NAVSHIPS 0900-004-8000
(FORMERLY NAVSHIPS 250-694-3)

REFLOATING

OF THE

U. S. S. MISSOURI
(BB-63)

NAVY DEPARTMENT
BUREAU OF SHIPS
WASHINGTON, D. C.

DEPARTMENT OF THE NAVY

BUREAU OF SHIPS

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1. NAVSHIPS 250-694-3, a ~~restricted publication,~~ is a comprehensive technical report submitted by the Salvage Branch, Bureau of Ships, covering the operations in connection with the refloating of the U. S. S. *Missouri* (BB-63).

2. The stranding of the U. S. S. *Missouri* on 17 January 1950 aroused great public interest. She was refloated 15 days later through the efforts and use of personnel and facilities which were almost exclusively of the Navy. Aside from the main objective, which was the refloating of the ship, the operation served as a valuable and realistic exercise in training of personnel in salvage work. Salvage played a vital role in the last war, and will again in any future emergency.

3. While no salvage measures of radically new conception were resorted to, the work involved was extensive and diversified. It is believed that this report will be of professional interest to most engineering officers as well as many line officers.

4. Copies of NAVSHIPS 250-694-3 may be obtained by authorized Naval Personnel upon request to the Bureau of Ships.

D. H. CLARK,
Rear Admiral, U. S. N.,
Chief of Bureau.

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I

PRELIMINARY

Ships have run aground in the past and will do so in the future, regardless of the improved aids to navigation that have been developed through the years. In most cases, the average person is not aware of the stranding unless it is in his immediate vicinity, and the salvage work that follows is not of sufficient general interest to merit attention except to those intimately concerned with the ship or the work of freeing her. Occasionally, however, a ship is involved in a marine disaster that arouses public interest. The U. S. S. *Omaha*, which stranded in the Caribbean Sea in July 1937, was such a ship. There was the submarine U. S. S. *Squalus* which sank in approximately 250 feet of water off Portsmouth, N. H., while on diving trials in May 1939. The U. S. S. *Lafayette* (ex-*Normandie*) which capsized alongside her berth in New York Harbor in February 1942, as a result of a fire, was another. There were, of course, others. Such a ship also was the U. S. S. *Missouri.*

On 17 January 1950 the U. S. S. *Missouri*, the only battleship in commission in the United States Navy, was proceeding to sea on a training cruise from the Naval Operating Base, Norfolk. She was well loaded with fuel, provisions, and ammunition, and in fact was in her full-load condition. At about 0825, which coincided very closely with high tide, the *Missouri* ran aground off Hampton Roads, Va. Her speed was about 12 knots, which resulted in her traversing shoal water a distance of three ship lengths (approximately 2,500 feet) from the main channel. She finally stopped at a point 1.6 miles bearing 266° T from Thimble Shoals Light, near Old Point Comfort, on a heading 053° T. The *Missouri* was refloated at 0709 on 1 February, on the morning high tide.

Upon getting underway the *Missouri's* drafts were recorded as 35′9″ forward and 36′9″ aft. Soundings taken soon after grounding were reported to be 29 feet forward and 30 feet aft. These drafts were believed from the start to be only approximate. A subsequent study of draft readings with the *Missouri* aground and comparison with actual tide readings revealed that at mean low water the ship was resting on a gradual slope with drafts as follows:

	Feet
Forward	25.1
Amidships	27.0
Aft	28.7

It was found that actual tides as recorded at Sewell's Point agreed very closely with those existing at the *Missouri's* location. At a tide of 2.6 feet, which was the actual height of water recorded at Sewell's Point at time of grounding, her drafts were determined to be as follows:

	Feet
Forward	27.7
Amidships	29.6
Aft	31.3

Initial reports had indicated that the actual height of tide that morning was 3.3 feet, which was recorded at Fort Monroe, or 0.7 foot above predicted, and, since the grounded location was not far from Fort Monroe, it was thought that the ship had grounded at an unusually high water. This fortunately was not the case as the later study showed the readings at Monroe to be consistently higher than at Sewell's Point or at the *Missouri's* location. In any event, the ship did ground at high tide.

It was apparent that the ship's propulsion plant would be inoperative during salvage operations due to clogging of injection and discharge seachests with sand. Power was lost incident to the grounding except for one emergency Diesel generator which continued to provide power for lighting. One main turbo generator was, however, restored to operation by the ship's force the same day and another during the next day. Moreover, potable water was available from the Naval Base as needed and fire and flushing water from portable 6″ submersible pumps rigged over the side, as well as from a fleet tug alongside. Good habitability was, therefore, quickly attained as well as sufficient power for other essential needs such as operation of deck winches which were later used with beach gear.

The approximate load on the ground of 12,000 tons, which was the difference in displacements before and after grounding as determined by draft marks, made it very apparent that the Navy was confronted with a major salvage operation, one that would require an appreciable period of time and would tax the ingenuity, skill, and patience of the men involved. The *Missouri* is big. Each inch of her mean draft lost in the grounding represented a weight of 150 tons that would have to be removed or the equivalent amount of buoyancy restored to refloat her. The fact that the ship had grounded at high water was indeed unfavorable. On the other hand, her being in a fully loaded condition was favorable.

II

DEVELOPMENT OF THE SALVAGE PLAN

Commander Cruisers Atlantic Fleet, the Type Commander, immediately took charge of salvage operations, with the Commander Norfolk Naval Shipyard as Deputy Commander of Operations. An analysis of the situation indicated that the *Missouri* was in no danger of loss or damage. She was in protected waters and not exposed to the destructive force of the elements. The salvage operation was not an off-shore salvage job where speed of action is of paramount importance. Moreover, the location was in the area of the Navy's greatest concentration of men, equipment, and facilities both afloat and ashore. Additional special salvage equipment could be readily provided from other areas to augment that which was available. In fact, if a ship of the Navy had to go aground, it could not have chosen a more convenient place. A consideration of the above factors, among others, led to the decision that the Navy could and would salvage the *Missouri* through its own efforts.

The lightening of the ship by removal of weights was an obvious step in the salvage. The *Missouri* was in practically her full-load condition and it was known that such weight removal would represent the biggest single factor in refloating her. Had she been in a lighter conditon of loading when she grounded, the salvage would, of course, have been considerably more difficult and might even have led to the necessity of off-loading permanent items of heavy equipment such as guns. Fortunately this was not necessary, nor contemplated even in original planning.

It was realized that when all readily removable weights such as liquids, ammunition, and stores had been taken off, the ship would be very close to her light condition, in which there would be a large trim by the stern. Accordingly, pontoons were considered and the decision made to install them at the stern. Dredging of an exit channel through the shoal water directly astern of the *Missouri* was almost as obvious a need as the removal of weights, particularly since it could be done quite readily and with no interference with other work. Advantage could also be taken of the presence of dredges to create a deep trough along each side of the ship with a view of settling her somewhat by the squashing out of the sand beneath her. Finally, whatever load there still remained aground after the above work had been completed would be small enough to pull off with a combination of beach gear and powerful tugs. A check of the stability characteristics of the ship in the conditions of loading through which she would pass showed her to be very stable with no remedial action necessary.

The general salvage plan adopted at the start of operations was, therefore, to refloat the *Missouri* to deep water:

(*a*) *By increasing her buoyancy and decreasing her displacement.*

(1) By removal of the maximum fluids, ammunition, stores, personnel, etc.

(2) By lifting her stern with pontoons.

(3) By dredging and tunneling the sand from under her and letting her settle further.

(*b*) *By pulling off.*

(1) With nine sets of beach gear.

(2) With 2 ARS(D) vessels fitted with specially powerful beach gear.

(3) With seven or eight pulling tugs.

(4) By using tugs for surging and twisting.

(*c*) *By dredging an exit channel.*

Tides would of course play an important part in the final refloating of the *Missouri*. Anything less than that at the time of grounding would necessitate additional work in one or all of the principal steps of the general plan. A greater tide than expected would serve to make the refloating easier to achieve and more certain. The general plan was predicated on the availability of about the same height of tide as existed at grounding, which would allow a modest factor of safety to take care of slight deviations. It was natural, therefore, that a target date of 2 February should be established for the refloating operation. Not only was the tide expected to be satisfactory, but there would be ample time to complete all the preparatory work that was required.

Since predicted tides were to be satisfactory for only several days before dropping to lower values again, full advantage had to be taken of the brief period when they were satisfactory. Not only was the combination of weight removal, gain in buoyancy due to pontoons and settling, and pulling effort to be sufficient to provide a suitable reserve, but, if for some reason there was no success in refloating on one day, additional measures would be ready for accomplishment prior to the next day's attempt. This did not reflect a lack of confidence with the extent of preparations planned, but rather it represented sound practice in providing for unforeseen contingencies.

The work involved would be varied, extensive, and rugged. A large number of men would be employed for relatively long hours. Some of them had previous experience in some phases of salvage work, but for most this was the first salvage operation with which they had personal contact. The situation was conducive to a series of accidents if suitable precautions were not taken and enforced. Safety was, therefore, to be stressed through education and insured with adequate and competent supervision. Salvage work, because of its nature, does not always adhere to customary factors of safety or it would not be done. Any deviations, however, should not be done through ignorance or lack of knowledge, but with a full understanding of the problems and with appropriate precautions.

The refloating of the *Missouri* was desired at the earliest practicable date. Even more important, however, was that the ship receive no additional damage as the result of salvage work which would necessitate subsequent prolonged repairs at the Naval Shipyard. Thoroughness was, therefore, to be favored over speed in case of any confliction between them.

The effort did not represent a total loss, however, for it proved to be a valuable exercise in coordinating a large group of vessels which was to prove useful later. One of its lessons was to fuel the tugs fully before succeeding pulling attempts in order to get their sterns, and consequently their propellers, well under water.

Dredging.—Dredging alongside and defueling started soon after the ship was grounded. The purpose of the dredging was to create a trench along each side to a depth well below the keel in order to encourage settling by the gradual sloughing of the sand under the ship. Eventually these trenches had a width in excess of 40 feet and a depth of more than 10 feet below the keel line. The Army Engineer dredge *Comber* did most of the work. Though having tremendous capacity, it could not get closer than about 10 feet to the hull. For removing this portion and for working the area under the counter at the stern, a civilian dredge, the *Washington*, was hired on 22 January. It worked continuously until the *Missouri* was refloated, except for several days when the seas were too rough.

The hope of appreciable settling of the ship did not materialize even when tunneling with high pressure water hoses and divers was resorted to in order to assist the caving in of the sand. From this viewpoint, it might be considered that the early removal of so much fuel was inadvisable and that weight, rather than being removed, should have been added. However, the wide and flat expanse of the ship spread the load so that unit pressures were of a relatively small order anyway. Since the ship was in full load condition, there were no ready means of increasing the load. Moreover, the removal of forward weights would shift the center of gravity aft and the pressures there would not be reduced accordingly, particularly since the bow began to move with the tide. Also, time was not an unlimited factor and there was enough to carry out the general plan only by constructive progress each day. Tunneling with high pressure nozzles was useful in starting messenger lines for pontoon chains, but was entirely inadequate to make any real showing against the volume of sand under the ship. The ground was composed of a medium coarse sand that packed hard where the pressure was greatest. Two thousand tons of fuel had been reinstalled aboard aft as ammunition was removed forward to assist the settling of the stern. No discernible movement was observed. Suction was not a problem on this job, particularly since, after removal of sufficient forward weights, there was some motion of the bow with rise and fall of the tide.

There was, of course, no question of the need for an exit channel from the stern of the *Missouri* to deep water. A channel 150 feet wide and with a minimum 35-foot depth at low water was easy work for the *Comber*. It could be done with no interference with work alongside ship, and moreover, it could also be done at night. The final connecting of the exit channel with the stern of the *Missouri* was accomplished by the commercial dredge which could work close to the hull.

Weight removal.—The off-loading of liquids, ammunition, and stores was the greatest single factor contributing to the salvage of the ship. The summary of planned weight removals which followed very closely what was actually removed was as follows:

Item	*Weight (tons)*
Boats and skids	44
Personnel	[1] 102
Ammunition	2,205
Dry provisions	199
Fresh provisions	91
Potable water	724
Reserve feed water	373
Fuel oil	7,973
Diesel oil	149
Total	11,860

[1] Not actually removed.

The removal of the first 8,000 tons consisting of fuel, some liquids, and stores was accomplished rapidly. The remainder, requiring greater handling, was off-loaded more slowly. With a view of gaining some settling of the ship due to squashing out of sand from under the stern where the pressure was greatest, 2,000 tons of fuel were placed back on board aft to increase that pressure as the forward ammunition was unloaded. This was later removed, together with the after ammunition which was left until last for the same purpose. All off-loading was completed 30 January.

Extensive as the weight removal was, it was made relatively easy by the availability, on short notice, of Naval Base and Service Force facilities in the area. Tankers, barges, cranes, tugs, and other floating equipment rendered excellent service and had only short distances to go. Unlike the open sea, the water, though occasionally choppy or rough, did not have the swells and surf to make weight handling difficult.

Beach gear.—What is beach gear? It is an item of equipment very familiar to all professional salvors but to few others, including many seafaring men. Its primary use is to pull a stranded ship back into deep water or to hold it firmly secured to keep it from broaching or being driven farther ashore. Many ships have been refloated through the pulling action available in several sets of this gear and there is no doubt that many more in the future will owe their safety to this equipment.

A set of beach gear, in brief, consists of one or more anchors, generally of a special type having excellent holding power, a shot of heavy chain, and several long lengths of heavy wire rope all connected together with special shackles and leading from the water to the stranded ship. Here, the heavy wire rope is secured with a carpenter stopper to a set of falls which, depending on its type, serves to multiply the pull exerted by a winch many times. The standard Navy set of beach gear, which is almost universally used by professional salvors also, consists of the following:

- 8,000-pound Eells anchor—has excellent digging in and holding properties.
- One shot (15 fathoms) of 2¼-inch chain—it not only helps the anchor to hold but adds spring to the line and guards against sudden pulls on anchor.
- 250 fathoms of 1⅝-inch (6 x 37) galvanized plow steel wire rope made up in 100- and 50-fathom lengths. The long scope reduces the loss in effective pull due to the vertical component. Additional lengths may be used to suit existing conditions.
- Four plate shackles for connecting wire rope, chain, and anchors. They are of type that can pass through chocks or around bitts.
- Two carpenter stoppers—used for grasping wire rope when heaving or stopping off when fleeting out falls between pulls. They are one of the most vital components of beach gear and operate on the principle of a sliding wedge which grips tighter as the pull is increased.
- One set of fourfold blocks rove off with 1,200 feet of ⅝-inch wire rope.
- One fairlead block for 1⅝-inch wire and one for ⅝-inch.
- One anchor buoy and retrieving wire.
- Suitable straps and shackles for securing standing and fairlead blocks.

Bureau of Ships Technical Bulletin No. 5 of January 1946 indicates that the efficiency of a set of falls of the type used, if rigged so that the pull of the winch is on the running block resulting in a 9-part arrangement, is 85.9 percent. The ship's deck winches that were used, as well as the portable salvage winches placed on board, develop a line pull of 7½ to 8 tons. Allowing for friction, therefore, and for the short tons used in rating of winches, a set of beach gear can develop a pulling force of about 50 long tons, which is almost double what can be expected from the largest and most powerful tugs that the Navy has, and more than three times the pull that can be exerted by the average seagoing tug of 1,500 horsepower. Not only is the strain that is applied continuous, but the beach gear wires are actually stretched and, like an elastic band, exert a powerful force in this condition.

Nine sets of this type of gear were installed on the U. S. S. *Missouri*, developing a total pulling force of 450 tons. Since they radiated at certain small angles with the longitudinal axis of the ship, only the component along this axis could be considered as effective to motion astern. There was also a slight loss due to the vertical inclination of the wires leading from the deck to the bottom of the water. Taking these into account, the net pulling force available still amounted to 400 tons. The type of bottom in the area was believed to provide good holding power for anchors. Nevertheless, to obviate any possibility of embarrassment and delay due to dragging, all anchors were doubled. This applied not only to the beach gear, but also to the *Salvager* and *Windlass*. Each of these vessels planted a special 10,000-pound Danforth anchor loaned by the manufacturer specifically for this operation, a standard 8,000-pound salvage anchor, and three 6,000-pound anchors. There is no question that all held firmly under all the conditions of pull.

Two specially designed salvage vessels, the U. S. S. *Salvager* (ARSD-3) and the U. S. S.

These pontoons are [illegible] approximate diameters.

As is usual with pontoons, the most difficult part of the work, and to which was devoted most of the time of installation, was the reeving of the chains under the hull. The customary practice was followed of running light messengers under the after ends of the barge by divers and then progressively pulling through larger wires, small chain, and finally the heavy chain to which pontoons were secured. A salvage-type mooring ship (ASR) was positioned on each side of the Nereus to handle the messengers as well as reeve the chains. The messenger wires were worked forward to the desired location by alternating the pull at each end on the winch drums to provide a back and forth sawing motion. This was the slowest part of the work, since occasionally a wire rope broke and the job had to be started over again. After a messenger wire of sufficient size had been worked into position, additional messengers were attached to it and pulled through, [illegible] finally, one main mooring chain was in place. The work was frequently interrupted [illegible] on account of weather. [illegible]

Figures 8 and 9 show the arrangement of pontoons at the scene. It will be noted that [illegible] of the pontoons through which the chains were passed followed the line of the chains and were therefore at an angle with the vertical. [illegible] with the bottom of the pontoons, water would be blown out to that level resulting in a slight loss of buoyancy. There was no difficulty in handling the chains and [illegible] pontoons [illegible] of the Nereus [illegible]

Eight of the 80-ton pontoons available were used in the refloating operation. [illegible]

The excess wire rope not dropped was figure-eighted on the fantail. The salvage ship then came alongside the Nereus and passed the end of the [illegible] wire rope to the stranded ship where it was reeved in and held by a carpenter stopper. The salvage vessel now proceeded toward the designated spot where the anchor was to be dropped, paying out the wire rope until finally, with the wire rope [illegible], the anchor was let go.

Pontoons.—The pontoons used in salvaging [illegible] the Nereus were the standard type maintained by the Navy at several widely separated areas. They were specifically designed for salvage of sunken submarines, and their first previous use was in the salvage of the U. S. S. Squalus which sank in May 1939 in approximately 240 feet of water off Portsmouth, N. H. Ten of these pontoons were [illegible] in Norfolk [illegible] Naval Shipyard where they had been stored and maintained (fig. 9). The pontoons are [illegible] steel cylinders 32 feet long and with an internal diameter of 12 feet. They are divided by transverse bulkheads into three compartments and provided with suitable flood, vent, blow, and chain valves. The rated buoyancy is 80 tons, while the dead weight of each is [illegible] tons. [illegible]

Figure 9.—[illegible]

The excess wire rope not draped was figure eighted on the fantail. The salvage ship then came alongside the *Missouri* and passed the end of the 1⅝-inch wire rope to the stranded ship where it was secured in and held by a carpenter stopper. The salvage vessel now proceeded toward the designated spot where the anchor was to be dropped, paying out the wire rope until finally, with the wire stretched taut, the anchor was let go.

Pontoons.—The pontoons used in assisting to refloat the *Missouri* were the standard type maintained by the Navy in several widely separated areas. They were specifically designed for salvage of sunken submarines, and their last previous use was in the salvage of the U. S. S. *Squalus* which sank in May 1939 in approximately 250 feet of water off Portsmouth, N. H. Ten of these pontoons were towed to Norfolk on two barges from the Boston Naval Shipyard where they had been stored and maintained (fig. 3). The pontoons are structural steel cylinders 32 feet long and with an internal diameter of 12 feet. They are divided by transverse bulkheads into three compartments and provided with suitable flood, vent, blow, and sluice valves. The total buoyancy is 80 tons, while the dead weight of each is 40 tons. With both ends flooded and the middle compartment empty, which is the usual submerged condition when handling the pontoon, it has a negative buoyancy of about 5 tons. Due to fixed concrete ballast, it is stable on the surface and will float upright if not restrained.

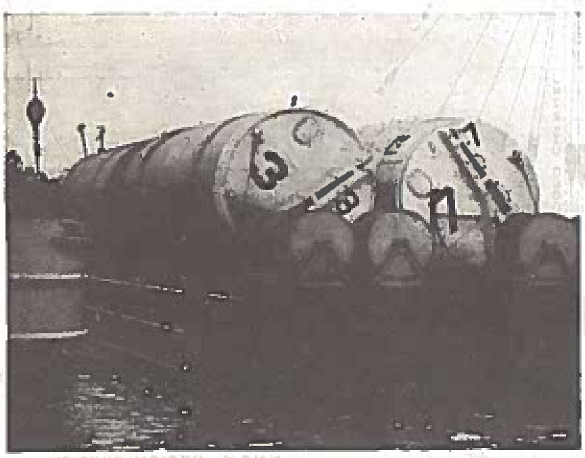


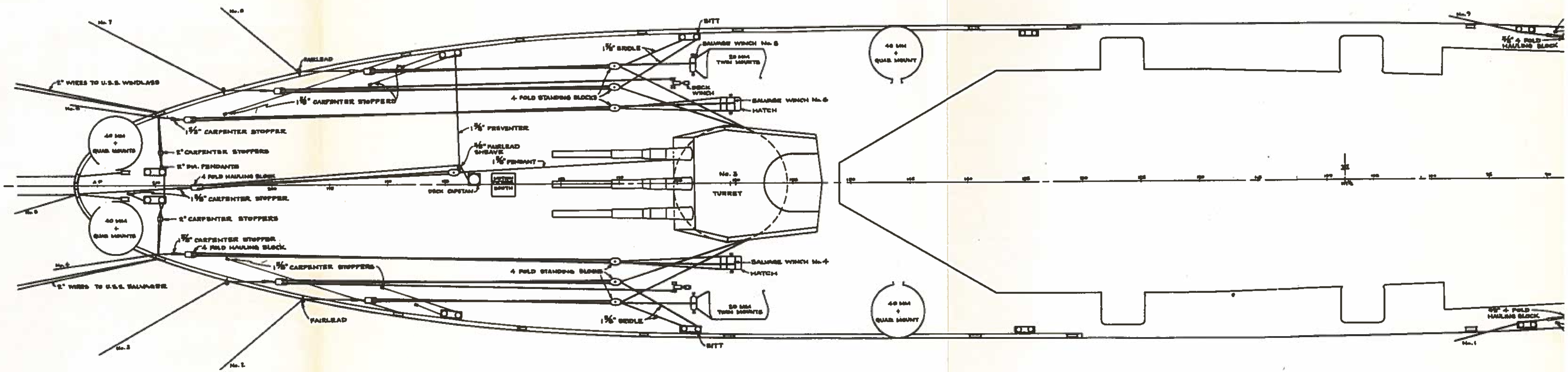
FIGURE 3.—Salvage pontoons were towed to scene on barges.

These pontoons can be and often are towed appreciable distances.

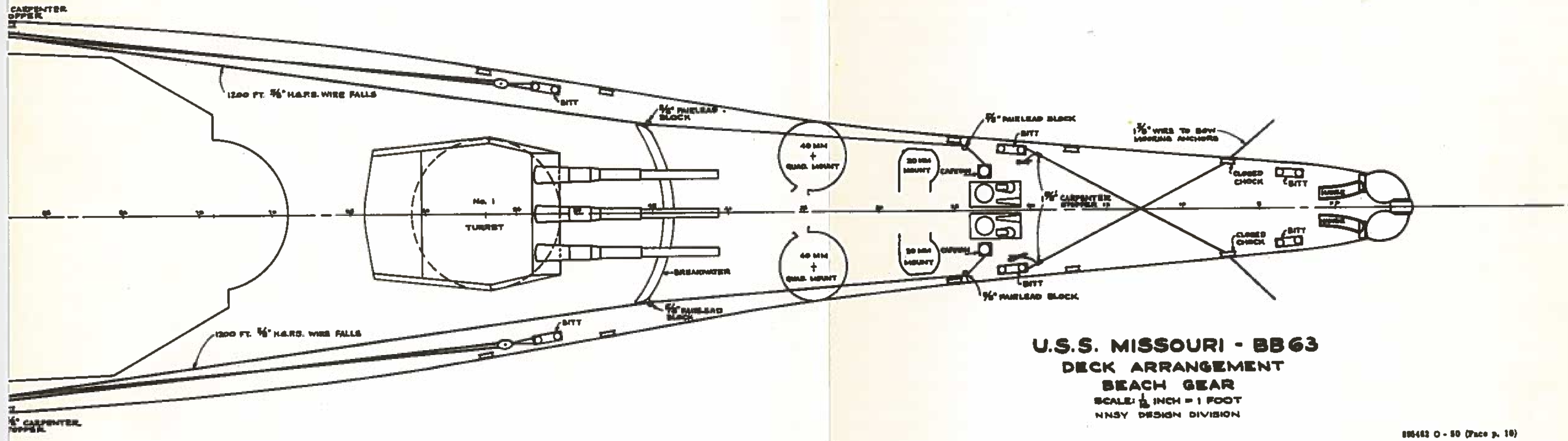
As is usual with pontoons, the most difficult part of the work, and to which was devoted most of the time of installation, was the reeving of the chains under the hull. The customary practice was followed of running light messenger wires under the after ends of the skegs by divers and then progressively pulling through larger wires, small chain, and finally the heavy 2½-inch chain to which pontoons were secured. A submarine rescue ship (ASR) was positioned on each side of the *Missouri* to service the divers as well as reeve the chains. The messenger wires were worked forward to the desired location by alternating the pull of capstans on the rescue ships to provide a back and forth sawing motion. This was the slowest part of the work, since occasionally a wire rope broke and the job had to be started over again. Once a messenger for a set of pontoons had been worked into position, additional messengers were attached to it and pulled straight through, again with a sawing motion, until, finally, the main securing chains were in place. This work was frequently interrupted by other necessary or urgent work alongside the ship.

