarine. The port pontoon was then blown until it floated up level alongside the starboard pontoon (as usual, the port pontoon rose one end first). The starboard pontoon was then blown until it was buoyant, after which it was cast loose, and the flood valves closed on both pontoons.

The *Falcon* then shifted position and quickly leveled off the stern pair of pontoons in the same manner.

One of the divers next went down with a blowing hose and blew out the port side ballast tanks Nos. 3, 4, and 5 through the open Kingstons. To get at the starboard tanks, it was necessary to wash the Kingstons clear, as the submarine had a bad starboard list. This was done and the starboard ballast tanks Nos. 3, 4, and 5 were blown dry.

The pontoons now being in position, lashing was started. The old lashings on the No. 3 pair of pontoons were found intact, with no work required. A pair of wires were measured off and sent down for installation as lashings on the new No. 2 pair of pontoons. The divers installed the wire lashing on the after chain, but were unable to install the wire on the forward chain as they found that the forward end of the port No. 2 pontoon had sunk until it rested on the bottom; the forward end of the starboard pontoon had correspondingly gone up. As no appreciable external leakage was visible, it was believed that the internal bulkhead must have leaked, allowing considerable water to flow to the forward end of the port pontoon and thus causing that end to sink. On account of the lateness of the hour, nothing could be done that night.

July 5 dawned with passable weather, a choppy sea, and a moderate swell. As the weather prospects for the next day were poor, it was decided to blow the submarine that day and get out before the next storm; consequently, diving commenced unusually early.

The first step was to level off the No. 2 pair of pontoons again. To do this, a pair of 1-inch wires was secured to the starboard pontoon, the forward end of which was floating high, and a vent hose to the surface was also connected to the vent valve at the high end. The diver also opened all flood valves on both port and starboard pontoons of the pair. The forward end of the starboard pontoon was then vented and the forward end of the port pontoon was blown. The wire line to the forward end of the starboard pontoon soon developed a strain; it was lowered away gently until the pontoon was level; meanwhile the forward end of the port pontoon floated up until that pontoon also was level. Both pontoons were then given additional air all around to insure buoyancy and the leveling wires were cast off. The remaining lashing wire was then secured across the deck of the submarine to the forward chain, and all essential lashings were complete.

Eiben went down forward to secure the open end of a diver's air line to the stem, to act as a telltale to indicate the rise of the bow. Eiben also opened the flood valves on the bow pair of pontoons.

Wickwire went down aft to secure a similar telltale to the stern and opened the flood valves on the stern pair of pontoons. Knowing that he was making the last dive on the job, on behalf of all the divers Wickwire kissed the *S-51* good-by and (demonstrating the firm faith of the divers in their work) promised to meet her next in the dry dock at New York. Wickwire came up shortly before noon.

Certain forward tanks, which on June 21 were dry, were on this occasion leftflooded. The No. 2 bow buoyancy tank was considered lost, as it was evident that the deck forming its tank top was dented enough to make it nonwater-tight and the capacity of the tank did not warrant repairs. The forward trimming tank and the water round torpedoes tank had vented themselves down practically to atmospheric pressure while the bow was at the surface. On sinking again, these tanks reflooded nearly full under the bottom pressure. Had time permitted they would have been blown down again, but the weather forecasts were such for the following day that it was considered unsafe to risk further work which would run the job over until July 6, when a promised storm would put the expedition in the same position as two weeks before. Work on the forward tanks was abandoned, but with regret.

Another consideration causing some anxiety was the fact that about 150 tons of buoyancy in the six forward pontoons was going to be unavailable for lifting the bow while the stern was up. (Pl. 5.) This resulted from the fact that when the stern rose to the surface, the six pontoons forward would assume the angle of the boat, about 25°. Under such an angle, the after half of each pontoon could be blown down only until the air reached the flood valve, when it would escape, leaving a considerable wedge of water, amounting to 25 tons per pontoon, which could not be blown out until the bow reached the surface and the pontoons leveled off. The reoccurrence of such a condition can be prevented in future operations by fitting a sluice valve in the center bulkhead with an outside control rod. By leaving the flood valve to the end of the pontoon which will rise first closed and the sluice valve open (this to be done after the pontoon has been leveled and lashed) all the water in the high end can be blown out through the low end flood valve, thus obtaining the complete buoyancy of the pontoon, for lifting while on the bottom.

It had been the intention originally to make sure of this buoyancy by blowing the after halves of all six forward pontoons dry before lifting the stern; the forward halves could be blown completely dry in any position. Plate 5 illustrates this. However, with the experience of June 22, in the background, this intention had to be abandoned; no chances could now be taken of letting the bow rise first, and it was considered imperative that the stern be up before any additional bouyancy (beyond what was necessary to float them) be given the six forward pontoons.

Confirming the soundness of this position, the last two divers up reported that the *S-51*, which up to the evening before had had a list to starboard of at least 20° was that morning nearly upright, with a list of not over 5° to starboard. It was clear that the submarine was again moving, with slight or no suction holding her.

The condition on the morning of July 5 of the compartments and tanks which were available on June 22, with the buoyancies which were expected in them when the ship rose, was as follows:

Compartment	Condition at noon, July 5	Buoyancy at noon, July 5	Expected buoyancy
No. 2 bow buoyancy tank	Flooded	0	0
Forward trim tank	do	2	2
Water round torpedo tank	do	1	1
Port ballast tanks 3, 4, 5	Dry	50	50
Starboard ballast tanks 3, 4, 5	do	50	50
C. O. C	Flooded	0	60
Engine room	do	0	96
Motor room	Three-fourths dry	100	137
Tiller room	do	12	12
After group oil tanks	do	25	33
Total compartments		240	441

Pontoons	Condition at noon, July 5	Buoyancy at noon, July 5	Attainable buoyancy
No. 1 pair (bow)	Just buoyant	20	110
No. 2 pair	do	20	110
No. 3 pair	Partly buoyant	80	110
No. 4 pair (stern)	Just buoyant	20	160
Total pontoons		140	490
Grand total for lifting		380	931
Reserve buoyancy in Nos. 1, 2, 3 pairs of pontoons (regained at surface)			150
Forward group oil tanks (to be blown at surface)			43
Additional attainable buoyancy at surface			193
Total buoyancy at surface for towing operations			1,124

It will be noted that the margin for lifting the bow from the bottom was not great, but it seemed adequate. Furthermore, in a pinch there was always available the forward group of oil tanks with a buoyancy of about 43 tons, which could be blown while on the bottom, although at the risk of bulging or bursting the tank top when on the surface. However, even if these tanks ruptured under such use for lifting, it could only happen at the surface and by then the lost buoyancy in the forward pontoons would again be available to counteract the loss of the forward fuel-oil tanks.

On the above calculations it was deemed best to proceed with the raising and risk no delay merely to obtain added buoyancy forward.

When the last diver had left the bottom the *Falcon* hauled clear, with the submarine about 150 feet away on the port beam and parallel to the *Falcon*. The mooring buoys ahead and astern were dragged clear to afford an approach for the *Sagamore*, which steamed in ahead and picked up both the buoyed-off bow towing lines to the submarine; and for the *Iuka*, which came in astern and similarly picked up the stern towline to the *S-51*.

On the *Falcon's* starboard side the mooring buoy there was dragged clear and the *S-50* moved in close aboard, where she anchored and a 2½-inch fire hose was run to her to carry compressed air to the *Falcon's* manifold.

On the *Falcon's* forward manifold, with 12 valves, were secured the blowing hoses to the compartments (4 hoses) and to the No. 1 and No. 4 pairs of pontoons (8 hoses). To the manifold on the port side, with 10 valves, were secured the hoses from the No. 2 and No. 3 pairs of pontoons (8 hoses) and the 2 telltale hoses leading to the bow and stern of the submarine. Below the manifold valve to each hose was secured a pressure gauge, so that the

pressure in any compartment or pontoon could be determined by shutting the line off momentarily from the manifold and permitting the pressure to balance in the hose with that in the compartment.

At 12.17 p. m. Wickwire was hauled out of the water and the compressed air was turned on both motor and engine rooms. With both low-pressure compressors and the high-pressure compressor on the *Falcon* going full speed, and all the air that the *S-50* was able to supply through the fire hose, it was possible to maintain a pressure in the manifolds of 90 pounds.

At 1.17 p. m. after blowing an hour, a stream of air started discharging at the surface over the engine-room hatch; blowing was kept up a few minutes longer to make sure both motor and engine rooms were dry.

At 1.25 p. m. air was turned on the C. O. C. Within a minute air started to discharge at the surface over the vicinity of the conning tower. This was a severe shock, as it could only indicate that the C. O. C. had previously been nearly dry, or that the air was escaping from the C. O. C. as fast as it entered, or that the blowing hose to the C. O. C. had carried away somewhere near the submarine. It being well known that the C. O. C. was practically flooded up to that time, it was deduced that no buoyancy was being gained or was going to be gained in the C. O. C., for all the air was escaping either through a broken hose or through possible damage over the conning tower.

No examination could be made, as the *Falcon* was not in diving position over the boat; to get her there would take several valuable hours from the afternoon; besides it was dangerous to bring the *Falcon* over the already buoyant stern of the *S-51*, not to mention the danger the diver ran of being caught on a rising boat.

Delay was undesirable in view of weather conditions.

A check of the situation showed a loss due to the C. O. C. of 60 tons; this loss was about equally divided between bow and stern due to the central position of the C. O. C. The stern could easily stand the loss; the bow could hardly afford it, but as even the bow still figured a small margin, it was decided to proceed. The use of the forward group of fuel-oil tanks with its 43 tons of buoyancy now began to appear necessary in spite of the possible danger of damaging the tank tops.

The C. O. C. was thus seen to be lost, but as it was isolated from the engine room abaft it, the latter compartment was in no way affected and there was then justified all the extra labor which had been expended by the divers in making each compartment a separate water-tight unit.

At 1.55 p. m. air was turned on both ends of the stern pair of pontoons and on the after ends only of the forward (No. 1) pair of pontoons.

At the same time, the pressure in both engine and motor rooms, which was equal to the bottom pressure, about 57 pounds, was reduced by opening their blowing hose vent valves on deck and allowing them to vent to the atmosphere until the pressure had dropped in them to about 35 pounds. The water could not reenter due to the nonreturn valve in the spill pipe in the engine-room salvage hatch. The reason for this reduction in internal pressure before raising the stern was that no salvage hatch had been fitted to the motor room. The regular hatch to that compartment was left in place and held down from the outside by an additional bolted strong back, but it was not desired to expose this hatch and strong back to any more internal pressure during the rise than was necessary, consequently the venting down before the rise.

At 2.06 p. m., after blowing the stern pontoons for only 11 minutes, a large mass of bubbles appeared at the stern; shortly after the stern pontoons broke through the surface, riding easily with over half their volume exposed. They were probably not over half buoyant when the stern started to rise. (See figs. 20 and 21.)

All air was immediately sent to the six forward pontoons, and blowing was continued on them as a group until at 2.45 p. m., when several air discharges at various spots forward showed that some of the pontoons were already dry. The pressure on the bow telltale hose had shown a slight increase as the bow sank in the mud when the stern rose, but it did not now show any tendency of the bow to lift.

At this time the *S–50* reported all the air in her high-pressure banks used up; she started up both her compressors, while the *S–3* maneuvered to come in alongside the *S–50* and run a high-pressure air line to her to help out. (See fig. 22.)

Meanwhile air was shut off all the six bow pontoons and then admitted to them through one hose at a time to test their condition. It was found that the No. 1 pair and the No. 3 pair were venting air from both forward and after ends and were consequently blown down to their limit. It was also found that the after ends of both pontoons in the No. 2 pair were venting air and were therefore also completely blown down. There remained only the forward ends of the No. 2 pair which were not yet blown dry; still it was recognized that even these must be nearly dry, as they had received about as much air as the other forward pontoons.

All air was now concentrated on the two hoses leading to the forward ends of the No. 2 pair. The situation was tense, as nearly an hour had gone by since the stern rose, and it was known to all the crew from the air just discharged over the bow that the pontoons there were apparently all dry.

Blowing was continued at reduced speed, since the *S–3* was not yet hooked up. The gauges on the lines to the forward ends of the No. 2 pair showed a steady increase in pressure in the pontoons; water was being forced out and no air was being discharged at the surface.

At this stage, at 3 p. m., it was noticed that the gauges on the No. 1 pair of pontoons, which had been steady for some time, suddenly dropped 4 pounds, and then continued to drop in pressure. A glance at the surface showed no indications whatever, but it was certain that the bow was rising and the men were so informed.

About 10 seconds later, the surface became turbulent over the entire length of the submarine and probably in 20 seconds more a number of geysers formed and the remaining six pontoons broke through the surface, floating practically level and spaced exactly as intended. (See fig. 23.)

On the surface, the six forward pontoons blew themselves clear of the residual water in their after compartments; no blowing from the *Falcon* was found necessary.

The air was put on the forward group of fuel-oil tanks at once and this group was soon blown clear.

Boats from the *Falcon* and *Vestal* ran alongside the pontoons and secured the flood valves and hoses for towing. The *S–50* and *S–3* shoved off and ran clear; the *Falcon* dropped astern of the *S–51* and took the stern towline from the *Iuka*. The *Iuka* steamed out and took station in tandem ahead of the *Sagamore*. (See fig. 24.)

At 4.20 p. m., the tow got under way headed northwest, as follows:

Iuka leading with a 100-fathom towline to *Sagamore; Sagamore* with 100 fathoms on each of the two forward lines attached to *S–51*, towing on the line shackled into the bullnose and with the line secured to the gun as a preventer; the *Falcon*, 150 feet astern of the *S–51*, with the *S–51's* stern line lead over the *Falcon's* bow to prevent the *Falcon* from dropping too far astern and parting the 20 hoses from compartments and pontoons which now all came aft from the *S–51* and ran over the *Falcon's* bow to the manifolds on the bridge. To tow the *Falcon*, an independent 10-inch manila line was run direct from the *Falcon's* bow past the port side of the submarine to the stern of the *Sagamore*. The *Falcon* was thus towed by the *Sagamore*, but was able to keep steady and close astern the *S–51* and to steer the submarine by the stern line to her.

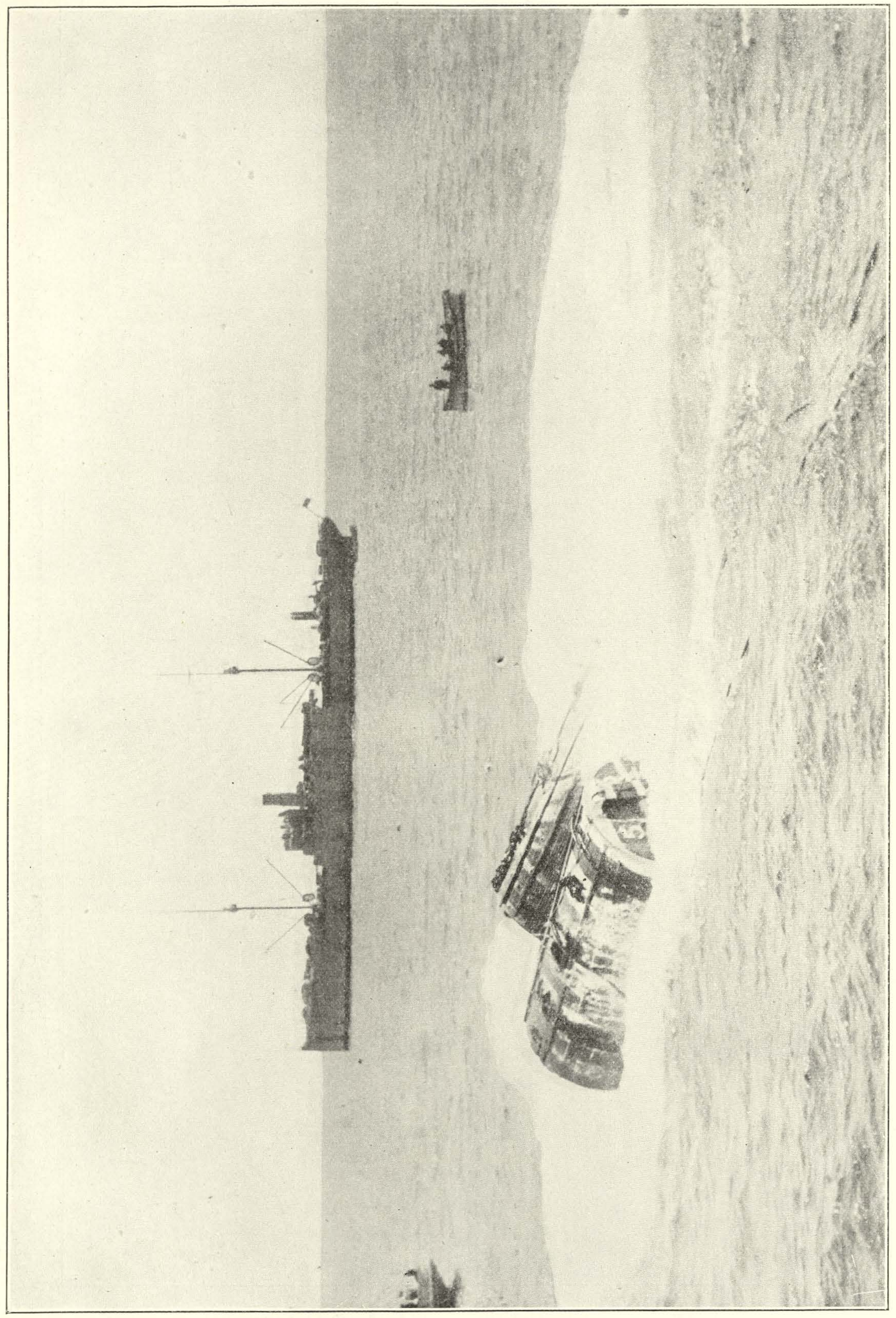


FIG. 20.—STERN PONTOONS BREAKING SURFACE. (NOTE ACTION OF AIR FROM PONTOONS)

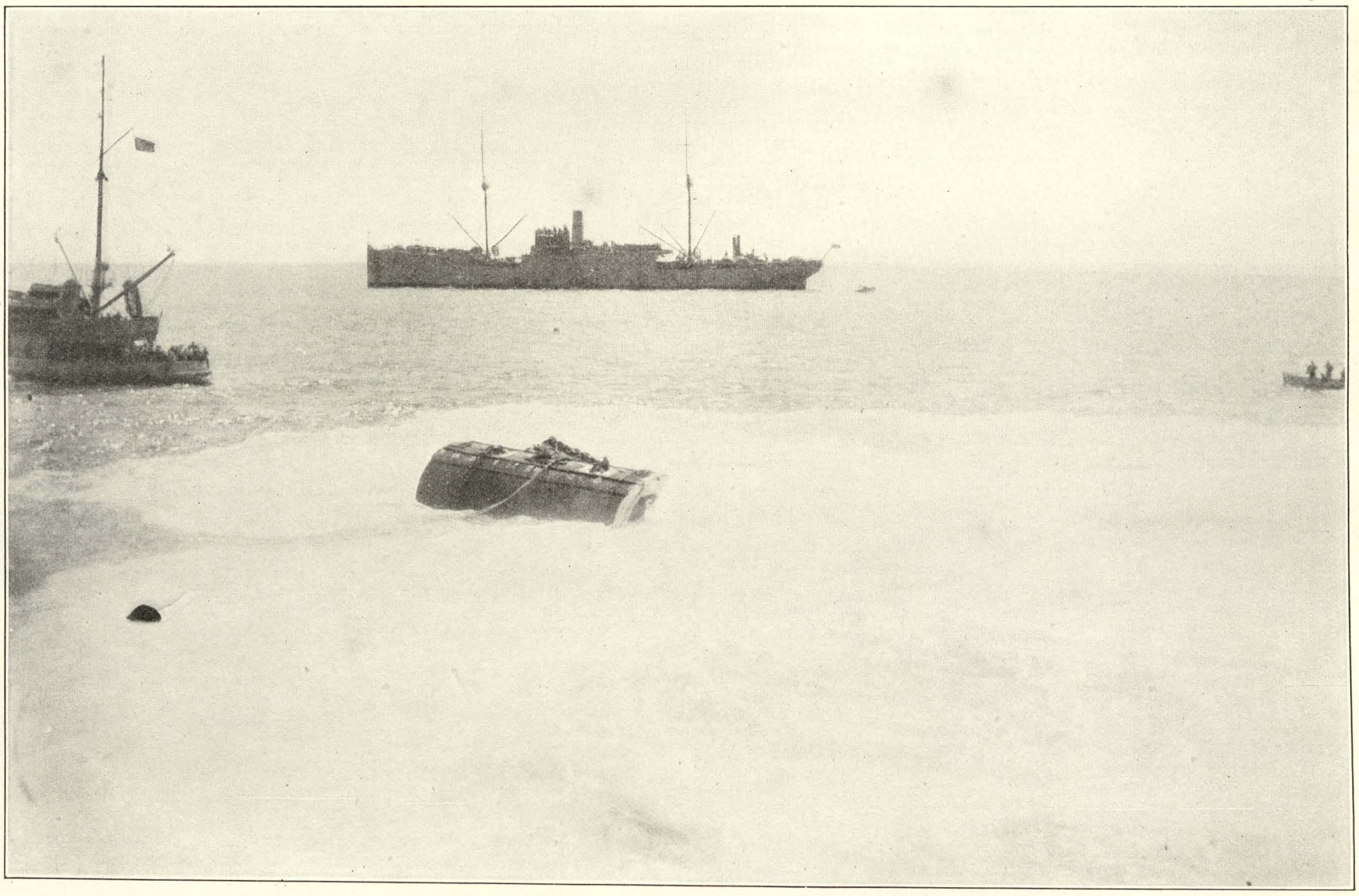


FIG. 21.—STERN PONTOONS BREAKING SURFACE. (NOTE ACTION OF AIR FROM PONTOONS)

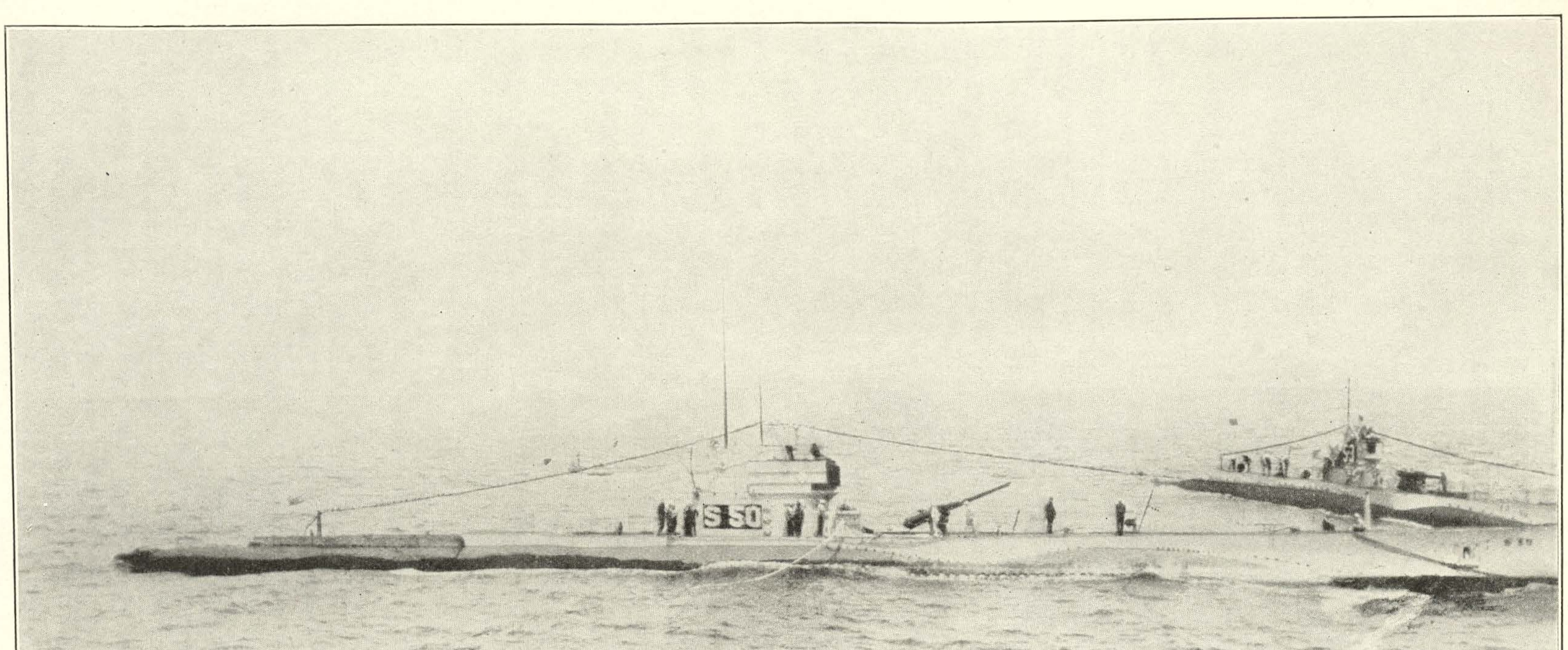


FIG. 22.—"S-50" SUPPLYING AIR TO "FALCON." "S-3" MANEUVERING ALONGSIDE "S-50." (NOTE 2½-INCH FIRE HOSE WHICH CARRIED AIR TO "FALCON")

The position of the *Falcon* was rather close to the *S-51;* this was required, as the *Falcon* was to be ready at all times to supply air to any compartment or pontoon which showed signs of leakage. For safety in this function, the hose leads were kept as short as possible and were so led as to avoid fouling between pontoons. Even with this close arrangement, the *Falcon* had 6,000 feet of air hose out to the *S-51*.

