Engineering News-Record

Devoted to Civil Engineering and Contracting. McGraw-Hill Publishing Company, Inc.

August 5, 1926

Raising Submarine S-51: Pioneer Engineering in Deep-Water Salvage

Keeping Salt Water Out of Lock-Controlled Waterways

Deep Caisson Cellar Walls Braced by Floor Steel Before Erecting Columns

Suggested Improvements in Macadam Road Design

Building New York's Third Subway System
Fourth Article of the Series

Irrigation District Served by Series of Pumping Plants

Dredges dammed up in elevated pools to facilitate disposal of excavated material

Pioneer Engineering in Deep-Water Salvage —Raising the Submarine S-51

A Brief Account of Open-Sea Diving Work at 132 Ft. Depth—Hull of Vessel Successfully Broken Loose From Clay Bottom—Underwater Repair Work—Tunneling With New Jetting Nozzle

ON JULY 9 a five months' struggle against the elements and against great technical obstacles came to a successful end when Lieut.-Commander Edward Ellsberg, of the Construction Corps, U. S. Navy, brought the hull of the rammed and sunk submarine S-51 to dry dock at the New York Navy Yard. The submarine had been raised after lying 132 ft. deep in the Atlantic Ocean east of Block Island for eight months, and, suspended by chain slings from a series of tank pontoons, had been brought through 20 miles of open sea and 130 miles of Long Island Sound and Hell Gate to the dock. The achievement was the product of precise calculations, inventive ingenuity, the skill of the best marine craftsmen, and a tremendous amount of dogged persistence. It proved the technical judgment and the courage of the men who early in the winter decided that the ship could be raised and who subsequently stuck to the work against all discouragements. Their plans finally succeeded at each stage of the undertaking—though at one point the resourcefulness of a machinist, who devised a new and completely successful under-water hydraulic excavator, was the vital factor in bringing about this success.

The story of how the campaign was fought through is Commander Ellsberg's own, set down here in impersonal form from his recital of the facts. It need only be prefaced with the reminder that on September 25, while engaged in maneuvers south of the Rhode Island coast, the S-51 was run down by the freight steamer "City of Rome" under way from Savannah to Cape Cod Canal, received a deep gash in her port side near the bow and sank almost immediately with practically all of her crew; that some days were spent in vain efforts to rescue those who might still be alive in the boat, hope being finally given up; and that thereupon the naval authorities decided that the boat could be raised and undertook the task.

During these first days of rescue attempt, two large derrick boats, of 250 tons combined lifting capacity, were sent out from New York to make an attempt to hoist the submarine to the surface. But these heavy vessels, unseaworthy in rough open water, had to wait five days in Point Judith Harbor for weather smooth enough to permit them to go out to the location of the wreck, 20 miles off shore, and then, after trying for half a day to lift the boat, were forced to give up the attempt as impossible and hurried back to safe harbor.

To come to Commander Ellsberg's story:

Conditions of the Work—It was necessary to raise a vessel weighing around 1,000 tons, lying on the bottom in water 132 ft. deep in the open ocean, out of sight of land in any direction. The bottom was a hard clay, practically a bed of shale, so hard that when the boat was sunk, going down bow first, it struck the bottom with a blow that buckled the shell in a series of wrinkles some 50 ft. back of the stem, in way of the torpedo compartment bulkhead. A wedge of the clay, brought up on the fluke of an anchor that had been lost in the early salvage operations and was later recovered, proved to be almost dry inside when broken open. Yet the ground was plastic enough so that under the weight of the ship it molded itself to the hull, which settled down into the bottom to a depth of some 7 ft. This hard and yet plastic bottom turned out to be one of the crucial elements of the problem.

It was already known that attempts to lift the ship by derricks were quite hopeless, at least out in the open sea, where at most two days out of seven were quiet enough for salvage work. The raising therefore had to be done either by providing sufficient internal buoyancy to cause the ship to float itself, or else by lifting the vessel by external buoyancy.