Plates 3 and 4 show the arrangement of pontoons at the stern. It will be noted that the hawsepipes of the pontoons through which the chains were reeved followed the lead of the chains and were, therefore, at an angle with the vertical. Since bottom discharges are in line with the bottoms of hawsepipes, water could be blown only to that level, resulting in a slight loss of buoyancy. There was no difficulty in reeving the wires and in installing the pair of pontoons at the bow of the *Missouri* just prior to the successful refloating on 1 February.

Eight of the ten pontoons available were used in the refloating operation. There were also available in the area, but not used, collapsible pontoons totaling 250 tons in buoyancy which were maintained at Bayonne, N. J., for emergency use. These are inverted bags with a large opening in the bottom and a blow connection at the top. They are made of a nylon fabric impregnated with neoprene and consequently are light and easily transported. Designed primarily for submarine salvage, they



2" WIRES TO U.S.S. WINDLASS
2" WIRES TO U.S.S. SALVAGER
No. 7
No. 8
No. 2
No. 3
No. 1
No. 9
FAIRLEAD
FAIRLEAD
40 MM + QUAD MOUNTS
40 MM + QUAD MOUNT
1⅝" CARPENTER STOPPERS
1½" CARPENTER STOPPER
2" CARPENTER STOPPERS
2" DIA. PENDANTS
4 FOLD HAULING BLOCK
1⅝" CARPENTER STOPPER
4 FOLD STANDING BLOCKS
1⅝" PREVENTER
⅝" FAIRLEAD SHEAVE
1⅝" PENDANT
DECK CAPSTAN
1⅝" BRIDLE
SALVAGE WINCH No. 5
SALVAGE WINCH No. 6
SALVAGE WINCH No. 4
20 MM TWIN MOUNTS
DECK WINCH
HATCH
BITT
No. 3
TURRET
⅝" 4 FOLD HAULING BLOCK



U.S.S. MISSOURI - BB63
DECK ARRANGEMENT
BEACH GEAR
SCALE: 1/16 INCH = 1 FOOT
NNSY DESIGN DIVISION

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10A

IV

SPECIAL STUDIES AND TESTS

A. ESTABLISHING MEAN LOW WATER AT MISSOURI LOCATION

A study of tides and drafts on the *Missouri* draft marks was made with a view of establishing mean low water at the ship with results as indicated on plate 5. Reading of draft marks was usually difficult because of the choppy condition of the water which resulted in appreciable surface waves. It was particularly difficult to observe within reasonable limits the time when the tide had reached maximum or minimum heights. Tide gages that would dampen surface effects were, therefore, designed and manufactured by the Norfolk Naval Shipyard. Four long steel piles made of six-inch pipe were driven alongside the *Missouri* draft marks by the shipyard, one at the bow, one at the stern, and one on each side amidships. The special tide gage was attached to each pile at the surface of the water. This gage consisted of a float inside of a pipe of large diameter, the float rising and falling with the tide. In the bottom plate of the submerged end of this pipe were several drilled holes which restricted the flow of water and thereby served to dampen the effects of surface waves. A vertical graduated scale attached to the top of the float indicated when the maximum or minimum tide was attained. These gages were quite effective and would have been more so if the restriction had been of greater degree.

All high and low tides as read on the *Missouri* draft marks were recorded starting 20 January. The actual height of water above mean low, as read at Sewell's Point, was then subtracted from the draft readings to give mean low water at the ship. This was done for each day and each tide through 29 January. By averaging the mean low water draft readings at each set of draft marks, mean low water was established at the *Missouri* as follows:

	Feet
Bow	25.1
Amidships (port)	26.8
Amidships (starboard)	27.3
Stern	28.7

The ship was known to have a slight starboard list while grounded as indicated on the inclinometer on the bridge.

Although the location of the *Missouri* was nearer Fort Monroe than the Naval Operating Base, it was noted that actual tides closely approximated those at Sewell's Point. In fact, at the end of the preparatory period just prior to refloating attempts, the Coast and Geodetic Office made special reports of height of tide for the location of the *Missouri*, which in all cases were the same as those at Sewell's Point corrected for a 30-minute time differential. The heights recorded at Fort Monroe, on the other hand, varied and were quite consistently higher than experienced at the scene. Such a report, in fact, on the day the *Missouri* grounded was initially misinterpreted as indicating an abnormally high tide of 3.3 feet at the time of grounding. Actually, tides were quite normal that day, being 2.7 feet in lieu of a predicted height of 2.8 feet, the *Missouri* having grounded at a 2.6-foot tide.

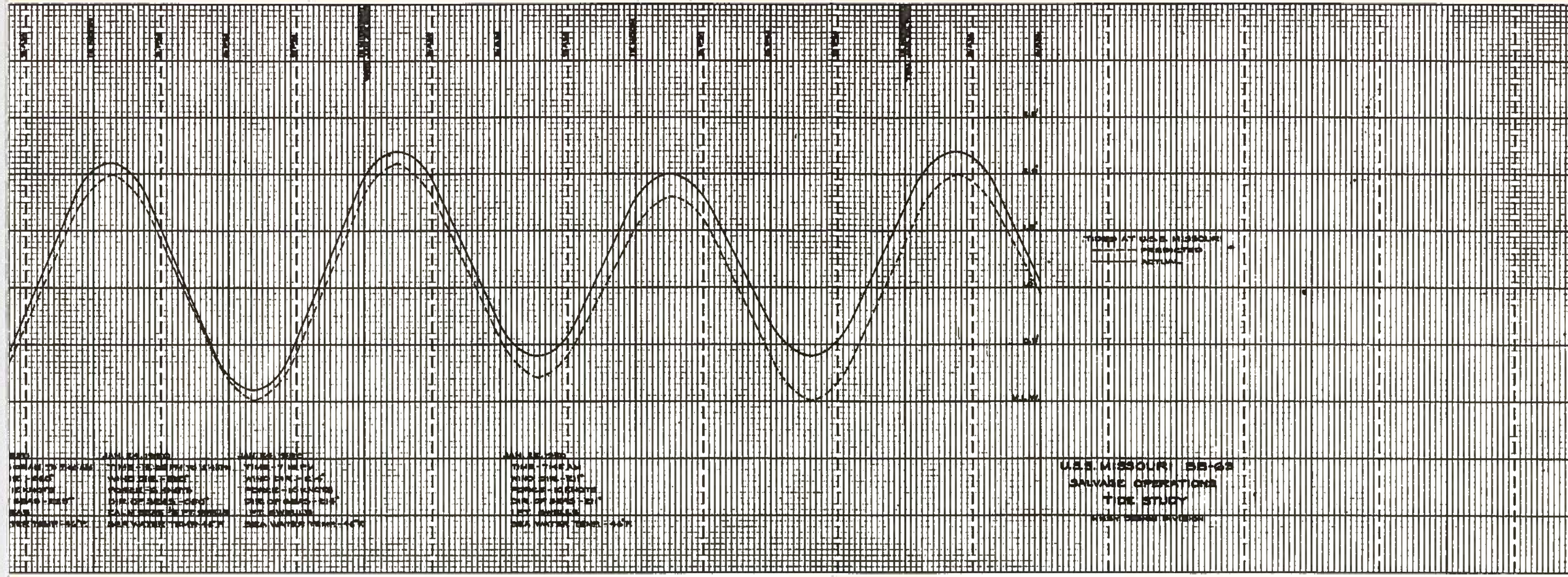
The direction and force of the wind have a considerable influence on the tides in the area. Persisting strong winds from the northeast will increase the height of water and have been known to cause increases amounting to several feet above predicted levels by driving the water in from the sea. It was for this reason that there was felt to be some, though small, chance of refloating the ship on 20 January using only tugs and the *Salvager* and *Windlass*, and, therefore, the effort was worth while. Conversely, southwest winds will do the opposite by forcing the water out. Plate 6 which indicates the actual tides that existed as compared to predicted shows the pronounced influence of the

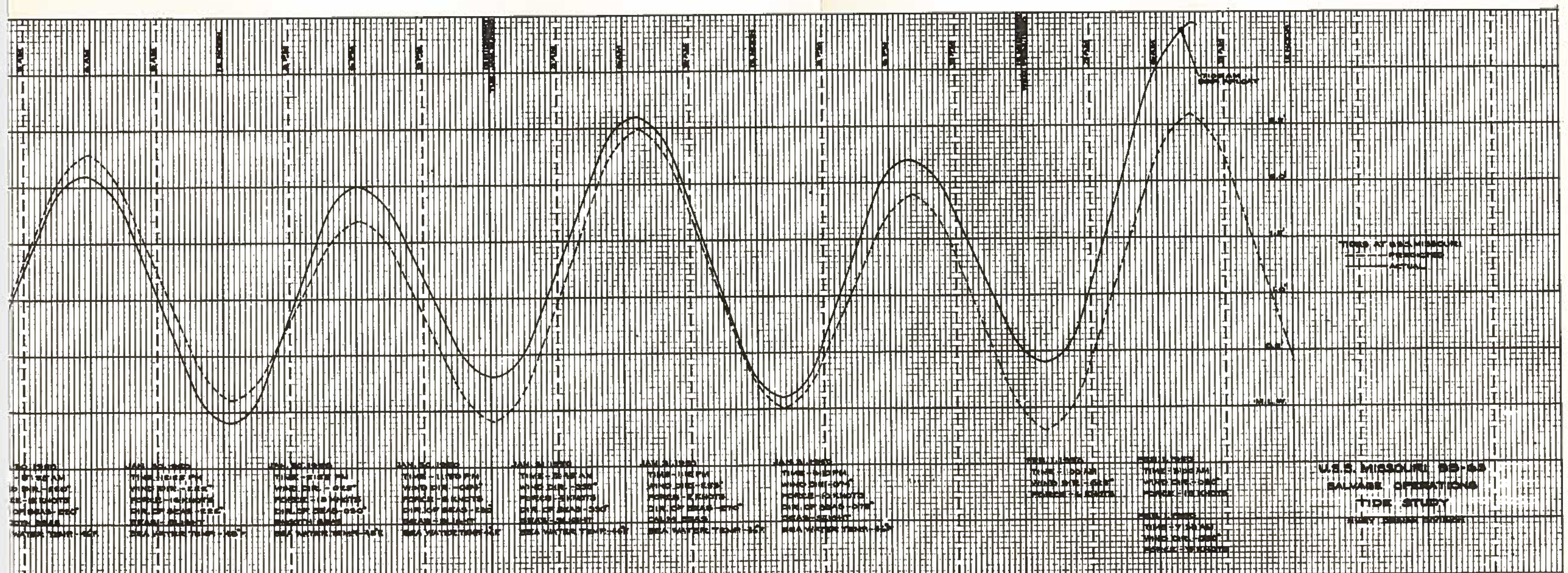
TIDAL AND DRAFT MARK STUDY

(The following data were recorded for purpose of correlating drafts at U. S. S. *Missouri* with actual tides.)

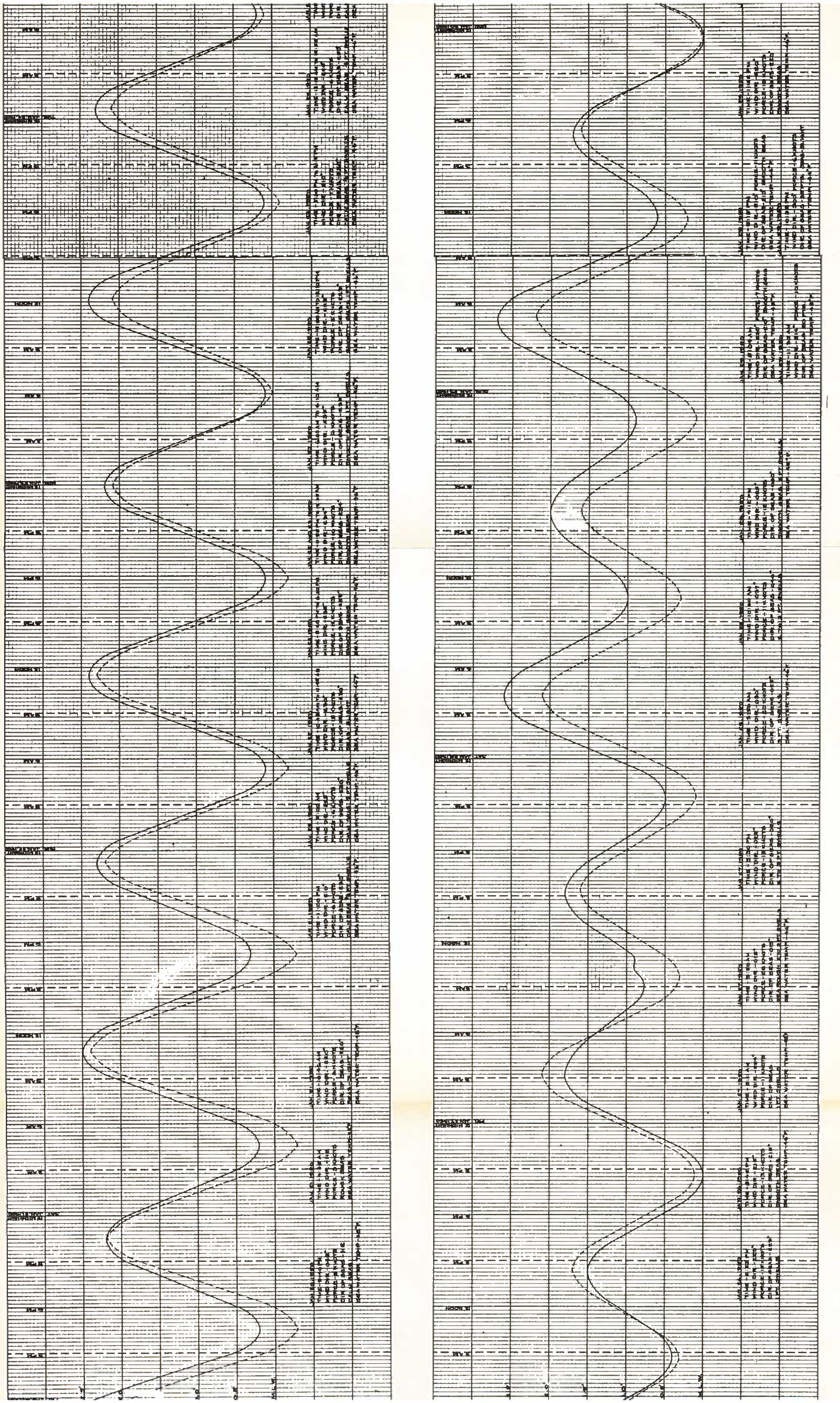
	At U. S. S. *Missouri* (Sewells Point—30 min.)			DRAFT MARKS											
	Time	Pred.	Act.	Bow (Average) 25. 1		Port Mid (Average) 26. 6		Stern (Average) 28. 7		Bow (Average) 25. 1		Stbd. Mid (Average) 27. 3		Stern (Average) 28. 7	
Jan. 17	0750	2. 8	2. 7												
	1418	-. 3	-. 7												
	2007	2. 1	1. 7												
Jan. 18	0214	-. 5	-. 9												
	0839	2. 8	2. 0												
	1505	-. 4	-1. 3												
	2056	2. 2	1. 4												
Jan. 19	0304	-. 5	-. 8												
	0924	2. 7	3. 1												
	1548	-. 4	. 3												
	2143	2. 2	2. 5												
Jan. 20	0350	-. 9	. 3												
	1003	2. 6	3. 1												
	1628	-. 3	. 2												
	2227	2. 2	2. 2	27. 0	24. 8	29. 0	26. 8	31. 2	29. 0	27. 0	24. 8	29. 8	27. 1	32. 2	29. 0
Jan. 21	0434	-. 3	. 2	24. 0	23. 8	26. 3	26. 1	28. 6	28. 4	24. 0	23. 6	26. 3	26. 1	28. 6	28. 4
	1047	2. 4	2. 5	27. 5	25. 0	28. 8	26. 3	31. 5	29. 0	27. 7	25. 2	29. 5	27. 0	31. 5	29. 0
	1708	-. 3	. 3	24. 8	24. 5	26. 0	25. 7	29. 0	28. 7	24. 8	24. 5	26. 9	26. 6	29. 0	28. 7
	2311	2. 2	2. 3	27. 4	25. 1	28. 8	26. 5	31. 0	28. 7	27. 5	25. 2	29. 8	27. 5	31. 0	28. 7
Jan. 22	0518	-. 2	. 1	25. 3	25. 2	26. 8	26. 7	29. 0	28. 9	25. 3	25. 2	27. 5	27. 4	29. 0	28. 9
	1126	2. 3	2. 4	27. 4	25. 0	28. 9	26. 4	31. 0	28. 6	27. 5	25. 1	29. 8	27. 4	31. 0	28. 6
	1747	-. 2	. 1	25. 2	25. 1	26. 9	26. 8	29. 0	28. 9	25. 2	25. 1	27. 4	27. 3	29. 0	28. 9
	2354	2. 1	2. 2	27. 3	25. 1	28. 8	26. 6	31. 0	28. 8	27. 3	25. 1	29. 6	27. 4	31. 0	28. 8
Jan. 23	0602	. 0	. 1	25. 2	25. 1	26. 8	26. 7	29. 0	28. 9	25. 2	25. 1	27. 5	27. 4	29. 0	28. 9
	1205	2. 1	2. 4	27. 5	25. 1	29. 0	26. 6	31. 2	28. 8	27. 5	25. 1	29. 9	27. 5	31. 2	28. 8
	1825	-. 1	. 1	25. 2	25. 1	26. 9	26. 8	29. 0	28. 9	25. 2	25. 1	27. 5	27. 4	29. 0	28. 9
Jan. 24	0038	2. 1	2. 3	27. 4	25. 1	29. 0	26. 7	31. 0	28. 7	27. 4	25. 1	29. 8	27. 5	31. 0	28. 7
	0648	. 1	. 2	25. 4	25. 2	26. 9	26. 7	29. 0	28. 7	25. 4	25. 2	27. 6	27. 4	29. 0	28. 8
	1245	2. 0	2. 1	27. 2	25. 1	29. 0	26. 9	30. 5	28. 4	27. 2	25. 1	29. 5	27. 4	30. 5	28. 4
	1906	0	. 1	25. 4	25. 3	26. 9	26. 8	29. 0	28. 9	25. 4	25. 3	27. 5	27. 4	29. 0	28. 9
Jan. 25	0124	2. 1	2. 2	27. 3	25. 1	29. 0	26. 8	31. 0	28. 8	27. 3	25. 1	29. 5	27. 4	31. 0	28. 8
	0728	. 2	. 4	25. 6	25. 2	27. 3	26. 9	29. 0	28. 6	25. 6	25. 2	27. 7	27. 3	29. 0	28. 6
	1329	1. 8	2. 0	27. 2	25. 2	28. 8	26. 8	30. 5	28. 5	27. 2	25. 2	29. 4	27. 2	30. 5	28. 5
	1949	0	. 4	25. 5	25. 1	27. 0	26. 6	(28. 5)	(28. 1)	25. 5	25. 1	----	----	(28. 5)	(28. 1)
Jan. 26	0214	2. 0	2. 2	27. 4	25. 2	(29. 3)	(27. 1)	30. 5	28. 3	27. 4	25. 2	29. 8	27. 6	30. 5	28. 3
	0834	. 3	. 4	25. 4	25. 0	27. 1	26. 7	28. 6	28. 2	25. 4	25. 0	----	----	28. 6	28. 2
	1418	1. 7	1. 5	26. 8	25. 3	28. 3	26. 8	(31. 0)	(29. 5)	26. 8	25. 3	28. 8	27. 3	(31. 0)	(29. 5)
	2038	. 1	0	25. 0	25. 0	26. 6	26. 6	29. 0	29. 0	25. 0	25. 0	27. 1	27. 1	29. 0	29. 0
Jan. 27	0306	2. 1	1. 8	26. 9	25. 1	28. 4	26. 8	31. 0	29. 2	26. 9	25. 1	29. 0	27. 2	31. 0	29. 2
	0934	. 3	. 8												
	1514	1. 6	1. 8	----	----	28. 4	26. 8	31. 0	29. 2	----	----	29. 3	27. 5	31. 0	29. 2
	2130	. 1	. 5	25. 8	25. 3	27. 5	27. 0	28. 5	28. 0	25. 8	25. 3	----	----	28. 5	28. 0
Jan. 28	0401	2. 1	2. 6	27. 3	24. 7	(31. 3)	(28. 7)	31. 0	28. 4	27. 3	24. 7	----	----	31. 0	28. 4
	1033	. 3	1. 0	26. 0	25. 0	27. 4	26. 4	(28. 5)	(27. 5)	26. 0	25. 0	28. 5	27. 5	28. 5	27. 5
	1612	1. 6	2. 0	27. 5	25. 5	28. 5	26. 5	31. 0	29. 0	27. 7	25. 7	29. 0	27. 0	31. 0	29. 0
	2224	. 1	. 9	25. 5	24. 6	27. 5	26. 6	29. 0	28. 1	25. 7	24. 8	28. 0	27. 1	29. 0	28. 1
Jan. 29	0456	2. 2	2. 7	27. 3	24. 6	28. 3	25. 6	31. 3	28. 6	27. 3	24. 6	----	----	31. 3	28. 6
	1129	. 2	. 6	25. 4	----	27. 2	----	28. 8	----	25. 4	----	27. 9	----	28. 8	
	1705	1. 6	1. 7	26. 8	----	28. 5	----	31. 0	----	26. 8	----	28. 8	----	31. 0	
	2317	0													
Jan. 30	0549	2. 3	2. 1												
	1220	. 1													
	1804	1. 7													
Jan. 31	0008	-. 1	. 3												
	0639	2. 5	2. 6												
	1307	0	. 1												
	1853	1. 9	2. 2												
Feb. 1	0100	-. 2	. 4												
	0530	2. 6	2. 8												
	0635	2. 6	3. 2												
	0700	2. 6	3. 3												
Feb. 1	0730	2. 6	3. 4												
	0800	2. 6	3. 3												

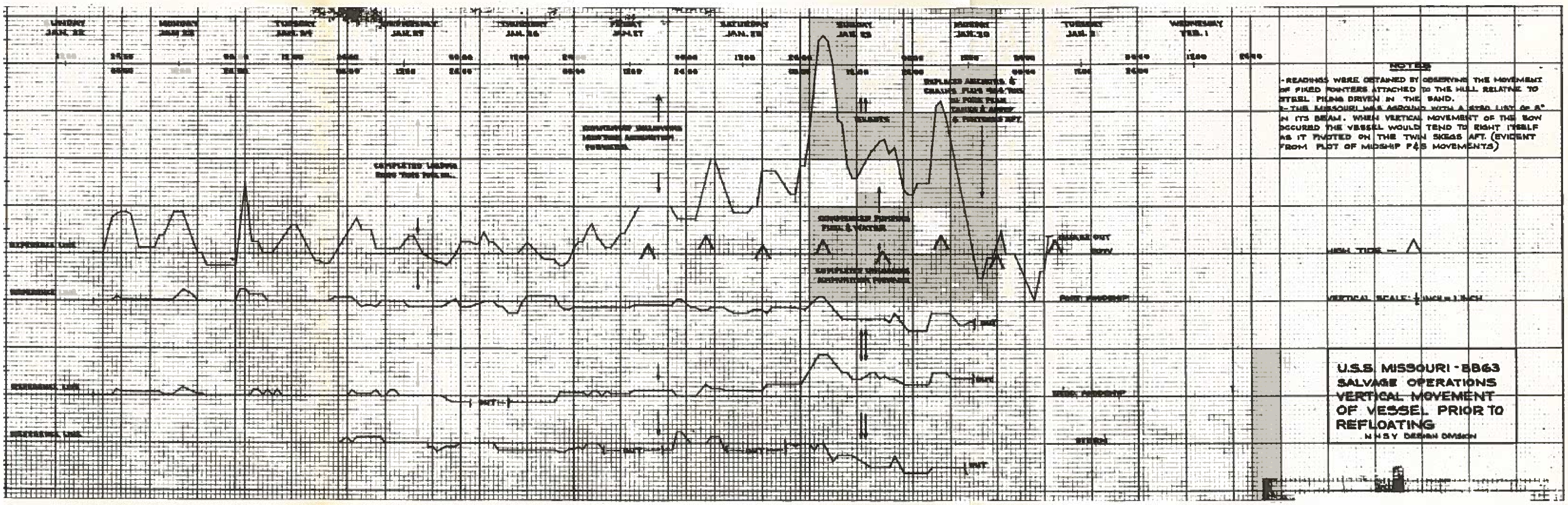
PLATE 5.