To avoid running up on the submarine, the *Falcon* did not steam ahead on her own engines, but permitted herself to be towed by the *Sagamore*, and for a considerable period in the early stages of the tow the *Falcon* kept her engines going at one-third astern.

The *Vestal* took station about 1,000 yards ahead of the *Iuka*, from which position she navigated for the squadron. (See fig. 25.)

The position of the pontoons during the tow is shown by Figure 26 and Plate 6. The stern pair of pontoons was farthest exposed, as was expected. The No. 1 and No. 3 pairs of pontoons were floating at about the water line designed, with slight cockbilling. The port pontoon of the No. 2 pair was just awash, while its mate was floating about one-fourth exposed. This relation was probably caused by the lashing wires for these two pontoons binding across the deck of the submarine and preventing the chains from rendering enough to equalize the submersion. All pontoons were seen to be exactly in the fore-and-aft alignment to which they had been set on the bottom.

The only part of the *S-51* which was clear of the water was her signal bridge over the conning tower; her No. 3 periscope which showed undamaged about 5 feet above the surface; and the stub of her mast which was exposed the same amount (the remainder of the mast had been removed as an obstruction during salvage work). The top of the periscope shears could be plainly seen about 6 inches below the surface, but nothing else was visible. From the periscope it was observed that the *S-51*, as slung between the pontoons, was floating with a steady list to starboard of about 10°. (See fig. 27.)

From the known lengths of the pontoon chains and the immersion of the pontoons at bow and stern the draft of the submarine was the same at both ends and was figured at about 32 feet. Taking account of the list of the *S-51*, this checked with the draft amidships as indicated by the top of the periscope shears, which point with the vessel erect was 33 feet above the keel.

This draft allowed a safe margin through all channels encountered and into the dry dock. A minimum depth of 35 feet was to be encountered above Hell Gate; the dry dock was stripped down to give the same clearance.

The first stage of the tow was on a course direct for Point Judith, to get over shoal water as soon as possible. An 8-mile run brought the tow to less than 100 feet depth. The speed at this time was slow, about 2 knots, later increased to 3, which brought the tow off Point Judith at dusk. The pontoons were riding with an easy undulating motion to a moderately choppy sea on the port bow, the submarine itself seemed steady, and everything was going well. There was no evidence of leakage anywhere, but it was decided as a precaution to keep the air going continuously on all pontoons and on all compartments with the idea of immediately expelling any water which might leak in before enough gathered anywhere to cause trouble.

As a further safeguard, the order was given before getting under way to close all flood valves on the pontoons. A check made after getting under way showed that the flood valve on the after end of No. 3 starboard pontoon turned freely but would not close; also, that as No. 2 port pontoon was awash the boat crew had not closed the valves on it.

This last condition was felt to be dangerous. If anything carried away the two air hoses to this pontoon, the pontoon would be entirely free to flood (which its awash condition would expedite) and such sinking would cause the loss of this pair of pontoons and possible disaster in the open sea.

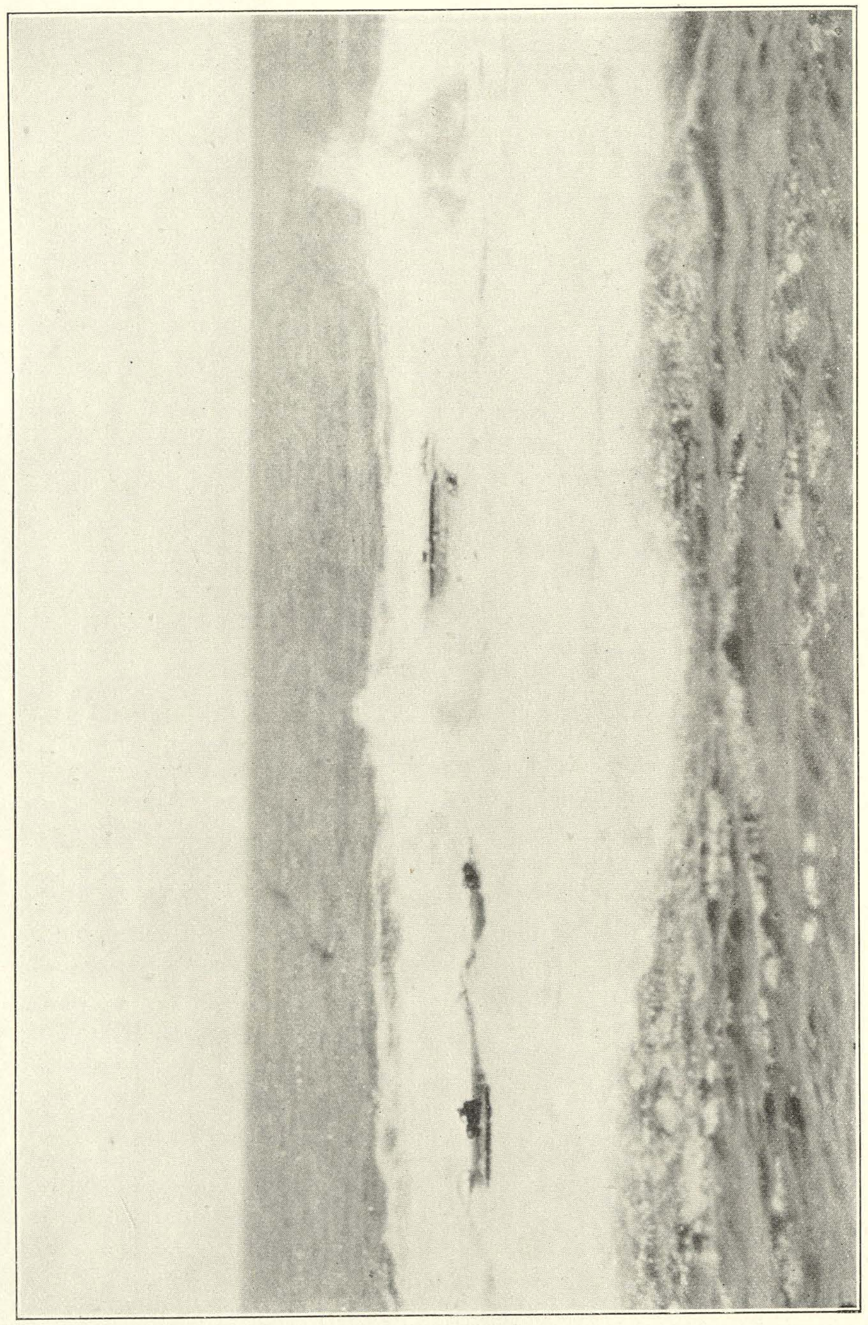


FIG. 23.—BOW PONTOONS BREAKING SURFACE

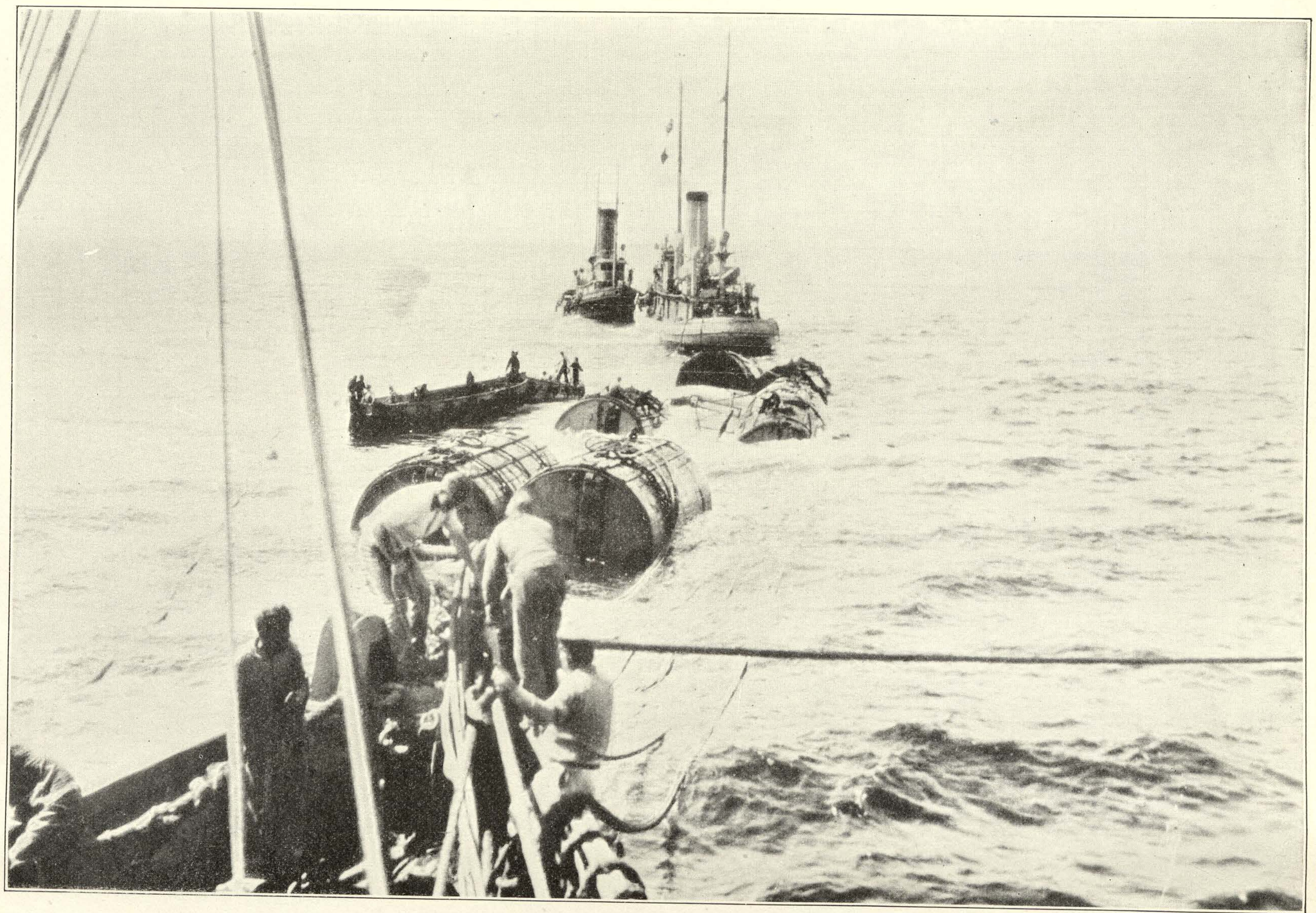


FIG. 24.—PREPARING TOW TO NEW YORK. "SAGAMORE" IN POSITION AHEAD OF "S–51" WITH "IUKA" AT HER BOW

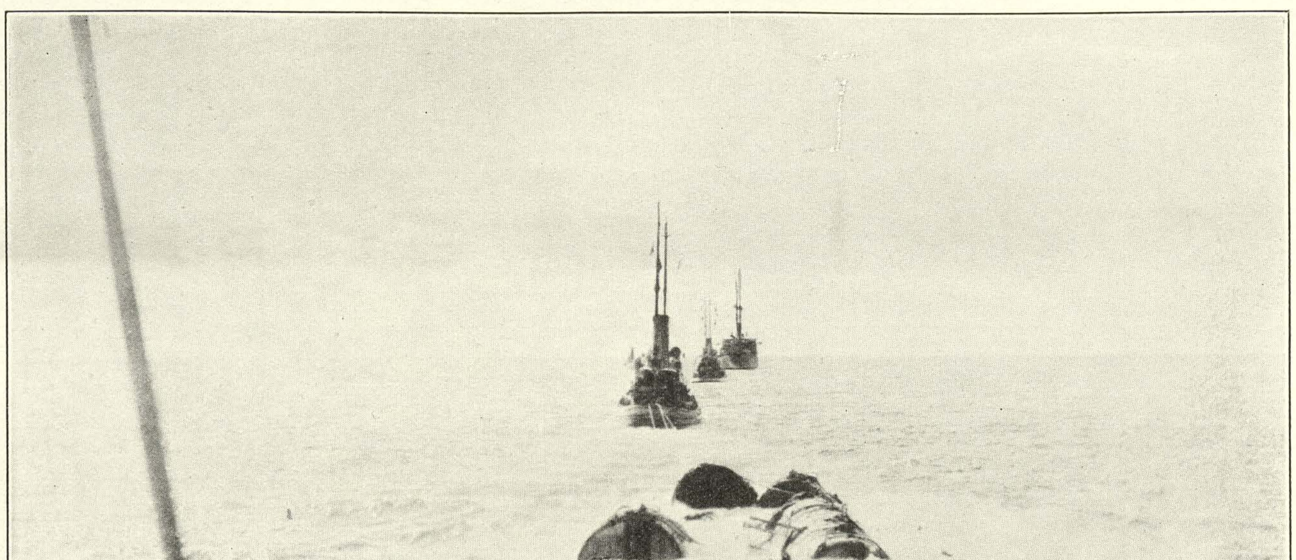


FIG. 25.—TOW UNDER WAY—"VESTAL" LEADING

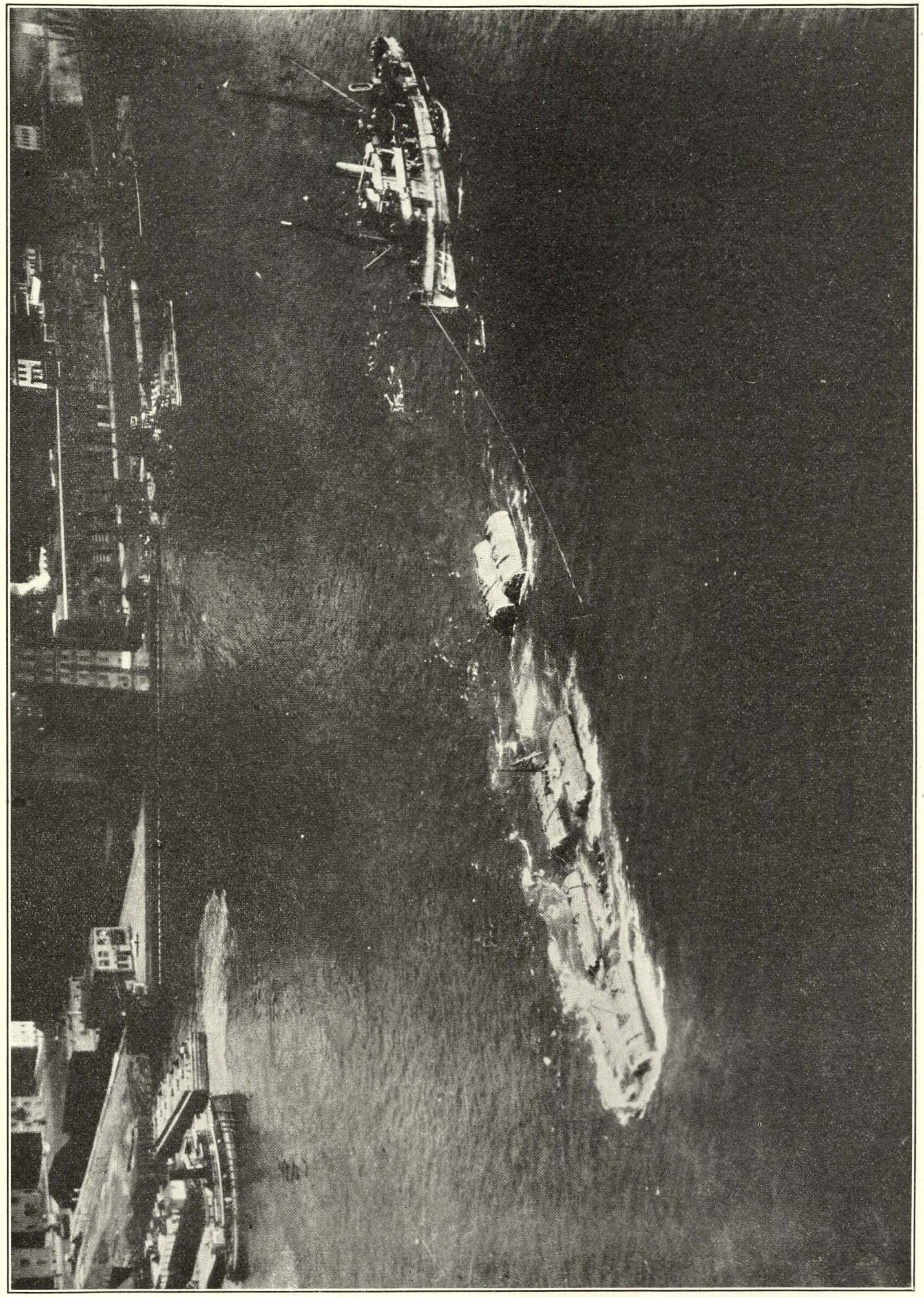


FIG. 26.—ARRANGEMENT OF PONTOONS

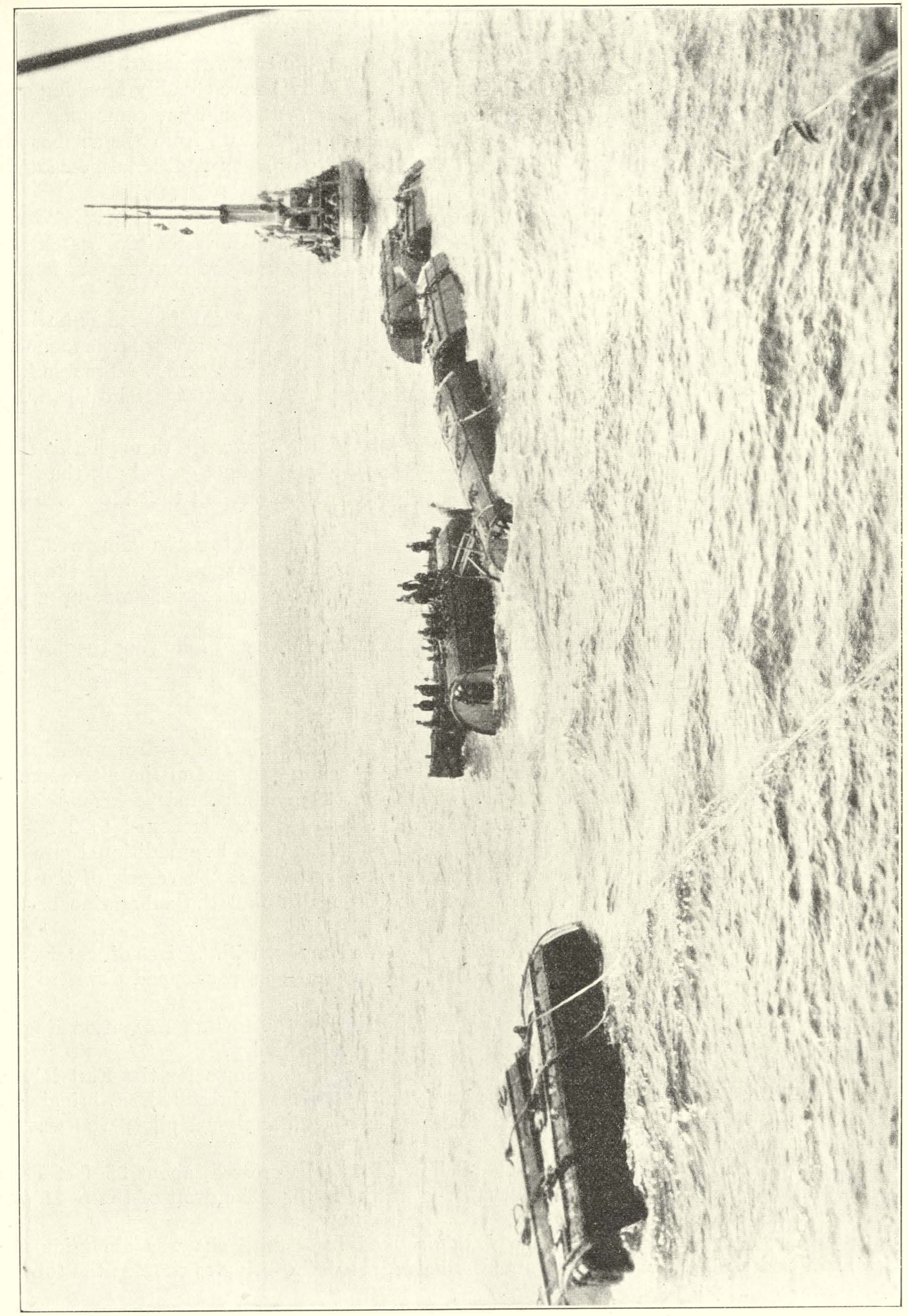


FIG. 27.—"S-51" AFLOAT ON PONTOONS. (NOTE TOP OF PERISCOPE SHEARS AND ANGLE OF HEEL)

When the condition of No. 2 port pontoon was reported, the tow was halted for about an hour and the surfboat sent out to close the flood valves. The seas were steadily breaking over this awash pontoon, which made work on it dangerous. The boat could not come alongside, but one by one Wickwire, Hawes, Lieutenant Kelly, and Schissel swam from the surfboat to the pontoon and finally succeeded in shutting off the flood valves; as an additional precaution, the blow valves were also closed.