The physical condition of the ship was known, in detail, from minute inspections by divers. Of the five compartments into which the ship is divided by four transverse bulkheads, it was believed that three could be made watertight and thus would be available to provide internal buoyancy. The second compartment from the bow—the bunk room and battery space—was cut wide open by the prow of the colliding steamer; the torpedo compartment in the bow also could not be made tight. With the three undamaged compartments supplemented by submersible pontoons it would be possible to provide the necessary buoyancy for lifting the weight of the ship. The great unknown element was the suction effect of the bottom, the adhesion of the hull to the clay in which it was embedded.

Previous naval experience gave good reason for apprehending a large suction effect. In the recovery of torpedoes that had settled in clay bottom it has happened that a lifting line attached to the tail broke the body of the torpedo in two, so firmly did the suction of the bottom hold it down. In the case of the submarine, if its steel shell was everywhere in intimate contact with the clay, a large part of the weight of the overlying water might act to hold them together; and at the depth here involved this meant a resistance or anchorage of perhaps 6,000 to 8,000 tons.

Before the submarine could be lifted, then, it would be necessary to break the suction. There was reason for thinking that this could be done, as by applying a slow steady pull at one end with a view to gradually loosening the boat from its bed. Later, actual trial showed that this part of the undertaking was easier than anticipated. The work therefore required that buoyancy be provided to lift the total weight, that this buoyancy be applied in such a way as to overcome the suction of the bottom, and that there be a sufficient reserve buoyancy for all emergencies while towing the vessel 150 miles to the New York Navy Yard, the only available docking place. Accordingly, eight buoyancy tanks, each a cylinder 13x32 ft., were provided, capable of giving a net lift of 80 tons per tank or 640 tons in all. These tanks were built with heavy hawse-hole castings for sling chains, and with the necessary means for admitting and blowing out water. Together with the three after compartments of the submarine (supplying 450 to 500 tons of buoyancy) they gave a total lifting power of about 1,100 tons.

Breaking the Suction—Before the equipment for lifting was ready, an attempt was made to break the suction of the bottom by using the undamaged submergence tanks of the submarine on one side for rolling the ship. The vessel as she lay on the bottom is roughly sketched in the adjoining cross-section, Fig. 3. The hull, slightly oval in shape, was lying with a list of about 13 deg. to port; the keel was embedded in the bottom, while the starboard bilge keel was clear. The body of the ship consisted of two concentric shells; the space between the two shells (and below the non-watertight upper portion of the outer structure) was subdivided into a number of separate tanks for use in submerging and emerging. Cylinders of high-pressure air in the ship, controlled by valve manifolds in the control room amidships, were the means of supplying air for emerging, while mechanically operated sea valves admitted water to submerge.

In spite of the collision and sinking, and months of submergence, the high-pressure air cylinders were found still intact, as was the piping and control bank except for certain pipes on the port side forward of the control room, which had been cut through in the collision and had emptied the cylinders to which they connected. The remaining high-pressure air proved to be sufficient for blowing out the intact port-side submersion tanks. The starboard tanks were left full, and thus a port-side lift of some 80 tons was applied, producing a righting moment of about 800 foot-tons in opposition to the list of the vessel.

Care and much courage were required for blowing out the tanks in this way. The divers, after orienting themselves in the control room and at the valve banks, had to turn specific plugs in specific banks of the group of manifolds, according to detail instructions from the men above, who knew the layout of the system from the construction plans. It must be borne in mind that the divers in performing these manipulations were deep inside the vessel after having entered by a narrow, tortuous passage, and that there was a chance of their being buried in the hull beyond rescue if the boat should suddenly roll over. Their work here called for steadfast courage. However, no accident occurred, and the tanks were successfully blown out.

The buoyancy lift on the port side as indicated was left on about a week, without noticeable effect. Then, over night, the ship rolled over until it had about the same list to starboard as formerly to port. The continued rolling moment must have brought pressure to bear on the starboard edge of the clay bed, slowly crushing it down and progressively loosening the contact between hull and clay at the port side until the boat was free to roll over in obedience to the righting moment.