U.S.S. MISSOURI (BB-63)
SALVAGE OPERATIONS
TIDE STUDY

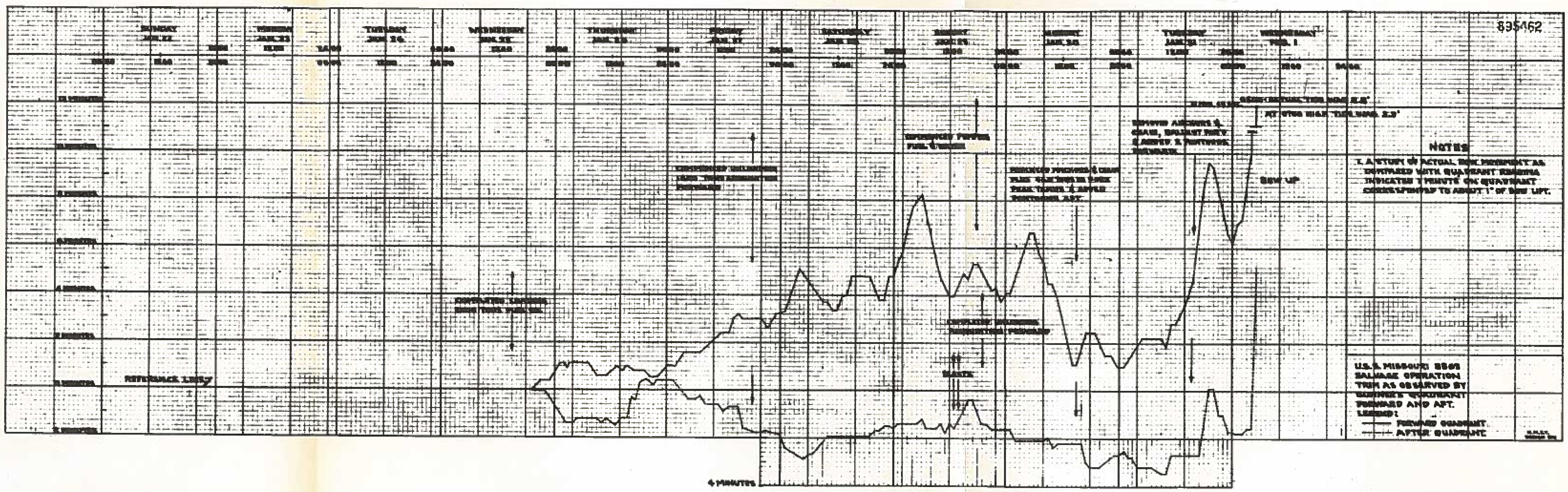

U.S.S. MISSOURI (BB-63)
SALVAGE OPERATIONS
TIDE STUDY

16A




NOTES
1-READINGS WERE OBTAINED BY OBSERVING THE MOVEMENT OF FIXED POINTERS ATTACHED TO THE HULL RELATIVE TO STEEL PILING DRIVEN IN THE SAND.
2-THE MISSOURI WAS AGROUND WITH A STBD LIST OF 5° IN ITS BEAM. WHEN VERTICAL MOVEMENT OF THE BOW OCCURED THE VESSEL WOULD TEND TO RIGHT ITSELF AS IT PIVOTED ON THE TWIN SKEGS AFT. (EVIDENT FROM PLOT OF MIDSHIP P&S MOVEMENTS)
HIGH TIDE —
U.S.S. MISSOURI - BB63
SALVAGE OPERATIONS
VERTICAL MOVEMENT
OF VESSEL PRIOR TO
REFLOATING
NNSY DESIGN DIVISION

16B



895462 O - 50 (Face p. 16) No. 3

16C

prevailing winds. The northeast wind that existed during the night prior to refloating at 0700 on 1 February, building up to a force of 19 knots by 0300, resulted in the very welcome high tide that was experienced and that contributed appreciably to the success that followed.

B. VERTICAL MOVEMENT OF "MISSOURI" PRIOR TO REFLOATING

Advantage was taken of the steel piles driven to support the tide gages to observe also any vertical motion of the ship. The piles were extended to the main deck edge of the *Missouri* and secured to the side with loosely fitted bracketed straps. A gage graduated in 1/4-inch increments was installed at the top of each pile and a pointer secured to the ship opposite the zero reading on the gage. It will be noted in plate 7 that the bow showed some vertical motion, with the tides, on 22 January when these gages were first installed. At this time, approximately 8,000 tons, consisting mostly of fuel oil and fluids, had been removed.

The effects of further weight removals, or additions, particularly when they were forward, was appreciable. Starting 27 January when the forward ammunition was removed, the bow showed a gradual net rise reaching a peak on the morning high tide on 29 January of 9 inches. When peak tanks had been filled, anchor and chain replaced, and pontoons installed at the stern, the bow returned to its position on the bottom. During the 31 January pull-off attempt, it was resting on the bottom.

The gage at the stern was of little use because it was struck several times by ships alongside and put out of commission. The midship gages indicated but slight movement at this location and such motion as existed was in the direction of reducing or eliminating the list. Because of the only small motion amidships as compared with the appreciable motion of the bow, it is considered that at least a good part of this motion was absorbed in a sagging of the ship. That the *Missouri* is flexible enough to sag noticeably was apparent by a comparison of her draft readings, after refloating, in the light condition and subsequently in the full load condition. A sag amounting to 4 1/2 inches resulted after loading.

A study of the vertical motion of the *Missouri* was also made with gunner's quadrants installed in the extreme forward amidships and after ends of the ship. One was installed in the forward boatswain locker, one in the boiler shop, and the third in the after crane room. These, of course, showed the changing declivity of their part of the ship rather than an actual increment of rise or fall. The effects of adding or removing weights are plotted in plate 8. It will be noted that these parallel those observed by external fixed gages quite closely. Declivity at the stern is plotted in the reverse direction to permit more readily comparison with external gage readings. It will again be noted that changes at the bow, particularly when of appreciable amounts, did not result in corresponding changes at the stern, which indicates that at least some of the motion was absorbed in a sagging of the ship.

C. UNDERWATER EXPLOSIVE SHOTS

The use of underwater explosive shots had been discussed and considered for some time as a means of settling the ship by jarring the sand under the hull and causing it to squeeze out into the dredged troughs on each side. The general feeling was that such shots would help, and, if unlimited time were available, that they would eventually result in appreciable settling. However, extended periods of time devoted to placing explosives and firing them would not only detract from other necessary work, but in many cases would cause a complete stoppage due to the safety requirements involved. Time could not be spared for an extensive program of the use of explosives, except as one of the tools to be held in reserve should other work in progress fail to refloat the ship, because of possible delay in meeting the dates when tides were to be satisfactory. Moreover, there was no guarantee that explosives would produce the desired degree of results.

To explore in a preliminary manner the effect of explosives, two shots were scheduled and fired during low tide on 30 January 1950 by the Underwater Explosion Research Division of the Norfolk Naval Shipyard, to which was left the choice of shot geometry and the execution of the scheme. Several factors had to be considered in arriving at a workable shot arrangement. They had to be made with a minimum of delay at the scene and with maximum safety to personnel. The intensity was to be such as to cause no structural damage to the *Missouri* and yet achieve the purpose of producing transient shock loads through the water and the sand upon which she rested that would crumble the foundation upon which she lay.

One scheme involved the use of small charges (i. e., less than 20 pounds of TNT) on the sand underneath the overhang of the stern; the other involved burying of two moderate charges (50 pounds of HBX–1) in the sand, one on each side, about 50 feet outboard of the after turret. The latter was chosen as most nearly meeting the basic requirements and promising the best results, and is shown in figure 4. Holes for placing the charges in the sand were blown by divers with high pressure tunneling nozzles.

Previous experience of the Underwater Explosion Research Division on full scale target tests indicated that one of the most important factors in insuring the successful detonation of a main charge was a foolproof, watertight booster-detonator hookup. This was provided for by the design and manufacture of a special booster-detonator assembly. Each charge was detonated on the *Missouri* by shorting the two leads of the firing cable across a 40-volt battery. Spare charges (5 pounds TNT) were available to produce a detonation of the main charge in case of misfire, but were fortunately not needed.

The starboard charge was fired before the port one was placed in position. Two loadings, or concussions, were felt on the stern of the ship on the first shot, and three were felt through the water in the small boat after the second. These observations and the fact that no pronounced plume developed as a result of these shots tend to confirm the conclusion that the gas globules produced by the explosions tended to remain on the bottom and not migrate toward the surface of the water. The above represented ideal conditions as far as jarring of the ship and ground bed were concerned, since the gas globule was able to pulsate and load the surrounding media several times and thereby do a maximum amount of work.

It was observed that each shot caused the stern of the *Missouri* to settle one-fourth inch. This confirmed previous beliefs that such a process would be slow and require more time than could be readily spared. Moreover, it is quite likely that succeeding shots would have resulted in successively smaller amounts of settling.

D. COEFFICIENT OF FRICTION

Friction is the resistance to motion which occurs when one body is moved upon another, and may be generally defined as the force which acts between two bodies at their surface of contact, so as to resist their sliding on each other. A greater force is required to start a body from a state of rest than to keep it in motion. The laws of friction, for dry or poorly lubricated bodies, indicate that at low pressures friction is directly proportional to the normal load on the two surfaces, and as this load increases to a high value, friction does not rise as rapidly. In total amount and in coefficient, friction is in-

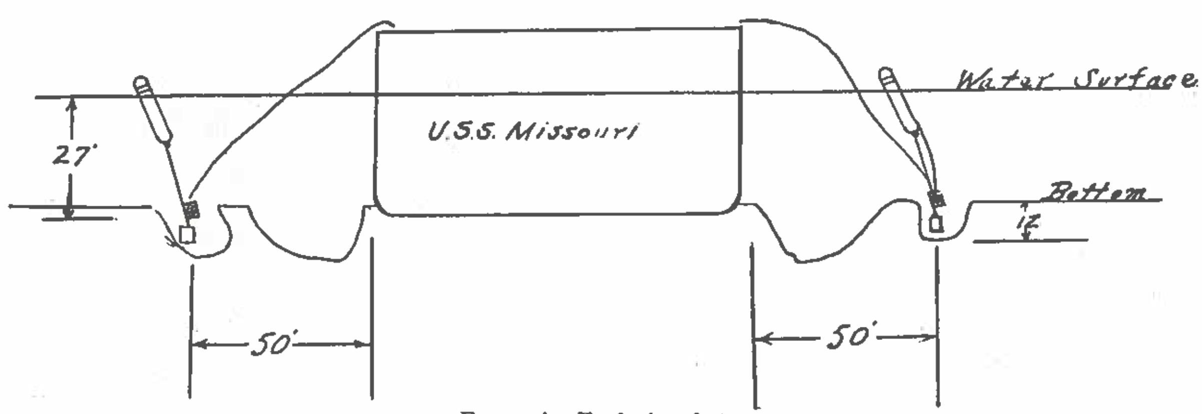


FIGURE 4.—Explosive shots.

dependent of the areas in contact so long as the total load remains the same. Again, this is true for moderate pressures only.

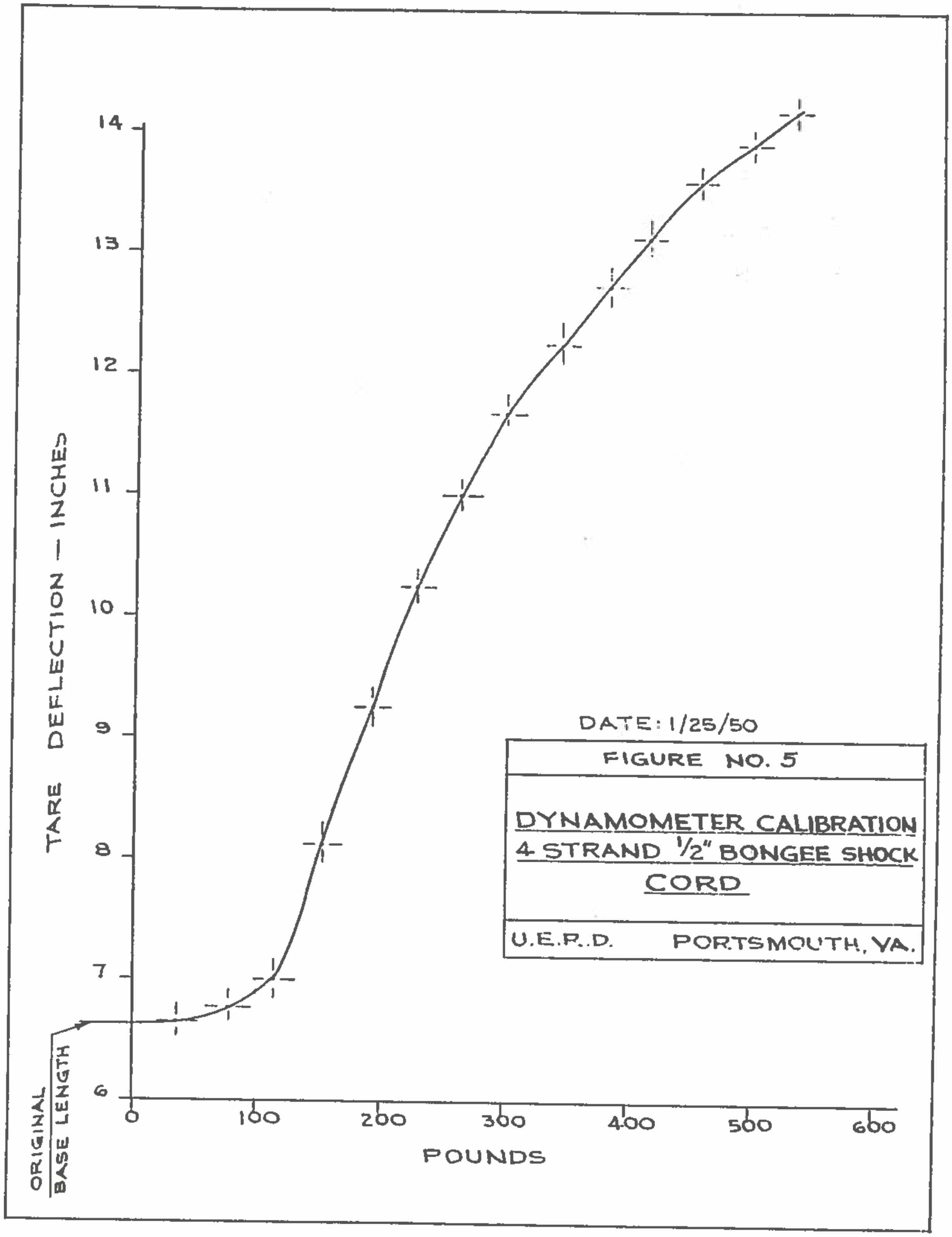
The above laws apply for solids or rigid bodies, but apparently are not as strictly applicable to soils. Professional salvors have often experienced that less effort may be required to pull a stranded ship sternward when weights on board are so shifted as to load the bow and float the stern. The concentration of load to a smaller area, particularly when a strain is applied, must result in some lateral motion of the sand and realinement of particles, resulting in less friction.

While there are no known standards for coefficients of friction between ship's bottoms and various types and natures of sand or ground, approximate values have been used by salvors based on past experience and shaded appropriately to reflect some special local condition or case. These rule-of-thumb values, in most cases, have served the purpose perhaps as well as those derived from more exact tests would have, for there are generally too many factors to consider in each case, no two of which are exactly alike. Friction will vary, not only with total pressure, but with the type and composition of bottom, with the slope of the surface, with the degree of rupture, if any, of the ship's hull, the number and type of appendages such as scoops, propellers, rudders, that may be protruding into the sand, and the extent or depth to which they protrude. Generally speaking, for an undamaged ship stranded on a smooth sandy beach with a normal slope, a pull equal to 30 percent of the lost buoyancy is accepted as the force required to move the ship. This is approximately a coefficient of friction of 0.3; 0.5 is the accepted coefficient if the bottom is hardpan or heavy gravel; about 0.8 if coral is involved; and 0.8 to indeterminate higher amounts if the bottom consists of rock which may protrude into dimples formed in the hull.

The *Missouri* in her stranded position was on a very gentle slope with a deep channel dredged immediately astern. The bottom may be classed as medium coarse sand with a sprinkling of small pebbles. Dredging of the deep troughs on each side and the exit channel had revealed larger rocks or small boulders, but these were at least 10 feet below the keel depth. By rule of thumb, an optimistic static coefficient of friction for the conditions existing could have been a value of 0.3. However, though on a slope, it was of such small magnitude as to be almost horizontal. It was definitely known that the stern, even after off-loading, would be well aground, and would be the leading end in the coming pull, tending to pile up the sand astern as motion started. A coefficient of 0.5 was, therefore, assumed, again by rule of thumb, to account for these factors and other unknown ones that might exist.

As a quick check on coefficients of friction, the Underwater Explosion Research Division of the Norfolk Naval Shipyard made some tests prior to the refloating of the *Missouri*. Samples of the bottom sand surrounding the ship were obtained by divers and these samples were matched as closely as possible for drag tests. In general, the material upon which the ship was stranded appeared to be composed of about 80 percent fine sand and 20 percent small pebbles up to 3/16 inch diameter. This mixture was closely duplicated from sand available at the shipyard and designated "Missouri type" sand. Several other materials were also chosen for tests and are labeled in the test results. These varied from mixtures of coarse sand through fine sand and clay.

The testing procedure varied slightly in the manner in which the loads were applied, but in general the test apparatus and testing method remained the same. A 2- by 3-foot, 40.8-pound, STS plate was chosen as the test vehicle and was pulled in the direction of its longest length over a sand bed about 8 inches deep. Ground loads were simulated by using cast lead pigs weighing approximately 38 pounds apiece, and these were added in small increments in the first procedure, and in total loads in the second. All pull loads were applied with a chain fall. Figure 5 indicates the dynamometer calibration. Pull measurements were made with a bongee rubber shock cord dynamometer for the first light load tests and with a calibrated Dillon 10,000-pound capacity dynamometer for all the higher ground load tests. Figure 6 shows arrangements for testing to determine coefficient of friction.


TARE DEFLECTION — INCHES
14
13
12
11
10
9
8
7
6
ORIGINAL BASE LENGTH
0
100
200
300
400
500
600
POUNDS
DATE: 1/25/50
FIGURE NO. 5
DYNAMOMETER CALIBRATION
4 STRAND 1/2" BONGEE SHOCK CORD
U.E.R.D.
PORTSMOUTH, VA.

Tests were first made at light ground loads (below 150 pounds per square foot) on both dry and wet coarse sand and gravel with results as indicated in figures 7 and 8. The reduction in static coefficient with increasing loads initially appeared inconsistent with expected behavior and accordingly additional tests were conducted for varying ground loads up to 1,400 pounds per square foot on several different mixtures. Wet clay was included only for academic reasons. The results of the tests for the various mixtures are indicated in the following figures:

Wet Missouri sand—Figure 9.
Wet Missouri sand and gravel—Figure 10.
Wet coarse sand and gravel—Figure 11.
Wet Missouri sand and clay—Figure 12.
Wet clay mud—Figure 13.
Total load tests on wet Missouri sand and gravel—Figure 14.

It will be noted that, except for clay, the curves show a decrease in static coefficient as the load is increased. This is also true in Figure 14 which represents tests in which an effort was made to reduce the possible influence of the method of loading on the results (i. e., adding load increments to an already loaded plate), by using fresh sand for each particular ground loading measurement series.

Although the test rig was somewhat crude, it is believed that the results were sufficiently accurate to show trends. Errors in reading thrust loads tend to be greater with the Dillon dynamometer for loads below 150 pounds per square foot than with the Bongee shock cord

FIGURE 6.—Arrangements for testing to determine coefficient of friction.

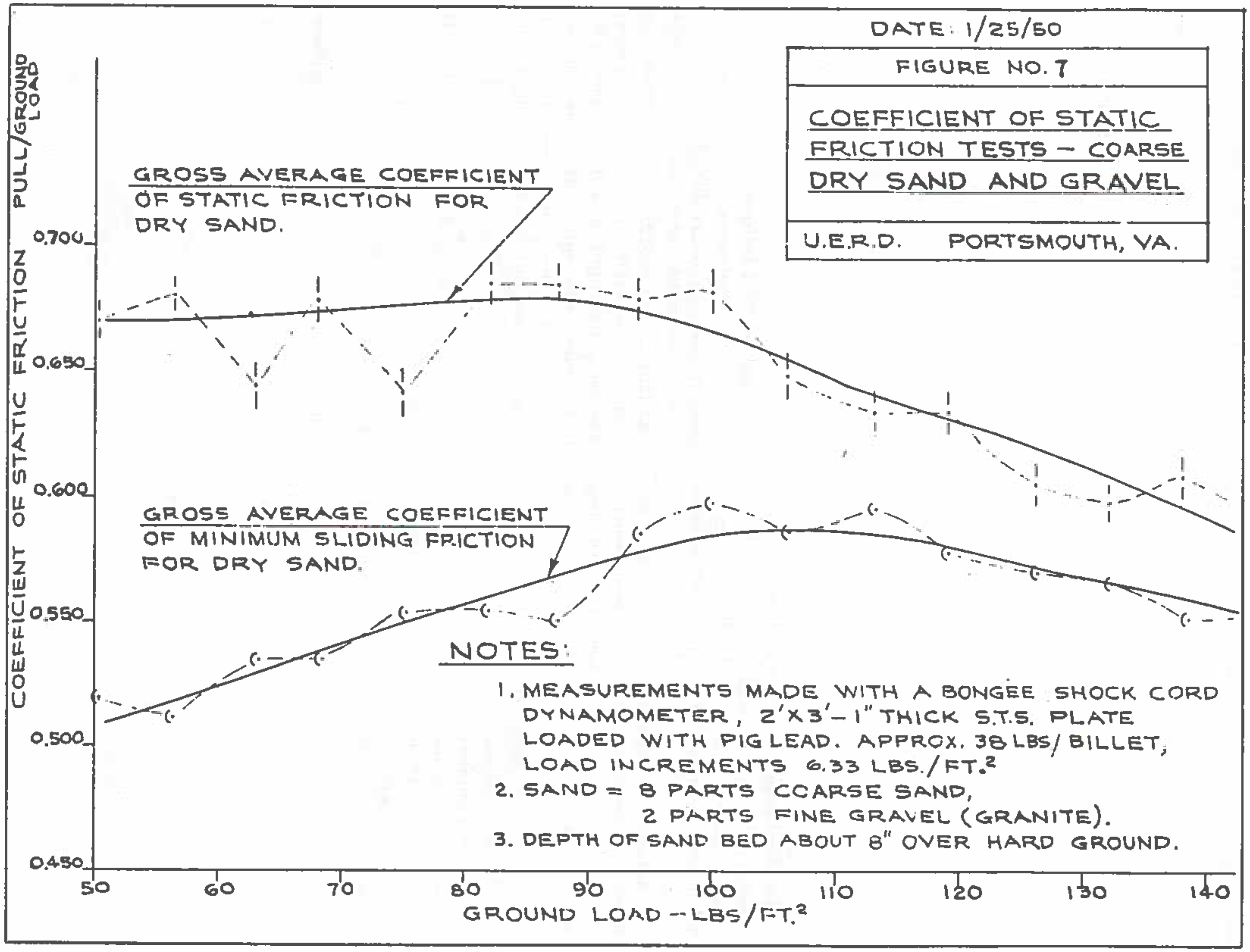


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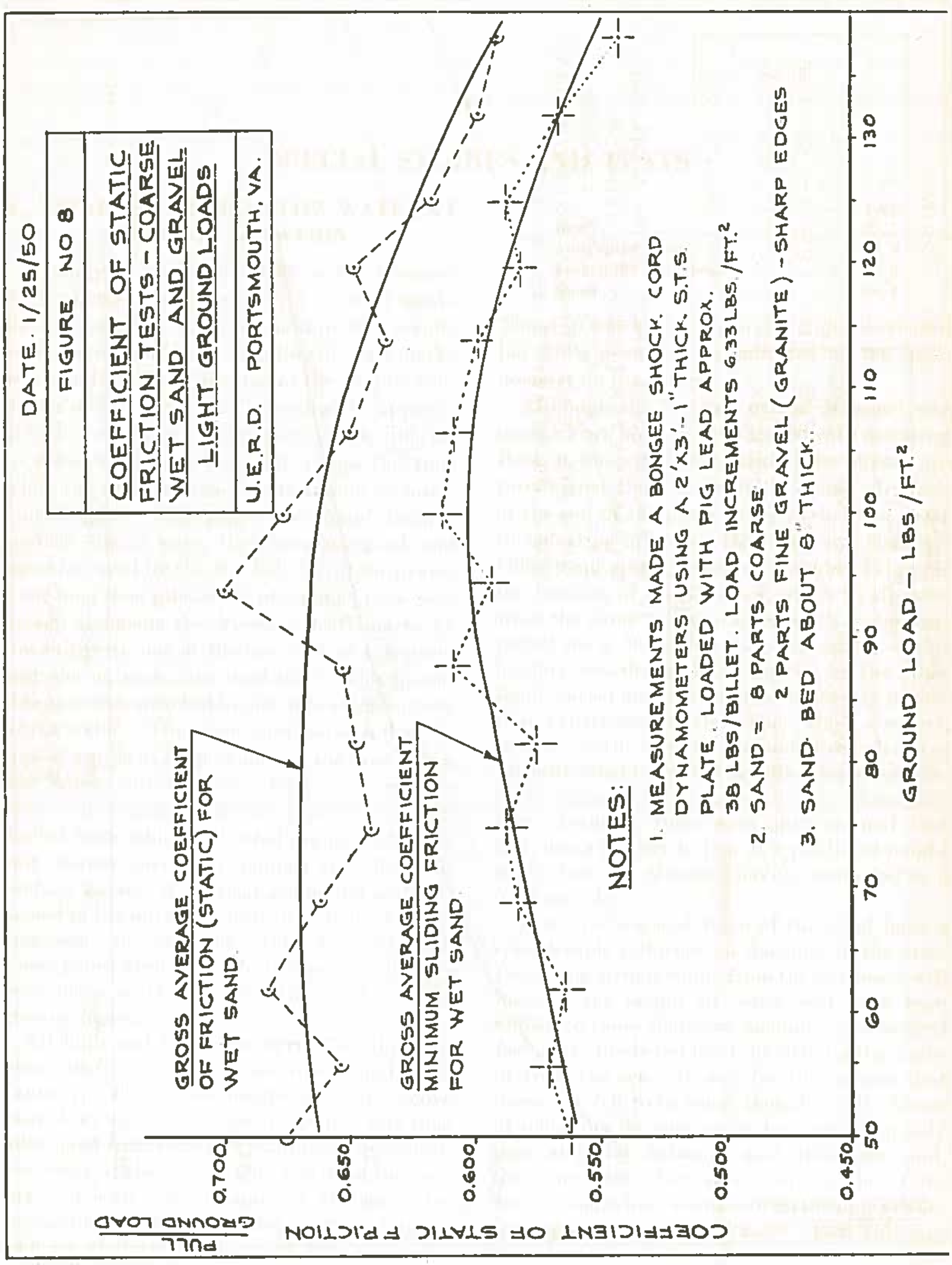
FIGURE NO. 7
COEFFICIENT OF STATIC FRICTION TESTS – COARSE DRY SAND AND GRAVEL
U.E.R.D. PORTSMOUTH, VA.
GROSS AVERAGE COEFFICIENT OF STATIC FRICTION FOR DRY SAND.
GROSS AVERAGE COEFFICIENT OF MINIMUM SLIDING FRICTION FOR DRY SAND.
NOTES:
1. MEASUREMENTS MADE WITH A BONGEE SHOCK CORD DYNAMOMETER, 2'X3'–1" THICK S.T.S. PLATE LOADED WITH PIG LEAD. APPROX. 38 LBS/BILLET, LOAD INCREMENTS 6.33 LBS./FT.²
2. SAND = 8 PARTS COARSE SAND, 2 PARTS FINE GRAVEL (GRANITE).
3. DEPTH OF SAND BED ABOUT 8" OVER HARD GROUND.
COEFFICIENT OF STATIC FRICTION PULL/GROUND LOAD
0.700
0.650
0.600
0.550
0.500
0.450
50
60
70
80
90
100
110
120
130
140
GROUND LOAD – LBS/FT.²