About 9 p. m. the course was changed to west, keeping inside the 10-fathom curve, and the tow steamed on through the darkness, speed somewhat over 3 knots. A careful watch was kept on the pontoons, illuminated by the *Falcon's* searchlights, and the compressors kept a steady stream of air going to the submarine.

Off Westerly, R. I., near midnight, a strong adverse tide was met and for nearly an hour the tow made no progress over the ground. After getting clear there, progress was smooth and the speed so set as to pass the first danger point, the Race, at slack water. Trouble here was especially not desired, as the deepest water on the journey, about 300 feet in depth, lay in the Race.

The *Vestal's* navigation was accurate, and about 4 a. m. the tow went through this spot at dead slack water, meeting no currents at all. When daybreak came, on July 6, the *S–51* was safely inside the sheltered waters of Long Island Sound and it was felt that the worst was over.

No further adverse tides of any strength were encountered. The tow was going well, and there was not the slightest sign of deeper immersion on any of the pontoons. On the contrary, by careful blowing a little more water was expelled, and the submarine came up a few inches higher.

Under these circumstances there no longer appeared any necessity of following the devious course along the north shore necessary to keep inside the 10-fathom curve, and a straight course was laid through the sound for Execution Rocks.

In smooth water, with no swells to cause motion of the pontoons, the *Iuka* and the *Sagamore* worked up to full power, and the *Falcon* went slow ahead. The tow soon reached a speed of 5 knots, which was maintained throughout the morning and part of the afternoon.

By late afternoon it was seen that the tow was making such unexpected progress that it would arrive too early at Execution Rocks. To avoid this speed was slackened to 2 knots, and for a while the tow steamed in a circle of about 2 miles radius to lose additional ground. It did not appear safe to stop or to anchor, as there was danger that the vessels of the tow would become tangled up, and especially that the *Falcon* might foul the submarine or the numerous hoses leading from it.

The navy yard, New York, reported No. 4 dry dock all ready, with 35 feet of water over the sill and about another foot over the blocks. The dock had been stripped down to the bearers to get the maximum draft possible.

A request was made of the yard to furnish a pilot to meet the tow off Execution Rocks, together with two yard tugs to assist in steering the *Falcon* if necessary.

Late in the evening the tow ceased circling and resumed its course for the East River. Off Hempstead, somewhat after midnight, the two yard tugs joined the squadron, bringing a civilian pilot from the East River Pilots' Association; also the navy-yard pilot, who was to handle the tow on entering the yard basin.

In the early morning of July 7 the most shallow spot to be crossed, about 35 feet deep below Execution Rocks, was passed without stirring up the mud. The draft of the *S–51* was between 32 and 33 feet.

Having cleared Execution Rocks, the *Iuka* dropped back until she was alongside the *Sagamore*, and tied up to the *Sagamore's* starboard side, the desire being to shorten the towing procession as much as possible. (See fig. 28.)

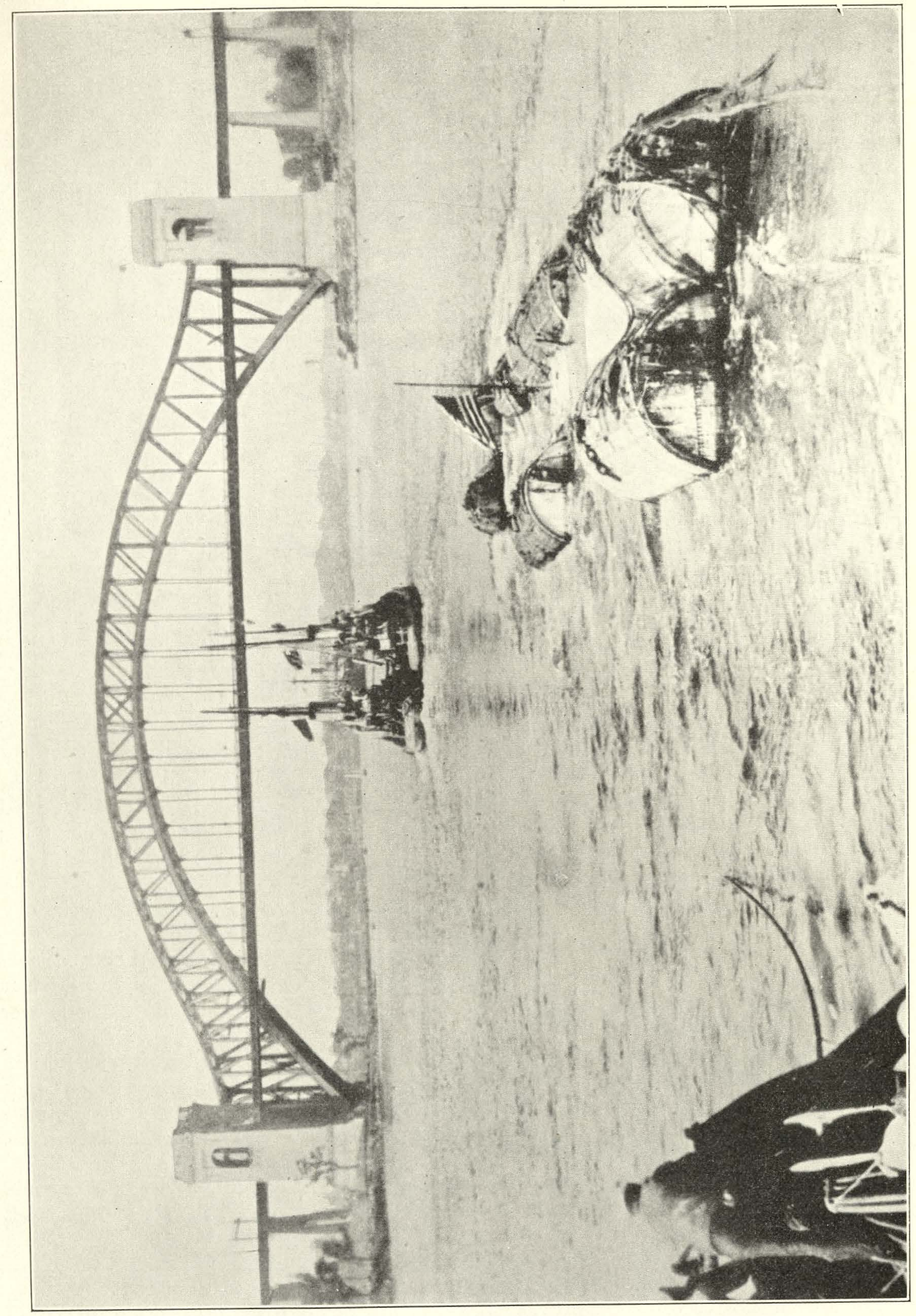


Fig. 28.—Tow approaching Hell Gate. "Iuka" alongside "Sagamore"

The civilian pilot took station on the *Sagamore* the officer in charge; and the salvage officer stayed on the *Falcon* as being closer to the *S–51*. The course expected was down the west side of the river on the Manhattan side, where 40 to 50 feet of water existed all the way.

As expected, the tow reached Hell Gate at high water slack and passed through with no difficulty, everything steering perfectly. The *S–51* kept a little to starboard of the line between *Sagamore* and *Falcon*, as the *S–51's* rudder was set at "hard right," the position it had when the ship sank. (See fig. 28.)

The tow now passed down the East River on the top of the morning high tide, passed to the westward of Blackwells Island, and was practically on its last mile with the entrance to the navy yard in sight, when it was observed that instead of following the *Vestal* the *Iuka* and the *Sagamore* were swinging off strongly to port, taking the *S–51* and the *Falcon* with them. Before the meaning or the reason for this unexpected maneuver could be learned there came a sudden bobbing of the pontoons at the bow of the *S–51*, the No. 2 pair, which was nearly awash, floated up completely light, and the *Falcon* found herself rapidly closing on the stern of the submarine. (Fig. 29.)

With but a few seconds available for action before ramming the *S–51*, the *Falcon* went full speed astern and put her rudder hard left. She just cleared the *S–51's* port quarter and reduced the collision to a minor impact with the No. 3 port pontoon abreast the conning tower. Here the *Falcon* stopped, having missed the important buoyant stern compartments and having avoided carrying away all the blowing hoses.

The *Falcon* and the *S–51*, which had been headed downstream, now started to swing to an ebbing tide and in a minute or two came to rest headed nearly upstream.

Meanwhile the *Iuka* and *Sagamore* had stopped, the towline to the submarine having come slack and the preventer towline to the submarine together with the line to the *Falcon* having been cut in the emergency by the *Sagamore*.

The cause of this occurrence was not at first grasped by the salvage officers. Knowing that a deep, broad channel existed for the pilot to follow, it did not occur to them than the *S–51* had grounded. Wild as the idea seemed, and with no reason for believing it probable, it was thought at first that the *S–51* had broken in two forward, thus releasing the No. 2 pair of pontoons and stopping the tow. But a hasty examination from the surfboat showed the submarine intact; in spite of having swung nearly 180° since grounding, the three pairs of pontoons still left lined up in a perfectly straight line which was impossible with the submarine in two pieces.

The next surmise was that *S–51* had hit a submerged wreck; this was being checked by soundings, when a fix obtained on the *Falcon's* bridge and plotted on the chart disclosed that the pilot had left the main channel to try to pass through a narrow side channel between two reefs, had misjudged his distances and the tide, and had run the *S–51* aground on Man-of-War Rock at practically the top of the high tide. The bow of the *S–51* was found to be in a little over 24 feet of water.

The tide had now turned and was starting to run a strong ebb. The two freed pontoons were tugging on their hose lines and were foul of the hoses to the No. 1 pair. The surfboat crew cast loose the hoses on the No. 2 pair and cleared the other hoses, the *Iuka* towed the two pontoons to the near-by navy yard, where the chains were found to have parted under the submarine, cut in half on the reef.

The air was kept going on all compartments and the remaining pontoons—so far as could be seen the interior compartments were still undamaged and buoyant and the six pontoons left seemed firmly attached.

A hasty estimate was made of the situation. Up to the moment of grounding, the No. 2 pair of pontoons showed by their immersion that they were exerting a net lift of about 120 tons, which was now lost. A check on the previous reserve buoyancy of the No. 1 pair and the No. 3

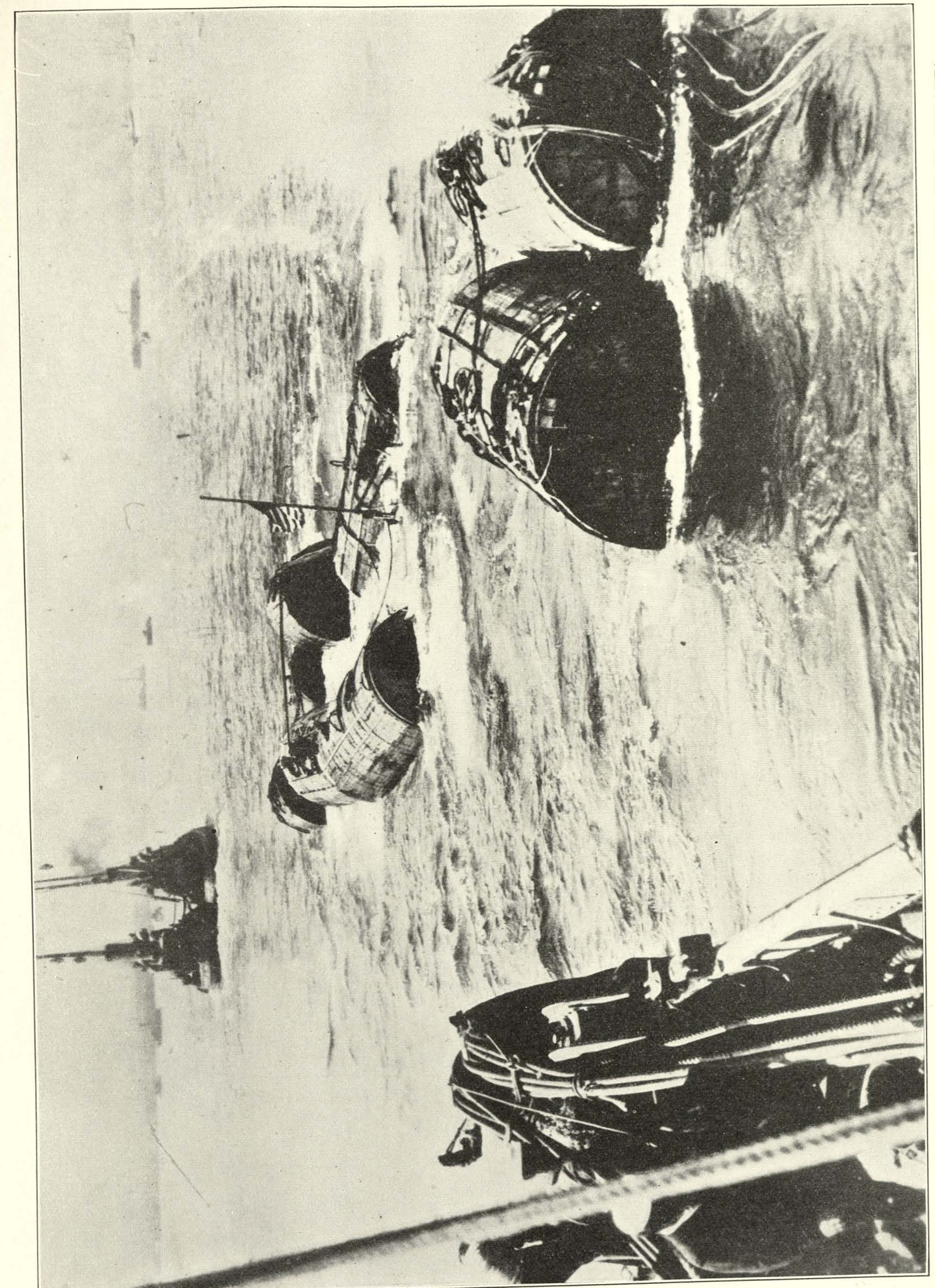


FIG. 29.—AT THE INSTANT OF GROUNDING ON MAN-OF-WAR ROCK. (NOTE NO. 2 PAIR OF PONTOONS RISING AND DRIFTING TO STARBOARD)

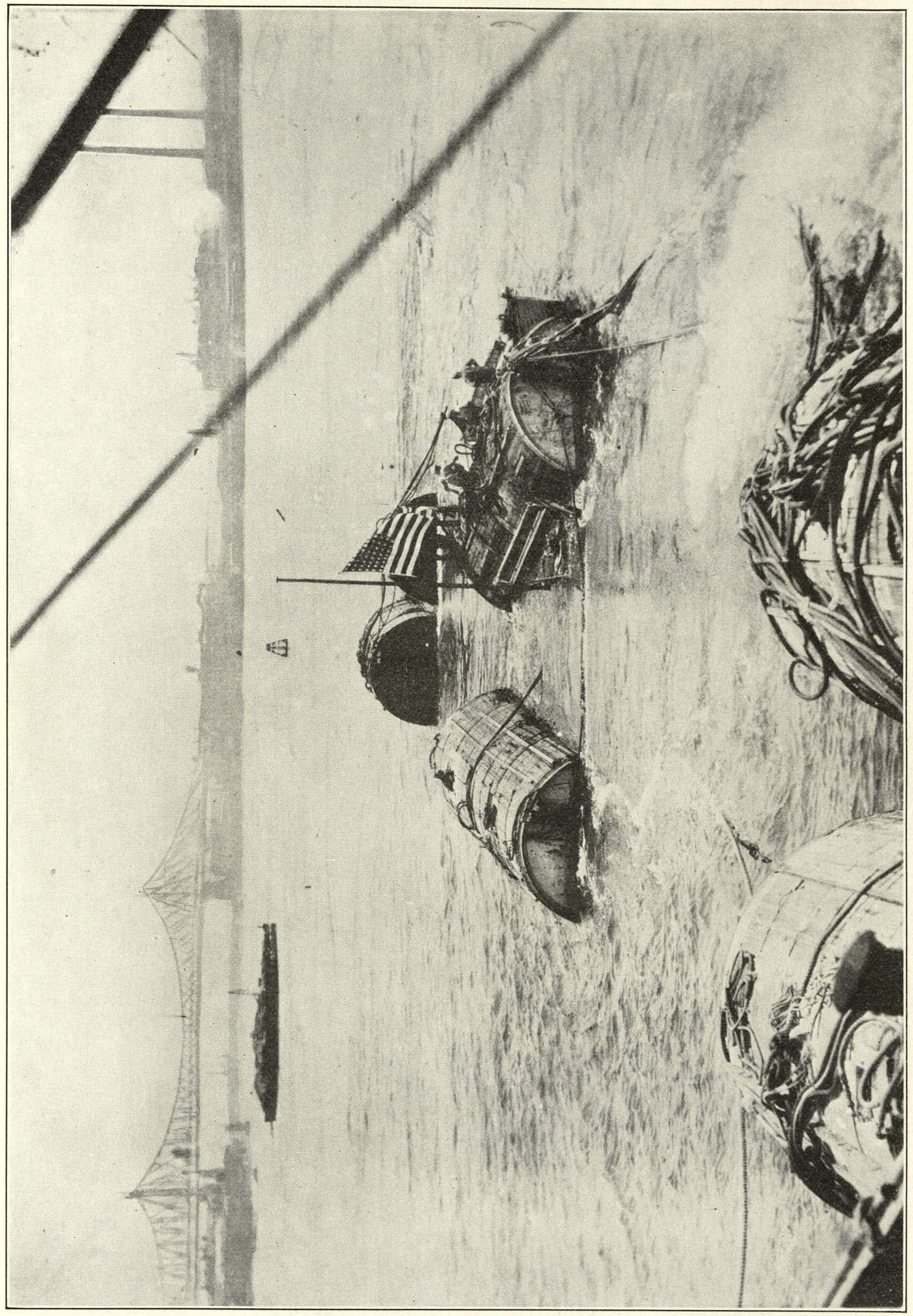


FIG. 30.—"S-51" ON MAN-OF-WAR ROCK. CLEARING HOSES IN PREPARATION OF LOWERING PONTOONS

pair showed a reserve in those two pairs of slightly more than this. If this reserve could be brought into action it would overbalance the lost buoyancy and would maintain at least as high a forward moment, as the No. 2 pair had been located exactly between the No. 1 and No. 3 pairs. (See fig. 30.)

To obtain this reserve, it was required that the four remaining forward pontoons be resecured just awash; if they could in addition be secured any lower than that, the bow might be lifted higher than ever to assist in floating it clear.

To carry out this plan, the yard was ordered to send out a 75-ton derrick with additional tugs and a rigging gang. Also, in case diving was necessary, the yard diving launch was sent for.

In case it turned out that extensive wrecking operations were necessary (it was estimated that two weeks might be required), the *Falcon* could not continue to hang on to the *S–51* as an anchor, and something was required to hold her in the tide. All her own moorings being still off Block Island, the Army engineer who had charge of East River dredging (and who had come aboard) very kindly provided two heavy anchors, chains, and buoys, which were given to one of the light yard derricks for planting up and down stream. The Army representatives also carefully plotted the position of the *S–51* with reference to their known soundings on Man-of-War Reef. These showed rocks upstream, on the Brooklyn side, and downstream. The bow of the *S–51* was pocketed, with clear water only on the side toward Manhattan.

Meanwhile the tide was running out strongly, certainly over 5 knots at that point, and it was plain that no diving was ever going to be possible there except for brief periods at slack water.

As the tide dropped, the No. 1 pair of pontoons floated higher and higher above the water, until they were taking very little load; to a lesser extent this was noted on the No. 3 pair; the stern pair floated unchanged. The reef forward was taking the weight off the bow pontoons, and as the tide dropped the *S–51* heeled more and more to starboard until it lay over at least 20°.

The diving launch arrived first. It was moored over the location of the lost pair of pontoons with the intention of examining the damage to the ship and the exact position of the *S–51* with reference to the reef; it was further intended to run new reeving lines under here in case it was possible to get them by the rocks. This last was for the purpose of running a new set of chains and resecuring the missing pontoons if that proved necessary to lift the bow clear.

About this time the first derrick, of 25-ton capacity, arrived from the navy yard. The tide had dropped over 3 feet and the bow pontoons were well out of water, neither one of them was taking as much as a 25-ton strain. The derrick was brought by two tugs, headed somewhat across the current against the No. 1 starboard pontoon, and held there by the tugs.

By slacking away the boom, it was able nearly to plumb the port No. 1 pontoon. A pair of wire slings, suspended from the boom, were shackled to the ends of the chains showing through the port pontoon hawse pipes. The derrick then took its maximum strain, the flood valves on the port pontoon were opened, and the air was vented from the pontoon to sink it. Very shortly the toggle bars on the hawse pipes came slack in the chains and were withdrawn. The pontoon was flooded down until it was awash, when the studs were burned out of the links in the chain just above the hawse pipes, the toggle bars were inserted in the new locations and the locking pins put back. A slight amount of air was blown into the pontoon until it came up hard against the toggle bars, when the derrick slacked away and cast loose the slings which were immediately secured to the chains on the starboard No. 1 pontoon. (See fig. 31.)