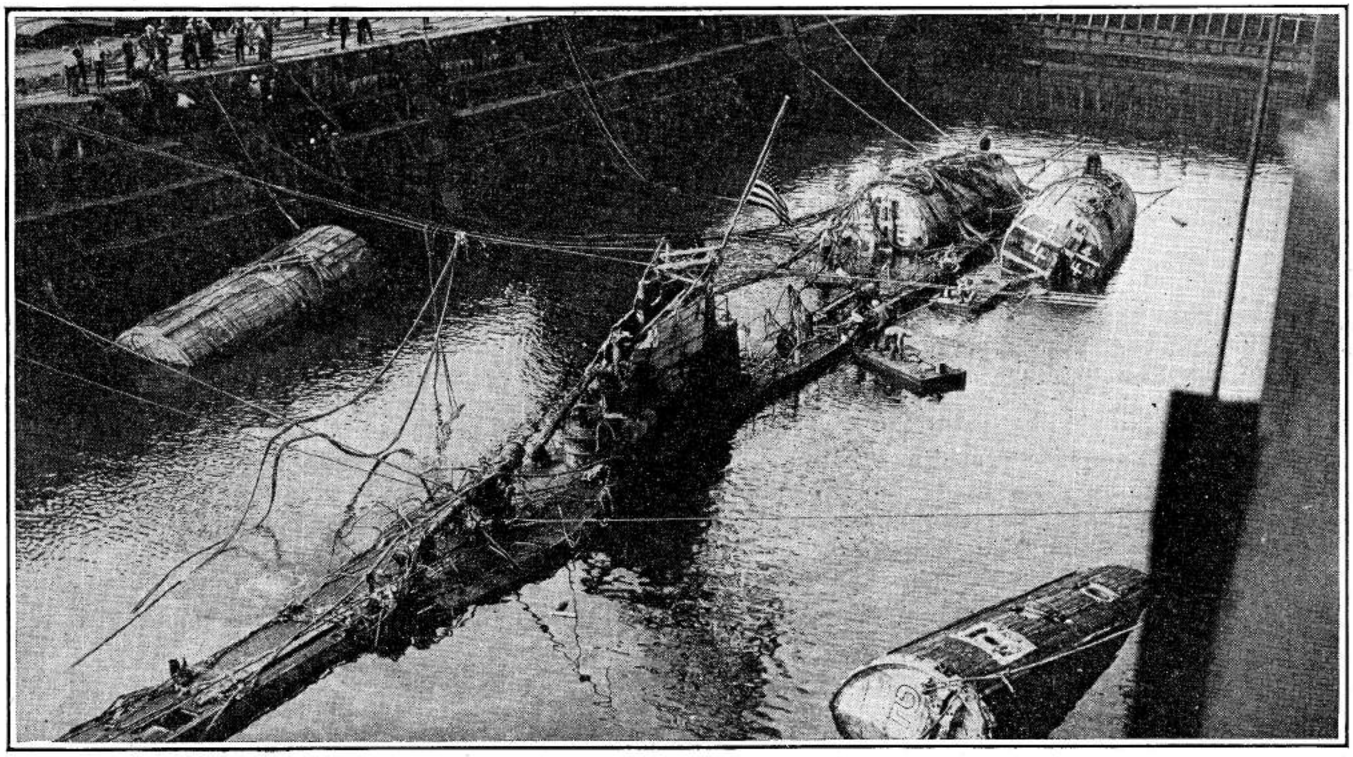

FIG. 1—SUBMARINE S-51 IN DRYDOCK AT BROOKLYN NAVY YARD

With this development the matter of the suction at the bottom disappeared from the problem. It was known that the boat could be broken loose whenever all was ready for the lifting.

Preparations for Lifting—Apart from providing the eight large tanks, two things had to be done: (1) Clear the water from the three rear compartments of the submarine in order to make these buoyant, and (2) Pass four pairs of chain slings under the hull for connection to the tanks. It turned out that each of these items involved almost interminable tasks and difficulties, which called for new expedients and methods almost daily.

Most of the work was done this spring, operations being resumed early in April. At the time of shutting down for the winter, in December, two large buoys had been placed by the lighthouse bureau, one on each side of the wreck, so that it could be found again. But when the working party arrived in April, it found the two buoys seven miles apart, neither one being near the estimated position. No such evidences as oil patches or air bubbles, which had made the wreck easy to find in November, were now available, and dragging had to be resorted to, using a wire drag and grapnels. Fortunately, on the second day a small piece of rubber hose brought up by the grapnels centered the search on a small area; within the day the drags struck something, and a diver who went down landed squarely on the deck of the submarine.