DATE. 1/25/50
FIGURE NO 8
COEFFICIENT OF STATIC FRICTION TESTS - COARSE WET SAND AND GRAVEL LIGHT GROUND LOADS
U.E.R.D. PORTSMOUTH, VA.
GROSS AVERAGE COEFFICIENT OF FRICTION (STATIC) FOR WET SAND.
GROSS AVERAGE COEFFICIENT MINIMUM SLIDING FRICTION FOR WET SAND
NOTES:
1. MEASUREMENTS MADE A BONGEE SHOCK CORD DYNAMOMETERS USING A 2'X3'-1" THICK. S.T.S. PLATE LOADED WITH PIG LEAD APPROX. 38 LBS/BILLET. LOAD INCREMENTS 6.33 LBS./FT.²
2. SAND = 8 PARTS COARSE 2 PARTS FINE GRAVEL (GRANITE) - SHARP EDGES
3. SAND BED ABOUT 8" THICK.
COEFFICIENT OF STATIC FRICTION
PULL / GROUND LOAD
0.700
0.650
0.600
0.550
0.500
0.450
50
60
70
80
90
100
110
120
130
GROUND LOAD - LBS/FT.²

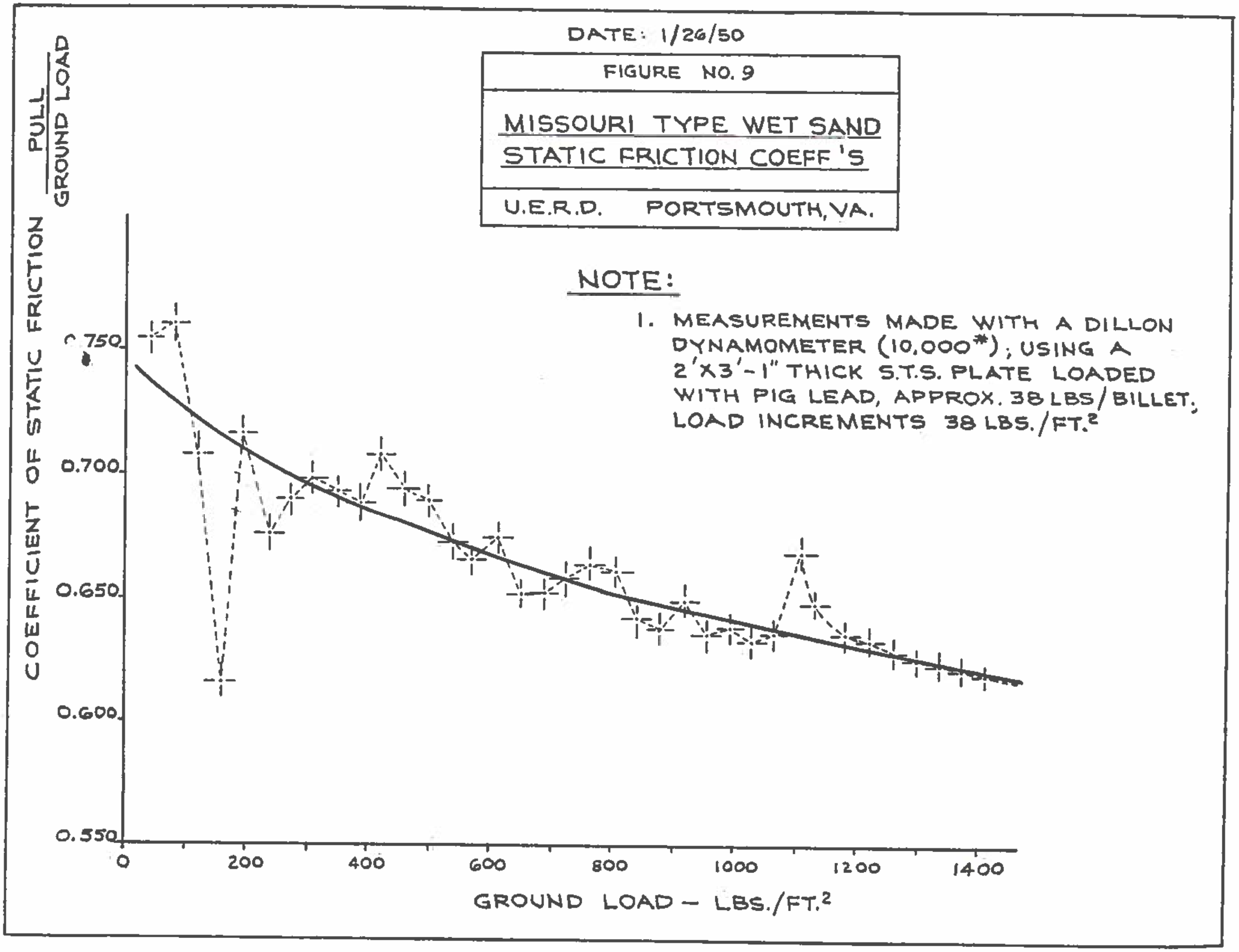

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FIGURE NO. 9
MISSOURI TYPE WET SAND
STATIC FRICTION COEFF'S
U.E.R.D. PORTSMOUTH, VA.
NOTE:
1. MEASUREMENTS MADE WITH A DILLON DYNAMOMETER (10,000#); USING A 2'X3'-1" THICK S.T.S. PLATE LOADED WITH PIG LEAD, APPROX. 38 LBS/BILLET, LOAD INCREMENTS 38 LBS./FT.²
COEFFICIENT OF STATIC FRICTION PULL / GROUND LOAD
0.750
0.700
0.650
0.600
0.550
0
200
400
600
800
1000
1200
1400
GROUND LOAD – LBS./FT.²

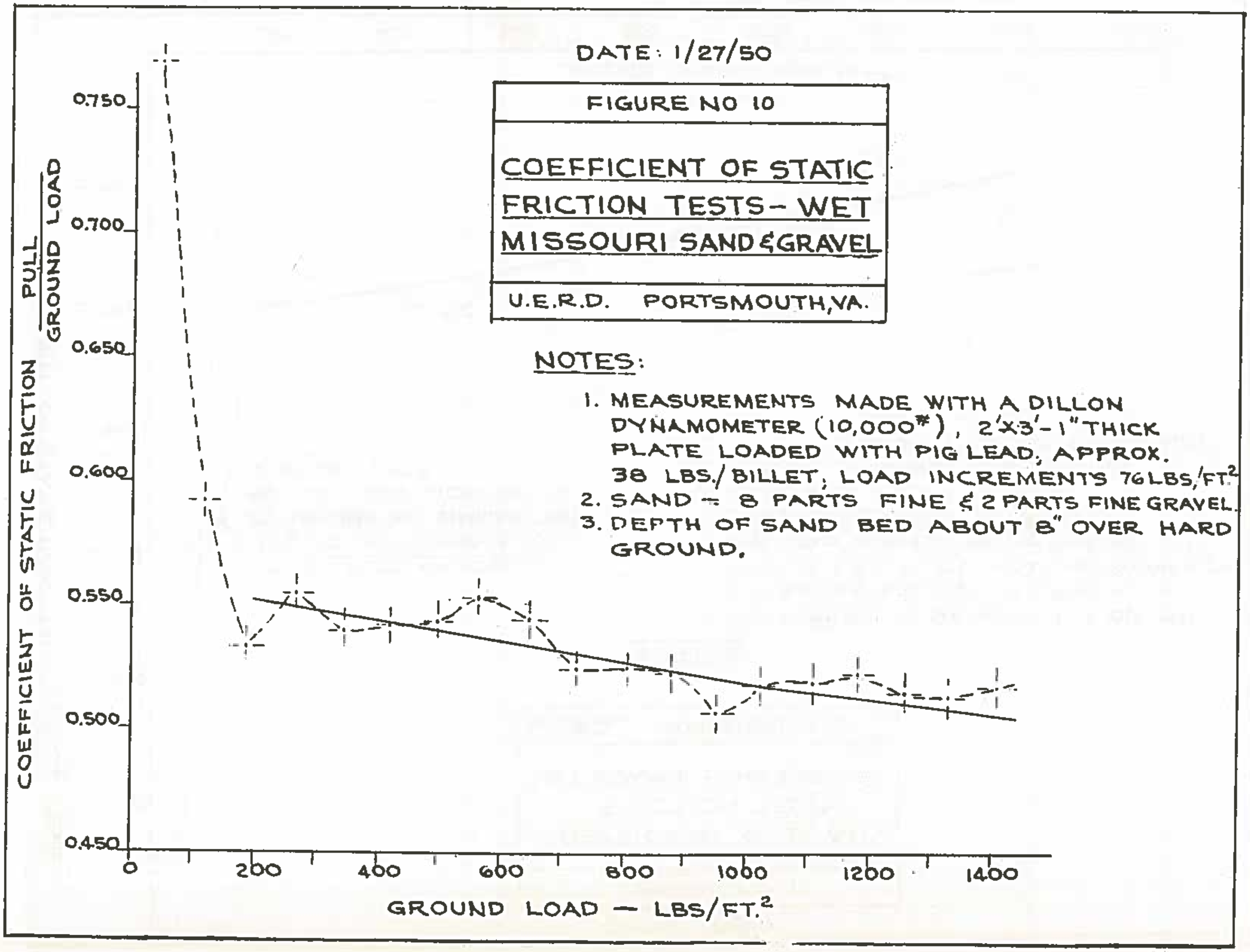
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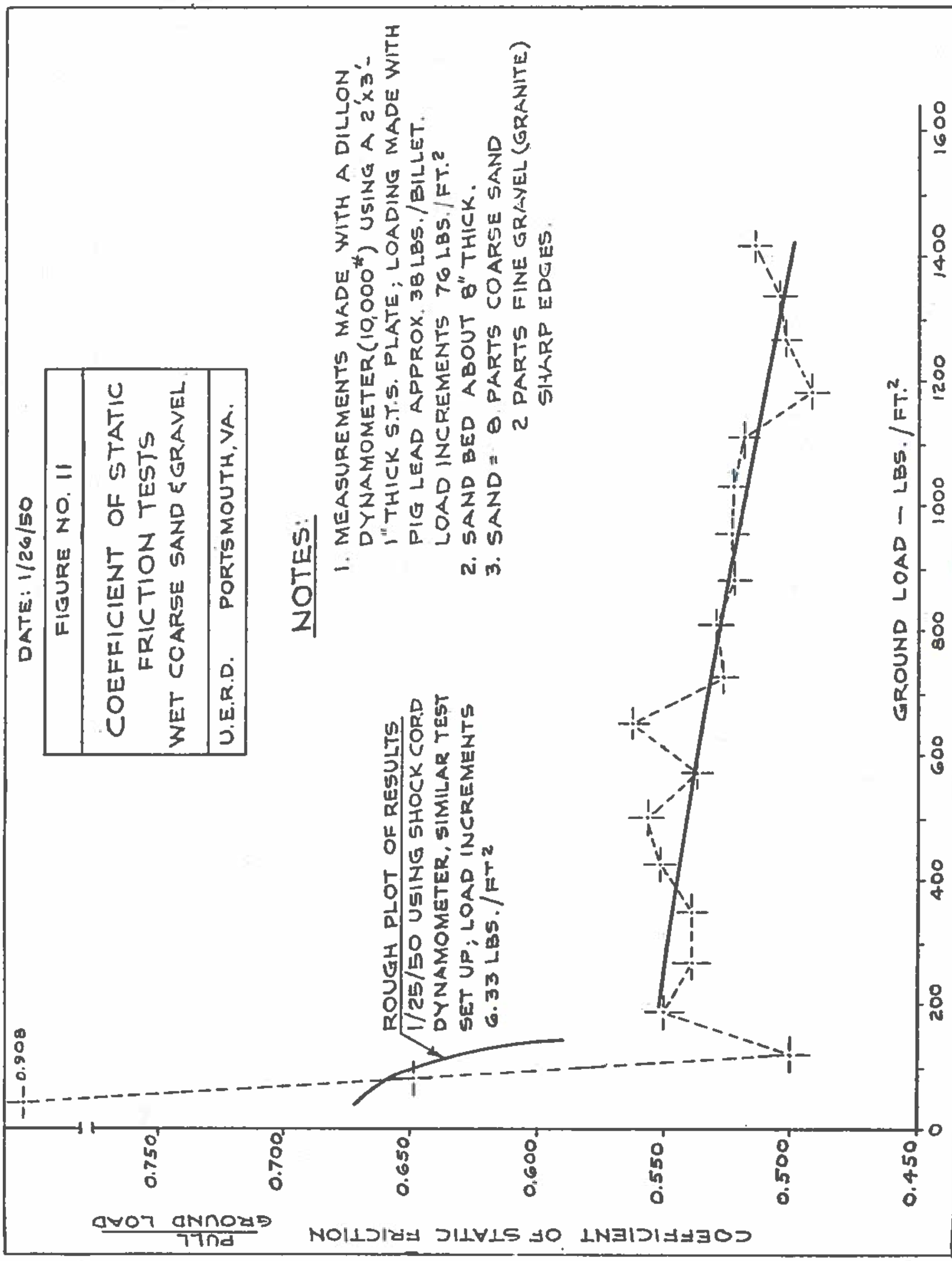
FIGURE NO 10
COEFFICIENT OF STATIC FRICTION TESTS - WET MISSOURI SAND & GRAVEL
U.E.R.D. PORTSMOUTH, VA.
NOTES:
1. MEASUREMENTS MADE WITH A DILLON DYNAMOMETER (10,000#), 2'x3'-1" THICK PLATE LOADED WITH PIG LEAD, APPROX. 38 LBS./BILLET, LOAD INCREMENTS 76 LBS/FT.²
2. SAND = 8 PARTS FINE & 2 PARTS FINE GRAVEL.
3. DEPTH OF SAND BED ABOUT 8" OVER HARD GROUND.
COEFFICIENT OF STATIC FRICTION PULL / GROUND LOAD
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0
200
400
600
800
1000
1200
1400
GROUND LOAD — LBS/FT.²


DATE: 1/26/50
FIGURE NO. 11
COEFFICIENT OF STATIC FRICTION TESTS
WET COARSE SAND & GRAVEL
U.E.R.D. PORTSMOUTH, VA.
NOTES:
1. MEASUREMENTS MADE WITH A DILLON DYNAMOMETER (10,000#) USING A 2'x3'-1" THICK S.T.S. PLATE; LOADING MADE WITH PIG LEAD APPROX. 38 LBS./BILLET. LOAD INCREMENTS 76 LBS./FT.²
2. SAND BED ABOUT 8" THICK.
3. SAND = 8 PARTS COARSE SAND 2 PARTS FINE GRAVEL (GRANITE) SHARP EDGES.
ROUGH PLOT OF RESULTS 1/25/50 USING SHOCK CORD DYNAMOMETER, SIMILAR TEST SET UP; LOAD INCREMENTS 6.33 LBS./FT²
0.908
COEFFICIENT OF STATIC FRICTION
PULL / GROUND LOAD
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0
200
400
600
800
1000
1200
1400
1600
GROUND LOAD — LBS./FT.²

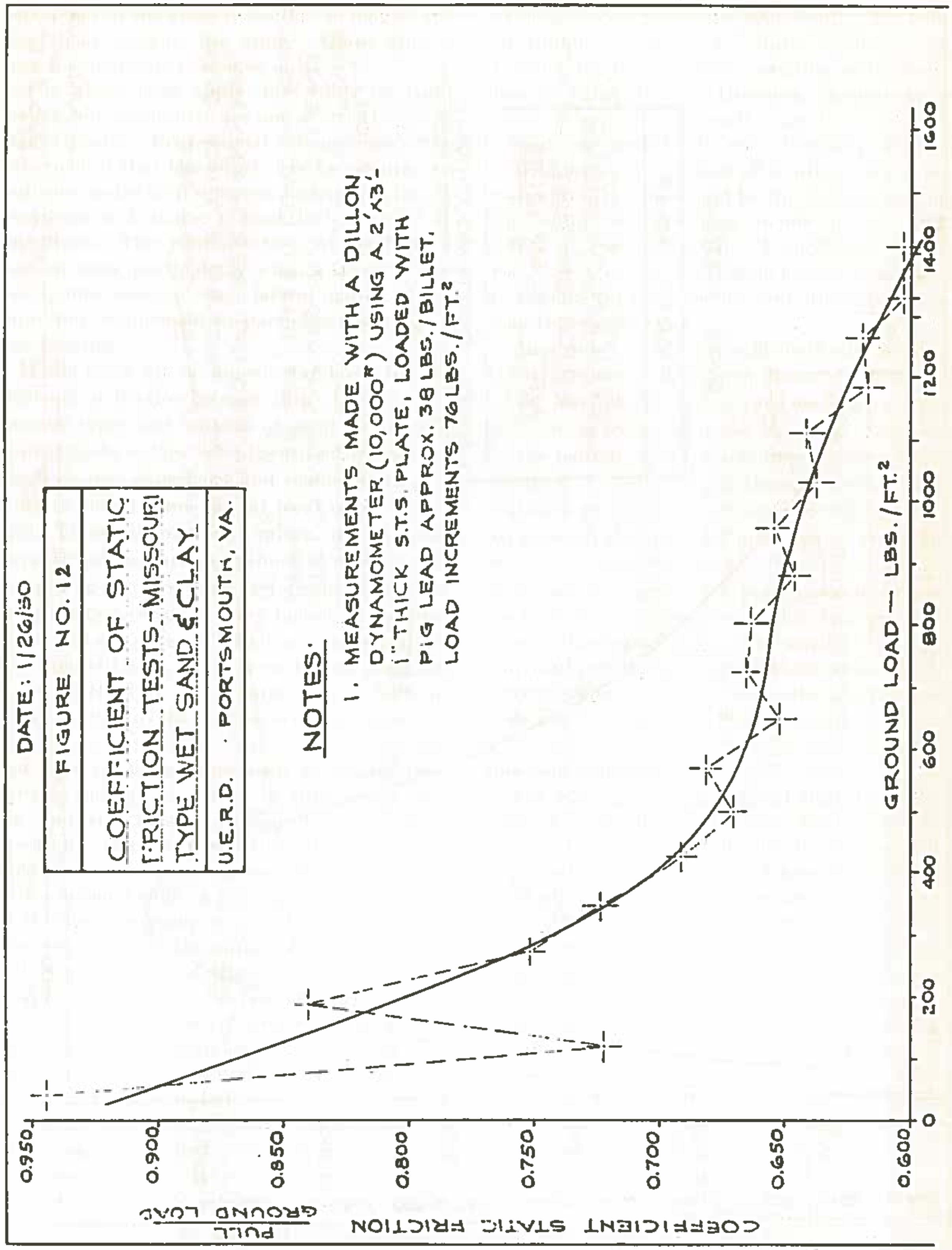

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FIGURE NO. 12
COEFFICIENT OF STATIC
FRICTION TESTS—MISSOURI
TYPE WET SAND & CLAY
U.E.R.D. · PORTSMOUTH, VA.
NOTES:
1. MEASUREMENTS MADE WITH A DILLON
DYNAMOMETER (10,000#) USING A 2'X3'-
1" THICK S.T.S. PLATE, LOADED WITH
PIG LEAD APPROX. 38 LBS./BILLET.
LOAD INCREMENTS 76 LBS./FT.²
COEFFICIENT STATIC FRICTION
PULL / GROUND LOAD
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0
200
400
600
800
1000
1200
1400
1600
GROUND LOAD — LBS./FT.²

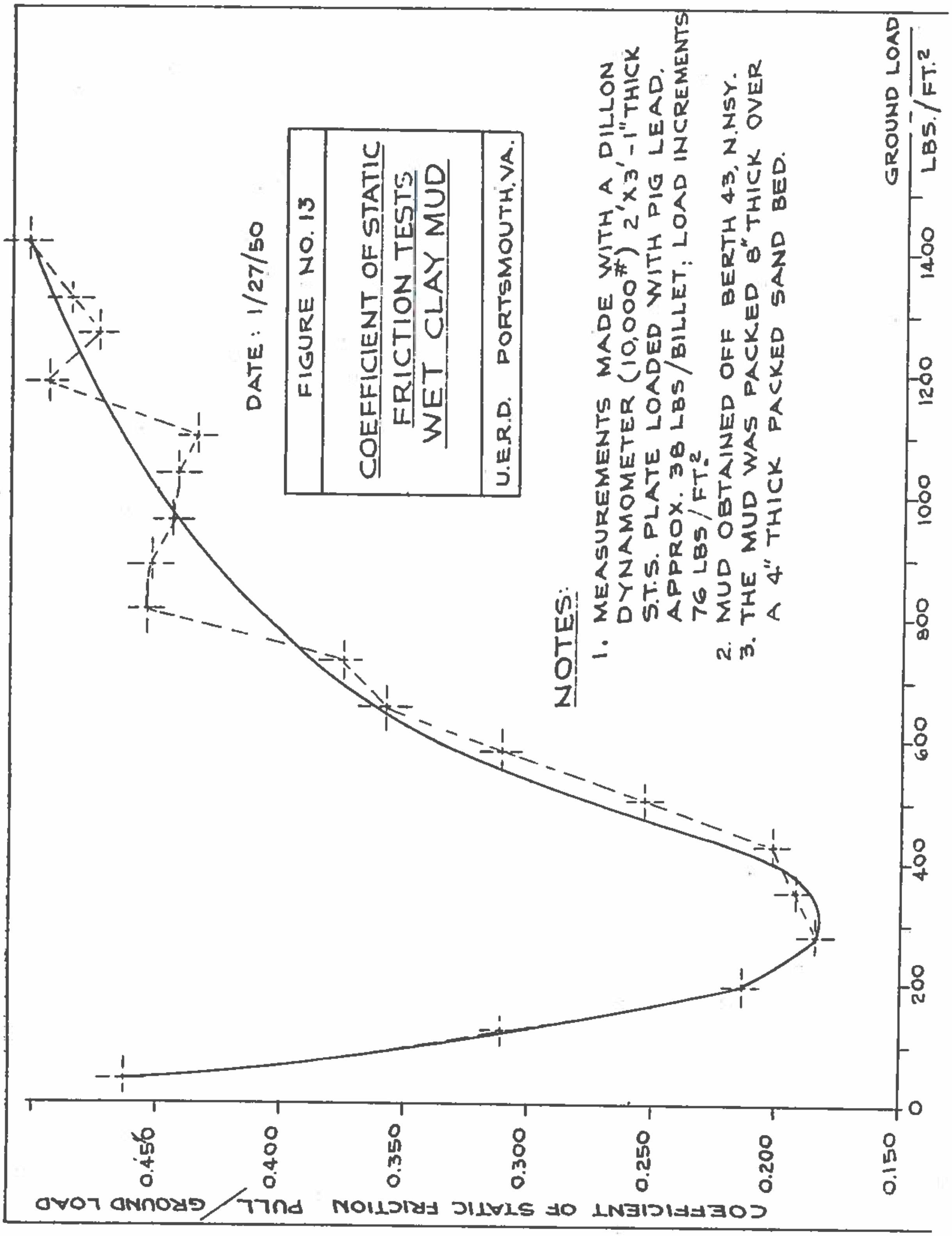
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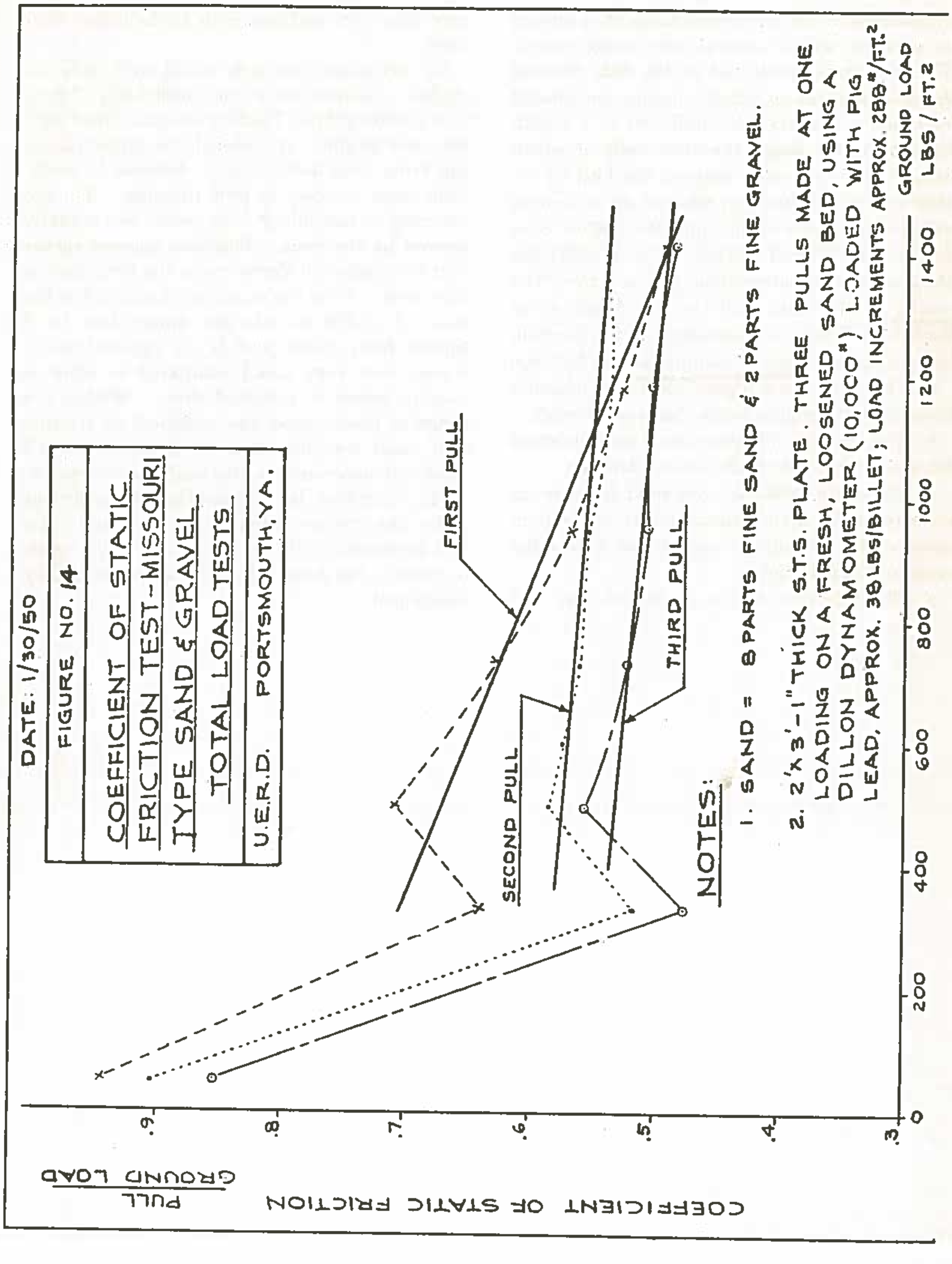
FIGURE NO. 13
COEFFICIENT OF STATIC FRICTION TESTS WET CLAY MUD
U.E.R.D. PORTSMOUTH, VA.
NOTES:
1. MEASUREMENTS MADE WITH A DILLON DYNAMOMETER (10,000#) 2'X3'-1" THICK ST.S. PLATE LOADED WITH PIG LEAD. APPROX. 38 LBS/BILLET; LOAD INCREMENTS 76 LBS/FT.²
2. MUD OBTAINED OFF BERTH 43, N.NSY.
3. THE MUD WAS PACKED 8" THICK OVER A 4" THICK PACKED SAND BED.
COEFFICIENT OF STATIC FRICTION PULL/GROUND LOAD
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0
200
400
600
800
1000
1200
1400
GROUND LOAD LBS./FT.²