Low-water slack came at this point in the early afternoon. The divers prepared to go down when the tide turned and the *Falcon*, *S–51*, and the derrick all started to swing upstream to the

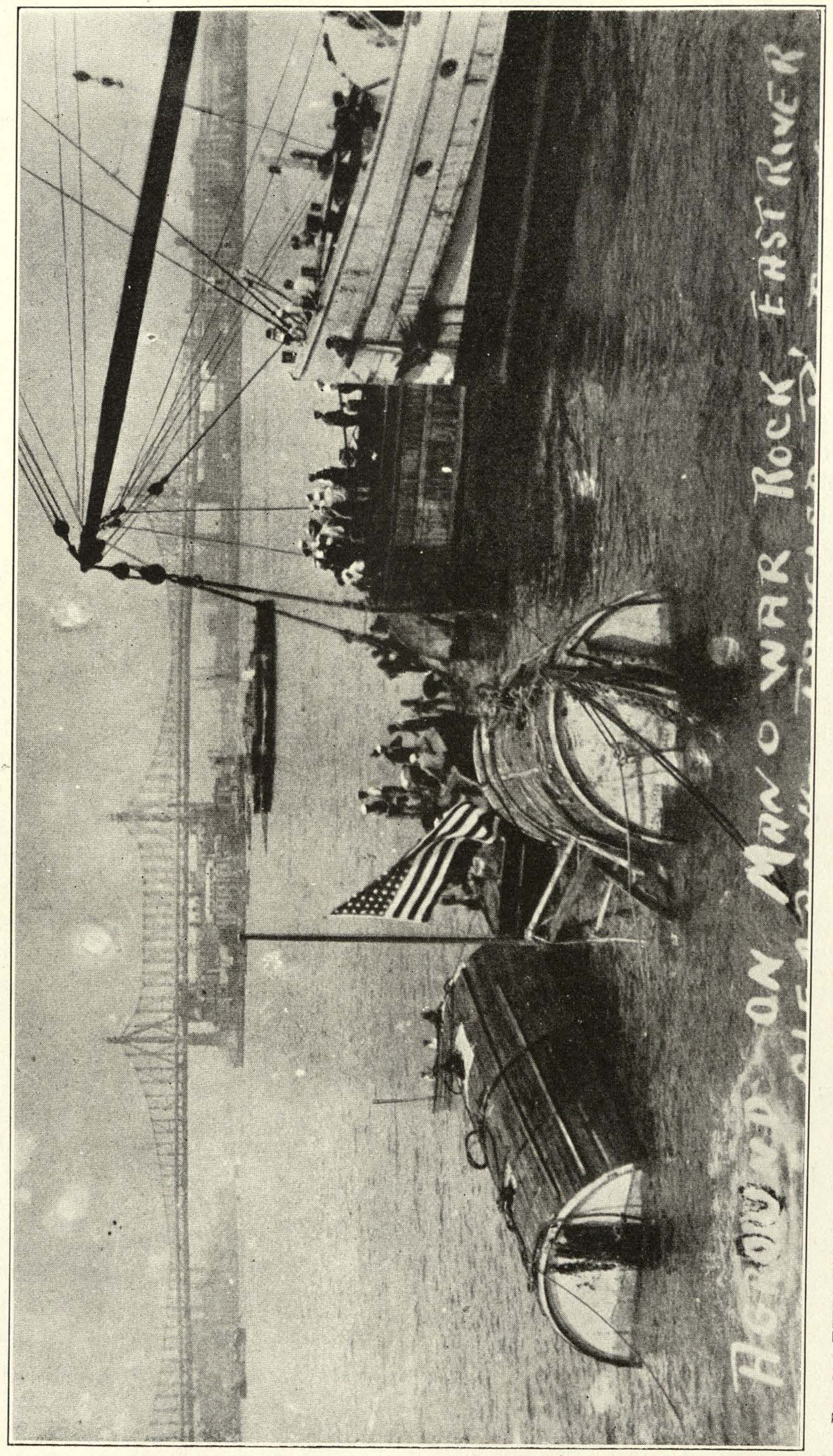


FIG. 31.—TWENTY-FIVE-TON DERRICK TAKING MAXIMUM STRAIN ON CHAINS OF PORT PONTOON. PONTOON BELOW SURFACE AND DIVING BOAT IN POSITION FOR INSPECTION OF BOTTOM

flood tide, with everything pivoting about the bow of the *S–51* as the center of rotation. The *S–51* came to rest, headed generally downstream, but about 45° with the direction of the main channel.

Two divers now went down for an examination. They found that from about frame 50 aft, the *S–51* was entirely clear of the reef; that she was resting on a shelf under her keel from this point for some distance forward, and that on her port side she was resting against a huge bowlder about 8 feet higher than the keel, which was apparently what was preventing a complete swing upstream. The *S–51* was lying well over on her starboard side, with her bilge keel on the rocks.

The divers thought it possible to get reeving lines under and an attempt was made. Using a 6-foot pine plank about 4 inches wide as a batten, with a 21-thread manila reeving line attached to it, the diver (Eadie) shoved it under the keel to upstream side, the idea being that the flood tide, which was now running strong, would carry the batten through. Eadie fed through over 100 feet of line which the current took, but so powerful was the tide that the line was apparently carried out straight beneath the surface and the batten did not show. By using a grappling hook from the surfboat and dragging on the upstream side, the line was soon hooked and the batten brought up. One reeving line was thus rendered through and the ends secured to the No. 3 pair of pontoons, but the current was now so strong that no more divers could work and no attempt was made to run the second reeving line then. The outside diving time appeared to be 40 minutes while the tide was turning; even the latter part of this period, the current was so swift that Eadie reported that to get to the bottom he had to haul himself down the descending line.

While the divers were working on the reeving line the derrick was holding up the chains to the starboard No. 1 pontoon, and this pontoon was flooded down for resecuring. A great deal of trouble was encountered here, for the tide, acting on the derrick and the pontoon, carried the pontoon over the top of the submarine, where it rested on the deck and would not sink far enough. Finally, with three tugs on the derrick steaming full speed against the current, the pontoon was dragged off clear to the starboard side, where it was sunk until it was awash and the toggle bars resecured.

As both of the pontoons of the bow pair had been sunk at low tide, there was gained at this point not only all the reserve buoyancy of the No. 1 pair, but also an added lift to reduce the draft at the bow, which was practically equal to the tidal range—about 4 feet.

The derrick now let go the slings to the starboard bow pontoon and endeavored to get clear; the three tugs had a struggle, as the tide swung them into the other pontoons, and managed just to drag the derrick clear, but at the expense of an 8-inch line from the *Falcon* to a downstream tug, which line had hastily to be cut to let the derrick pass astern.

It was now mid-afternoon and the tide was coming up. The 25-ton derrick had only barely been able to handle the chains on the light bow pontoons; for the midship pair it was inadequate and was sent away to anchor.

The tugs brought the much heavier 75-ton derrick into position against the port side amidships, where they held it stemming the tide, with the port No. 3 pontoon under its bow. Here the chains from the port pontoon were secured to the boom of the derrick, using a 1½-inch wire pennant on each chain. The derrick now took a strain, estimated at about 50 tons, which caused the toggle bars to come slack shortly after flooding commenced.

As this pair of pontoons happened to be the ex-*F–4* pair of 80-ton pontoons, with smaller flooding and venting valves than the pontoons built at New York, flooding was much slower. As the day was passing and the tide rising, expedition was essential. To facilitate flooding, the ¾-inch vent and flood valves on top were unscrewed to permit the air to escape faster. The pontoon was at this period about 3 feet out of water, with the toggle bars still in the chains but several feet above the tops of the hawse pipes. It was intended to put the valves back when only about 1 foot of the pontoon showed above the surface.

Three people were on the pontoon under the overhang of the derrick's bow, the salvage officer and two members of the *Falcon's* crew, Badders and Schissel.

At this instant, without warning and, so far as could be seen, without reason, the wire slings both parted, the released chains came down, bringing the toggle bars with a crash on top of the hawse pipes of the pontoon, which promptly submerged and disappeared under the bow of the derrick; the bow of the derrick, with its strain suddenly released, jumped several feet in the air, and the starboard No. 3 pontoon floated up entirely light. Relieved of this support against the starboard side of the conning tower, the submarine, which was already badly listed to starboard, now rolled farther so that the periscope and all parts of the signal bridge, which had before been visible, disappeared completely from view. The submarine was thought to have rolled over completely. With the support of the No. 3 pair of pontoons now gone, an added load was thrown on the stern pair of pontoons, which sank about 4 feet deeper in the water. Fortunately the reserve in this pair of pontoons was large, and this added load did not wholly submerge them; if it had, the stern of the submarine would, of course, then have gone to the bottom and the wrecking operation would have become more complicated.

The three men on the pontoon found themselves partly submerged; the pontoon came to a stop about 3 to 4 feet under water, and then the forward end of it floated up until it was about 1 foot clear of the surface; the after end stayed submerged and the water covered the pontoon nearly to the forward hawse pipe. A brief glance showed that the toggle bar in the forward hawse pipe was gone and there was no chain in sight in it (the derrick crew claimed this toggle bar broke in half under the impact). The pontoon was in a precarious position, with its four top valves removed and three of the holes submerged; it was free to fill and sink (it had no great amount of buoyancy left then anyway) and if it did without having two chains secured to it and with no valves or air hoses attached, it was questionable what could be done to it by divers in that tide. Action was taken instinctively—the three men on the pontoon promptly shoved their thumbs into the three submerged vent-valve openings to prevent the escape of air and stop further flooding, and the derrick crew were ordered to make some ¾-inch wood plugs immediately. The man plugging the hole at the low end could barely keep his face above water; the other two were better fixed. The first wood plug was driven into the low end hole by Schissel, who stayed under water a considerable period to accomplish it; the two middle holes were easily sealed temporarily and then the valves were resecured to them and the air hoses coupled up.

The pontoon was now inspected. The after end chain appeared all right, with its toggle bar resting across the hawse pipe; the forward end hawse pipe was just out of water, the toggle bar was missing, and the end of the chain could be felt about 4 feet down the hawse pipe, where it was hanging on two parts of a 6-inch manila line which had fortunately been secured as a preventer to the end of the chain when the derrick took its first strain. (It was an invariable rule of the salvage operation from the beginning to put a preventer line on everything wherever it was possible.)

The preventer line was cautiously tested and it was found that only the weight of the chain itself was on it (the chain was slack under the submarine). It was carefully worked up until the eye of the 1½-inch wire came out (the wire had parted just above the eye splice), when a heavier line was secured to the eye. The chain was then worked up on these lines until it showed above the hawse pipe, when a new toggle bar was inserted in it and secured, which occasioned considerable relief.

The mate pontoon was now flooded down until the port pontoon floated just awash, when all valves were properly replaced. The port pontoon was then in satisfactory awash position, and work was started to sink its mate, the starboard No. 3.

An inspection between the pontoons showed that the position of the submarine was not as bad as had first appeared when the slings let go. The remains of the periscope could still be seen a foot under water, its angle indicated that the ship was lying over from 30° to 40° to starboard.

Using a new pair of 1½-inch wire pennants, doubled this time, though there was now practically no strain on the chains, the derrick took a lift on the chains and held them while the starboard pontoon was sunk. As an added precaution, an extra toggle bar was secured, and as the chain links came clear of the hawse pipes one at a time, the studs were burned out and a new toggle inserted before the existing toggle was removed; in this way a toggle bar was kept close to the hawse pipe at all times while the pontoon sank.

The pontoon had to be kept well to starboard to clear the bridge as it went down. This was possible, as high-water slack was approaching and the current was easing off.

The resecuring of the starboard No. 3 pontoon was finished as darkness came on, and the derrick was taken away. The bow pair of pontoons had for some time completely disappeared below the rising tide (fig. 32); the middle pair of pontoons was also completely covered as the tide reached its maximum.

Preparations were now rapidly made for attempting to get free. The *Sagamore* was anchored on the Manhattan side of the river and a line run to her from the *Falcon;* the wreck was starting to swing and was lying then practically athwart the stream; it would have swung downstream if not for this support.

The *Falcon* was astern of the *S-51*, headed in the same direction (toward the Brooklyn side) with only the original stern line secured to her, this line leading over the *Falcon's* bow It consisted of a 1½-inch chain bridle completely encircling the *S-51's* stern inboard of the shafts, with 150 feet of 1¾-inch wire shackled to the bridle and lead to the *Falcon*, where the end was secured.

Both bow lines to the submarine had either been cut or carried away on first grounding.

The *Iuka* was secured to the *Falcon's* starboard side, headed opposite to her and two yard tugs were secured to the *Falcon's* port side, also heading in the opposite direction.

At 9.30 p. m., everything was secured, the tide was up, and had started to ebb. All vessels were ordered to stand by, and the air was turned on the pontoons. As the pressure required was low, compared to that needed off Block Island, this operation was much more rapid.

In a few minutes the stern pair of pontoons (which were not being blown) started to rise farther out of water, and very shortly the No. 3 pair showed slightly above water and then vented all around, showing themselves dry. All air and the searchlights were turned on the bow pair; these soon vented all around and then rose until the starboard bow pontoon barely showed above water; the port bow pontoon, although dry, remained completely covered.

All indications were that the bow had been lifted at least 4 feet and was off the rocks.

On signal the *Sagamore* heaved on her line, the *Falcon* went astern on her engine, the other tugs started ahead, and the wreck moved with no apparent strain.

The line to the *Sagamore* was let go, and, guided by the other tugs, the tow started downstream after getting well over to the Manhattan side; the *Falcon* and the *S-51* were now towing stern first, but the other vessels were headed in the direction of motion. The *Sagamore* up anchored and took station ahead with a line to the *Falcon's* stern.

By now the current was strongly ebbing; the make-up of the tow was not wholly ideal. The *S-51* was going backward, drawn by the line to the *Falcon*, but there was no line on the

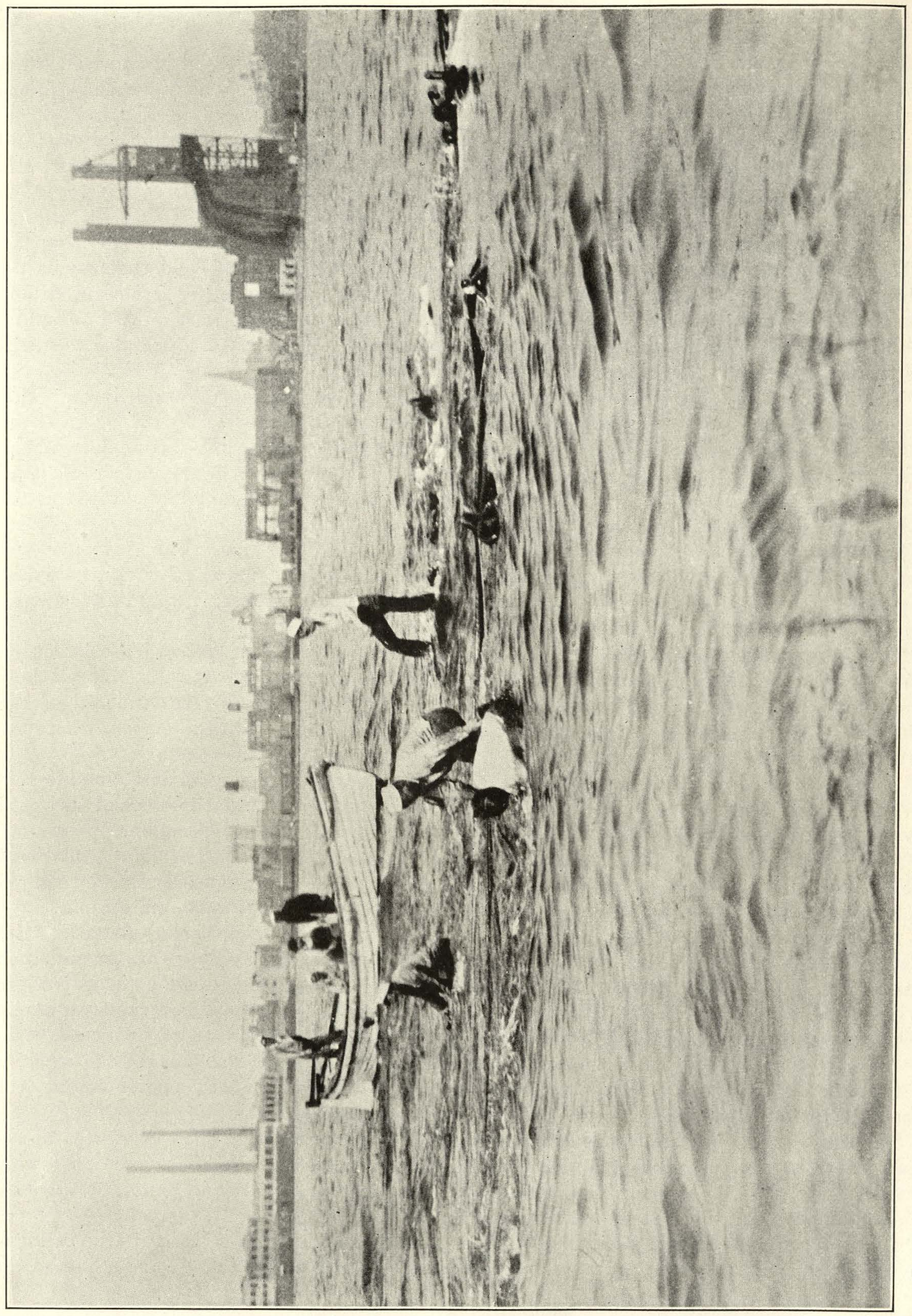


Fig. 32.—Bow pontoons below the surface at Man-of-War Rock. Crew opening valves

submarine's bow nor any vessel there to guide that end and hold it in position. The general situation at Man-of-War Rock and the lack of time prevented any other arrangement; the tow had to be taken as it was.

Below the Williamsburg Bridge the tow worked over to the Brooklyn side and made a turn to the left to enter the navy-yard basin. Here the strong tide caught the *S–51* and *Falcon* broadside and swung them downstream; to avoid fouling her propeller the *Falcon* had to cut loose the line to the *Sagamore*.

The current swept the tow downstream below the navy yard, swinging it around meanwhile, and by the time the tow had stopped swinging and was once more headed toward the yard it was half a mile below the yard and losing ground against the tide.

At this stage the *Falcon* was going full speed astern and the three other tugs full speed ahead; in spite of this the whole tow was still gradually drifting down the river, and the solitary line to the *S–51* was under a terrific strain. The reserve buoyancy of the *S–51* was now negligible; if the towline parted, the air hoses would all be carried away and the submarine would sink in a very few minutes—much before anything could be done.

Fortunately, while intended only for a stern guide line, the possibility of having to tow by it had been kept in mind when the stern line was designed; it was adequate to the occasion and had been well secured by the divers while on the bottom off Block Island.

Now for an hour it took the full strain of four heaving vessels while they battled to hold their own against the tide; the *Sagamore* at last got another line to the *Falcon's* stern and threw her power into the struggle; the drifting stopped and almost by inches the tow moved up the river and finally fought its way into the quiet waters of the navy-yard basin. Here the *S–51* was tied to one of the piers, the *Falcon* close by, pumping air continuously.

The reserve buoyancy forward, about 180 tons on leaving Block Island, was now less than 14 tons, the submarine was rolled far over to starboard, her bow had been torn off by the towline shackled into it when she suddenly stopped on hitting the rocks, and the light bridge structure had been smashed by the heavy roll to starboard against the starboard No. 3 pontoon.

It was 11 p. m. when the *S–51* at last came into the yard, and it was the earnest desire of the salvage crew to run her into the dry dock before anything more happened, but the docking crew had long since been dismissed, as no hope was felt in the yard that the *S–51* could be brought in in the near future. Even then the salvage crew would have docked the ship themselves, but the tide had dropped so far since high water at 9 p. m. that with her 33-foot draft aft the *S–51* was hardly likely to drag across the sill.

Nothing could be done except to keep on pumping air through the night and wait for the next high tide.

The morning of July 8 the submarine was found in the same condition as the night before, barely afloat forward. The starboard list was not quite as bad as when last seen on the reef, for the starboard No. 3 pontoon was again bearing against the conning tower and had reduced the list to between 20° and 30°.

The submarine was swung and headed for the dry-dock entrance. A number of air lines were prepared on the dock to couple up in place of the *Falcon's* hoses, and when all was ready the *Falcon* closed off all blowing hoses, passed them over to the top of the stern pair of pontoons, and let go the stern towline. (See fig. 33.)

With about 35 feet of water over the sill, the *S–51*, drawing 33 feet aft and less forward, was hauled into the dock and pulled over the center of the dock without trouble. All dock air lines were coupled up and blowing started again; it was observed that the bow had gone down a few inches while the air connections were broken. (See figs. 34 and 35.)

Fig. 33.—"FALCON" PREPARING TO PASS AIR HOSES TO TOP OF STERN PONTOONS. "S-51" ABOUT TO ENTER DRY DOCK

Two divers now went down to examine the sill for lines astern of the *S-51* before putting the caisson in place. They found two lines which had originally been the towline to the *Falcon* and the preventer towline to the *S-51's* bow; these were hauled clear of the sill and the caisson put in place.

Pumping the dock commenced, and the *S-51* soon landed fore and aft. Another examination by divers showed everything clear along the keel (blocks had been removed to clear all pontoon chains).

Before going further it became necessary to straighten up the ship. A wire line was passed around the remains of the mast just above the periscope shears and from this a heavy tackle run to the port side of the dock and around a fourfold purchase to a capstan. A 10-inch manila line was taken down by one of the divers and tied around the gun mount just forward of the conning tower. This line was lead to the port side of the dock through a block to the main fall of a 50-ton dock crane. A third line, but somewhat smaller, was secured to the towing fair-lead aft and also lead to port.

As a preventer to avoid letting the ship roll to port after she straightened up, a heavy manila line was run from around the base of the mast to the starboard side of the dock, where it was tended on a capstan.

Everything being ready, the three port lines were heaved in gradually and the ship came up slowly, perhaps 10°, when the 10-inch line to the gun parted on the dock and the other lines had to be slacked away; the *S-51* rolled back to her original position.

The broken ends of the 10-inch line were tied together and another pull taken with practically the same result. The 10-inch was then discarded and a diver toor down and shackeled a 2-inch wire line into the chain bridle around the gun. This line was taken to the crane, but on taking a heave it was noted that as the vessel came up the strain on the line increased instead of decreasing, as might have been expected, since the free water inside the boat (which was causing the list) was free to adjust itself to each new position as the ship came erect and the heeling moment should have been zero with the ship upright.

The block through which the 2-inch wire line was passed threatened to carry away the straps holding it to the dock when the *S-51* was still over 10° from erect; consequently everything was slacked back, and while a heavier block and wire lashings were being provided, the problem was attacked from another angle.

It was deduced that as the *S-51* straightened up, the starboard No. 3 pontoon and the starboard No. 1 pontoon (but especially the former) touched the deck of the submarine, and any further straightening of the submarine resulted in lifting these two pontoons out of water, while the port side pontoons were being correspondingly submerged against the force of their buoyancy; as the stern was rounded on top this did not happen in the case of the No. 4 pair of pontoons. This would account for the increasing strain on the hauling lines as the *S-51* straightened up.

To overcome this, the four interfering pontoons were flooded a little to reduce their pull and then with lines to the starboard side of the dock, the No. 1 starboard and the No. 3 starboard pontoons were hauled enough to starboard to get them clear of the deck.

When the new block for the 2-inch wire line was ready, another pull was taken and conditions were improved. The *S-51* was gradually hauled up until she was practically vertical, keeping a good strain on the starboard preventer line to see that she did not go by that point. The ship was purposely held with a list of 1° or 2° to starboard and the dock pumped down a few feet. Another preventer line was run to starboard and then all bilge blocks hauled. These were considered unreliable, and further pumping ceased while four pairs of divers on each side went down and started shoring up under the bilge keels.