Sealing the Compartments—As to the first of the two jobs; all of the doors between compartments were found open, the water having come in too suddenly when the collision occurred to give time for the least protective action. Various interconnecting valves were open. A number of pipe lines communicating between compartments and tanks and the outside had to be cut and blanked off. A butt joint in the outside shell plating near the rear of the motor compartment was leaking badly on its entire 5-ft. length. Several rivets were pulled loose and leaking near the stern, where an anchor had been dropped over the tiller room and had dented the shell. Overcoming these and many other difficulties so as to restore all possible internal buoyancy was a long and tedious campaign, of which, however, only one or two items can be mentioned here.

The leaking butt joint of the plating was calked very effectively by first filling the open space between the plate ends, about one-eighth inch wide, with improvised lead wool made by bunching up electrical fuse wire, and then split-calking the two plates. The leaking rivets over the tiller-room were sealed by replacing one rivet by an expanding lead plug whose upper end was then calked down, and by calking the heads of the other rivets very carefully. Large pipe lines that could not be controlled were cut by unbolting them at joints and making plate-iron blank flanges, marking and drilling them for the bolt holes, and bolting them in place with gaskets.

Grouting was resorted to for one or two special troubles. Two large automatic check valves on exhaust lines from the compartments had to have the valve flaps locked down, since as built they were free to open outward and thus would open under the internal air pressure which would be applied in blowing out the compartments. No feasible way of doing this could be found until the plan was conceived of grouting solid the space above the valve, thereby holding it down securely. Experiments were made with various cement and grout mixtures, and from these alumina cement was selected as giving the best assurance of working satisfactorily. Accordingly, a 1-in. pipe was screwed into the casing over the valve, carried up to the surface and to the deck of one of the salvage tenders, a height of nearly 150 ft., and cement grout was pumped down until the bonnet and pipe would take no more. After a day's setting the valve proved to be tight.

In all these and associated operations, much cutting, drilling and calking had to be done down in the depths. An oxy-hydrogen torch was developed which would cut steel successfully under water, and Commander Ellsberg, who developed it, made the first under-water cuts with it. Pneumatic drills, calking, chipping and riveting hammers were used with entire success, usually with about 150 lb. air pressure—giving about the same effective pressure as when working with 85 to 100-lb. air under ordinary conditions. Drilling was done in plates as thick as 1 in. The chief difficulty with the air tools was that as soon as they started operating they discharged a great cloud of bubbles in the water, so that the operator was quite unable to see his work but had to be guided by touch.

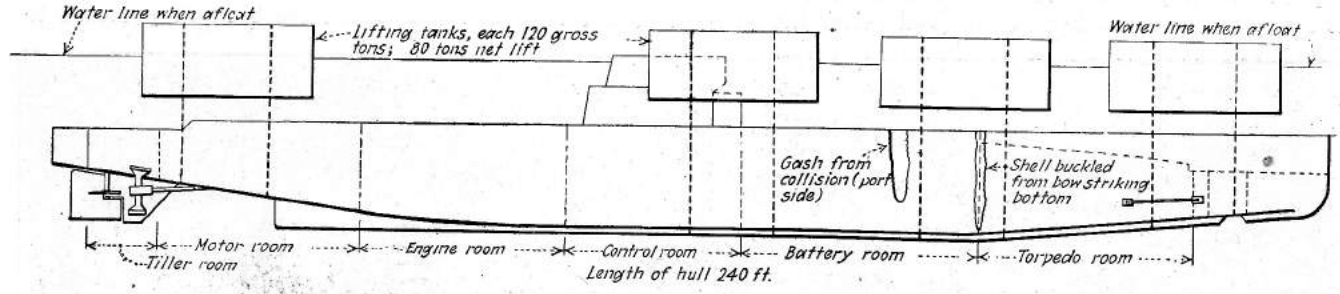

FIG. 2—COMPARTMENTS AND PONTOONS USED TO PROVIDE THE REQUIRED BUOYANCY

Tunneling Under the Hull—However difficult the necessary work within the hull of the ship, yet the placing of the pontoon slings was in certain respects the critical part of the work. The slings were to be of large stud-link anchor chain, of 2½-in. bar diameter. Three of the eight slings could be placed directly, the bow and stern parts of the ship being clear of the bottom; the other five, however, had to be passed through tunnels dug in the clay under the hull.