DATE: 1/30/50
FIGURE NO. 14
COEFFICIENT OF STATIC
FRICTION TEST-MISSOURI
TYPE SAND & GRAVEL
TOTAL LOAD TESTS
U.E.R.D.
PORTSMOUTH, VA.
FIRST PULL
SECOND PULL
THIRD PULL
NOTES:
1. SAND = 8 PARTS FINE SAND & 2 PARTS FINE GRAVEL.
2. 2'X3'-1" THICK S.T.S. PLATE. THREE PULLS MADE AT ONE LOADING ON A FRESH, LOOSENED SAND BED, USING A DILLON DYNAMOMETER (10,000#) LOADED WITH PIG LEAD, APPROX. 38 LBS/BILLET; LOAD INCREMENTS APPROX. 288#/FT.2
COEFFICIENT OF STATIC FRICTION
PULL
GROUND LOAD
.3
.4
.5
.6
.7
.8
.9
0
200
400
600
800
1000
1200
1400
GROUND LOAD
LBS / FT.2

dynamometer, but at higher loads they should be accurate within several percentage points. The tests were conducted in the flat, whereas the *Missouri* was on a slight incline and should have had a slightly less coefficient as a result. Except for the skegs, the after ends of which were clear of the sand bottom, the hull of the after end of the *Missouri* tapered up in a curve with less tendency to dig into the bottom once motion was induced. Also, the sand under the *Missouri* was actually submerged in water. The results of the tests made by the Underwater Explosion Research Laboratory of the Norfolk Naval Shipyard may be summarized as follows:

a. Fine sand has a higher coefficient of static friction at all ground loads than coarse sand.

b. The addition of gravel to a sand mixture decreases the static coefficient of friction.

c. The static coefficient over sand decreases at a fairly uniform and constant rate at loads in excess of 200 pounds per square foot within the range of loads tested.

d. The behavior of the coefficient over wet clay does not conform with its behavior over sand.

In retrospect, the tests could well have included a comparison of the coefficients of friction resulting from loading unequal areas with the same weight. As labeled, the curves resulting from these tests show a decrease in coefficient with increase in unit pressure. Though this may be possible, it is not what was actually proved by the tests. The tests showed rather that the coefficient decreases as the total load is increased. Even the maximum load used in the tests of (1,400 pounds per square foot by 6 square feet) 8,400 pounds, or approximately 4 tons, was very small compared to what is usually found in stranded ships. Within the range of loads tested, the coefficient of friction over sand was found to be above 0.5 in all cases but decreased as the load was increased. It can, therefore, be inferred that the coefficient under the greater loads found in actual cases will be considerably less than 0.5, which tends to confirm the rule-of-thumb values previously mentioned.

V

CALCULATIONS—ANALYSIS OF RESULTS

The calculations that were made to show predicted loads on the ground and drafts on floating for the expected refloating on 31 January 1950 and on 1 February 1950 are indicated in part I of appendix A. Part II shows actual conditions for the two days and a comparison of these with those that were predicted.

Drafts of the *Missouri* recorded by the ship's force just prior to getting underway on 17 January 1950 indicated that it was in full-load condition and displacing 57,216 tons (assuming three-fourths salt). No reading was taken of the amidship draft marks and so there was no way of determining whether the ship had acquired a hog or a sag due to this loading. All calculations, therefore, neglected such a factor. After the ship had been refloated, repaired in drydock, and again reloaded to full-load condition preparatory to going to sea for an extended period, a reading of all draft marks, including those amidships, showed that in the full-load condition the *Missouri* had a sag amounting to 4½ inches and was approximately 450 tons heavier than had been assumed. Considerable time was devoted, after the ship had been refloated, to account for a difference of approximately 625 tons between actual and predicted calculations without success. It was, therefore, gratifying to learn of the sag which accounted for most of the difference.

For the 31 January refloating attempt, the actual load on the ground with the 2.6-foot tide that existed that day was very close to 1,131 tons. Although the bow had not lifted, it was very close to the point of starting to do so. The pulling force available and used that day consisted of the following:

	Tons
Beach gear	400
Salvager and *Windlass*[1]	200
13 large tugs (ARS, ASR, ATF)	390
Total pulling force	990

[1] Allowing 100 tons per ship was very conservative. Actually there is reason to believe each pulled almost double this amount.

A static coefficient of friction of 0.5 had been assumed as the value conforming with existing conditions and even providing some margin of safety. The pulling force should, therefore, have been ample not only for the existing load, but for one appreciably greater. All efforts to move the *Missouri* on that day proved futile.

For the 1 February 1950 refloating the actual load on the ground with an unexpectedly high tide of 3.3 feet was 719 tons. The bow had been lightened in comparison with the previous day by installing two pontoons forward and removing water in the forward peak tanks, in two bow void tanks, removing sludge oil, and removing anchors and chain. The bow had lifted in excess of 30 inches.

It is interesting to note that had a tide of 3.3 feet occurred on 31 January, the load aground under the conditions of load and trim that day would have been in the order of 211 tons, or less than one-third of that experienced on 1 February. From this point of view, the decision to load the bow somewhat to reduce the ground reaction aft was well-advised. That the ship was not refloated on 31 January is difficult to account for even in retrospect.

No attempt was made to twist the ship by pulling the bow from side to side, except for a push with small tugs, a factor which is believed to have materially contributed to the success of the following day. Whether this could have been readily done with the bow not afloat is problematical. The static coefficient of friction was possibly higher than assumed. The tests that were made on coefficients indicate higher values, but these were at very low loads. Friction would be quite indeterminate if the ship were impaled somewhere along her bottom on some obstruction as a large buried boulder or wreck. Rudders and propellers were all well clear.

The pulling force available on 31 January did not quite equal the expected amount. There was an effective loss in pulling force of two sets of beach gear due to entanglement. There was also, at the end of the pulling attempt, a loss in pull of two large tugs due to breaking of towline while surging. Allowing for 45 tons for each set of beach gear and 30 for tugs, a total of 150 tons could be assumed as having been unavailable. Allowing a further deficit of perhaps 50 tons due to lack of coordination as a result of darkness and fog, the total would amount to 200 tons. This would still leave 790 tons effective. The coefficient of friction on 31 January was, therefore, in excess of $\frac{790}{1,131}$ or 0.7.

The fact that much of the deficit noted above was probably compensated for by a greater pull by the *Salvager* and *Windlass* than they were given credit for would result in a still higher coefficient. The holding power of the ground was good and all anchors had been doubled more as a precaution and because so many were available than because of need. There was no evidence of any dragging. In all cases, beach gear wires (1⅝-inch high-grade plow steel) and the bow wires from the *Salvager* and *Windlass* (2-inch wires of same material) were stretched very tightly. In fact, in most cases some of the preservative of the core was squeezed out.

It was originally believed that some buried obstruction, such as had caused the rupture in the bottom plating in the way of the three oil tanks, contributed to the resistance against the pull. There was very little confirmation of this, however, since the only pronounced dimples in the hull, as observed in drydock, were immediately forward and aft of the ruptured area. While there may have been some degree of added resistance as a result of the damage, the most likely explanation for not refloating was the failure to slew the bow from side to side and the failure to obtain maximum pulling effort from the means available.

The pulling force available for the refloating on 1 February was 930 tons, there being two less tugs used for this purpose. The ship can be assumed to have first moved during the later stages of the twisting operation, at which time the towlines of pulling tugs and half of the beach gear were not under strain. The tide had not yet reached its peak and so the load aground was undoubtedly appreciably in excess of 719 tons. The coefficient of friction under these conditions was, therefore, a value less than $\frac{400}{719}$ or less than 0.56. That it was still not of a very low order was indicated by the strain still required following the twisting operation, when the pull of the tugs was exerted in addition to beach gear and the *Salvager* and *Windlass*.

VI

CONTINGENCY MEASURES—AVAILABLE BUT NOT USED

Barge for providing buoyancy at stern.—There were a number of measures that had been discussed and tentatively held in reserve for use in case of continuing lack of success in refloating the *Missouri*. They were in the nature of "something up the sleeve" for an eventuality that was not expected to arise, but for which it was nevertheless advisable to be prepared. One of these was the provision of additional buoyancy at the stern of the *Missouri* by the use of a special barge that was available at the Norfolk Naval Shipyard. The barge involved, normally used by the Underwater Explosion Research Division of the Shipyard for conducting underwater explosion tests, has the following characteristics, and appeared suited for use as a small floating drydock:

	Feet
Length	150
Beam	50
Molded depth	25

Controlled draft from 5 to 24 feet on an even trim.

Its trim can be controlled so that the deck edge of one end can be submerged to a depth of 6 feet while the bottom of the opposite end is exposed an equal amount. In this condition of trim it was determined that a buoyancy of approximately 1,100 tons could be obtained by

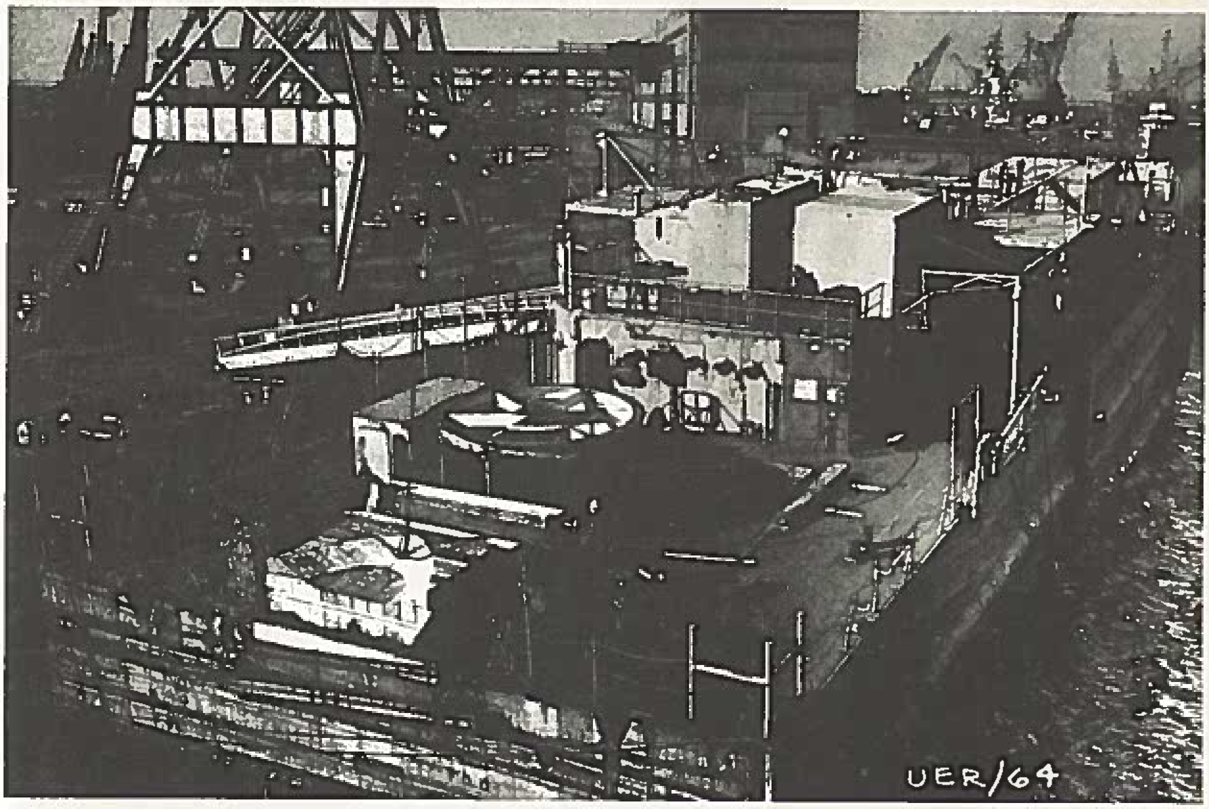


FIGURE 15.—Test barge adapted to lift stern of U. S. S. *Missouri*. Note cribbing on stern and pipe rails forward. Latter were to keep towing hawsers to tugs astern of *Missouri* clear of structure on barge. Though not used, this barge was on way to scene of stranding at time *Missouri* was refloated and would have been used had refloating proved unsuccessful on 1 February.

pumping. A strength analysis of the barge was made to determine that there was sufficient strength to make such a lift and the shoring that was necessary to distribute the concentrated load was installed. Strain indicators were provided for placing on the deck and sides to give a positive check of the magnitude of the lift applied. The submerged end of the barge was to rest against heavy I-beam spuds protruding through the bottom of the *Missouri* hull and welded to its internal framing. It was to be held both laterally and fore and aft by wire rope as shown in plate 9. Figures 15 and 16 show views of the barge with poppet-like cribbing at one end conforming to the shape of the *Missouri* hull.

Its position was to be directly astern of the *Missouri* from which led not only three towlines to the pulling tugs astern, but the lines to the *Salvager* and *Windlass*, as well as one set of beach gear. Its positioning was, therefore, not going to be easy, but at the same time it did not present an insurmountable problem. Heavy pipe railing had been installed on the barge for towlines to rest on and to prevent them from becoming entangled in the barge superstructure. All work involving preparation of the barge was accomplished by the Norfolk Naval Shipyard. It had been decided to use it on 2 February and it was, in fact, on its way to the scene of the stranding at the time the *Missouri* was refloated on 1 February.

Waves of passing destroyers.—The use of ships steaming by at appropriate speed and creating a series of waves that would momentarily increase the buoyancy has occasionally been resorted to in other known salvage operations. This method is often quite effective

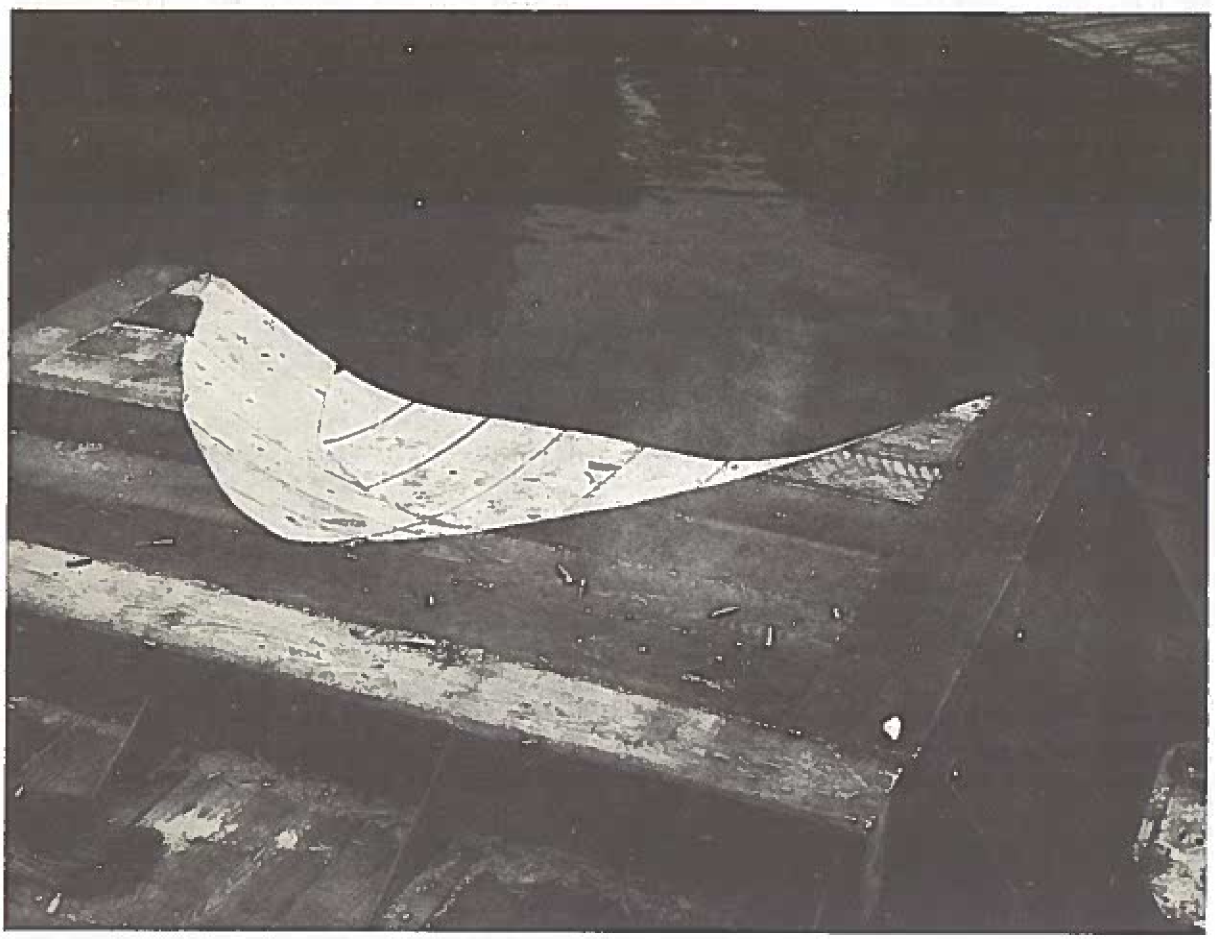
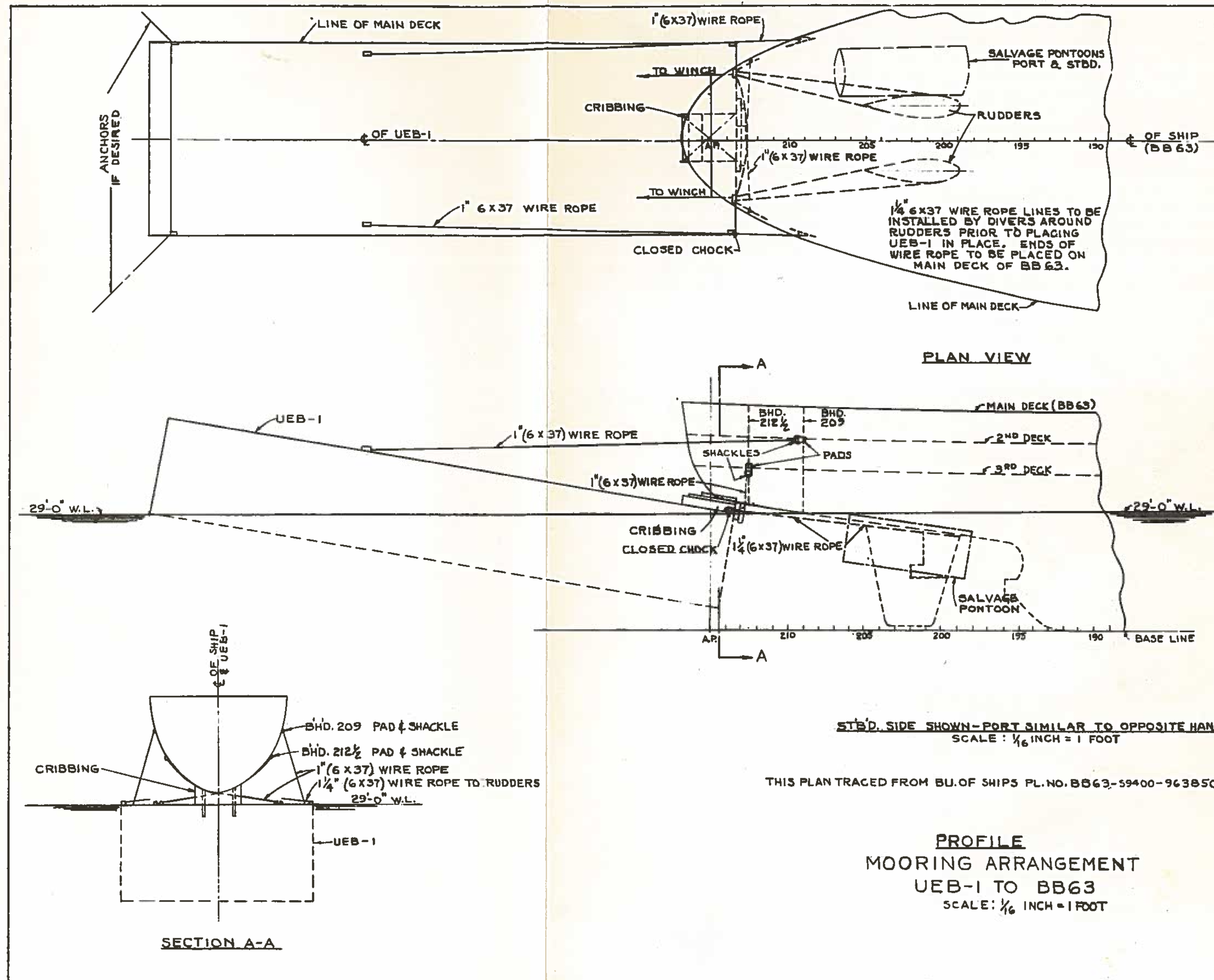


FIGURE 16.—Wood cribbing on barge formed to fit curved hull of U. S. S. *Missouri*.



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where it can be used if a good strain is applied to beach gear and pulling craft at the same time. Not only is there a momentary gain in buoyancy, but a rolling or rocking motion may be induced which would help in moving the ship. It contributed materially to the refloating of the U. S. S. *Omaha* in 1937 which was previously referred to. The wave-making ability of destroyers was observed on 30 January at the scene of the *Missouri* when three destroyers were directed to steam at several speeds, starting at 20 knots, parallel to the fore and aft axis of the ship. The size of the resulting waves as they hit the side of the *Missouri* was very appreciable as was evidenced by the rise and fall as well as the violent motion of the large tugs alongside. The waves, of course, hit only one side of the ship and their height was accordingly not truly indicative of the net buoyancy induced. Had this plan needed to be used, consideration could well have been given to the creating of a series of waves by destroyers passing across the bow of the *Missouri*, provided there was found sufficient depth of water for maneuvering. The waves would have progressed perpendicular to the fore and aft axis of the ship and, with her bow well lightened, could have induced a rocking motion as well as a momentary increase in buoyancy. This, in fact, was the method used in the case of the U. S. S. *Omaha*. Waves from such a direction would not eliminate but would result in less danger of damage to any ships that might be required alongside. Because of this possibility of damage, it was decided not to resort to wave-making unless it was actually needed. It could definitely not have been used in conjunction with the test barge secured at the stern of the *Missouri*.

Beach gear.—Nine sets of gear were used during the refloating, with all anchors backed up by a second one. This represented all the salvage anchors and half of the remaining components of the beach gear on the three ARS salvage ships that were present. An additional six full sets of beach gear, including anchors, had been brought to the scene from storage at Bayonne, N. J. Additional beach gear was available on the numerous ATF tugs on the scene, each of which has an allowance of one set of beach gear. There was, therefore, an abundance of this type of equipment ready and available had the need arisen for installing more.

Pontoons.—A total of eight structural pontoons were installed to provide buoyancy in the locations desired. An additional two were available but not installed. There were also collapsible pontoons available totaling 250 tons of buoyancy that were held in reserve for use if needed. Pontoons of this type are relatively light and quite easily transported. Additional ones could have been made available on short notice had they been needed.