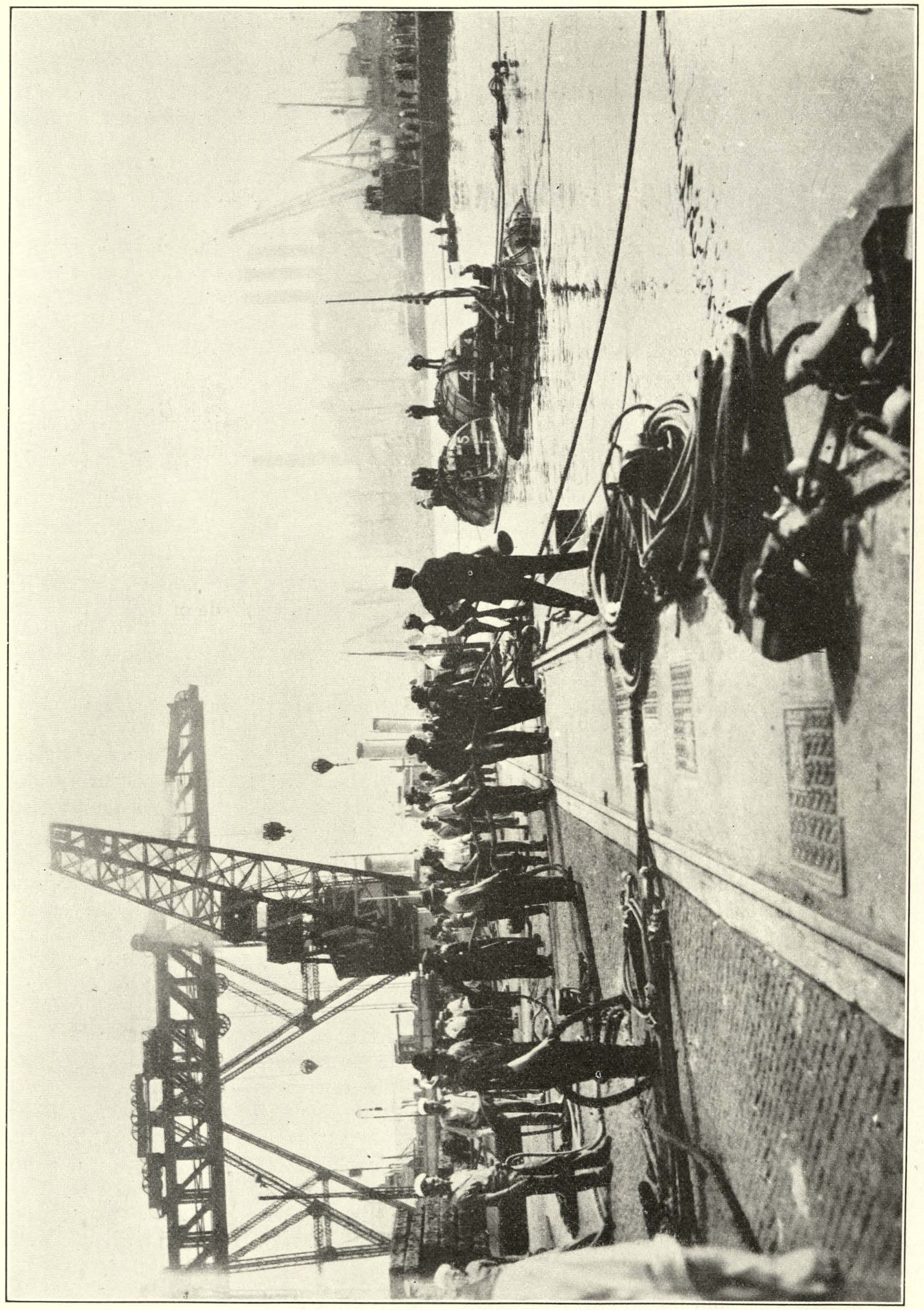


Fig. 34.—"S-51" ENTERING DRY DOCK

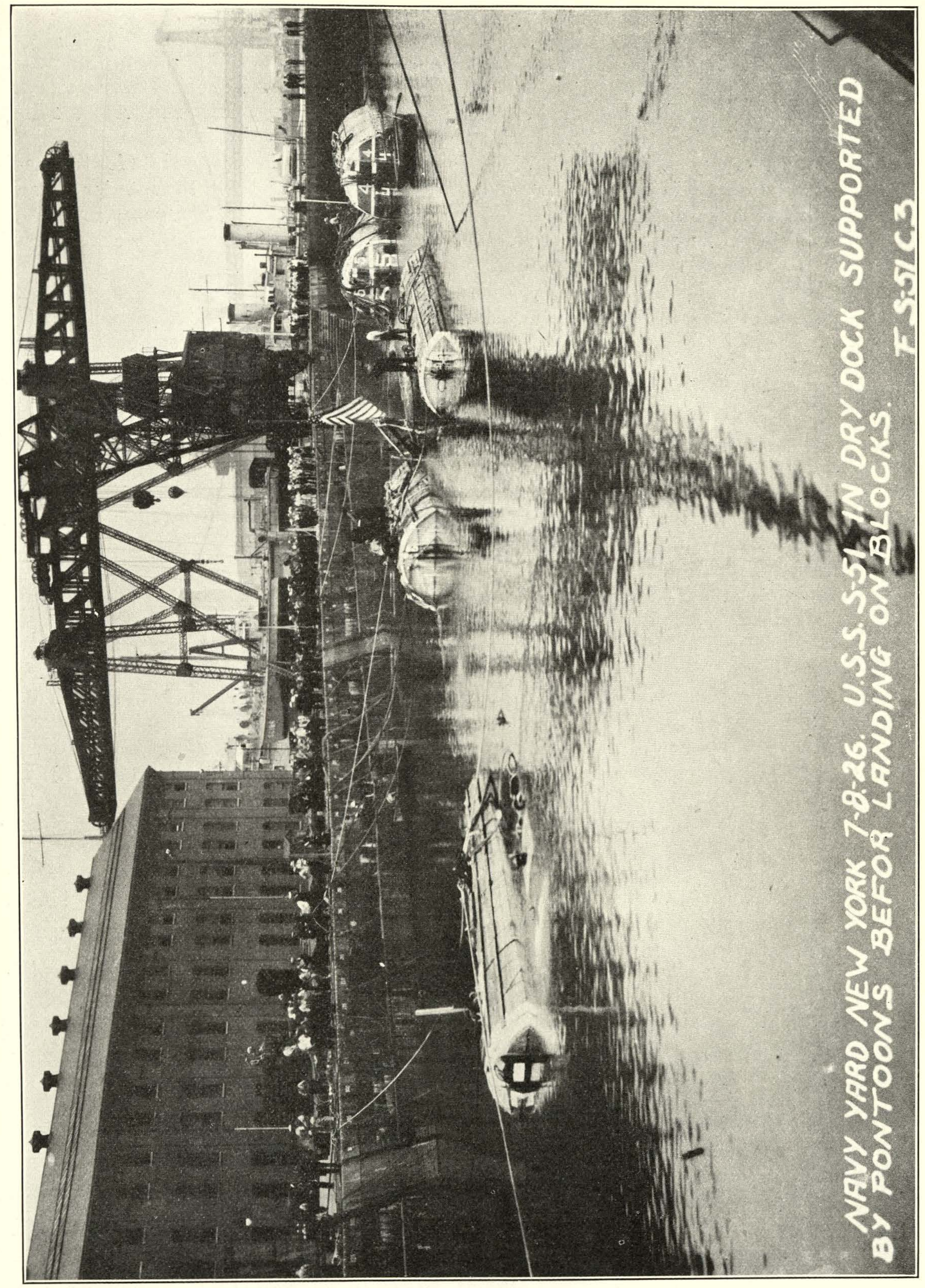


Fig. 35.—"S-51" IN DRY DOCK. (NOTE ARRANGEMENT OF PONTOONS

This shoring was completed late in the afternoon, when pumping was resumed until the deck showed about one foot above water. (See fig. 36.) Then the pontoon chains were released from the pontoons and the latter hauled clear. Two long oak shores were run from the dock to the starboard side against the deck.

Work now ceased and no further pumping was attempted, since it was too late for the medical party to start a search inside the boat and it was not desired to leave the interior forward (where most of the bodies were expected to be) exposed to the air longer than necessary.

On the morning of July 9 the dock was quickly pumped down and a number of additional shores placed under the bilge keels. (See fig. 37.)

The salvage job was now completed. (See fig. 38.)

An inspection of the *S–51* in dock after unwatering resulted in the finding of the bodies of 2 officers and 16 men. Some bodies were found in every compartment from bow to stern. As 9 bodies had previously been recovered by divers and 3 men survived, it appeared that 6 members of the crew were missing, having managed to escape from the boat but only to drown outside.

Structurally the *S–51* was found with a large gash resulting from the collision (see fig. 39) and with a deep wrinkle in the shell in way of the torpedo room bulkhead (see fig 40). In addition the bow, which had been intact during salvage operations and during the tow, was torn away by the towline shackled into the bullnose when the *S–51* hit Man-of-War Reef. (See fig. 41.) This carried away the upper part of the stem casting and the starboard shell plate riveted to the stem; these pieces were hauled aboard the towing tug with the towline. (See fig. 42.) The bridge structure, which was very light, was originally bent slightly to port by leaning against the starboard No. 3 pontoon after the events of June 22. It was found that this contact had torn off the valve on the upper end of the voice tube from conning tower to bridge, and it was the loss of this valve which resulted in making the C. O. C. nonwater-tight on July 5. (The end of this voice tube was easily accessible, and it could have been quickly plugged had it been found necessary to seal up the C. O. C. to raise the boat.)

The bridge itself was found badly bent to port from leaning against the starboard No. 3 pontoon when the *S–51* nearly rolled over while aground in the East River. (See fig. 43.)

The main keel was bent and there were numerous dents on the starboard side below the bilge keel where the vessel had grounded on the reef; there were no ruptured plates from this cause. (See fig. 44.)

Aside from the above, there was no other major damage nor was there any deterioration of hull or indications of corrosion, electrolytic or otherwise. The exterior paint was intact, with only light marine growth in spots. The interior paint was peeling in spots, but without corrosion. All cork sheathing was, of course, water soaked and loose.

No corrosion or deterioration of the Diesel engines or other machinery had taken place; cleaning and oiling was all that was required for functioning again. Most surprising of all, the large electrical motors throughout the ship were found in condition to run after washing, cleaning, and baking. Many of the ship's circuits were found, however, with water inside the armor; renewal here was required.

The main battery cells were found intact; no signs of explosion or deterioration from chlorine gas or acid were visible. The cells and connections were in good shape, but the lead plates required renewal.

After making temporary repairs to the hull, and such preservation work on machinery as was immediately necessary, the *S–51* was floated out of dock on her own buoyancy to await action on reconditioning. (See fig. 45.)

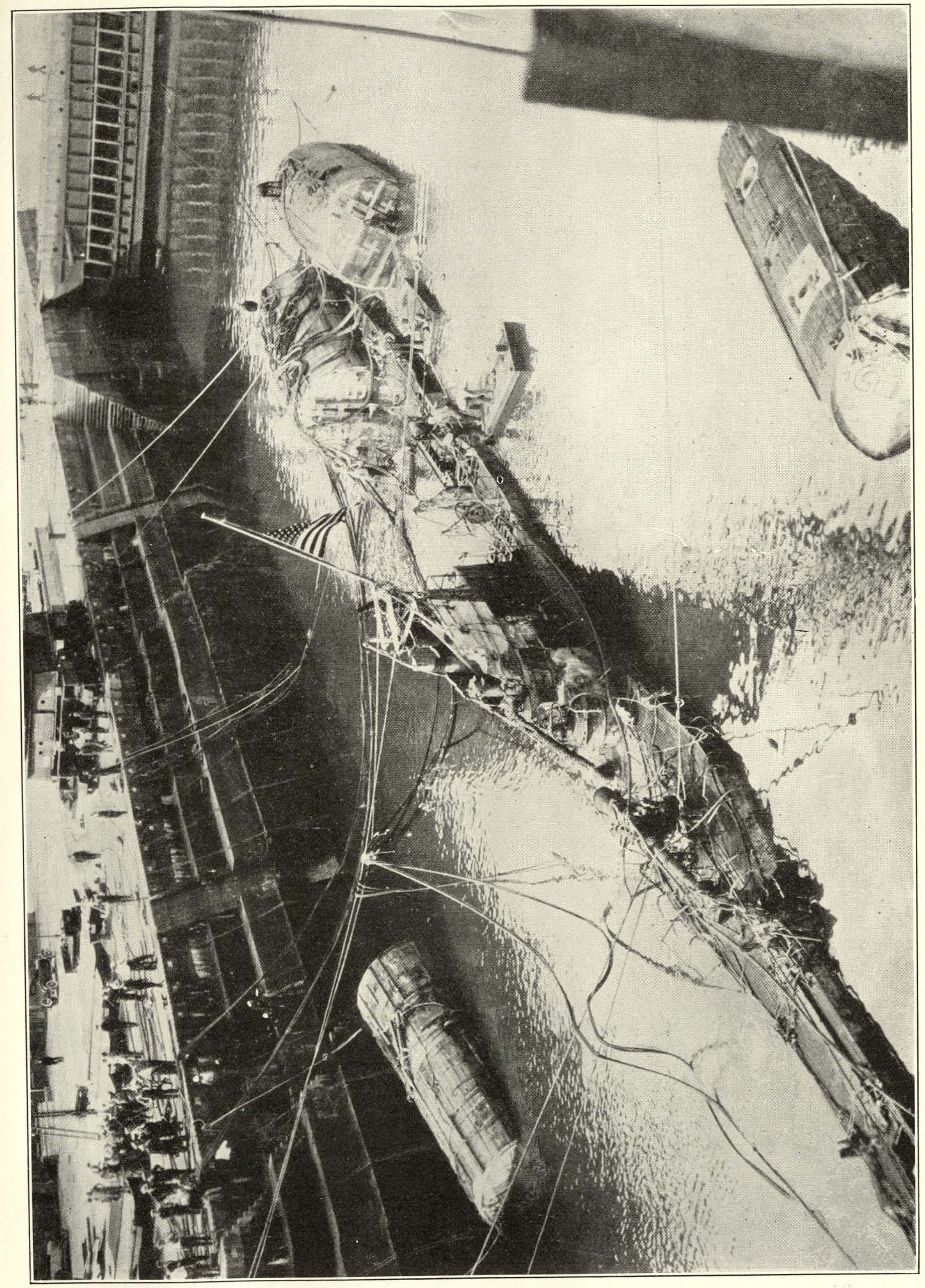


FIG. 36.—"S-51" ON BLOCKS. DECK ABOUT 1 FOOT ABOVE WATER

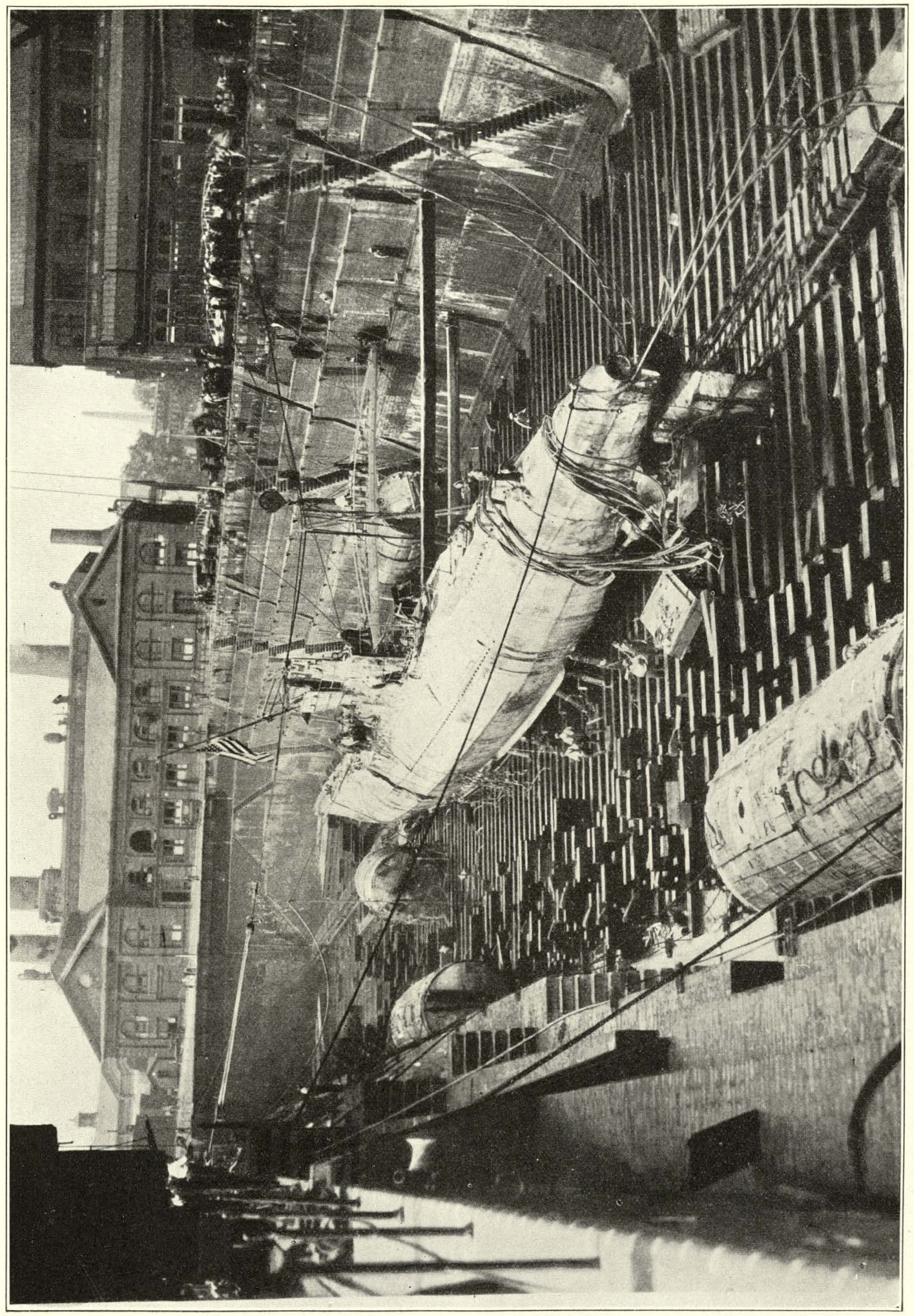


Fig. 37.—"S-51" IN DRY DOCK. DOCK PUMPED DOWN AND BILGE SHORES IN PLACE

Fig. 38.—DIVERS WHO SALVAGED "S-51"

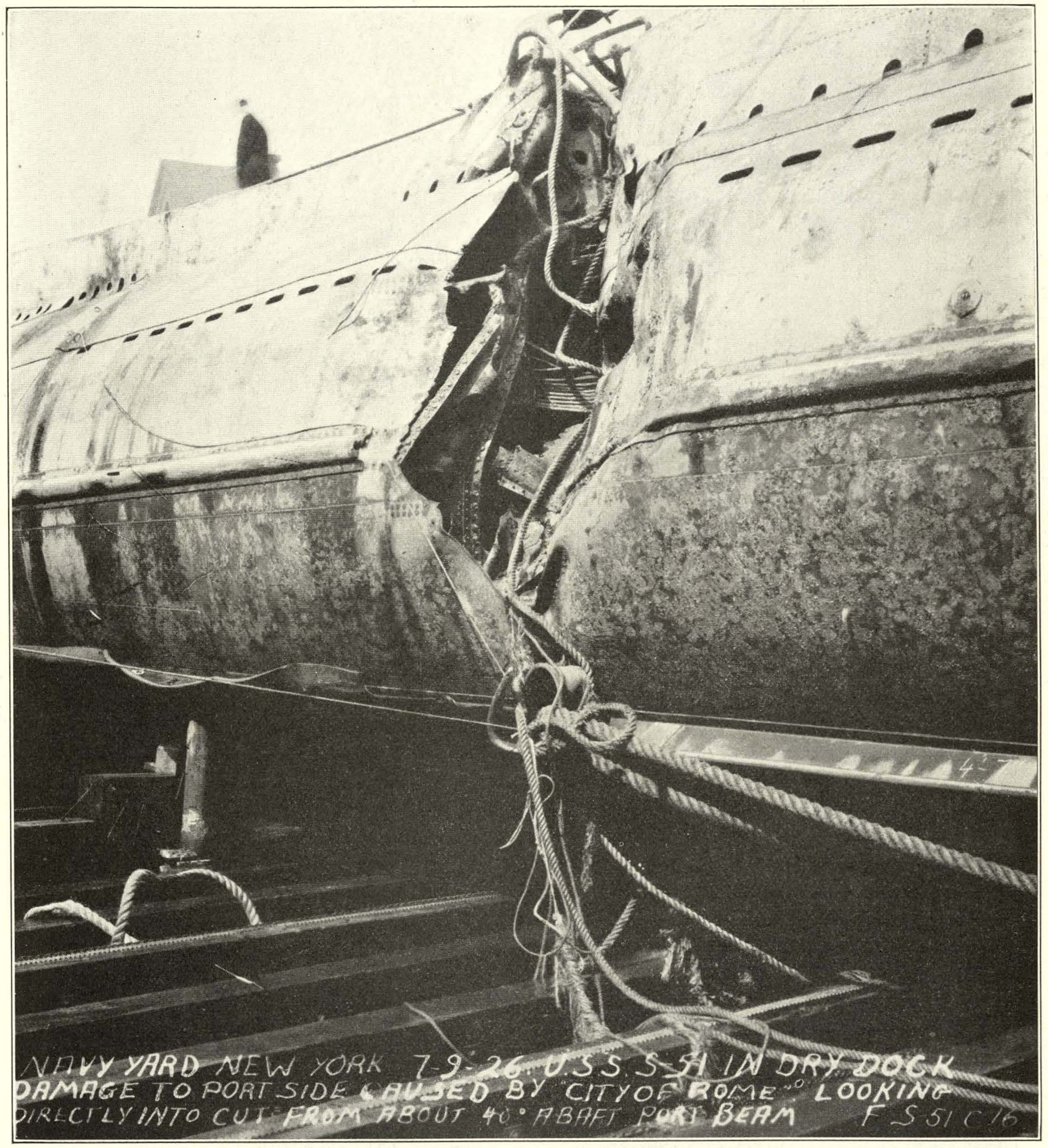


FIG. 39.—DETAIL VIEW OF GASH RESULTING FROM COLLISION WITH "CITY OF ROME"

FIG. 40.—PORT SIDE VIEW SHOWING WRINKLE CAUSED BY BOW STRIKING BOTTOM AFTER COLLISION WITH "CITY OF ROME"

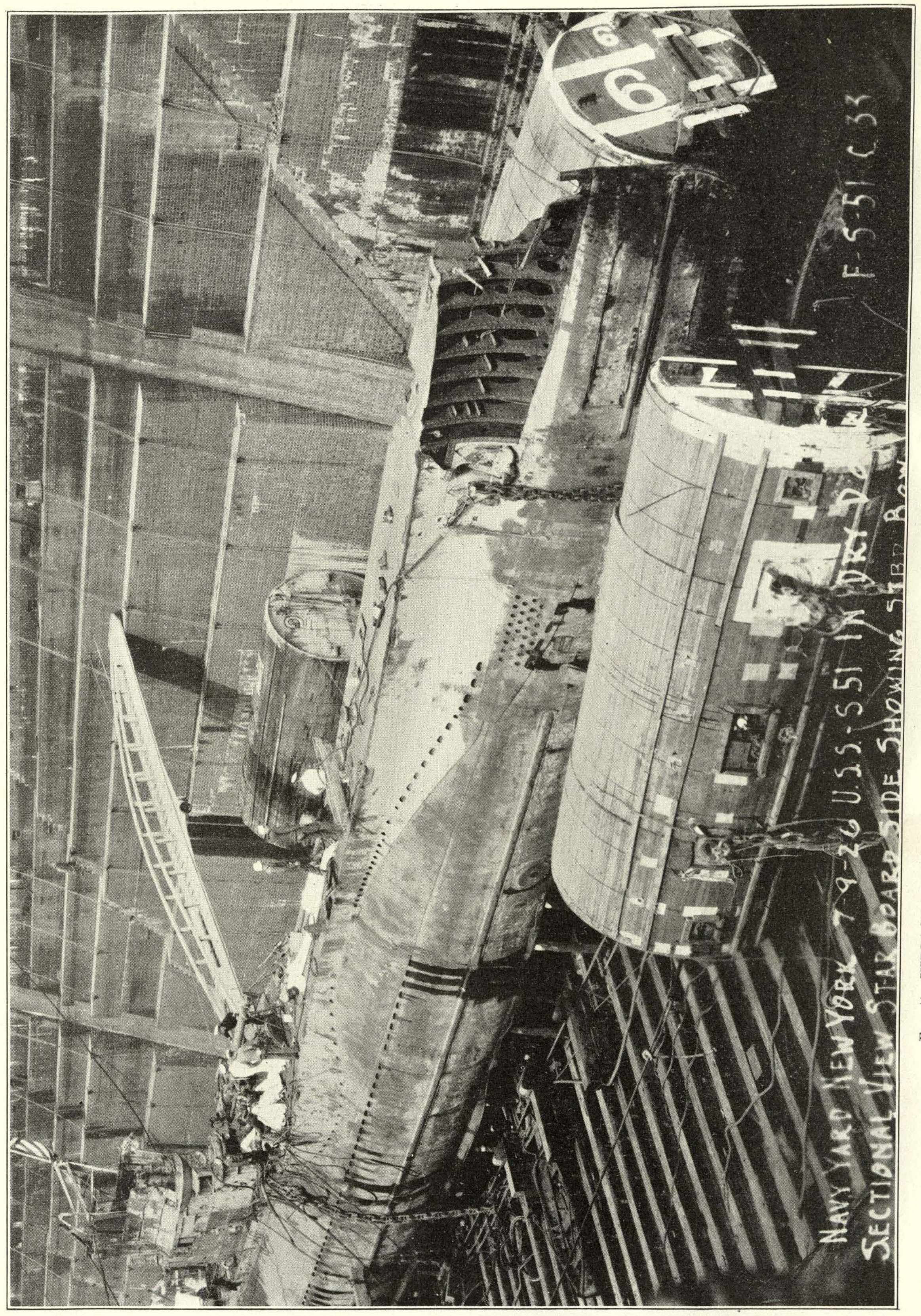


Fig. 41.—View showing damage to bow caused by grounding on Man-of-War Rock

Fig. 42.—"S-51" bow plating and stem casting on board "Sagamore"