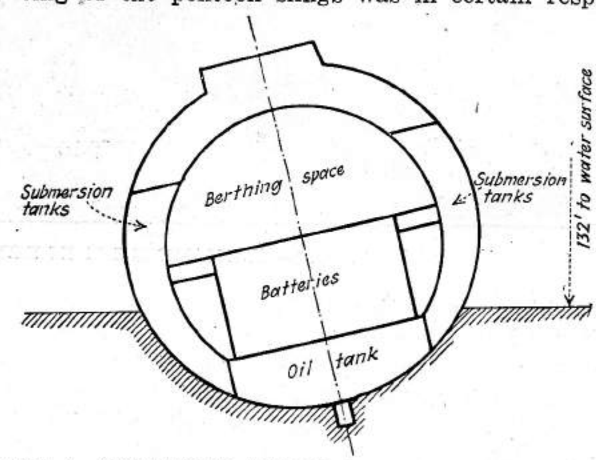

FIG. 3—SUBMARINE S-51 BEFORE RAISING—SKETCH CROSS-SECTION

The clay was both hard and sticky, and in the first tunneling operation, last December, divers working in shifts at a tunnel from one side only worked continuously (so far as weather permitted) for five weeks without being able to reach the keel. It was necessary to work with water jets. No progress could be made with shovels, as it took five minutes to dig a shovel in and fifteen minutes to pry the clay loose from the shovel blade. On the other hand when the diver tried a 2½-in. hose and nozzle the reaction of the 50-lb. jet promptly shot him back many yards away from his work, while the hose writhed around in the water; his effective weight was hardly more than 60 lb., and he could not hold against the reaction. It was necessary to reduce the jet to 1 or $1\frac{1}{2}$ in., and with this equipment, using 70-lb. pressure, the divers were able to dig in.

Work was infinitely slow under these conditions. The small stream had little digging power and its flow volume was too small to wash the loosened material back out of the hole. The tunnel tended to fill in behind the digger, so that sometimes after working in he had to turn around and wash his way out again. In addition, when after a few days of digging it was necessary to stop because of rough weather, the water refilled much of the completed tunnel.

In April, when work was resumed, two sets of divers working from opposite sides of the hull managed to tunnel their way down to the keel in two weeks of hard work; then, one of them shoving his foot through the final wall, the other succeeded in hitching a $\frac{3}{8}$-in. line to it, and the first sling was provided for. The small line was used to pull a $1\frac{1}{4}$-in. manila rope through, this in turn pulled a 1-in. plow steel rope through, and this served for hauling in the heavy sling chain for attaching the pontoons.

In establishing this connection under the hull, the two divers made the second longest dive of the entire enterprise, working at full depth for $2\frac{1}{2}$ hours — most of which was spent in trying to find the foot that had been pushed through and hitching the line to it.

A New Excavator Jet—It became evident that five tunnels would require a hopelessly long period of time, unless a quicker way of working could be found. Meantime, however, a machinist's mate, Waldern by name, assigned to running one of the engines on the salvage tender, conceived a plan for a nozzle that would have no jet reaction. In his idle time he made such a nozzle, and when completed asked that it be tried. It was tried, and it turned out to be a complete success.

This nozzle, to fit a $2\frac{1}{2}$-in. hose, had a full size forward jet, and five smaller jets pointing backward at an angle to balance the forward reaction and at the same time to clear the debris out of the hole. With this nozzle, a diver had no difficulty in handling the jet, even at 150 to 200 lb. pressure, and a tunnel was put through in two days' work, excavating from one end only.

Diving Under High Air Pressure—All of the great amount of diving work done in carrying out these tedious operations had to be done under air pressures of 58 to 65 lb. per sq.in.—as compared with the 50-lb. pressure which is the extreme maximum for caisson foundation work, or 40-lb. (90-ft. depth) usually considered the greatest depth at which effective diving can be done.