Explosive shots.—Any gain in buoyancy as a result of explosive charges buried alongside the ship was found to be of a small order and would probably be too time-consuming for greater results. Several such charges would, however, encourage a movement of the ship if set off at a time when maximum pull of beach gear and tugs was exerted. The tugs that were alongside would have to be positioned sufficiently clear of the charges to obviate chances of damage.

VII
GENERAL OBSERVATIONS

The U. S. S. *Missouri* was refloated within 15 days after grounding. At least as far as United States naval ships are concerned, it was the largest stranding salvage operation on record. There was nothing particularly unique or distinctive about this operation that would differentiate it from others on ships hard aground except the physical size of the *Missouri* and the volume of work that resulted therefrom. No salvage measures of radically new conception were resorted to, except possibly the extent dredges were used for creating an exit channel and the trenches alongside, the work for the most part having followed orthodox methods that had been used successfully in the past. It is generally admitted that no two salvage jobs are exactly alike in the problems they present. The *Missouri* salvage may claim some distinction in having utilized most of the orthodox measures instead of just several which the average stranding requires.

There is a difference between an off-shore stranding, which is the more common case, and one within the sheltered waters of a harbor. In the former, the work is more of an emergency nature with a premium on the promptness with which adequate assistance can be provided. The ship is exposed to the winds and seas which can and do assume large proportions. The ship should be considered in great danger, for the weather conditions, even if favorable at the time, can change rapidly for the worse. There are many cases on record of ships broaching broadside to the beach and breaking up because of the sand being washed away progressively from the ends or of being driven further ashore and pounding on rocks. Unorthodox measures are often in order, such as flooding compartments to load the ship to keep her from broaching or being driven farther ashore, rather than lightening, until adequate provisions have been made for pulling her off. Often a ship is endangered by continued futile efforts to pull with tugs when the ship is too hard aground. There are, however, many occasions when such effort is justified if, in the meantime, more adequate assistance has been sent for and is not being delayed because of such efforts. An off-shore stranding may not be near adequately equipped Navy salvage facilities, in which case there should be no hesitation in using commercial facilities if they are more promptly available.

The *Missouri* was stranded, not off-shore, but in protected waters with no real danger of further damage. Salvage work was, however, pressed vigorously as such work always is, with a view of refloating her as soon as possible. For the most part, it was handled as though it were an off-shore job which was in close proximity to extensive Navy facilities of all types.

A particular effort was made throughout the operation to insure that the *Missouri* received no additional damage due to salvage work in progress. There would have been no advantage in refloating her a day or two sooner if, by so doing, some damage was incurred that required several weeks in drydock to repair. The painstaking leveling of high spots in the exit channel, for example, or the effort to insure that propellers and rudders were clear of obstructions, was well worth while if extensive drydock work was obviated as a result. The only damage occasioned by salvage work was a number of nicks in propellers due to passing of pontoon chains; there was only relatively minor damage due to grounding. The only compartments that were ruptured out of a total of about 450 in contact with the skin of the ship were oil tanks B–29–F, B–37–F, and B–43–F. The Naval Shipyard effected complete repairs in 5 days.

Of greater concern than damage to the ship was injury to personnel. Throughout the entire salvage operation, involving many men of all types and degrees of experience and inexperience engaged in work of a hazardous nature, there were no lost time accidents. Such results are truly noteworthy and are not obtained through chance.

The primary objective of the salvage operation was of course the refloating of the *Missouri*. It served, however, another important purpose. It was a means of training men under actual rather than simulated conditions on a very large scale. While emphasizing salvage, this training included seamanship as well as all the artificer type of work that the Navy is concerned with. Its influence in the matter of logistic support reached beyond the Norfolk area. A high degree of cooperation was exhibited by all Navy activities called upon for services of varying types, as well as by the United States Army Engineers under whom the dredge *Comber* operated. That it was unexpected and consequently unrehearsed only served to make the salvage operation more valuable from this point of view.

The desirability of maintaining salvage equipment in several locations in operating condition is borne out by the *Missouri* salvage. Submarine salvage pontoons arrived on the scene shortly after being requested. Assorted equipment maintained at Naval Supply Depot, Bayonne, and the Salvage School played an important part in the operation. The cost of maintaining this equipment for a number of years could be considered more than paid for by their contribution to the salvage. The value of the specialized training schools maintained by the Navy was also reflected in the work. Among these are the Deep Sea Diving School, which is the primary source of new divers for submarine rescue vessels, and the Naval School (Salvage), which supplies personnel trained in fundamentals to salvage ships.

The organization was simple and effective. It consisted of the regular staff of the type commander who was in charge of the salvage operation. The existing staff was already geared, through daily practice, to handle most of the work, including communications, movement of ships, material matters, and problems of supply. This staff was temporarily augmented by a number of officers with previous experience in the various phases of salvage work to follow. Navy activities represented on the staff by temporary members included the Service Force Atlantic Fleet, Submarine Force Atlantic Fleet, Bureau of Ships, Supervisor of Salvage, and Ammunition Depot, Crane, Ind. The Norfolk Naval Shipyard was relied upon for varied important services and was well represented by its commander, who was deputy commander of the salvage operation as well as chief technical advisor. Close liaison with the various activities likely to contribute to the operation was therefore assured. The different phases of the operation, such as ship movements, beach gear, pontoons, diving, communications, material matters including compilation of weights, progress reports, and displays were assigned to specific officers for progressing and supervision. Differences were resolved in daily meetings of the entire staff with the commander and deputy commander.

The cost of the salvage of the *Missouri*, exclusive of the pay of uniformed personnel and of the cost of repairs of the damage sustained in the grounding, was approximately $225,000. About $80,000 of this amount was absorbed by the two dredges, one of which was a commercial facility working under contract, the other a United States Army vessel which employed a civilian crew. The remainder of the cost was due to the miscellaneous work undertaken by the Norfolk Naval Shipyard, the Naval Operating Base, and the replacement or repair of the many items of equipment used.

APPENDIX A

U. S. S. *Missouri* (BB63)

Part I—PREDICTED CONDITIONS FOR 31 JANUARY AND 1 FEBRUARY

Flotation draft and trim data were calculated for several conditions, based on a displacement of 57,216 tons at the time of leaving the Naval Operating Base at Norfolk, Va., on 17 January 1950.

These calculated conditions are as follows:

Condition A—Loaded on leaving base.

Condition B—Unloaded for flotation.

Condition C—Unloaded (condition B) plus six pontoons at stern and Peak Tanks A-1-W and A-2-W filled 100 percent with sea water.

Condition D—Unloaded (condition B) plus six pontoons at stern, two pontoons at bow, anchors and chain off, sludge oil in B-15-F, B-16-F, and B-61-F removed.

The following calculations were made prior to refloating and were the basis for all predictions for loads aground and refloating drafts.

Condition A

Drafts reported by ship at time of leaving Naval Operating Base prior to grounding:

35′ 9″ forward.
36′ 9″ aft.
36′ 3″ resulting mean draft.

Displacement of ship at above drafts:

57,650 tons (salt water).
56,800 tons (one-half salt water).
57,225 tons average of above (three-fourths salt).

Displacement 57,216 tons full load from U. S. S. *New Jersey* (BB62) Inclining Experiment Data of 13 June 1943.

The decision was made to use the full load displacement of 57,216 tons as the basis for all weight calculations. The longitudinal center of gravity for the vessel was taken from the inclining experiment, viz., 20.96 feet aft of frame 108.

Detailed Weight Changes for Condition "B"

Item	Weight (tons)	Forward lever (feet)	Forward moment (foot-tons)	Aft lever (feet)	Aft moment (foot-tons)
Boats and skids	44			280.0	12,320
Personnel	102			43.7	4,457
Ammunition	2,205	14.8	32,634		
Dry provisions	199			269.0	53,531
Fresh provisions	91			264.1	24,033
Potable water	724			51.1	36,996
Reserve feed water	373			39.1	14,584
Fuel oil	7,973	21.5	171,420		
Diesel oil	149			22.6	· 3,367
Total	11,860	4.6	54,766		

With minor exceptions, lever arms for above items of weight were taken from the actual full load condition as recorded in U. S. S. *New Jersey* (BB62) Inclining Experiment Booklet, with frame 108 as reference point.

Condition B—Unloaded

Item	Weight (tons)	Forward lever	Forward moment	Aft lever	Aft moment
Condition A	57,216			20.96	1,199,364
Weights removed	−11,860	4.6	−54,766		
Condition B	45,356			27.7	1,254,130

Mean draft at three-fourths salt = 29′ 8″.
Longitudinal center of buoyancy = 10.68 feet aft of midship.
= 8.68 feet aft of frame 108.
Trimming lever = 27.7 − 8.68 = 19.0 feet aft.

$$\text{Trim} = \frac{45{,}356 \times 19}{6{,}300} = 137 \text{ inches} = 11.4 \text{ feet by stern.}$$

$$\text{Correction to mean draft for trim} = \frac{92 \times 11.4}{149.5} = 7 \text{ inches.}$$

Mean draft corrected = 29′ 1″ } When afloat.
Forward draft corrected = 23′ 4″½ }
Aft draft corrected = 34′ 9½″ }

Detailed Weight Changes for Condition C

PONTOONS

Item	Buoyancy (tons)	Aft lever (feet)	Aft moment (foot-tons)
Pontoons:			
Frame 174	160	264	−42,240
Frame 182	160	296	−47,360
Frame 203	160	380	−60,800
Total added buoyancy	480		−150,400

PEAK TANKS

Item	Weight (tons)	Forward lever	Forward moment
Peak tank A-1-W	222	416	92,352
Peak tank A-2-W	242	396	95,832
Total added	464		188,184

Condition C

Predicted for 31 January pull-off try:

6 pontoons aft.
Peak tanks full.

Item	Weight (tons)	Forward moment	Aft lever	Aft moment
Condition B	45,356		27.7	1,254,130
Pontoons (6 aft)	−480			−150,400
Peak tanks	+460	188,184		
Condition C	45,340		20.2	915,546

Mean draft ¾ salt = 29′ 8″.
L. C. B. = 10.65 feet aft of midship.
= 8.65 feet aft of frame 108.
Trimming lever = 20.2 − 8.65 = 11.55 feet aft.

$$\text{Trim} = \frac{45{,}340 \times 11.55}{6{,}280} = 83 \text{ inches} = 6.9 \text{ feet aft.}$$

$$\text{Correction to mean draft for trim} = \frac{92 \times 6.9}{149.5} = 4 \text{ inches.}$$

Mean draft corrected .... = 29′ 4″
Forward draft corrected ..... = 25′ 10½″ } When afloat.
Aft draft corrected .... = 32′ 9½″

Detailed Weight Changes for Condition D

Item	Weight	Forward lever	Forward moment	Aft lever	Aft moment
Anchor chains (removed)	95	346	32,870		
Anchor (removed)	27	441	11,907		
2 Pontoons frame 19 (added)	[1] 160	356	56,960		
Sludge oil:					
B15F (removed), B16F (removed)	119	54	6,426		
B61F (removed)	53			78	4,134
2 pontoons:					
Frame 174 (added)	[1] 160			264	42,240
Frame 182 (added)	[1] 160			296	47,360
Frame 203 (added)	[1] 160			380	60,800
Total reduction in weight	934				46,371

[1] Buoyancy.

Condition D

Predicted for 1 February pull-off:

- 6 pontoons aft.
- 2 pontoons forward.
- Anchors and chain removed.
- 172 tons of sludge oil removed.
- Peak tanks empty.

Item	Weight	Aft lever	Aft moment
Condition B	45,356	27.7	1,254,130
Items removed	934		46,371
Condition D	44,422	27.2	1,207,759

Mean draft at ¾ salt = 29′ 2¼″

L. C. B. = 10 feet aft of midship = 8.0 feet aft of frame 108.
Trimming lever = 27.2 − 8.0 = 19.2 feet aft.

$$\text{Trim} = \frac{44{,}422 \times 19.2}{6{,}250} = 136 \text{ inches} = 11.3 \text{ feet by stern.}$$

$$\text{Correction to mean draft for trim} = \frac{90 \times 11.3}{149} = 7 \text{ inches.}$$

Mean draft corrected .... = 28′ 7½″
Forward draft corrected ..... = 22′ 11½″ } When afloat.
Aft draft corrected .... = 34′ 3½″

Study of Predicted Load Aground

Based on the drafts of the U. S. S. *Missouri* (BB63) while aground it was known that the vessel was resting on a slope giving her a trim of 3.6 feet by the stern. Since condition B (unloaded) indicated an afloat trim of approximately 11½ feet by the stern, it was apparent that the bow of the vessel would rise before the stern. Calculations were made to determine the following:

1. Depth of water required to lift bow.
2. Buoyancy at pivot.
3. Pivot pressures.

The point of pivot was assumed to be at frame 190 since it was reported that the skegs were cleared by dredging and tunneling aft of this point. By plotting the moment of buoyancy for various water lines at 3.6-foot trim aground and the moment of weight for the various conditions about frame 190, it was possible to arrive at the mean draft to pivot. Chart 1 shows this plot. Calculations for the moment curves are as follows:

Frame 190 to frame 108 = 82 × 4 = 328′ aft of frame 108.

Moment of weight

Condition	Displacement (tons)	LCG aft, frame 108	Lever arm (feet)	Moment (foot tons)
B	45,356	27.7	300.3	13,620,000
C	45,340	20.2	307.8	13,960,000
D	44,422	27.2	300.8	13,360,000

Calculations for moment curves

MOMENT OF BUOYANCY

Mean draft	Displacement ¾ salt	Displacement correction, 3.6-foot trim	Displacement 3.6-foot trim	LCB aft, 108	LCB [1] correction, 3.6-ft. trim	LCB forward, frame 190	Moment of buoyancy
28	42,300	295	42,595	6.4	12.6	315.4	13,434,000
30	45,900	335	46,235	9.0	14.9	313.1	14,470,000
32	49,500	360	49,860	11.6	17.2	310.8	15,496,000

[1] Calculation for correction to LCB for 3.6′ trim.

$$\text{Lever} = \frac{\text{Moment to change trim 1}'' \times \text{trim in inches}}{\text{Displacement}}$$

$= \frac{6{,}100 \times 43.2}{42{,}595} = 6.2.$ Then LCB corrected for 3.6′ trim = 6.2′ + 6.4′ = 12.6′.

$= \frac{6{,}300 \times 43.2}{46{,}235} = 5.9.$ Then LCB corrected for 3.6′ trim = 5.9′ + 9.0′ = 14.9′.

$= \frac{6{,}500 \times 43.2}{49{,}860} = 5.6.$ Then LCB corrected for 3.0′ trim = 5.6′ + 11.0′ = 17.2′.

Calculations for moment curves—Continued

PIVOT DRAFTS AND PRESSURES

Condition	Pivot draft (mean)	Displacement at pivot draft (tons)	Correction for trim (tons)	Correction displacement at pivot draft (tons)	Displacement afloat (tons)	Pivot pressure (tons)	Load aground [2] (tons)
B	28′ 4″	42,930	300	43,230	45,356	2,126	
C	29′ 0″	44,120	310	44,430	45,340	910	640
D	27′ 10″	42,040	290	42,330	44,422	2,092	1,122

[2] The pivot pressures listed above are at tides when bow just starts to lift. The loads aground, for the tides that were expected, would be as follows:

Condition C (expected tide 2.5′):

Load aground=910 tons as bow starts to rise when mean draft is 29′ or height of tide is 2.1′. As tide continues to rise to 2.5′, load will change. At 2.5′ tide, bow will float at (draft of 20.9′ chart 2 for moment of 13,960,000 and tide of 2.5′).

Displacement=44,700 tons.

Load aground=45,340−44,700=640 tons.

Condition D (expected tide 2.6′).

Load aground as bow starts to lift=2,092 tons which occurs at a mean draft of 27.8′. This is equivalent to a tide of 0.9′. As tide rises to 2.6′, bow will be afloat at draft of 21.7′.

Displacement=43.300 tons.

Load aground=44,422−43,300=1,122 tons.

Part II—ACTUAL CONDITIONS ON 31 JANUARY AND 1 FEBRUARY

The purpose of the following calculations is to ascertain the actual displacement and weight aground at the time of the 31 January and 1 February pull-off operations. These calculations are based on drafts observed in drydock No. 8, Norfolk Naval Shipyard, at 1500 on 1 February. At this time, the *Missouri* was in the same condition as at the time of refloating with the exception of several known minor, weight changes.

Drafts as read on entering drydock No. 8 on 1 February 1950, NORNAVSHIPYD:

	Port	Starboard	Mean
Forward	28′11″	28′11″	28′11″
Midship	31′0″	30′6″	30′9″
Aft	32′7″	32′3″	32′5″

Trim by stern 3′ 6″. Mean draft 30′ 8″.

	Tons
Displacement at above mean draft (35.5 cu. ft./ton NNSY)	46,700
Addition to displacement for trim at 97 tons per foot	340
Total displacement	47,040

At the time of entering drydock there were four pontoons still in position, frames 174 and 182, of which only the after pair were still effective, 1,251 tons of ballast had been added forward, and the extreme bow and stern pontoons had been removed. (The extreme after pair of pontoons were not effective during refloating operation.)

Calculation for position of longitudinal center of gravity:

$$\frac{\text{Moment to alt. trim 1 inch} \times \text{trim in inches}}{\text{Tons displacement}}=\text{lever arm for trim.}$$

$$\frac{6{,}400\times 42''}{47{,}040}=5.71\text{-foot lever arm for trim by stern.}$$

L. C. B. at 30′ 8″ mean draft=9.93 feet aft of frame 108.

L. C. G.=9.93+5.71=15.64 feet aft of frame 108.

Determination of actual refloating condition of 1 February:

	Tons	LCG from frame 108 (feet)	Foot-tons moment
Displacement at NORNAVSHIPYD	47,040	15.64 aft	+735,705
Ballast added after refloating	−1,251	291.4 fwd	+364,596
Bow pontoons removed after refloating	−160	356.0 fwd	+56,960
Aft pontoon, frame 174	−160	264.0 aft	−42,240
Total [1]	45,469	24.52	1,115,021

[1] Actual displacement at the time of the refloating on 1 February 1950 as determined from drafts read while in drydock and corrected for changes noted above.

The predicted condition for the February 1 attempt (condition D):

	Tons	LCG from frame 108 (feet)	Foot-tons moment
	44,422	27.2	1,207,759

Known deviations from the above prediction were as follows:

	Tons	LCG from frame 108 (feet)	Foot-tons moment
			Aft
Aft Pontoons (frame 203)	+160		+60,800
Personnel	+102		+4,457
F. O.	+62		+1,333
Salvage and yard equipment	+100		+24,800
	44,846	29.0	1,299,149

The above figures indicate a difference of 623 tons between the actual and predicted conditions for 1 February 1950.

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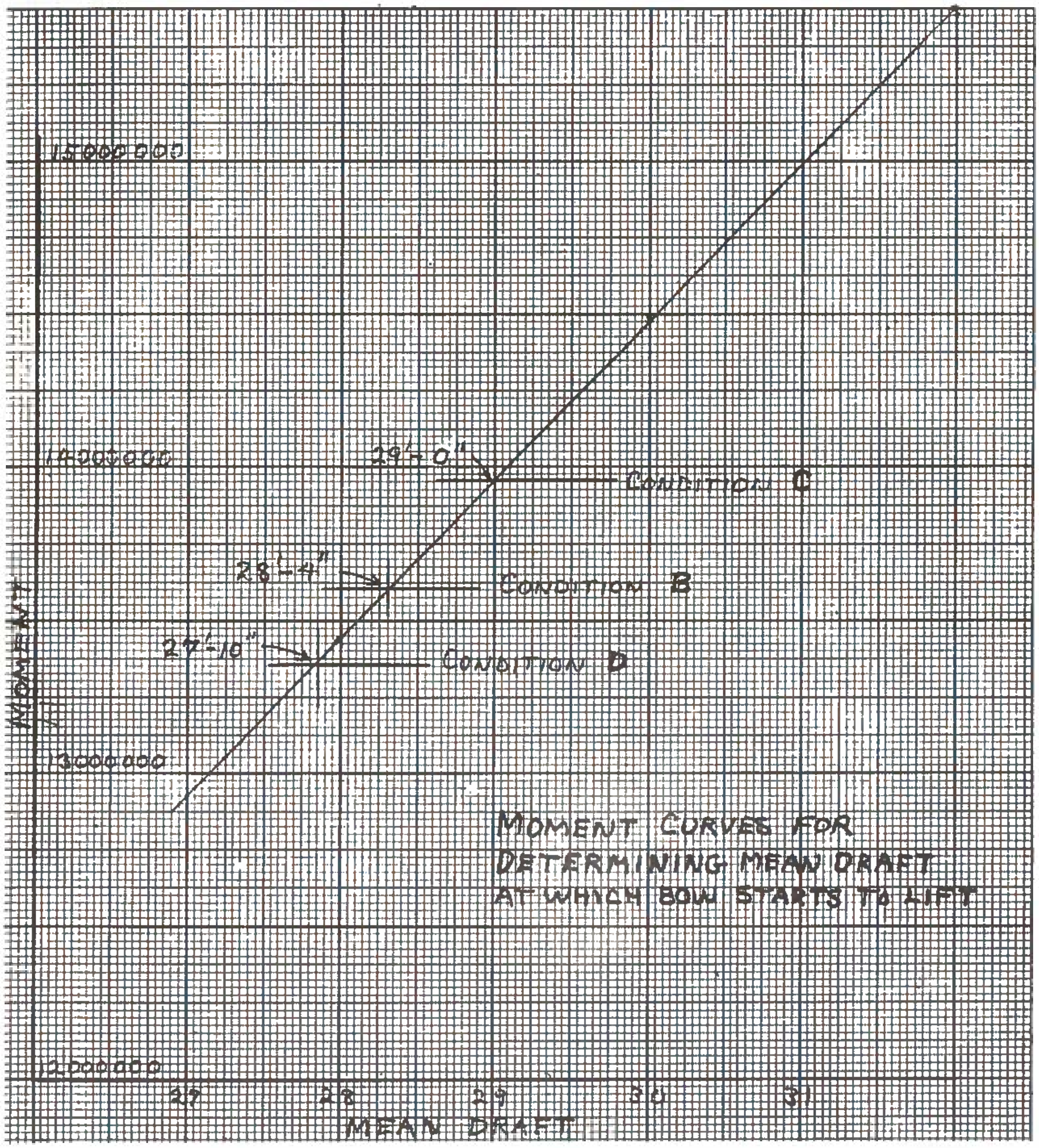

15000000
14000000
13000000
12000000
29'-0"
Condition C
28'-4"
Condition B
27'-10"
Condition D
Moment Curves for
Determining Mean Draft
at which Bow Starts to Lift
27
28
29
30
31
Mean Draft
Moment

Chart 1.

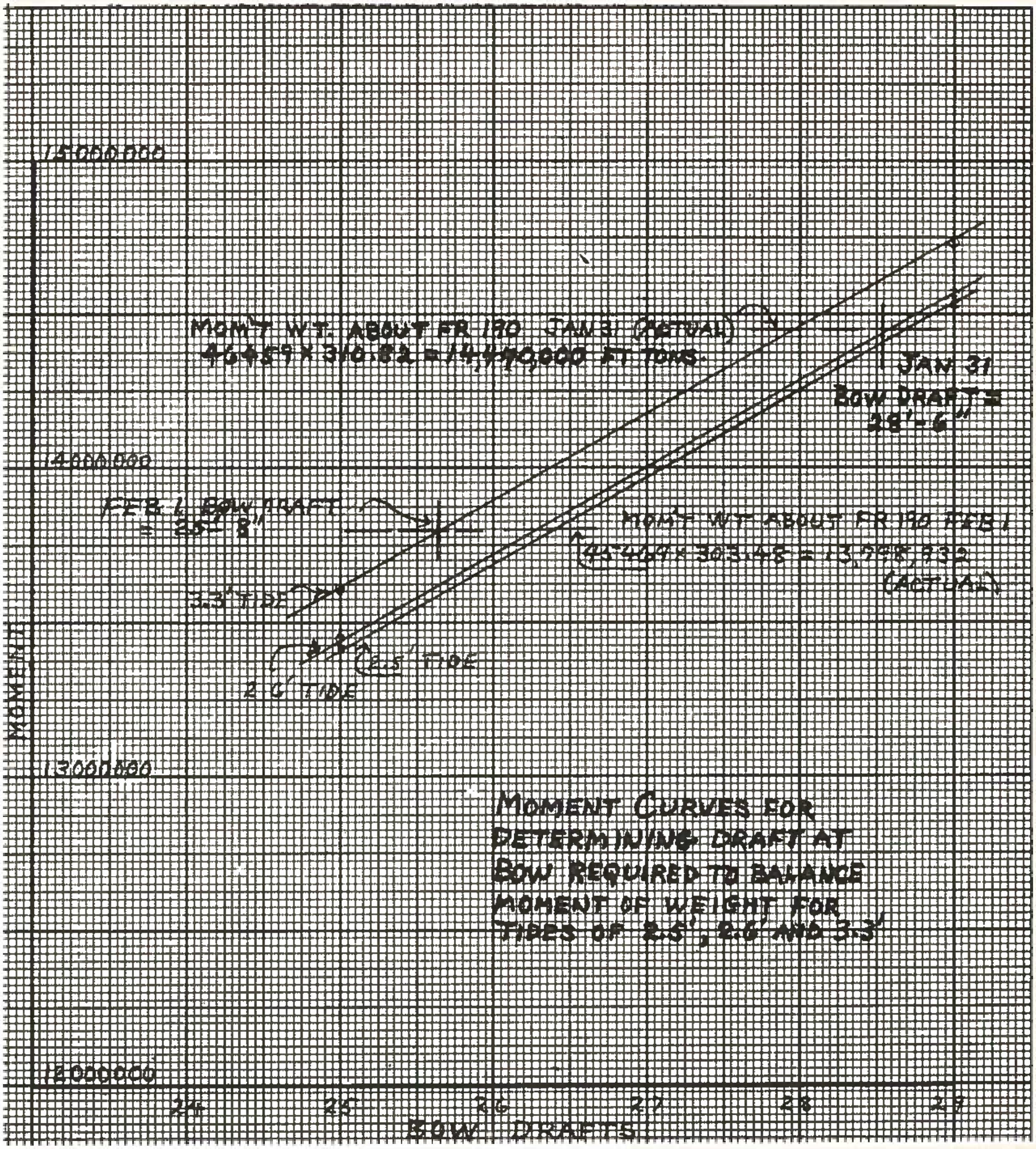

15000000
14000000
13000000
12000000
MOM'T WT. ABOUT FR 190 JAN 31 (ACTUAL)
46459 X 310.82 = 14,440,000 FT TONS.
JAN 31
BOW DRAFT =
28'-6"
FEB 1 BOW DRAFT
= 25'-8"
MOM'T WT ABOUT FR 190 FEB 1
45469 X 303.48 = 13,998,932
(ACTUAL)
3.3' TIDE
2.5' TIDE
2.6' TIDE
MOMENT
MOMENT CURVES FOR
DETERMINING DRAFT AT
BOW REQUIRED TO BALANCE
MOMENT OF WEIGHT FOR
TIDES OF 2.5', 2.6' AND 3.3'
24
25
26
27
28
29
BOW DRAFTS

Chart 2.