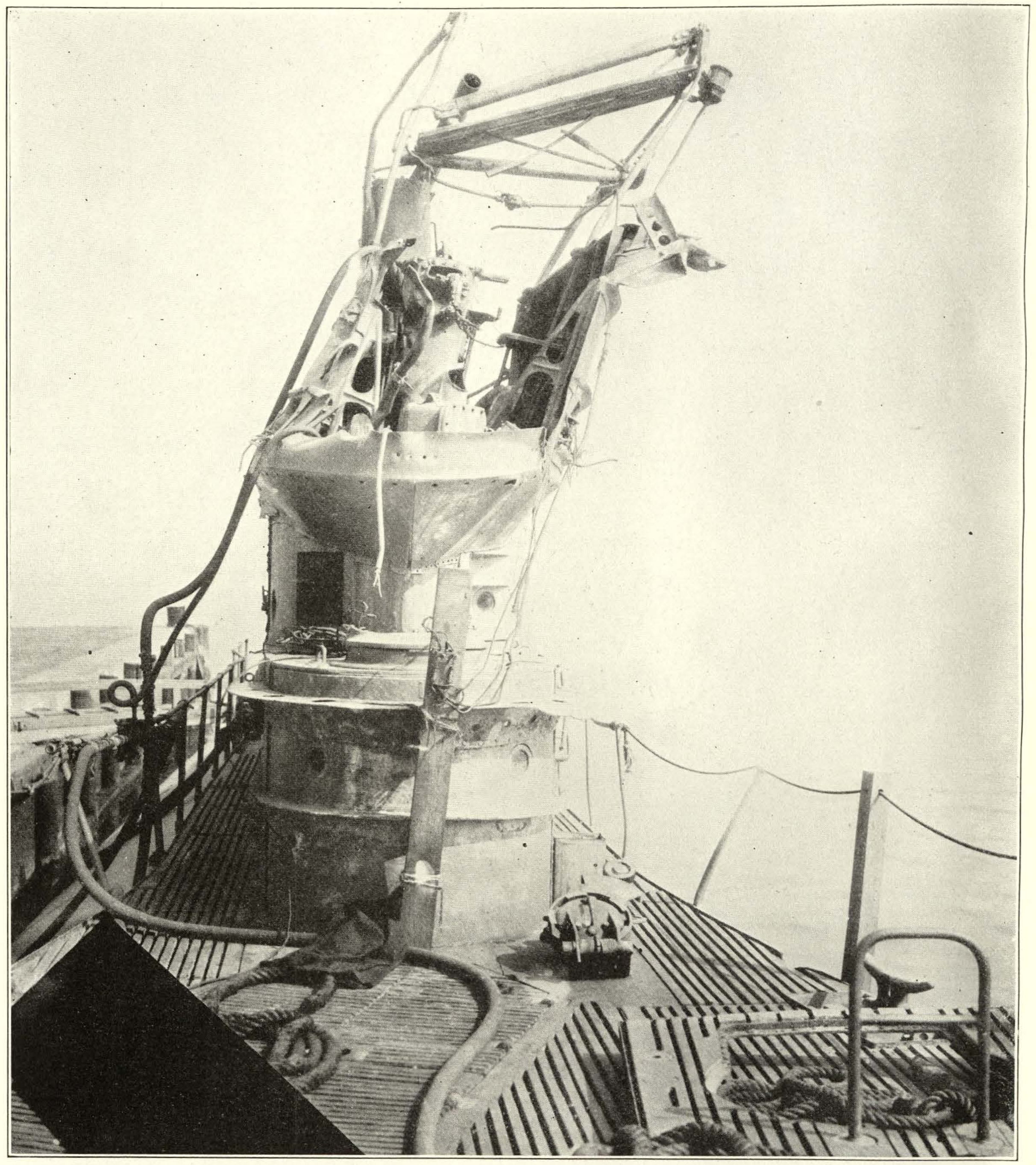


FIG. 43.—VIEW OF BRIDGE BADLY BENT TO PORT FROM LEANING AGAINST STARBOARD NO. 3 PONTOON

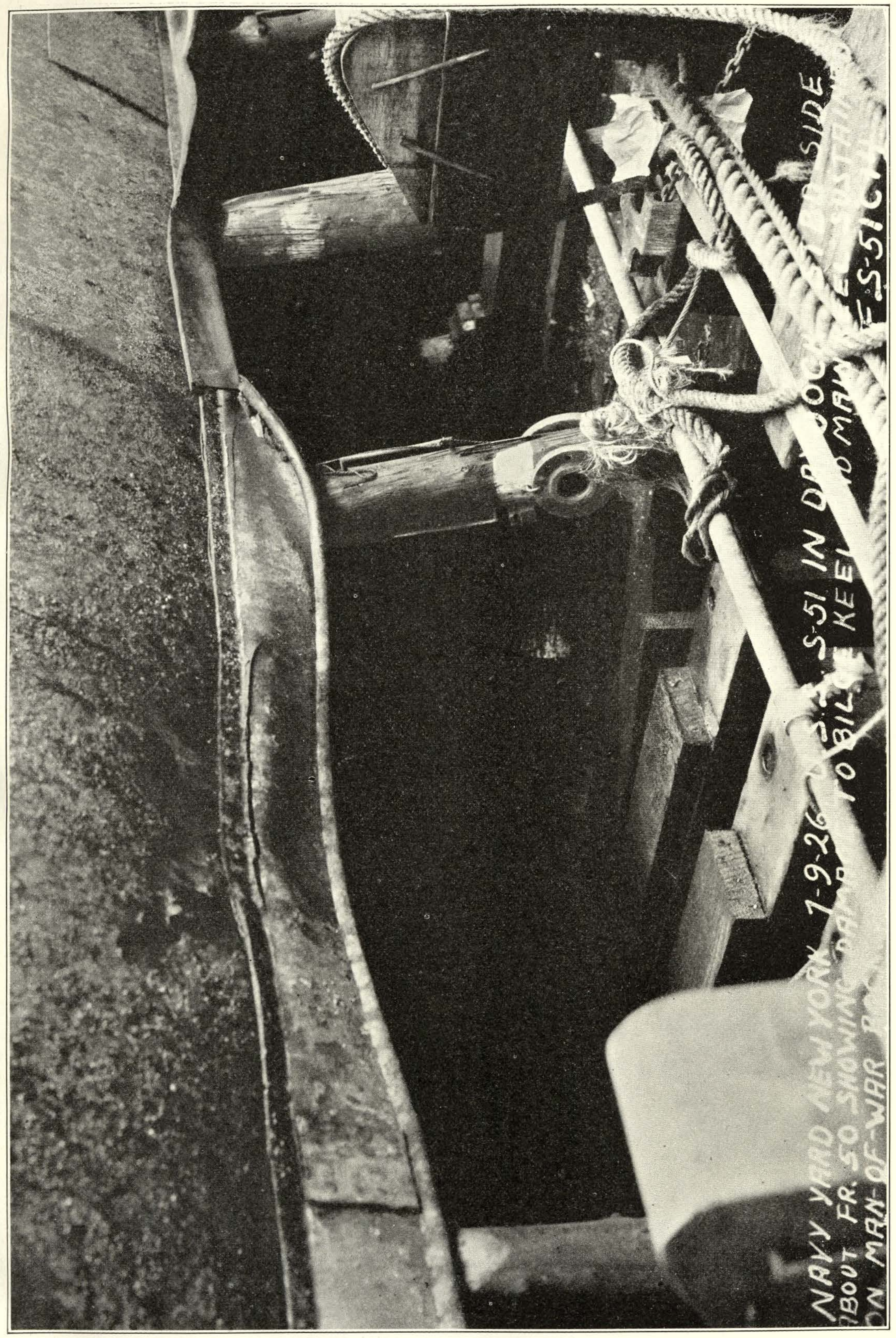


FIG. 44.—DAMAGE TO BILGE KEEL AND MAIN KEEL DUE TO GROUNDING ON MAN-OF-WAR ROCK. (NOTE PIECES OF STONE ON BILGE KEEL)

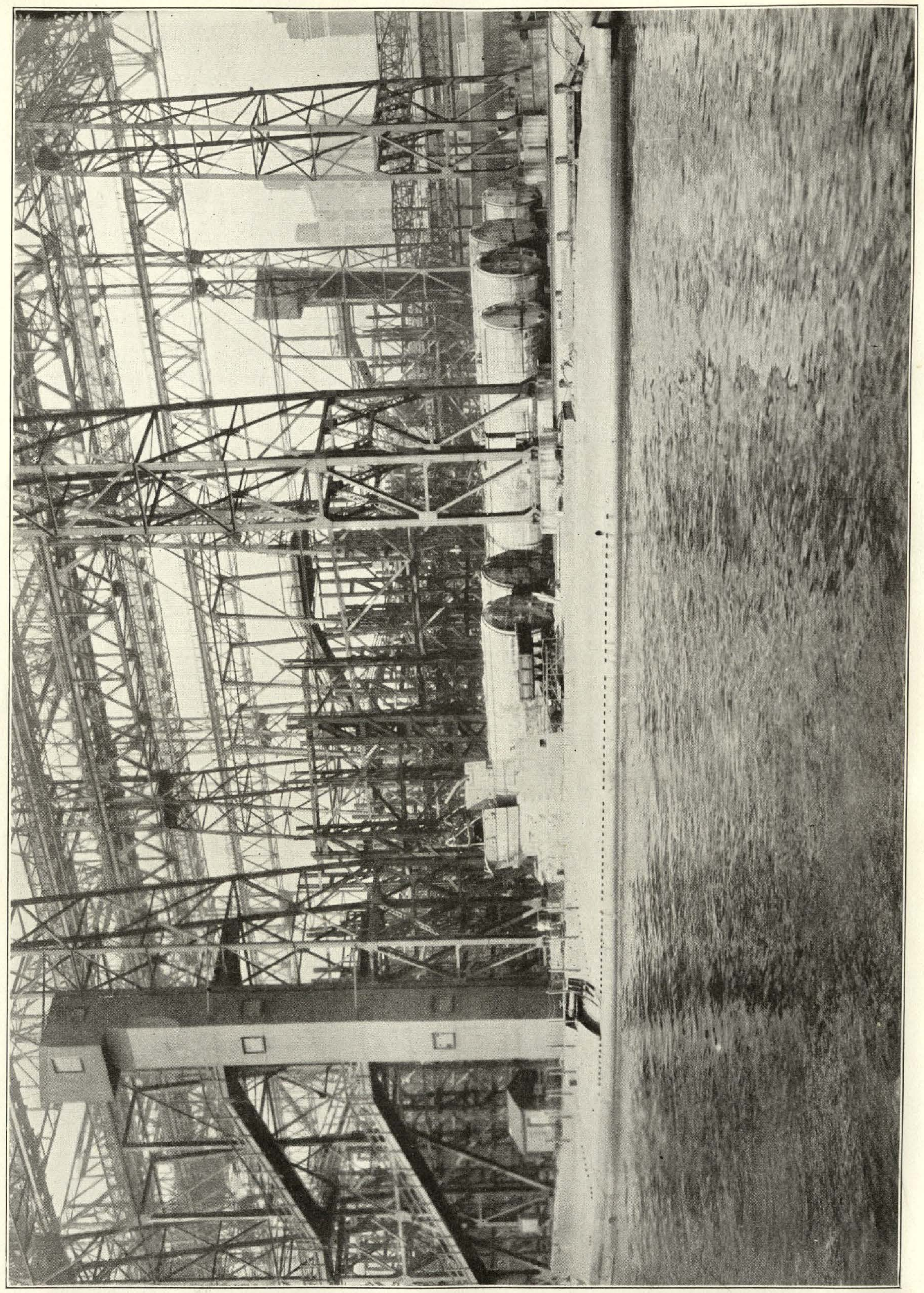


FIG. 45.—"S-51" AFLOAT ON HER OWN BUOYANCY

The foregoing is a brief description of the conditions found, the methods and materials used, and the difficulties encountered in salvaging the *S-51* and bringing her 150 miles to dry dock. For future operations, it is possible that the experiences set forth above may be of value. But for a correct estimate of the whole job, it is desired to state that the success of the job was far more due to the courage, the energy, and the devotion of the men engaged, both as divers and on deck, than to the material. Human endurance was always the limiting factor; it was badly stretched in salvaging *S-51*. For the next operation of a similar nature, the most important feature is to provide the men in adequate numbers; the material can always be quickly fabricated.

APPENDIX A

The diving crews on the *S–51* were composed of the following men:

FALL OPERATIONS, OCTOBER 16 TO DECEMBER 6, 1925

Anderson, George, rigger.
Bailey, Henry, gunner's mate, first class.
Carr, William Joseph, boatswain's mate, first class.
Eadie, Thomas, chief gunner's mate (reserve).
Eiben, Joseph, chief torpedoman.
Frazer, James W., chief torpedoman.
Ingram, James C., chief torpedoman.
Kelley, J. R., chief torpedoman.
Michels, Fred George, chief torpedoman.
Smith, Francis G., chief torpedoman.
Wilson, Raymond C., chief torpedoman.

SPRING OPERATIONS, APRIL 26 TO JULY 8, 1926

Anderson, George, rigger.
Bailey, Henry, gunner's mate, first class.
Boyd, David H., torpedo man, third class.
Carr, William J., boatswain's mate, first class.
Clark, G. W., seaman, second class.
Davis, A. H., torpedoman, second class.
Eadie, Thomas, chief gunner's mate (reserve).
Eiben, Joseph, chief torpedoman.
Ellsberg, Edward, lieutenant commander (C. C.).
Grube, Carl, seaman, first class.
Henry, E., torpedoman, third class.
Holden, G. F., torpedoman, first class.
Ingram, James C., chief torpedoman.
Kelley, J. R., chief torpedoman.
Madden, Jos. C., rigger.
McLagan, E. M., gunner's mate, first class.
Michels, Fred G., chief torpedoman.
Sanders, S. A., chief torpedoman.
Smith, Francis G., chief torpedoman.
Wickwire, William S., gunner's mate, first class.
Wilson, Raymond C., chief torpedoman.

The following men made one dive each on the job and were then forced to quit for various reasons:

Anderson, Frank, shipwright.
Applegate, C. L.,[1] coxswain.
Dewberry, T.,[1] chief torpedoman.
Horan, H., torpedoman, first class.
L'Heureux, J. W., torpedoman, first class.
Clark, A. D., seaman, first class.
Clemens, Harry R., seaman, first class.
McNeil, Andrew R., torpedoman, third class.

[1] Made four dives.

APPENDIX B

Plate 10 is a general arrangement plan showing the proposed layout of submarine rescue vessels based on recommendations made in the case of the U. S. S. *Falcon* after the completion of the salvage of the *S–51*.

APPENDIX C

DIVING OPERATIONS IN CONNECTION WITH SALVAGE OF THE "S–51"

(From report of Lieut. Henry Hartley, commanding officer, U. S. S. *Falcon*)

1. In commencing the spring operations on the *S–51*, the marker buoys that were planted at the end of the fall operations having dragged out of position during the winter, it was necessary to locate the vessel by grappling. The nature of the grapnel catches was ascertained by sending down a diver. When the catch was identified as the *S–51* a diver attached a buoy line to the vessel and made a report as to its general position. After determining the approximate heading of the submarine, the planting of necessary moorings was undertaken. Manila hawsers of 8-inch circumference and 120 fathoms long and two 4,000-pound and four 6,000-pound anchors were used for this purpose. It was decided to plant one mooring ahead, one mooring astern, and two bow and two quarter moorings 50° from the ahead and astern moorings. Buoys were first planted to indicate the desired location of the moorings. The marker buoy was passed close aboard with the *Falcon* heading in the same direction as the submarine. A cork buoy was planted over the wreck, three ship lengths from the marker buoy. This operation was repeated on the opposite heading and on the four other desired compass headings. When all of the markers were placed the moorings were planted in the locations marked by the buoys. By this method the six moorings were planted by the *Falcon* in three and one-quarter hours.

2. After the moorings were planted the first diver used the marker buoy line as a descending line, taking with him a 3½ or 4 inch manila line which was secured to the vessel and buoyed at the upper end for permanent use as a diver's descending line. The boat boom was guyed aft as far as the rigging permitted and the after boom was guyed forward, both booms being topped up so that a single whip from the boom head would clear the vessel's side about 2 feet. Four-inch single lines, marked every 10 feet, were run from the winch to a block at each boom head. The lower ends of these lines were fitted with eye splices and screw shackles. Two stages, 3½ feet square, were made from flat bar and fitted with iron bails, about 6 feet long, to each corner and rigged so that they could be slung from the booms.

3. The divers were dressed near the places where the stage whips plumbed, there being provided for this purpose small benches or dressing stools fitted with shelves under the seat for the small tools, breastplates, washers, nuts, etc. While the divers were being dressed, the hose and telephone cable were made ready, hooked up, and tested. When the diver was dressed and had tested his own 'phone, he mounted the diving stage and was hoisted over the side clear of the rail. The stage was then dropped until the diver was submerged a foot or so below the surface. At this point the stage was stopped until the diver had tested his air and telephone and checked the water-tight integrity of his diving dress, etc. If any defects were found, the diver could be hoisted aboard on the stage in a very few seconds. When the diver reported ready, the stage was led to the descending line. After any material or tools he was to carry down were given him, he left the stage and descended on the descending line, the tender paying out hose and cable as the weight of the diver took it. This permitted the diver to stop his descent at any time, and thereby control his descent. However, he was not allowed to descend at a rate greater than 1 foot per second, as he must take the necessary precautions to build up his air pressure as he descends. The time required for descent varied with the individual, but

for 135 feet slightly over two minutes was the average time of descent. When the diver reported that he had reached bottom, his working mate was put over and lowered in the same manner.

4. At all times when divers were down one diver was kept on deck fully dressed except as to his helmet and ready to descend in case of emergency. This is considered of the utmost importance in all deep-sea diving.

5. When the diver reported ready to ascend or when he had been down the allowed maximum length of the time, he was told to come to the descending line. The descending line was passed through a screw shackle attached to the diving stage and the stage lowered to the proper distance. The diver was hauled up by his tenders at a rate of about 1 foot per second and landed on the stage. After the first diver was landed his mate was brought up in the same manner. When both were on the stage, the stage was unshackled from the descending line, which was then clear for the other diving stage. The timekeeper, who was an experienced and reliable chief petty officer, kept a record of the time the diver reached and left the bottom, and the time for decompression. After the diver had mounted the stage the rate of ascent was governed by the decompression table in the Diving Manual, except as noted herein.

6. The routine which was carried out in getting the diver out of cold water as quickly as possible after one hour at 132 feet was as follows:

(*a*) The stage was first lowered to 80 feet. After receiving the diver's report that he was safely on the stage, the stage was held at certain depths for various periods of time as follows:

Depth:	Time (minutes)
80 feet	4
70 feet	6
60 feet	8
50 feet	10
Total	28

(*b*) After the 10-minute decompression at the 50-foot depth the stage was hoisted as rapidly as possible and the diver landed on deck. About 20 seconds were then required to remove the diver's belt, shoes, and helmet, after which he was assisted into the outer lock of the recompression chamber, undressed and given dry clothes, hot coffee, etc., and passed into the inner chamber. About two minutes from the time he started from the 50-foot stage were required to get the diver under pressure again. The initial air pressure in the recompression chamber was stepped back one stage (equivalent to water pressure at 60 feet) and then held at the various stages, indicated below:

Air pressure equivalent to:	Time (minutes)
60 feet	10
50 feet	12
40 feet	15
30 feet	18
20 feet	20
10 feet	25
Total	100

7. The medical officer kept strict watch over the divers' diet and physical condition. Colds, indigestion, minor attacks of bends, or too long a stay in the water on the previous day usually rendered one or two divers unfit for work. It was necessary to exercise considerable care to insure the divers did not overstrain themselves due to overzealousness and pride in their work. The amount of work the men were called upon or allowed to do was governed by the physical condition and experience of the various individuals. In assigning work extreme care was taken

to assign the easier tasks to the more inexperienced divers in view of the psychological effect of failure upon the morale of the individual.

8. Diving could not be carried on when the ship was rolling as much as 10° or 12° as the pumping up and down of the diver on the stage injured the ear drums and caused nausea. Working under unfavorable weather conditions or at night was profitless, and except in emergency the work accomplished did not compensate for the wearing effect on the divers.

9. The number of divers and the number of dives per day, etc., involved in the spring and fall salvaging operations of the *S-51* were as follows:

	Fall operations	Spring operations
Total days	50	68
Days one or more dives made	21	51
Days weather prevented diving	29	17
Total number of dives	226	374
Average number of dives per diving day	7.8	7.33
Maximum number of divers available	11	[1] 24
Minimum number of divers available	5	No record.

[1] Only 15 of these men were used. The others after making one or more dives were disqualified due to their being physically unable to stand the strain.

10. The minor difficulties encountered on the job are too numerous to cover fully and many of them were of themselves inconsequential. However, some of the experiences may be of interest and some of the observations may be of benefit in future operations of this nature and will, therefore, accordingly be cited:

(*a*) Too great importance can not be given to the question of satisfactory telephones, diligent and intelligent tending, and judgment and experience of the officer in charge of the diving. As an illustration of the value of the necessity for vigilance and initiative on the part of a tender, one instance may be cited. On May 21 the man tending the telephone called to the tender to haul the diver up quickly. The tender thus warned called for help and several men assisted him to haul the hose and cable. As a result of this prompt action, the diver was alongside the ship and all hose and cable in when he emerged at the surface. The diver was quickly hauled aboard and decompressed in the tank with no ill effects. When the telephone man was questioned he stated that he had only heard what he thought was a "frightened squawk."