Because of these unprecedently severe conditions, work was limited to one hour, and $1\frac{1}{2}$ to 6 hrs. time was taken for decompression, either by raising the diver very slowly or by putting him in a recompression tank on board the tender after emerging. In spite of all precautions, many cases of bends occurred, but there were no fatalities, though one case was dangerously severe.

Submarine Returned to Port—After the successful placing of the sling chains the pontoon tanks were sunk,

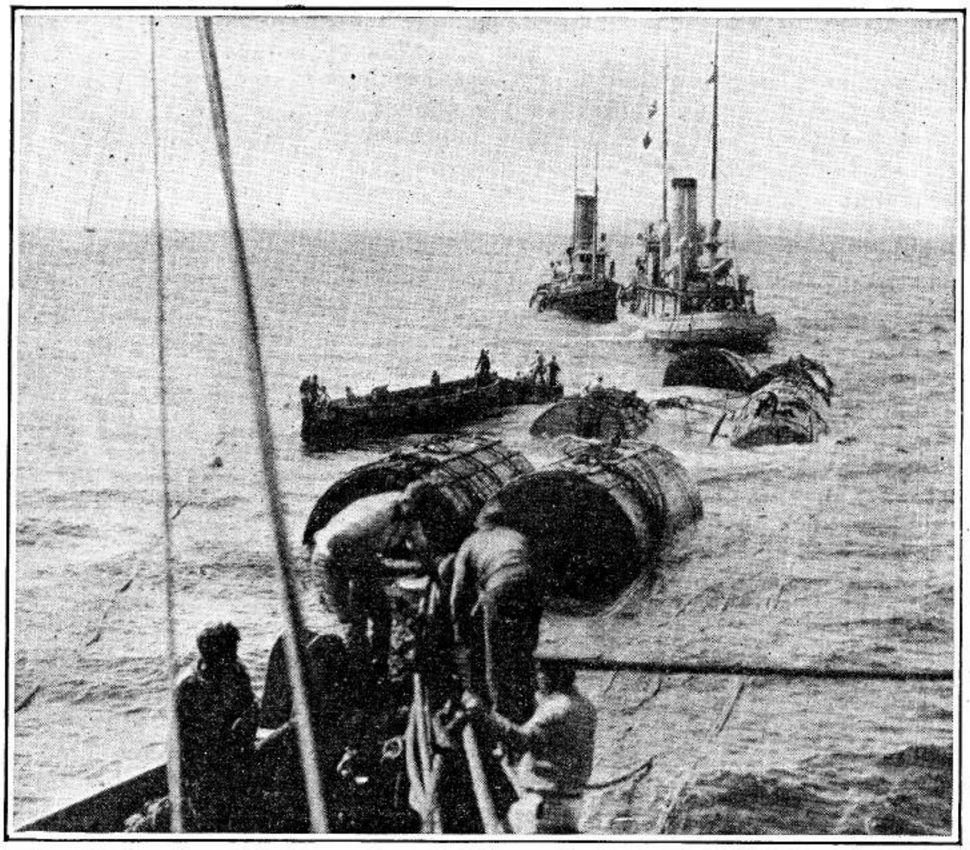

FIG. 4—ON THE WAY TO NEW YORK

the chains were pulled through the hawse-holes in the tanks and secured with nickel steel toggles. Blowing out the tanks and the sealed compartments of the submarine, preceded by application of a lift one end first, to break the suction, brought the hull to the surface and made all ready for the tow to the Navy Yard. There were two almost disastrous interruptions, one occurring in the course of the trip to New York, when a pilot grounded the submarine on Man-o-War Reef, in the East River, south of Hell Gate; but aside from cutting one pair of the sling chains, causing the loss of two pontoons, and requiring the readjustment to the other pontoons to compensate, this produced nothing worse than half a day's delay, the hull being practically uninjured by the grounding.

Steel in Excellent Condition—When finally docked in the Navy Yard, the S-51 showed no injury to her framework and plating from the eight months' submersion, but appeared entirely sound except for her mechanical injuries and the deterioration of paint, battery plates and other perishable equipment. The steel of the structure was free from rust, and the vessel is fit for reconditioning.