Determination of actual refloating attempt condition of 31 January 1950:

	Tons	LCG from frame 108 (feet)	Foot-tons moment
DD #8	47, 040		+735, 705
Ballast	−1, 251		+364, 596
Anchor and chain	+122		−44, 700
Sludge oil	+119		−6, 430
Sludge oil	+53		+4, 134
Peak tanks	+464		−188, 184
A4V and A5V	+72		−24, 912
Aft pontoons, frame 174	−160		−42, 240
Actual	46, 459	17.18 aft	797, 969

Condition C as predicted for January 31 attempt:

	Tons	LCG from frame 108 (feet)	Foot-tons moment
	45, 340	20. 2	916, 546

Known deviations from above prediction were as follows:

	Tons	LCG from frame 108 (feet)	Foot-tons
A4V and A5V	+72		*Fwd.* −24, 912
Aft pontoons, frame 203	+160		*Aft* +60, 800
Personnel	+102		+4, 457
F. O.	+62		+1, 333
Salvage and yard equipment	+100		+24, 800
	45, 836	21. 4	982, 024

The above figures indicate a difference of 623 tons between the actual and predicted for the January 31 attempt.

Calculations for Moment of Buoyancy Versus Bow Draft

Height of tide	Bow draft	Draft at L. C. F.	Displacement (¾ salt)	Trim	Moment to trim 1″	Trim lever	C. B. aft amidships even keel	C. B. forward frame 190, trimmed	Moment of buoyancy about frame 190
3. 3	25	29. 11	44, 280	7. 51	6, 190	12. 6	9. 9	307. 5	13, 620, 000
3. 3	29	30. 65	47, 030	2. 99	6, 370	4. 9	11. 9	313. 2	14, 730, 000
2. 6	25	28. 65	43, 500	6. 71	6, 130	11. 4	9. 3	309. 3	13, 460, 000
2. 6	29	30. 21	46, 240	2. 18	6, 320	3. 6	11. 3	315. 1	14, 570, 000
2. 5	25	26. 59	43, 380	6. 59	6, 120	11. 2	9. 2	309. 6	13, 430, 000
2. 5	29	30. 14	46, 100	2. 06	6, 310	3. 4	11. 2	315. 4	14, 540, 000

Tons Aground

Tons aground based on actual (not predicted) conditions:

31 January refloating attempt (2.6′ actual tide)

Mean draft at which bow would lift=29.9′ (chart 1).

Height of tide necessary for bow to lift=29.9−27.0 (draft) amidships (at M-L-W)=2.9′.

But actual tide was only 2.6′.

Therefore bow did not lift.

Draft forward (25.1+2.6) = 27. 7′
Draft amidships = 29. 5′
Draft aft = 31. 3′
Displacement at 29.5′ mean draft = 45, 000
Correction for 3.6′ trim (91×3.6) = 328
Corrected displacement = 45, 328
Displacement of ship when afloat = 46, 459
Tons aground = 1, 131

1 February refloating (3.3′ actual tide)

For a moment of weight of 13,798,932 foot tons, bow would lift when mean draft (chart 1) = 28. 7′

Bow draft then=$28.7-\frac{3.6}{2}$ = 26. 9′

Draft to which bow lifted (chart 2) = 25. 6′

1 February refloating (3.3′ actual tide)

Determination of draft aft:

Draft forward = 25. 65′
Draft frame 190 = 31. 65′

Trim to frame 190 = 6. 0′

Distance bow to frame 190=190×4=760′.

Slope of W. L.=$\frac{6.0}{760}$=0.00790′ per foot.

Distance between forward and after perpendicular =860′.

Total trim = 860×0. 00790= 6. 80′
Aft draft = 25. 6+6. 8 = 32. 4
Mean draft = 29.0′.

Displacement at 29.0′ mean draft = 44, 150
Correction for 6.8′ trim (88.5×6.8) = 600

Corrected displacement = 44, 750
Displacement of ship when afloat = 45, 469

Tons aground 719

Tons aground on 31 January if a 3.3′ tide had occurred in lieu of 2.6′:

25.1 + 3.3 = 28.4′ Bow draft if bow not lifted.

27.9′ Draft of bow at 3.3′ tide with stern still aground (bow would have lifted 0.5′).

Draft at Frame 190 = 31.65′

190 × 4 = 760′. Trim = 31.65 − 27.9 = 3.75′

Slope of W. L. = $\frac{3.75}{760}$ = 0.00493′ per foot.

860 × 0.00493 = 4.24′ trim.

Draft forward	27.90′
Draft aft	32.14′
Mean draft	= 30.02′

Displacement at 30.02 mean draft	= 45, 850
Correction for 4.24 trim (94 × 3.65)	= 398
Corrected displacement	46, 248
Displacement of ship when afloat	46, 459
Tons aground	211

Drafts of Ship for Refloated Condition of 1 February

At the time of entering drydock, the following drafts were recorded, and displacement determined, at 35.5 cubic feet per ton for NNSY: Fwd, 28′ 11″, amidship, 30′ 9″, aft 32′ 5″.

The displacement for the mean draft above = 47,040 tons.

After correcting for weights added or removed since refloating, an actual displacement of 45,469 tons was determined as refloating displacement.

The following calculations will determine the drafts existing at time of refloating:

Actual displacement, 45,469 mean draft = 29′10″ at 35.25 cubic feet per ton. C. B. = 10.8′ aft amidships = 8.8′ aft frame 108. 24.52 − 8.8 = 15.72 = lever arm.

$$\text{Trim} = \frac{45{,}469 \times 15.72}{6{,}300} = 113.5' = 9.46' = 9'5.5''.$$

Correction to mean draft for trim =

$$\frac{91 \times 9.46}{150} = 5.67'' = 6''.$$

Mean draft corrected = 29′4″		
Forward draft = 24′7″	Drafts afloat.	
Aft draft = 34′1″		

Similarly for predicted drafts, with known deviations accounted for:

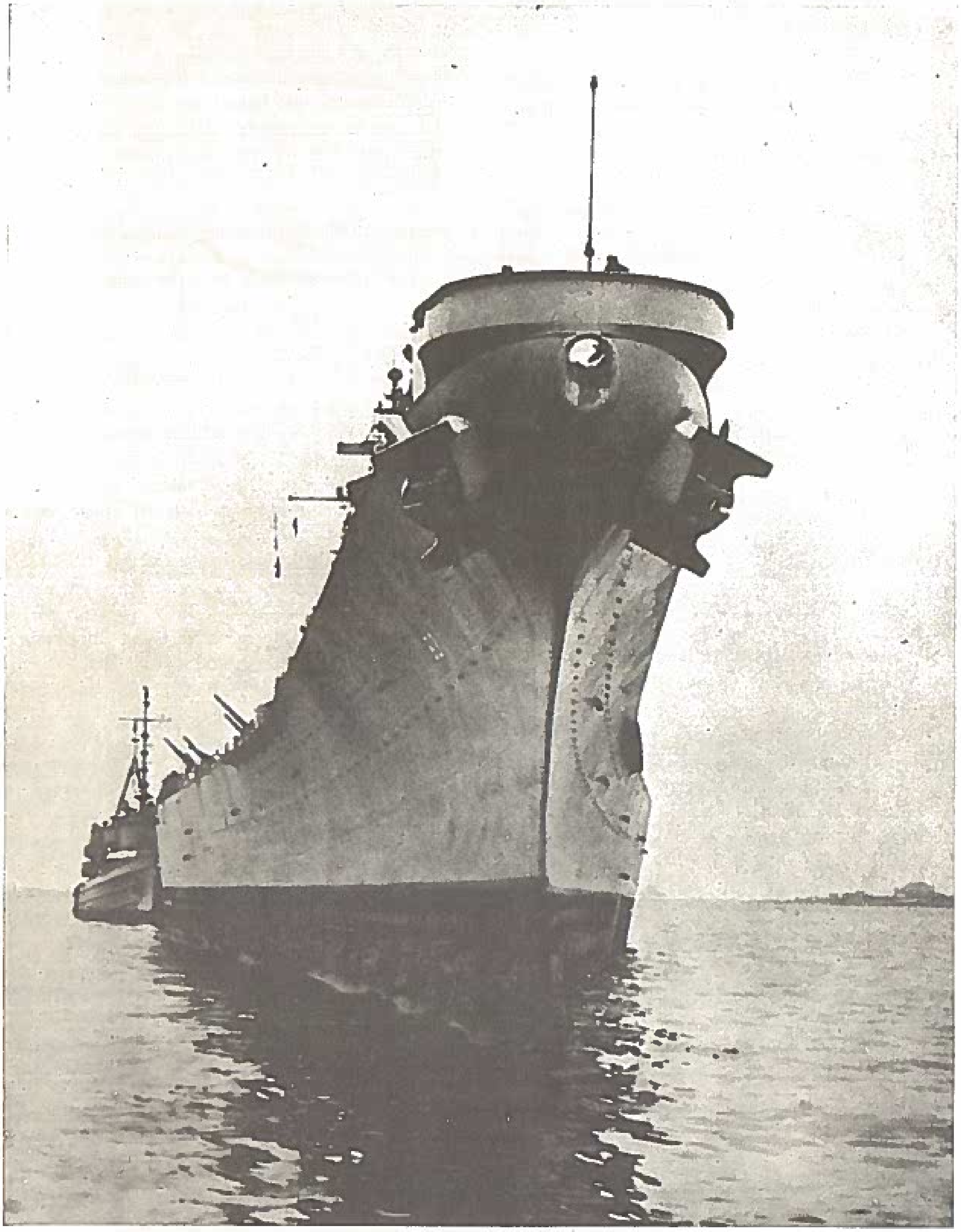
Predicted displacements 44,846 mean draft = 29′ 5″.

C. B. = 10.3′ aft amidships = 8.3′ aft frame 108. 29.0 − 8.3 = 20.7′ = lever arm.

$$\text{Trim} = \frac{44.846 \times 20.7}{6270} = 148'' = 12'\ 4''.$$

Correction to mean draft for trim = $\frac{91 \times 12.33}{150}$ = 7.5″.

Mean draft corrected = 28′ 9½″	
Forward draft = 22′ 7½″	Drafts afloat.
Aft draft = 34′11½″	

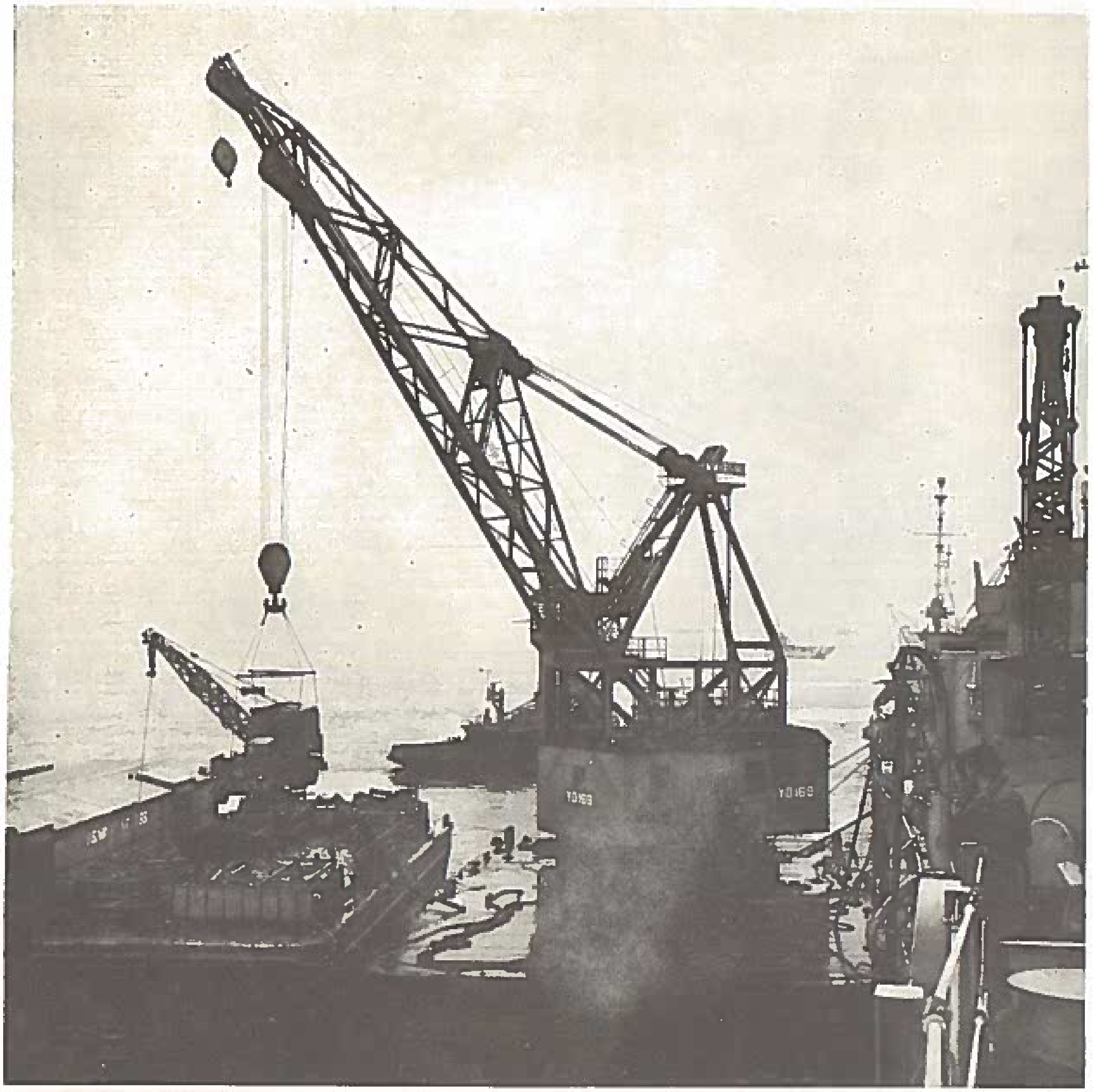


The *Missouri* soon after grounding.

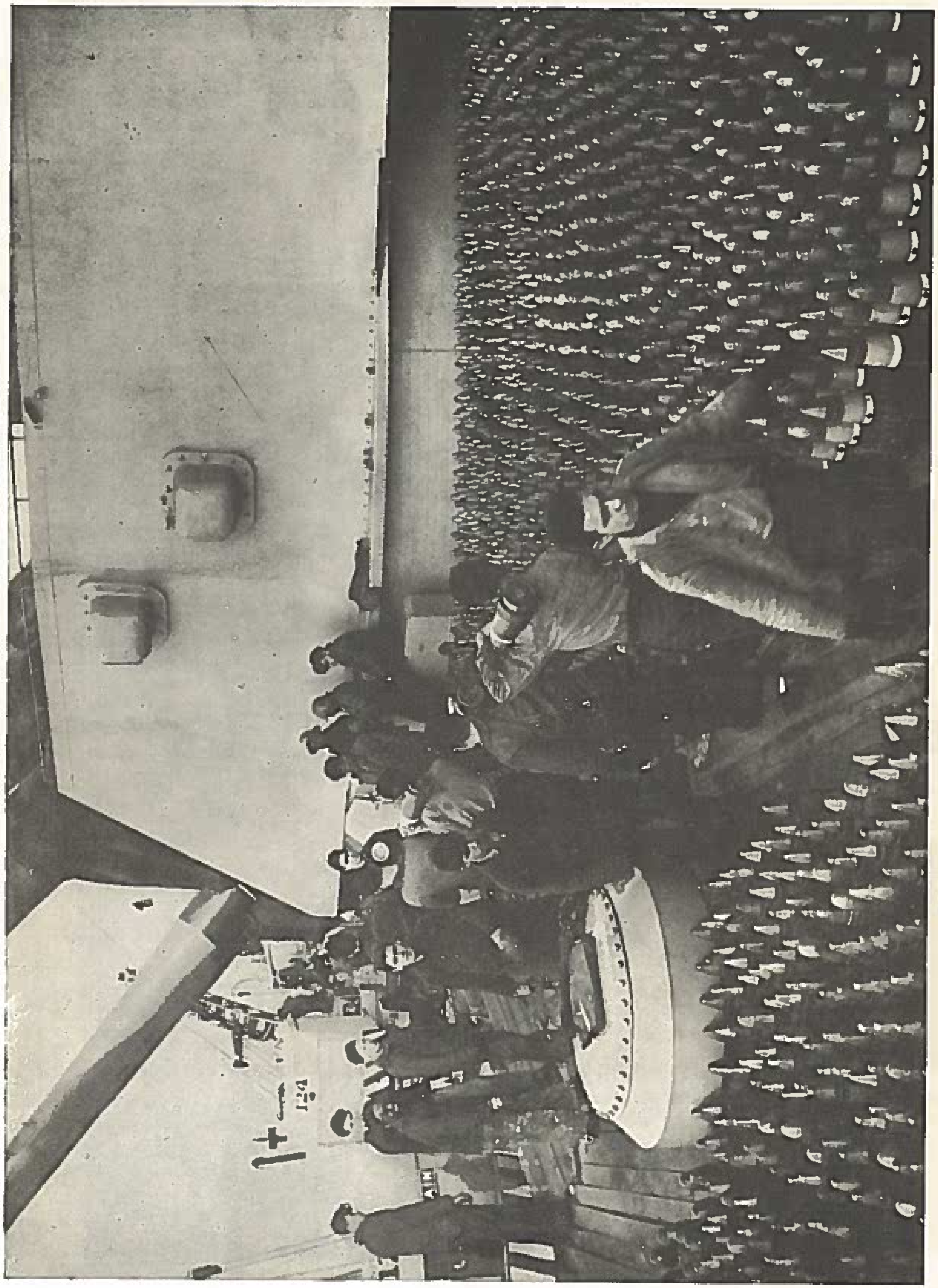
U. S. S. *Missouri* with ships alongside and astern during an early pulling attempt.

U. S. S. *Missouri* with ships alongside and astern during an early pulling.

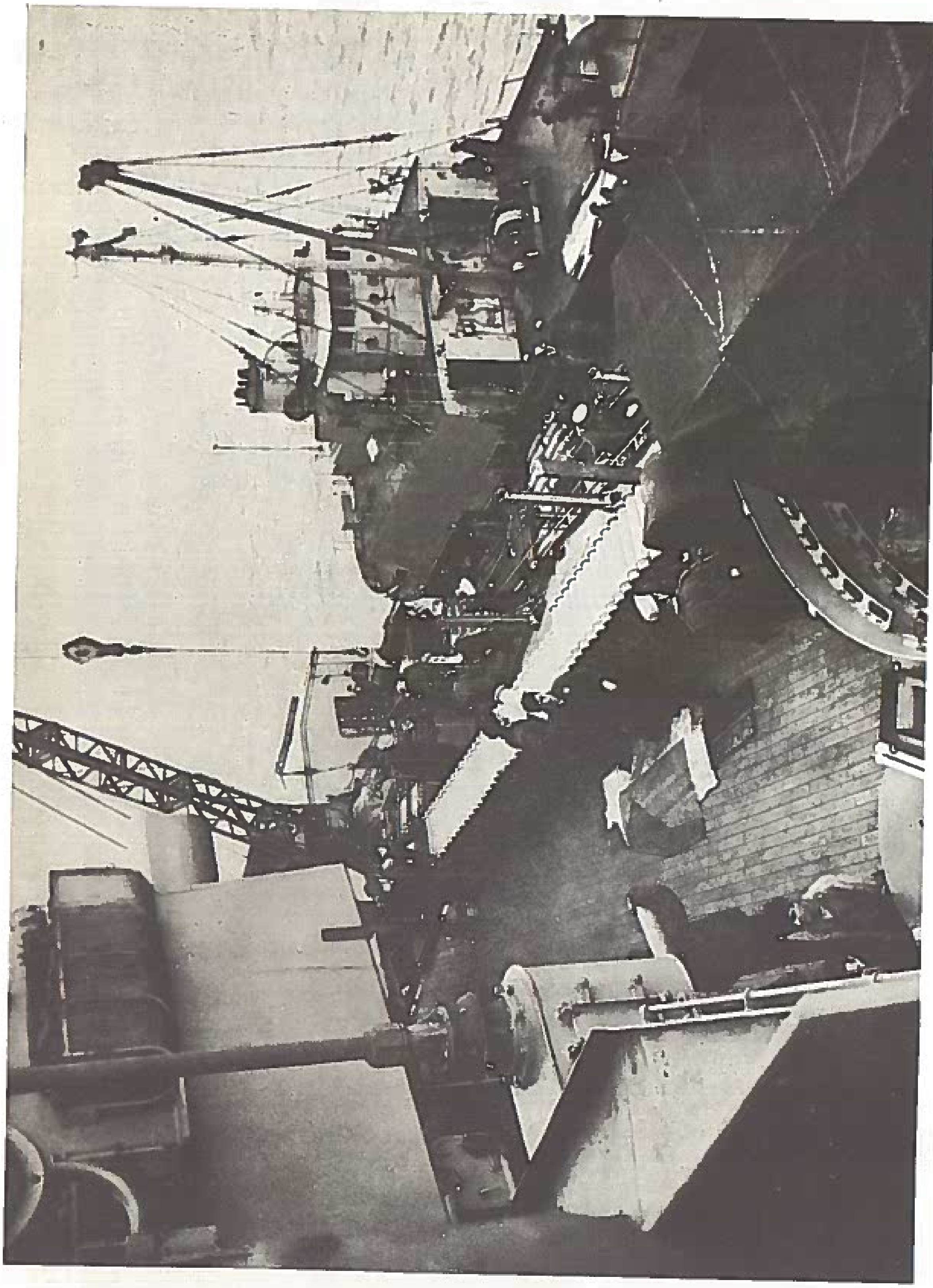
Water churned up by straining tugs during unsuccessful pull attempt on 20 January. Involved were 4 ATF's, 2 ASR's, 2 ARS's, 2 ATA's, and a number of small YTB type tugs. Approximately 8,000 tons, mostly fuel, had been removed from the *Missouri* and considerable dredging along each side had been accomplished.



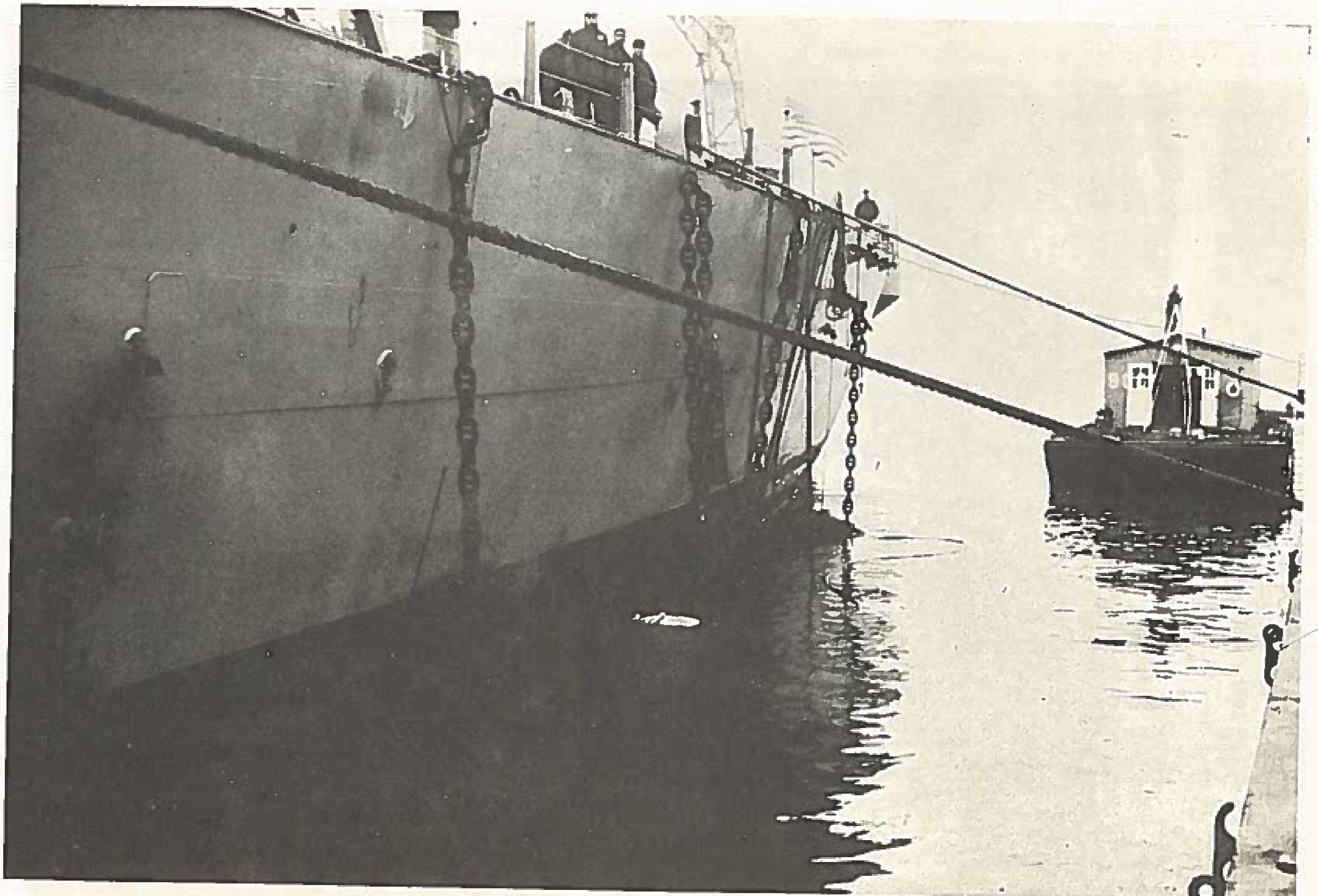
Barges and floating crane from Naval Base for off-loading ammunition. The availability of such facilities in the area on short notice was an important factor contributing to the success of the salvage operations.