(*b*) On three different occasions the tunnels caved in while divers were working in them and in one case the diver could not free himself. There were also three cases in which the divers' lines became fouled and the divers were unable to clear themselves. In the latter part of the fall operations considerable difficulty was experienced due to the air lines freezing and two cases of complete stoppage of air to the diver occurred. In both cases quick action prevented any serious effect on the diver.

(*c*) There was one case of caisson disease from which the diver recovered after several weeks in the hospital. It developed during his first descent. The hose became fouled and he was unable to clear himself with the result that he probably got excited and frightened and overtaxed his strength. In another case where the diver overexerted himself he developed heart murmurs and was restrained from further diving. There was one case of a slight rupture to one ear drum due to the failure to build up proper air pressure during descent. Further diving by this diver was also prohibited. One diver also developed an attack of bends of such severity as to disqualify him for further deep diving on this particular project. The ship's records show 13 cases where divers were treated in the recompression tank for bends serious enough to incapacitate them for one or two days.

(*d*) Under normal conditions divers were limited to one dive of a maximum length of one hour daily. During the fall operations in the endeavor to complete the salvage before the weather made further diving impossible, divers fit for duty made two dives of about one hour each daily. The physiological effect of this on the divers was very marked and toward the end of the operations from 50 to 75 per cent of the divers were incapacitated each day due to mild attacks of bends or colds. It is probable that with the dives limited to one per day, a greater number of hours on the bottom could have been secured. Ordinarily, if a diver remained on the bottom over one and one-half hours, he was not permitted to dive the next day. The longest time on the bottom by any diver in a single dive during the entire operation was 3 hours and 13 minutes. The maximum permissible time can be varied somewhat with the individual, but until a man's capacity and endurance is well known, the one-hour period mentioned above should not be exceeded.

(*e*) The use of the decompression chamber in deep-sea diving offers many advantages. It permits the diver to get into dry comfortable clothing in a place where he can rest, attended by a medical officer, and be given food and drink as necessary; thus contributing to his comfort and the safe-guarding of his health. It reduces by 50 per cent the actual time divers are submerged, thereby permitting the availability of almost double the number of divers for work on the bottom.

(*f*) During the fall operations the divers started work using the regular rubber cuff and snapper and were usually fully decompressed on the stage. Due to the reduced circulation of blood in the wrist and hand caused by the snapper and the exposure of the bare hands to the cold water for long periods, the hands become numb, causing considerable discomfort, and as the weather grew colder attacks of bends became more frequent, with the result that toward the end of the operations practically all the divers working regularly suffered attacks of bends. During the spring operations the regulation tender two-finger stall and thumb molded gloves were cemented direct to the sleeve, avoiding the discomfort experienced in the fall. In addition the procedure for decompressing outlined above was used, reducing the time the diver was in the water by about 50 per cent. A very remarkable reduction in the number of cases of bends reported was noted.

(*g*) Much could be said about various methods of sending gear, tools, and material down to the diver, but there are so many variations due to the classes and characteristics of material to be handled that no discussion can be complete. However, it is considered essential that in securing and sending gear below every effort should be made to facilitate the removal of the lowering gear and eliminate all unnecessary effort on the part of the diver. The tender who superintends this work should be an experienced diver in order to avoid fouling the diver's hose and lines, prevent delays, and assist the diver on the bottom to the maximum extent possible.

APPENDIX D

MODIFICATIONS TO SALVAGE PONTOONS

1. The design of the pontoons used on the *S–51* salvage operation was prepared for the pontoons which were used in raising the *F–4* from 46 feet of water in Honolulu Harbor. Owing to the shallowness of the water in which they were used, no particular difficulty was experienced, but it was reported at the time that the cylinders showed a decided tendency to become unmanageable and heavy as soon as the water-plane area had vanished. The urgency of the requirements for pontoons in connection with the salvage of the *S–51* was so great that no attempt was made to alter the design used in connection with the construction of the pontoons for the *F–4* and six additional pontoons from these plans were built at the navy yard, New York.

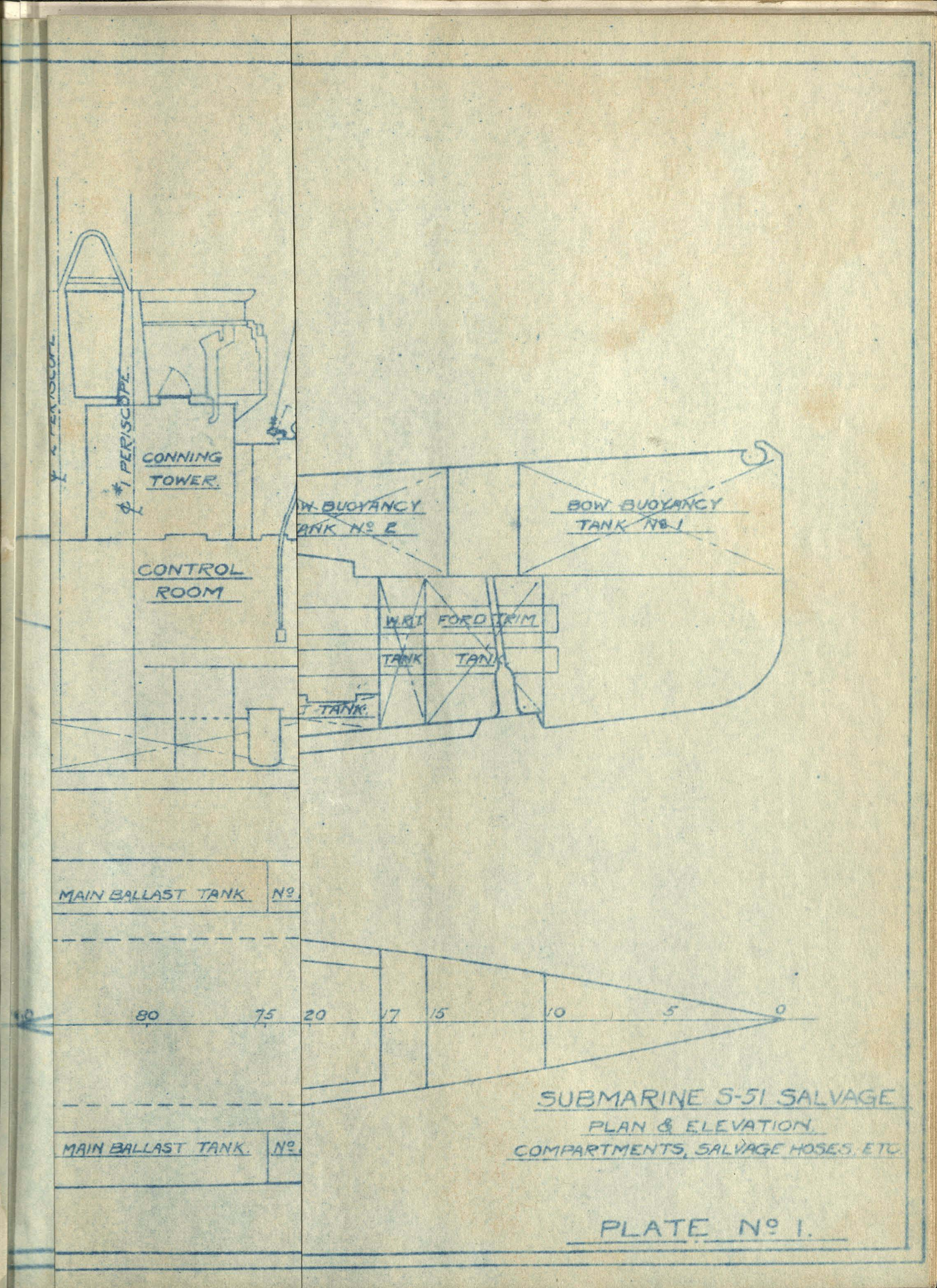
2. The report of the salvage operations describes the difficulty encountered in handling the salvage pontoons when submerged partially filled with water. The difficulty encountered was due to the fact that the pontoons on submergence had negative longitudinal stability. This resulted from the loss of external water plane after submergence in combination with a large internal free surface, the pontoons at this stage being about two-thirds full of water. As a result of this condition the pontoon immediately upon submerging, unless restrained, had a strong tendency to upend and remain in a vertical position.

3. During the salvage it was determined by experiment that the pontoons with a negative weight of 10 tons had sufficient water inside to reduce the internal free surface to the point where the pontoons could be lowered horizontally. However, handling the 10-ton load was a more or less difficult operation, and the flooding of the pontoons to the proper stage involved some danger of injury to the personnel operating the flood valves. These difficulties were very much increased by rough weather.

4. Another difficulty experienced with the pontoons was the loss of lift due to taking an angle in the raising operation. When the vessel being lifted took an angle as one end lifted, the submerged pontoons at the other end took nearly the same angle. The effect of this was to leave in the high end of the pontoon a considerable amount of water below the flood valves on that end which could not be expelled. This condition is indicated on Plate No. 5.

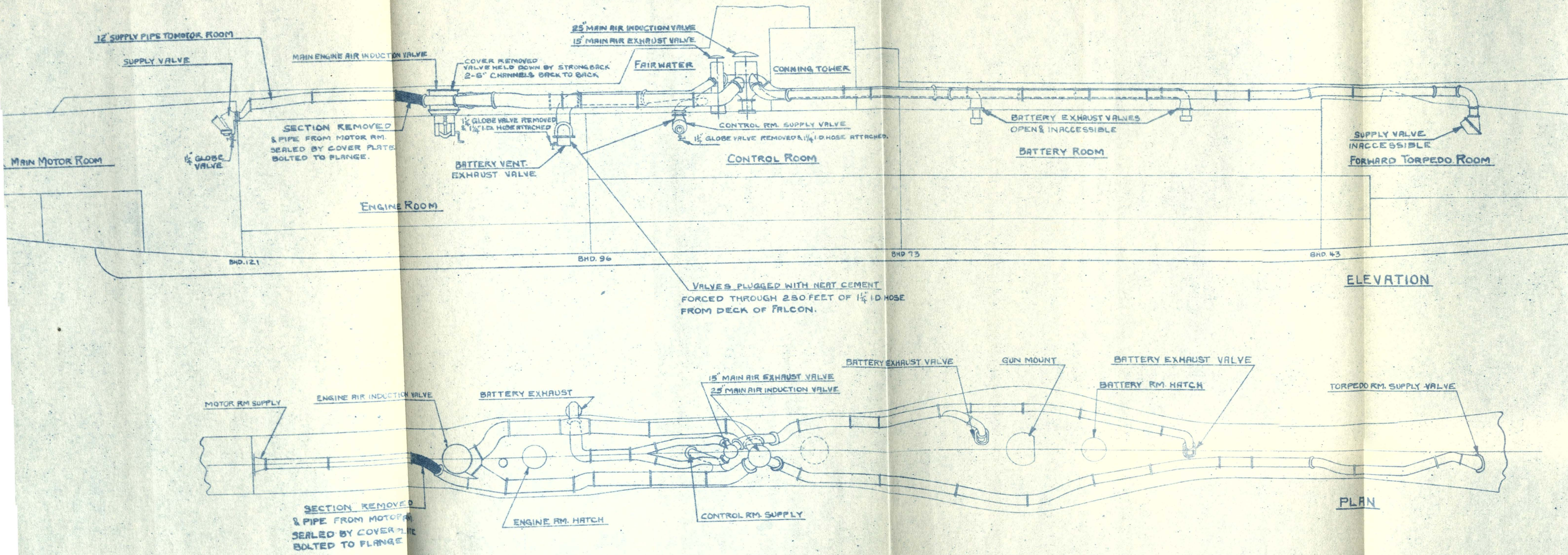
5. In order to correct these defects it was decided to cut out the existing athwartship bulkhead and build in its place two bulkheads so placed as to divide the pontoon into two similar end compartments and one middle compartment. The bulkhead spacing was chosen so that when the two end compartments were completely flooded and had therefore, no free surface and the central compartment was completely dry, the pontoon would have about 3-ton negative buoyancy. In this condition the pontoons act as fixed weights and can be lowered in essentially the same manner as any other dead weight. A sluice pipe with a valve was provided between the two end compartments so that when it was determined which end of the submerged vessel was to be first lifted, the flood valve in the end of the pontoon which would rise first with the boat could be closed and the sluice valve opened. With this arrangement, all the water can be blown out through the flood valve at the lower end and the entire buoyancy of the pontoon realized.

6. Plates 8 and 9 show the salvage pontoons after being altered in accordance with the above. These alterations have been actually completed on salvage pontoons YSP 5 to 10, inclusive, but have not been undertaken on YSP 1 to 4, inclusive. The negative buoyancy of the pontoons as altered, with the end compartments filled and the center compartment dry, has been determined by test to be approximately 6,000 pounds.



SUBMARINE S-51 SALVAGE
PLAN & ELEVATION
COMPARTMENTS, SALVAGE HOSES, ETC.

PLATE Nº 1.



SUBMARINE S-51 SALVAGE

VENTILATION

PIPING & VALVES

PLATE No 2

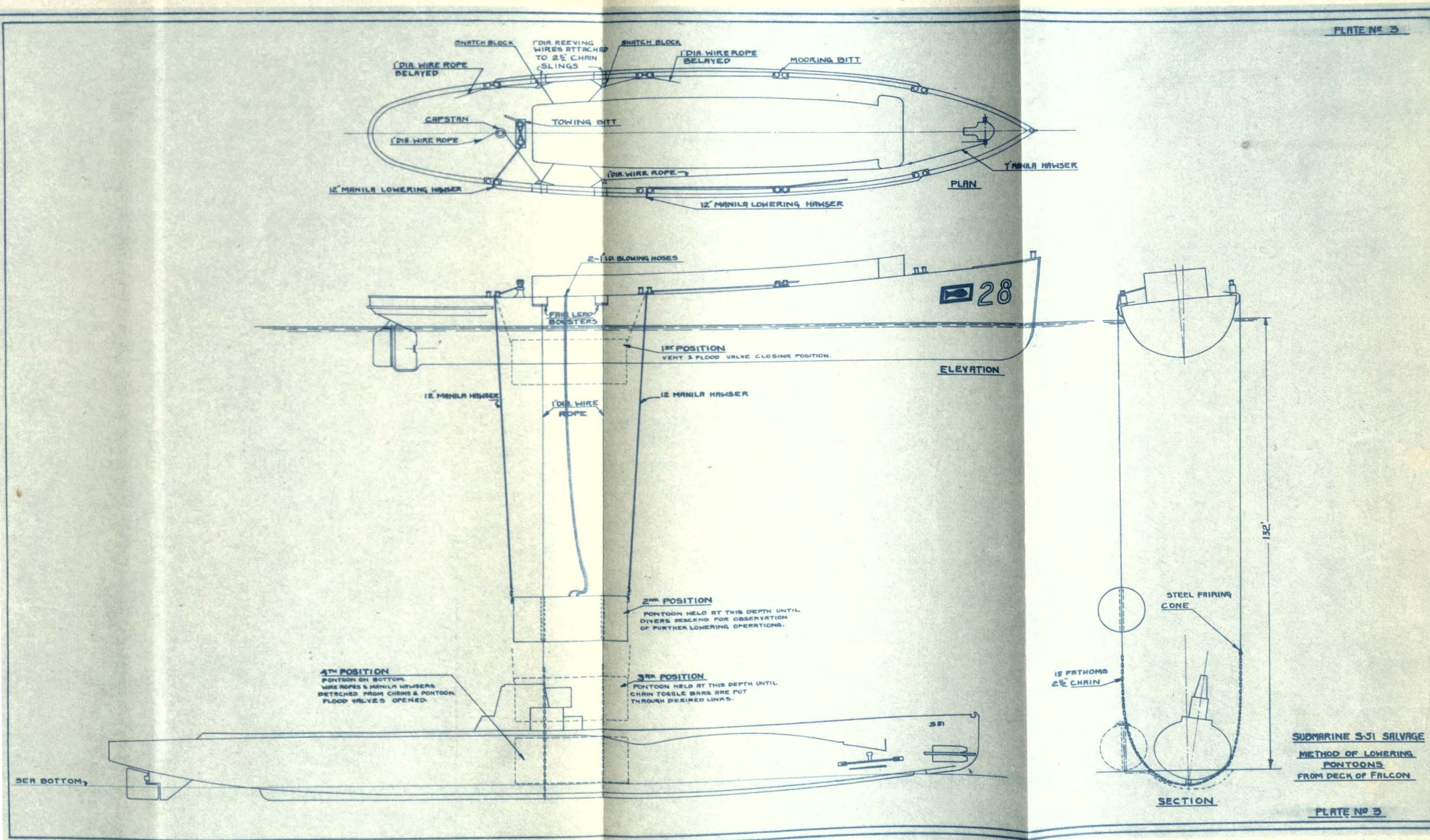


PLATE Nº 3
SNATCH BLOCK
1" DIA. REEVING WIRES ATTACHED TO 2½" CHAIN SLINGS
SNATCH BLOCK
1" DIA. WIRE ROPE BELAYED
1" DIA. WIRE ROPE BELAYED
MOORING BITT
CAPSTAN
TOWING BITT
1" DIA. WIRE ROPE
7" MANILA HAWSER
1" DIA. WIRE ROPE
12" MANILA LOWERING HAWSER
PLAN
12" MANILA LOWERING HAWSER
2-1½" I.D. BLOWING HOSES
28
FAIR LEAD BOOSTERS
1ST POSITION
VENT & FLOOD VALVE CLOSING POSITION.
ELEVATION
12" MANILA HAWSER
1" DIA. WIRE ROPE
12" MANILA HAWSER
2ND POSITION
PONTOON HELD AT THIS DEPTH UNTIL DIVERS DESCEND FOR OBSERVATION OF FURTHER LOWERING OPERATIONS.
4TH POSITION
PONTOON ON BOTTOM.
WIRE ROPES & MANILA HAWSERS DETACHED FROM CHAINS & PONTOON.
FLOOD VALVES OPENED.
3RD POSITION
PONTOON HELD AT THIS DEPTH UNTIL CHAIN TOGGLE BARS ARE PUT THROUGH DESIRED LINKS.
S51
SEA BOTTOM
132'
STEEL FAIRING CONE
15 FATHOMS 2½" CHAIN
SECTION
SUBMARINE S-51 SALVAGE
METHOD OF LOWERING PONTOONS FROM DECK OF FALCON
PLATE Nº 3

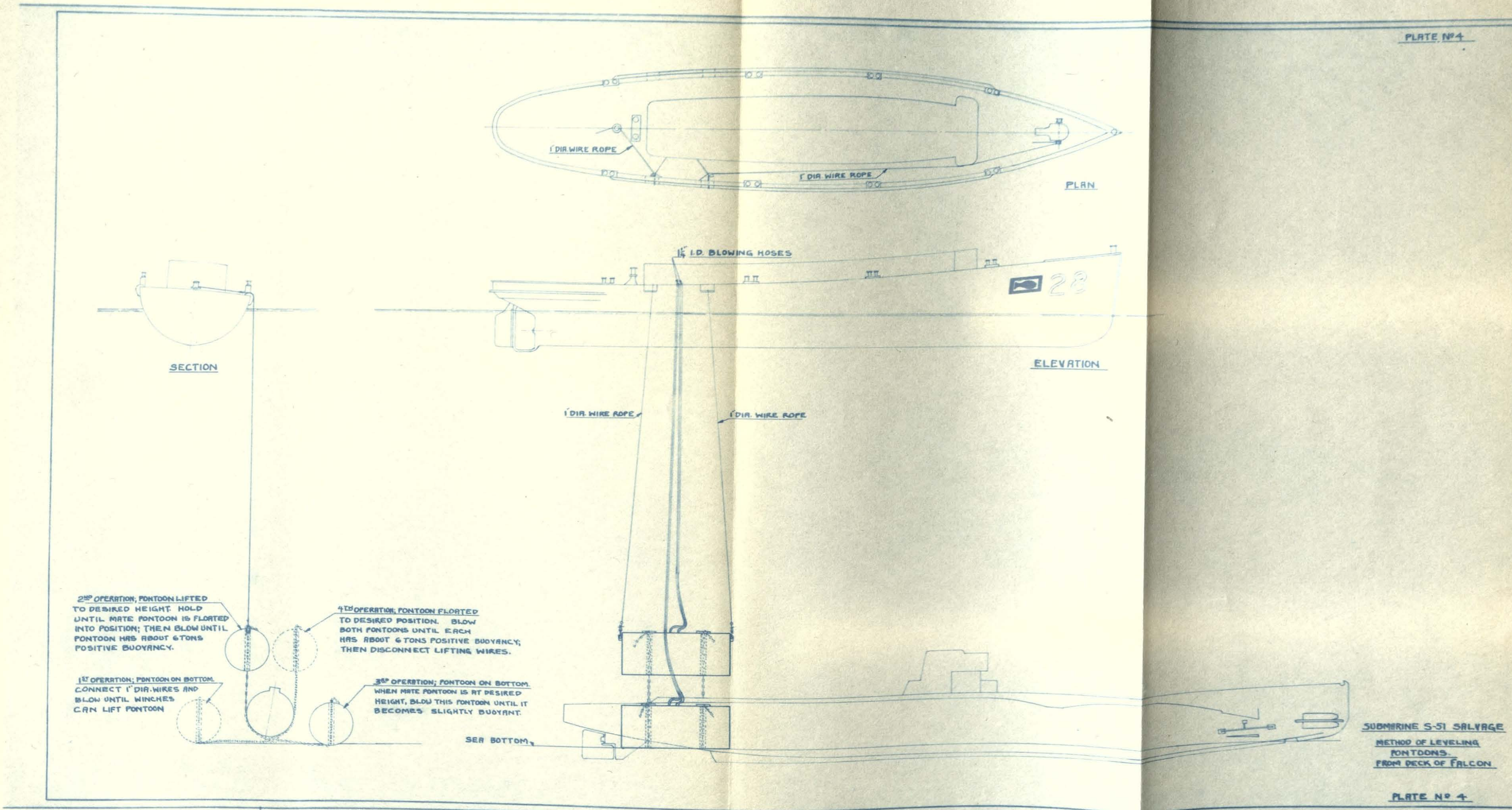


PLATE No 4
1" DIA. WIRE ROPE
1" DIA. WIRE ROPE
PLAN
1½" I.D. BLOWING HOSES
28
SECTION
ELEVATION
1" DIA. WIRE ROPE
1" DIA. WIRE ROPE
2ND OPERATION; PONTOON LIFTED TO DESIRED HEIGHT. HOLD UNTIL MATE PONTOON IS FLOATED INTO POSITION; THEN BLOW UNTIL PONTOON HAS ABOUT 6 TONS POSITIVE BUOYANCY.
4TH OPERATION; PONTOON FLOATED TO DESIRED POSITION. BLOW BOTH PONTOONS UNTIL EACH HAS ABOUT 6 TONS POSITIVE BUOYANCY; THEN DISCONNECT LIFTING WIRES.
1ST OPERATION; PONTOON ON BOTTOM. CONNECT 1" DIA. WIRES AND BLOW UNTIL WINCHES CAN LIFT PONTOON
3RD OPERATION; PONTOON ON BOTTOM. WHEN MATE PONTOON IS AT DESIRED HEIGHT, BLOW THIS PONTOON UNTIL IT BECOMES SLIGHTLY BUOYANT.
SEA BOTTOM
SUBMARINE S-51 SALVAGE
METHOD OF LEVELING PONTOONS.
FROM DECK OF FALCON
PLATE No 4

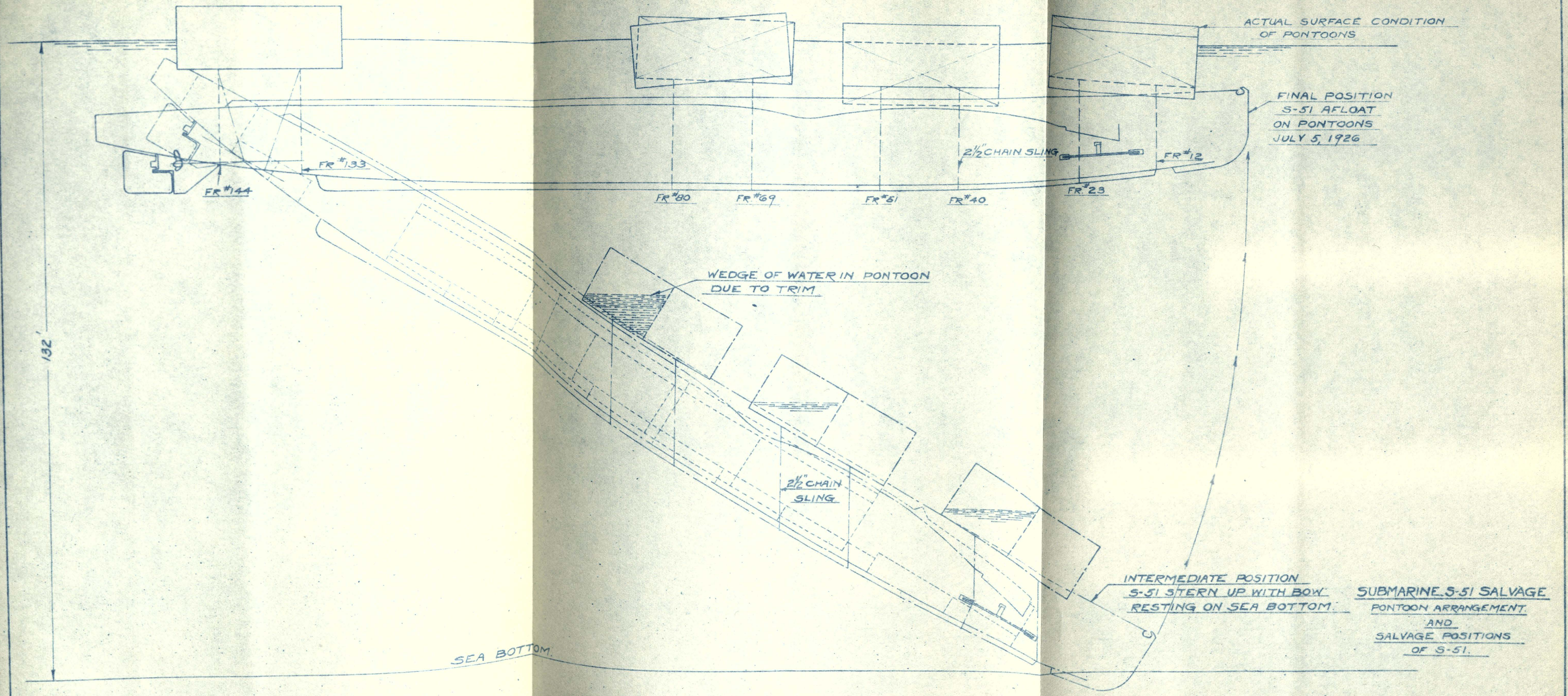
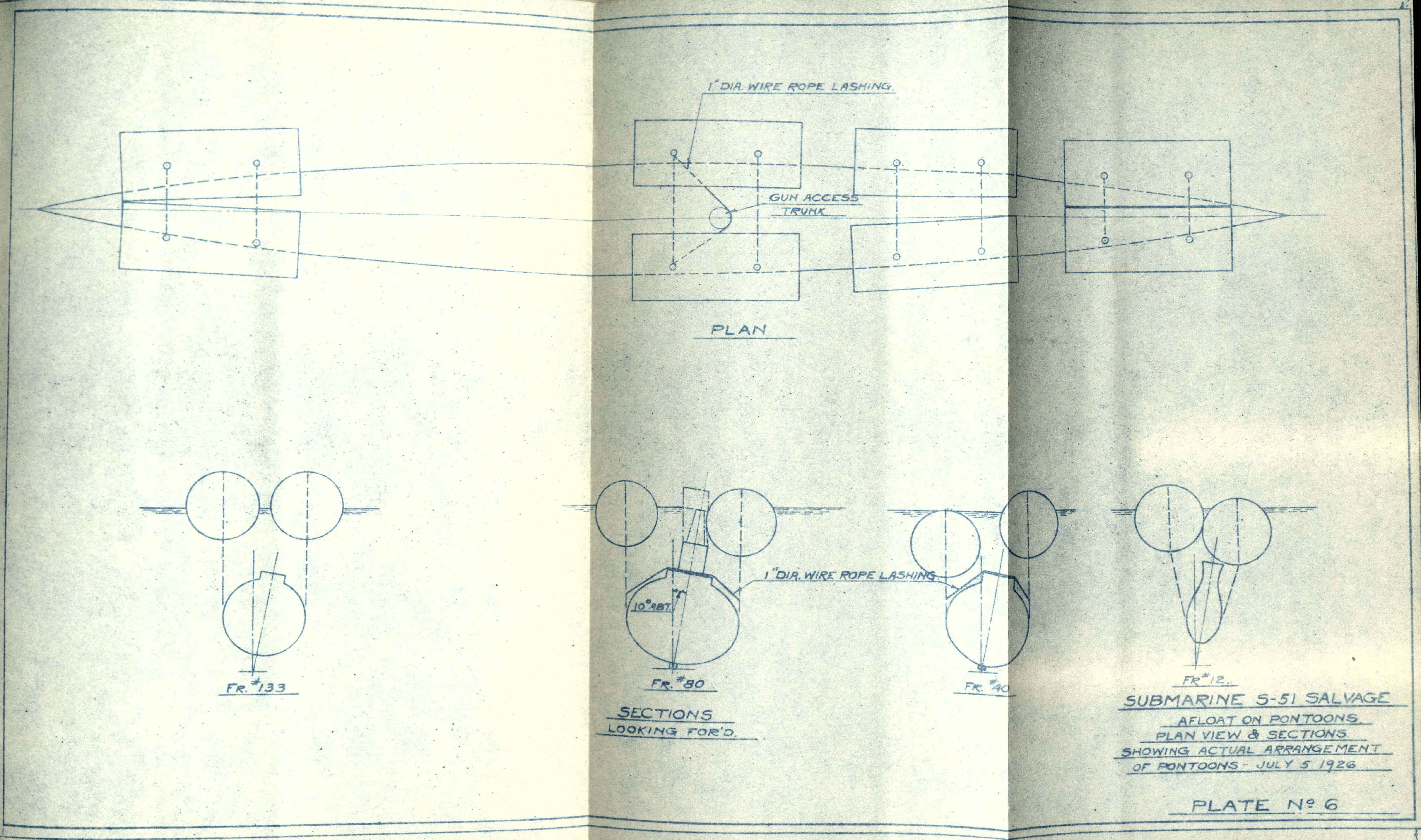

ACTUAL SURFACE CONDITION OF PONTOONS
FINAL POSITION S-51 AFLOAT ON PONTOONS JULY 5, 1926
2½" CHAIN SLING
FR #12
FR #133
FR #144
FR #80
FR #69
FR #51
FR #40
FR #23
WEDGE OF WATER IN PONTOON DUE TO TRIM
132'
2½" CHAIN SLING
INTERMEDIATE POSITION S-51 STERN UP WITH BOW RESTING ON SEA BOTTOM.
SEA BOTTOM.
SUBMARINE S-51 SALVAGE
PONTOON ARRANGEMENT AND SALVAGE POSITIONS OF S-51.

PLATE Nº 5.


1" DIA. WIRE ROPE LASHING.
GUN ACCESS TRUNK
PLAN
1" DIA. WIRE ROPE LASHING.
10° ABT.
FR. #133
FR. #80
FR. #40
FR. #12
SECTIONS LOOKING FOR'D.
SUBMARINE S-51 SALVAGE
AFLOAT ON PONTOONS
PLAN VIEW & SECTIONS
SHOWING ACTUAL ARRANGEMENT
OF PONTOONS - JULY 5 1926
PLATE Nº 6

S-51 FALL SALVAGE OPERATIONS

DAILY RECORD

1925		1925		1925		1925		1925		
		OCT. 30	X	NOV. 10	X	NOV. 21	X	DEC. 2	**X**	
OCT. 20	**X**	31	**X**	11	X	22	**X**	3	**X**	
21	**X**	NOV. 1	X	12	X	23	**X**	4	**X**	
22	X	2	X	13	**X**	24	**X**	5	**X**	
23	X	3	**X**	14	**X**	25	**X**			
24	X	4	**X**	15	**X**	26	**X**			
25	**X**	5	X	16	**X**	27	**X**			
26	**X**	6	**X**	17	**X**	28	**X**			
27	**X**	7	X	18	X	29	**X**			
28	X	8	**X**	19	**X**	30	X			
29	**X**	9	**X**	20	X	DEC. 1	**X**			

NOTE:

X INDICATES A NON-DIVING DAY.

X INDICATES A DIVING DAY.

S-51 SPRING SALVAGE OPERATIONS

DAILY RECORD

1926		1926		1926		1926		1926		
APRIL 23		MAY 9	**X**	MAY 25	**X**	JUNE 10	X	JUNE 26	X	
24	X	10	X	26	X	11	X	27	X	
25	X	11	X	27	X	12	X	28	X	
26	**X**	12	**X**	28	X	13	X	29	**X**	
27	X	13	X	29	X	14	X	30	X	
28	**X**	14	X	30	X	15	X	JULY 1	X	
29	**X**	15	X	31	X	16	**X**	2	X	
30	X	16	**X**	JUNE 1	**X**	17	X	3	X	
MAY 1	X	17	**X**	2	**X**	18	**X**	4	X	
2	X	18	X	3	**X**	19	X	5	X	
3	X	19	X	4	**X**	20	X			
4	**X**	20	**X**	5	X	21	X			
5	X	21	X	6	**X**	22	**X**			
6	X	22	X	7	**X**	23	X			
7	X	23	X	8	**X**	24	X			
8	X	24	**X**	9	**X**	25	X			

SUBMARINE S-51 SALVAGE

RECORD OF DIVING DAYS

PLATE No. 7

TRIM LINE

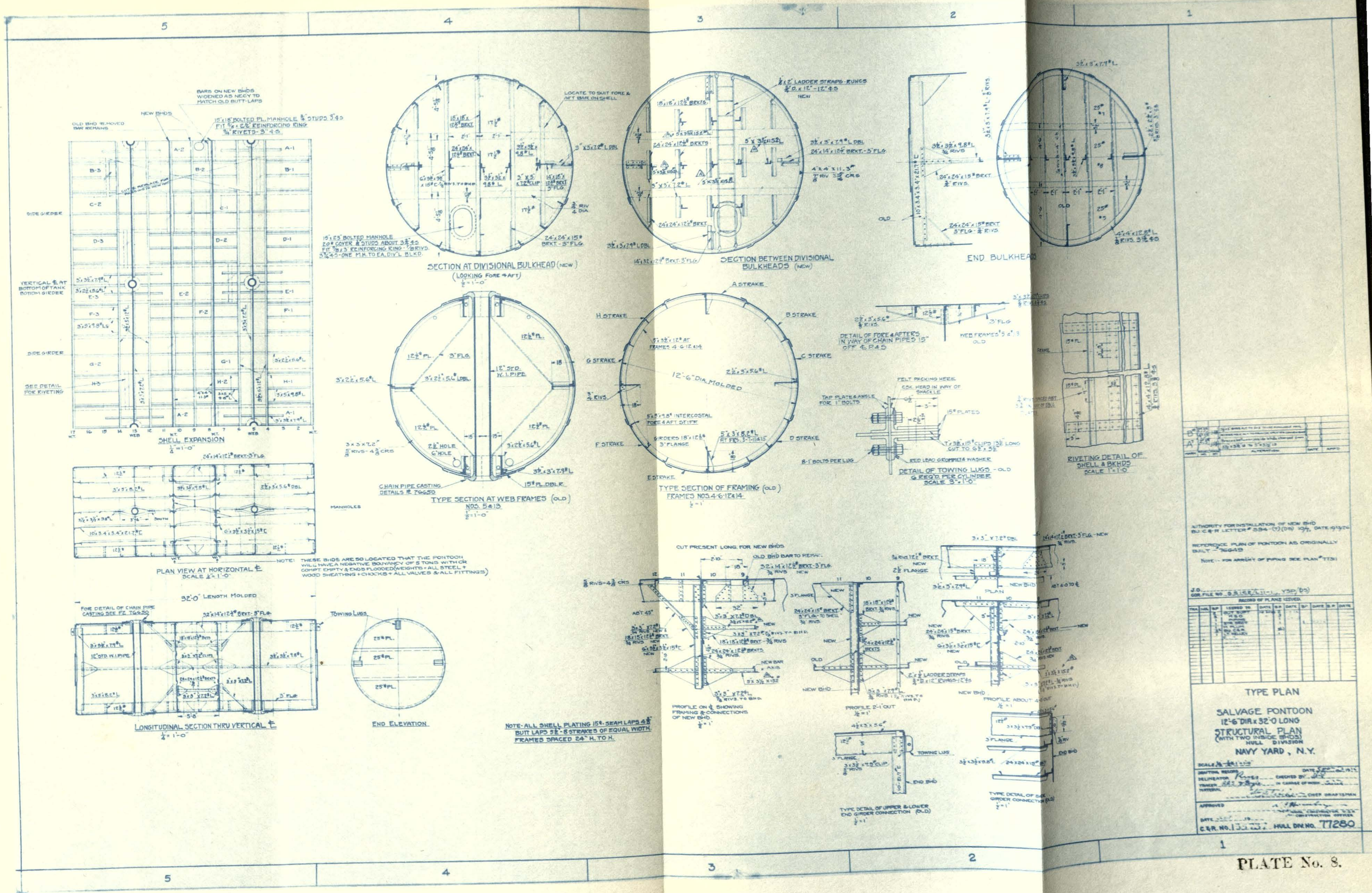

SHELL EXPANSION
PLAN VIEW AT HORIZONTAL ℄
32'-0" LENGTH MOLDED
LONGITUDINAL SECTION THRU VERTICAL ℄
TOWING LUGS
END ELEVATION
SECTION AT DIVISIONAL BULKHEAD (NEW)
SECTION BETWEEN DIVISIONAL BULKHEADS (NEW)
END BULKHEAD
TYPE SECTION AT WEB FRAMES (OLD)
12'-6" DIA. MOLDED
TYPE SECTION OF FRAMING (OLD)
DETAIL OF TOWING LUGS - OLD
RIVETING DETAIL OF SHELL & BKHDS
TYPE PLAN
SALVAGE PONTOON
12'-6" DIA x 32'-0 LONG
STRUCTURAL PLAN
(WITH TWO INSIDE BHDS)
HULL DIVISION
NAVY YARD, N.Y.
HULL DIV. NO. 77280

PLATE No. 8.

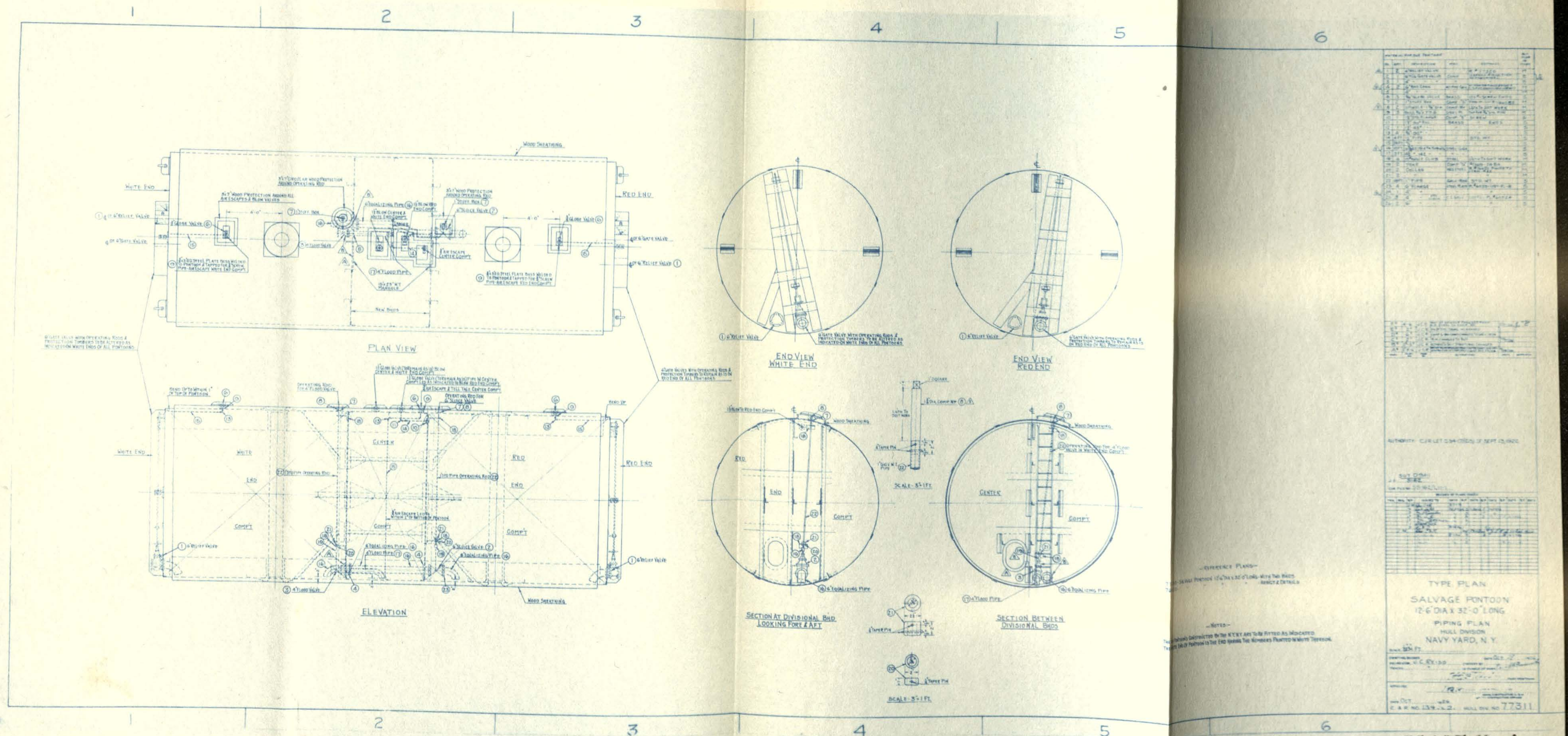
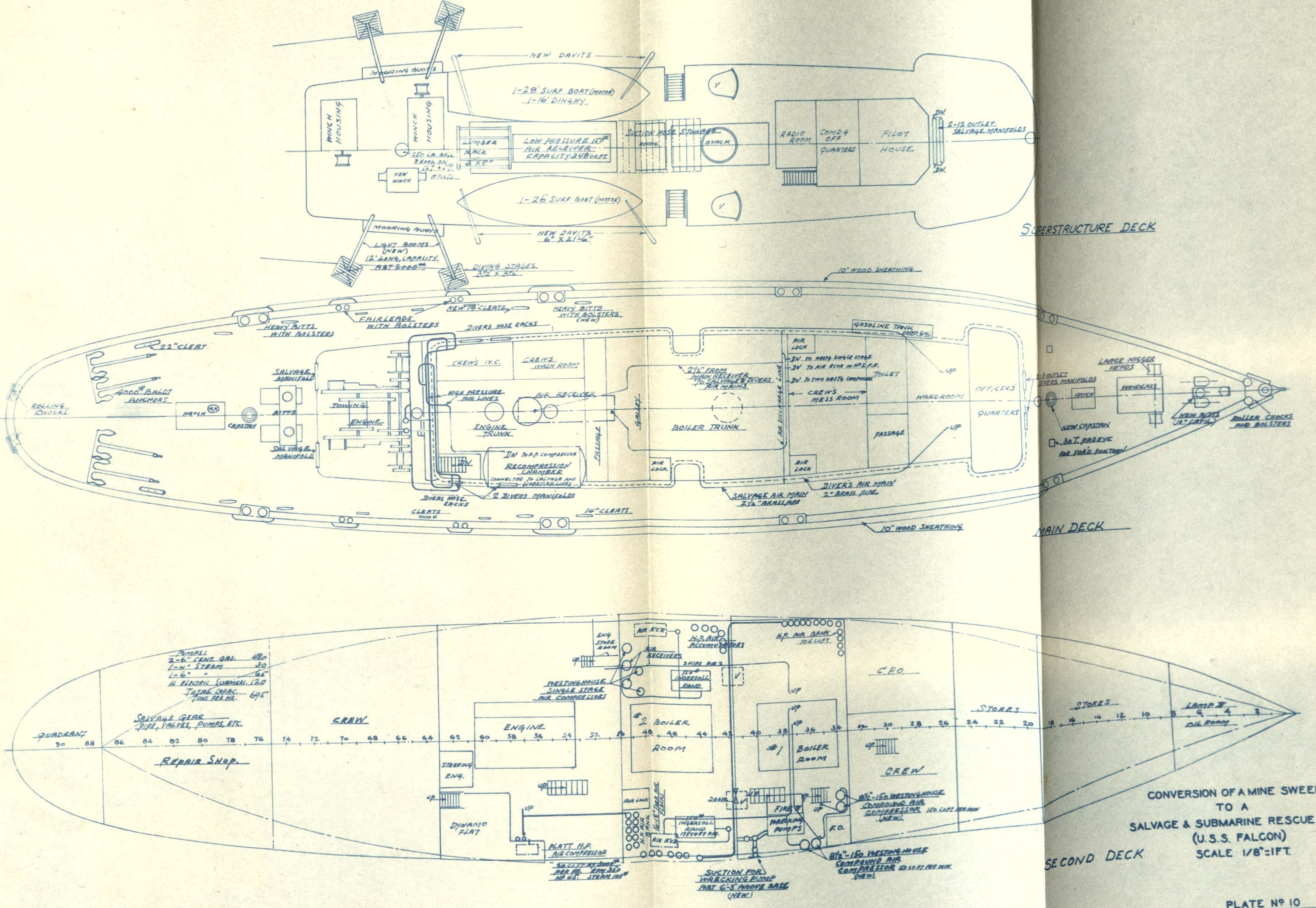

PLAN VIEW
ELEVATION
END VIEW WHITE END
END VIEW RED END
SECTION AT DIVISIONAL BHD LOOKING FORE & AFT
SECTION BETWEEN DIVISIONAL BHDS
WHITE END
RED END
CENTER
TYPE PLAN
SALVAGE PONTOON
12'-6" DIA X 32'-0" LONG
PIPING PLAN
HULL DIVISION
NAVY YARD, N.Y.
HULL DIV. NO. 77311

PLATE No. 9.



CONVERSION OF A MINE SWEEPER TO A SALVAGE & SUBMARINE RESCUE VESSEL (U.S.S. FALCON)
SCALE 1/8"=1FT.

PLATE No 10