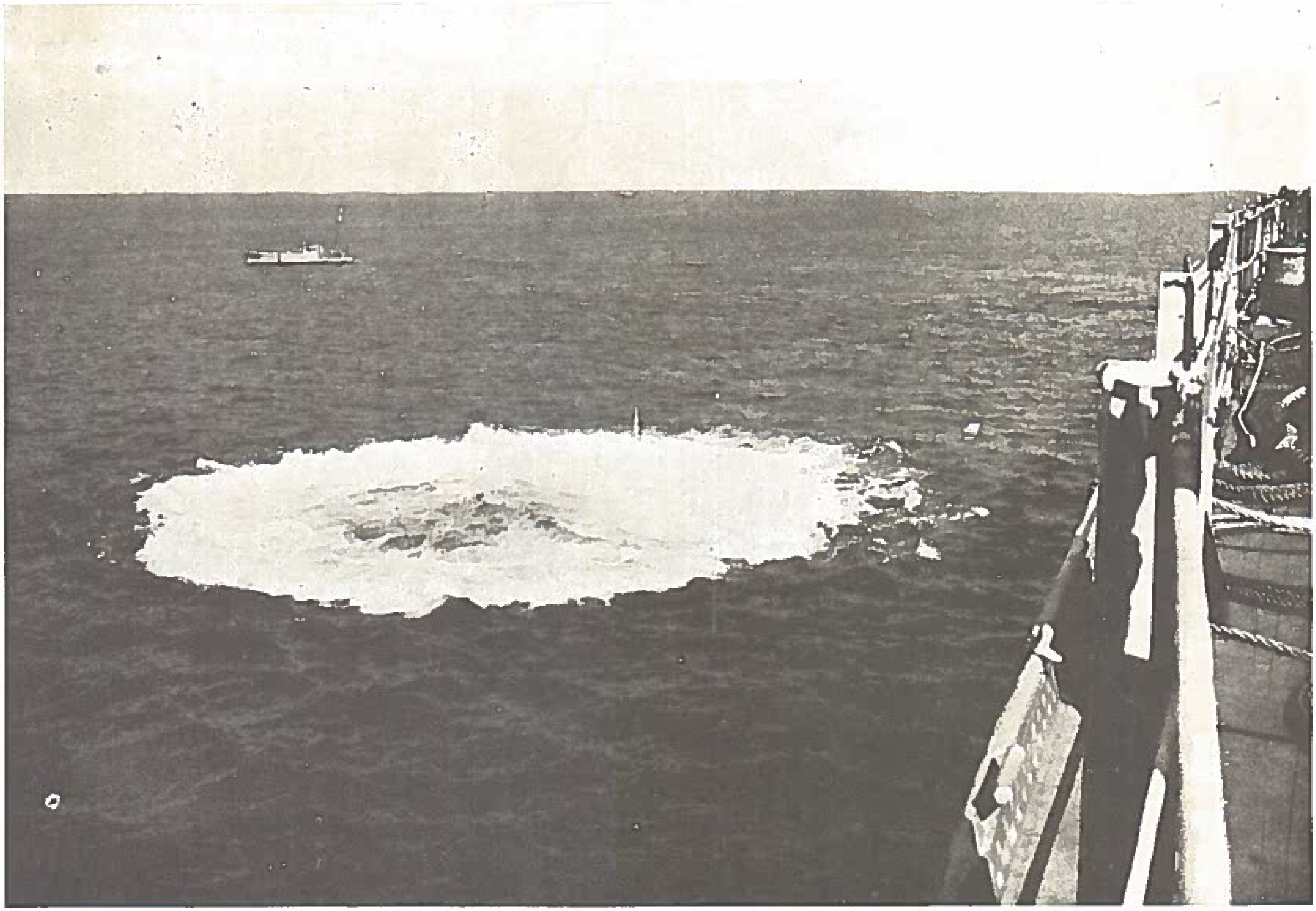
Off-loading of ammunition was a big job and an all-hands affair.



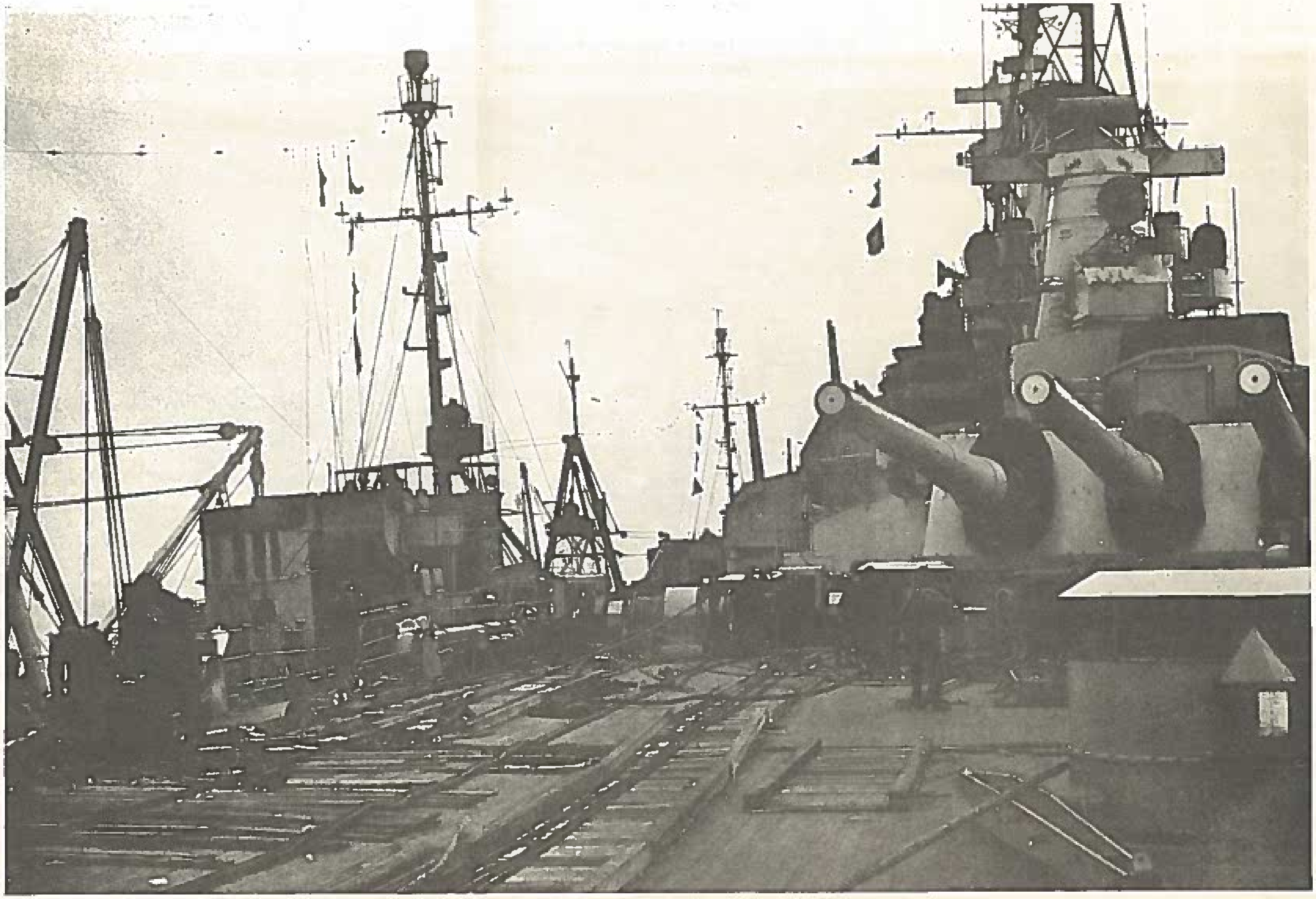
Placing ammunition on barges alongside.



Heavy chains reeved under skegs at stern of ship to which pontoons were secured. Tip of one pontoon visible at water's edge. Pontoons used were sent by Boston Naval Shipyard where they are maintained for submarine salvage purposes. Each pontoon has a buoyancy of 80 tons. Six were installed at the stern of the *Missouri* and two at the bow.

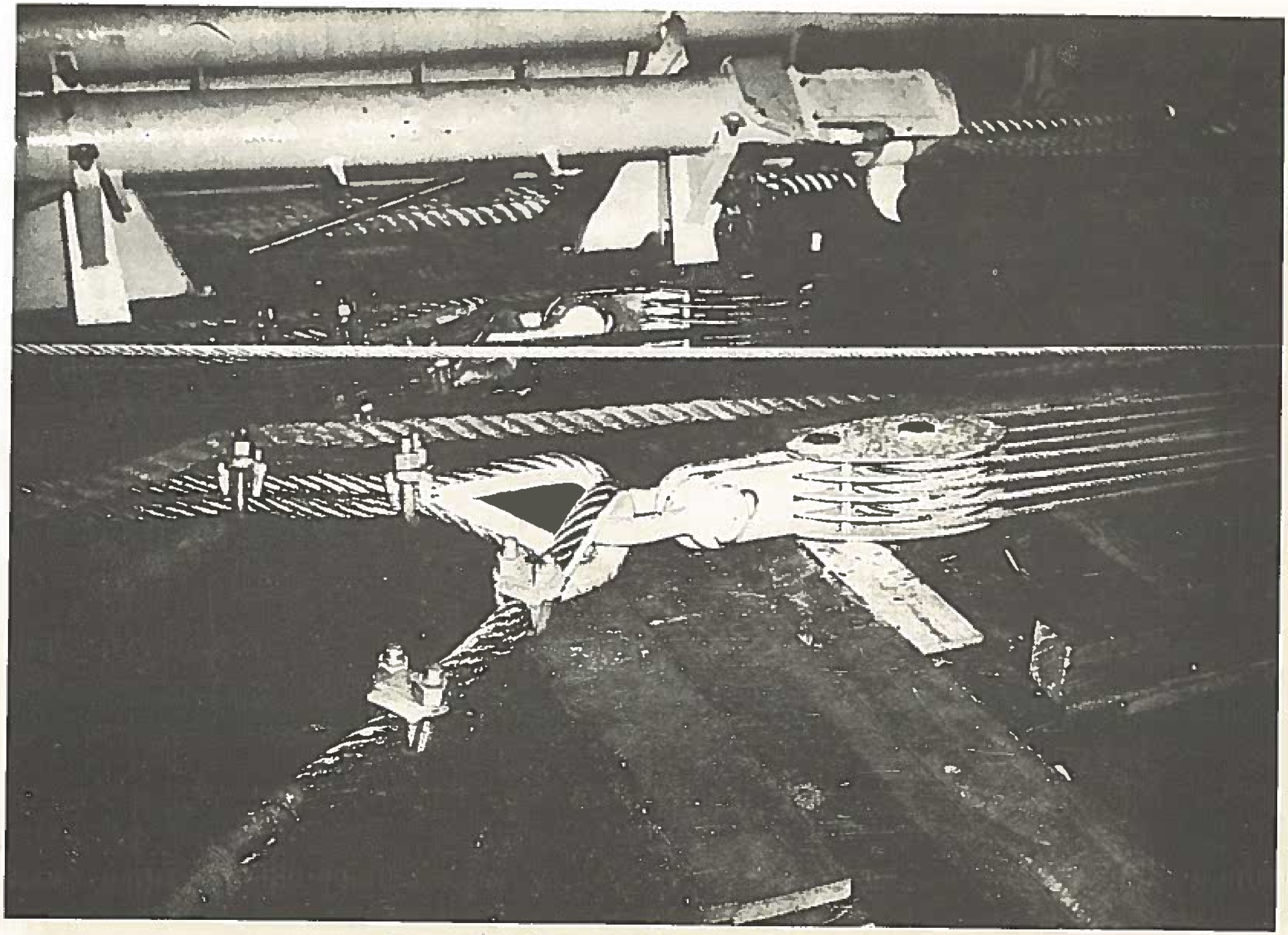


Explosion of 50-pound charge. Gas globule tended to remain underwater and resulted in two concussions that were felt on the stern of the *Missouri*. *Missouri* stern settled one-fourth inch.

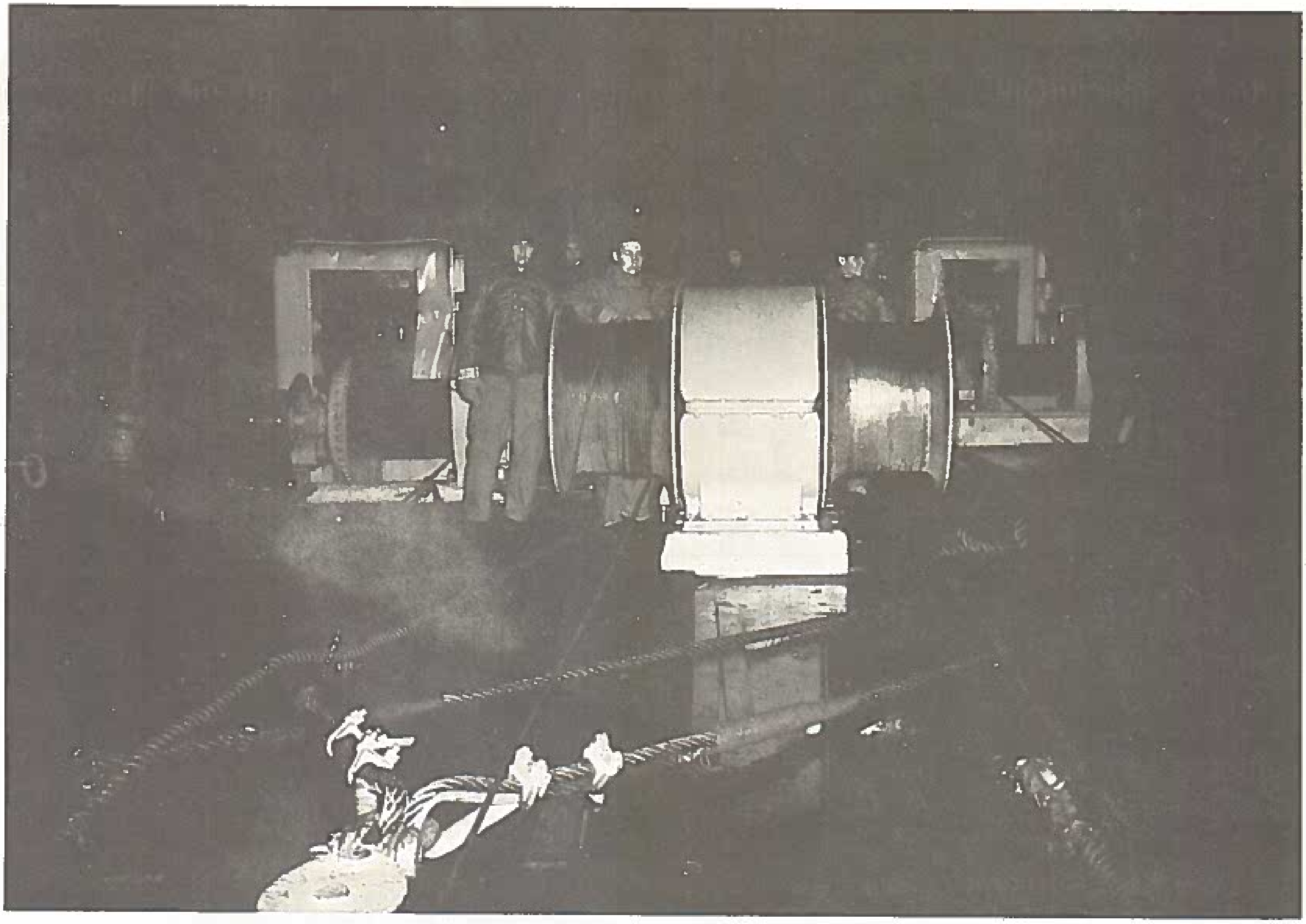


Three sets of beach gear being rigged on port side aft. Note two portable gasoline-driven salvage winches and ship's electric winch. Wood troughs are to protect the wood deck from being damaged by the running block of the beach gear falls. A similar three sets of beach gear were rigged on the starboard side, and one amidships aft, in addition to two sets leading to the bow capstans.

Portable gasoline-driven salvage winch mounted inside a hatch coaming with bridle to standing block of beach gear falls around outside of coaming. The coaming was suitably shored on the inside.



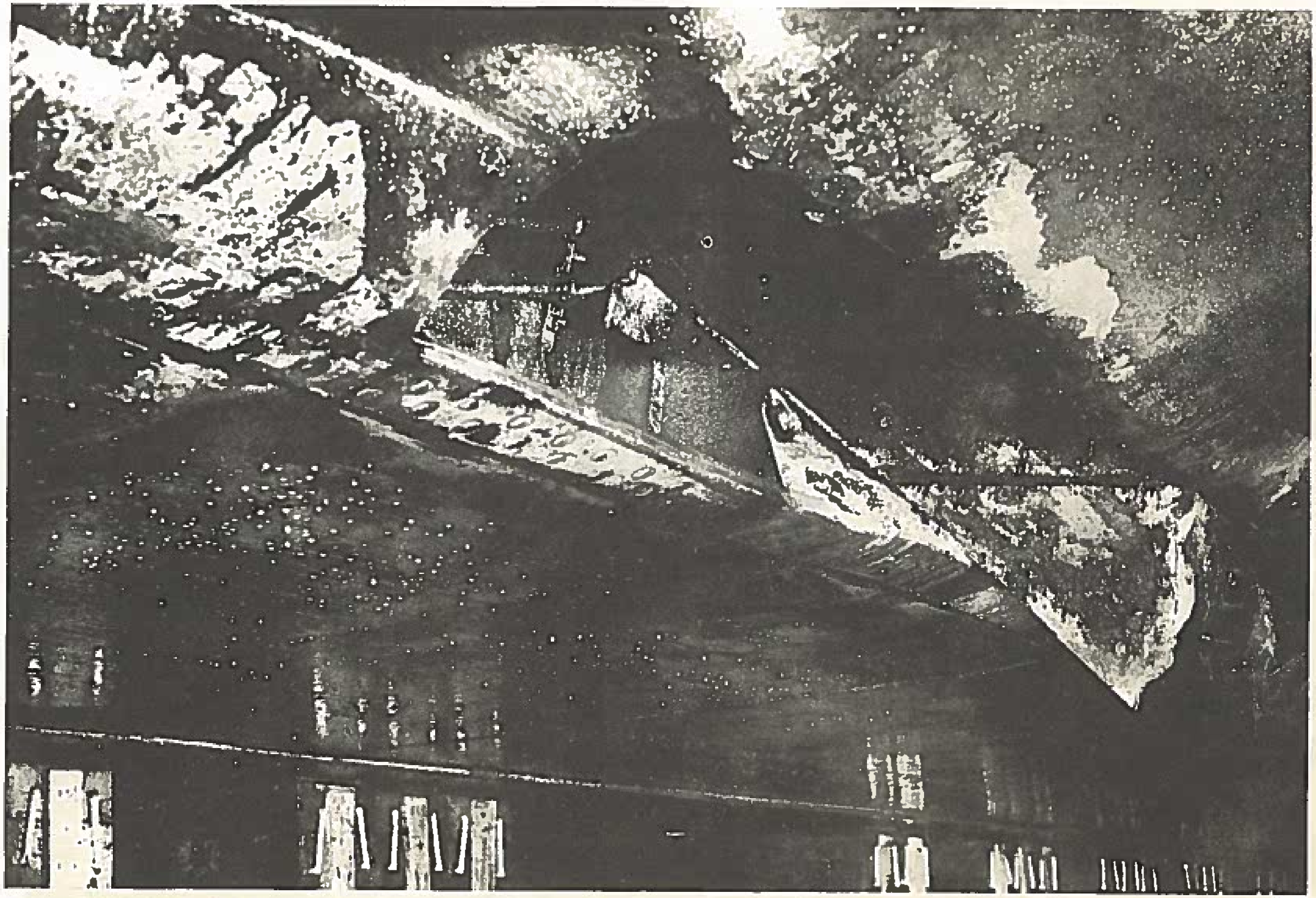
Standing block of beach gear falls secured to holding bridle.



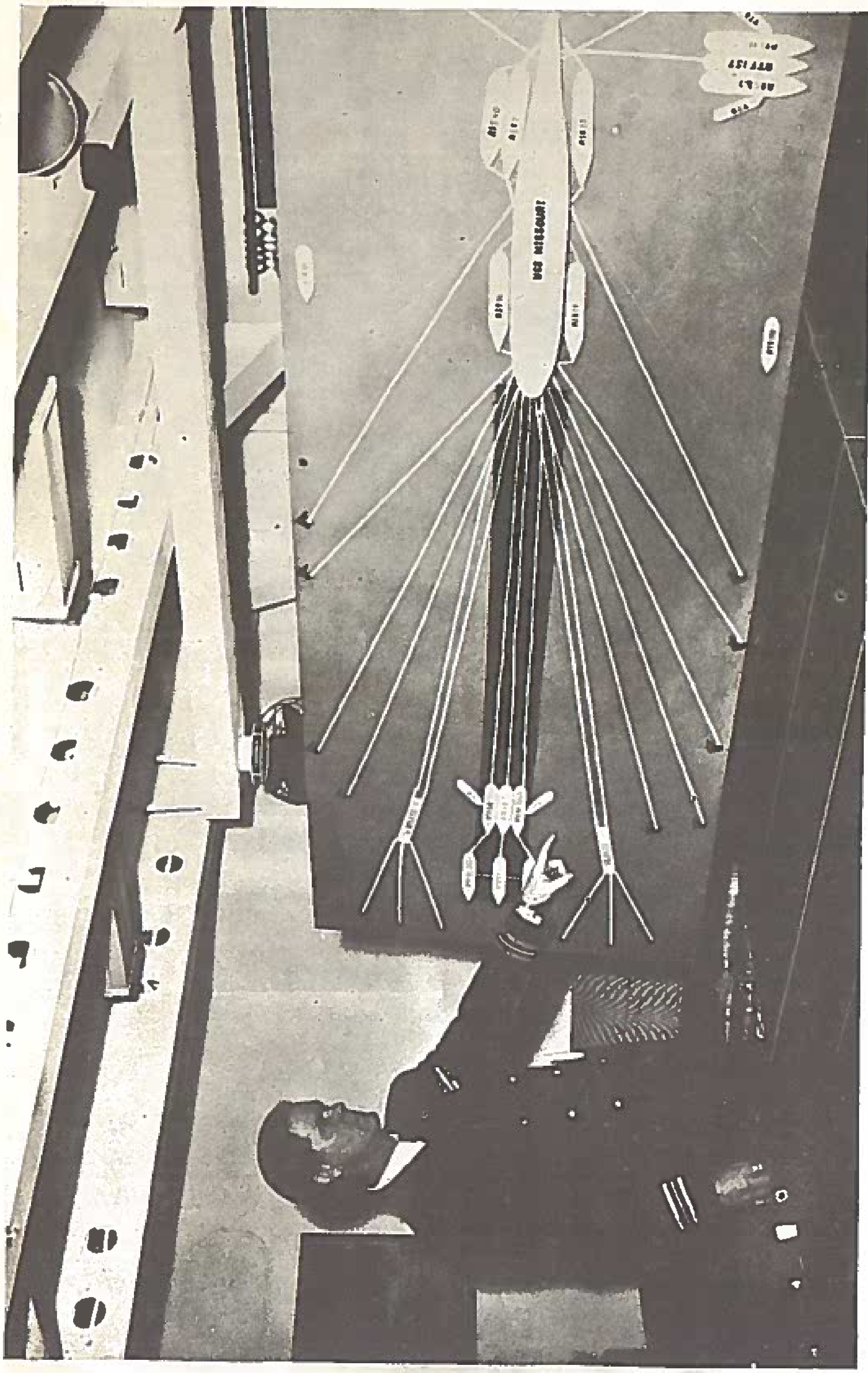
It was dark on the morning high tide on 31 January.   Winches manned for taking a strain on beach gear.

Heading into drydock after refloating.

Damaged plating in way of oil tanks B-29-F, B-37-F, B-43-F. Divers located the damaged area and described its extent after attempts to pump these tanks proved futile. Just prior to refloating, these tanks were dewatered with air pressure.



Damaged hull plating. The cause of the damage was unknown. Scraping marks extending forward and aft of the rupture indicated that the ship had passed over a heavy obstruction such as an old forgotten wreck or large boulder. Pieces of old metal were found protruding from the damaged hull by divers, giving some credence to old buried wreck belief.



Model showing arrangement of beach gear and pulling craft used on 1 February 1950 when the *Missouri* was refloated.

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