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FR-3404

FULL SCALE SHOCK TESTS - USS NIAGARA APA87

PART 1 - TECHNIQUES AND INSTRUMENTATION

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FULL SCALE SHOCK TESTS - USS NIAGARA APA87

PART 1 - TECHNIQUES AND INSTRUMENTATION

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January 17, 1949

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DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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ABSTRACT

Underwater noncontact explosives were fired against the USS NIAGARA APA87 to determine: (a) Forces on a foundation generated (during shock) by a flexible body such as a boiler, and (b) failures of shipboard electronic equipment and the effectiveness of shock mounts. To study forces on the boiler foundation, the boiler was remounted on flanged cylindrical supports to which were fastened strain gages, velocity gages, reed gages, and accelerometers. Ten identical sets of electronic gear were mounted in various parts of the ship, each set being secured to a mounting bracket to which were also fastened velocity meters, reed gages, and accelerometers, all designed and installed to obtain specific velocity and displacement data in prearranged directions. Each set of electronic gear consisted of 3 Navy Type BN IFF equipments, one mounted solidly to the bracket, the second mounted through 1 inch of rubber, and the third mounted through 3/8 inch of rubber. The strain gages and the velocity meters were all wired to cables leading to an instrument barge moored 50 feet from the NIAGARA; the other instruments were self-recording. Twenty-five explosive charges ranging from 250 to 1200 pounds of HBX-1 were fired at distances of zero to 325 feet from the ship and at depths ranging from 17 to 134 feet.

This report, describing the techniques and instrumentation employed, is the first in a series, and as the results are analyzed additional reports will be made.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem F03-07R

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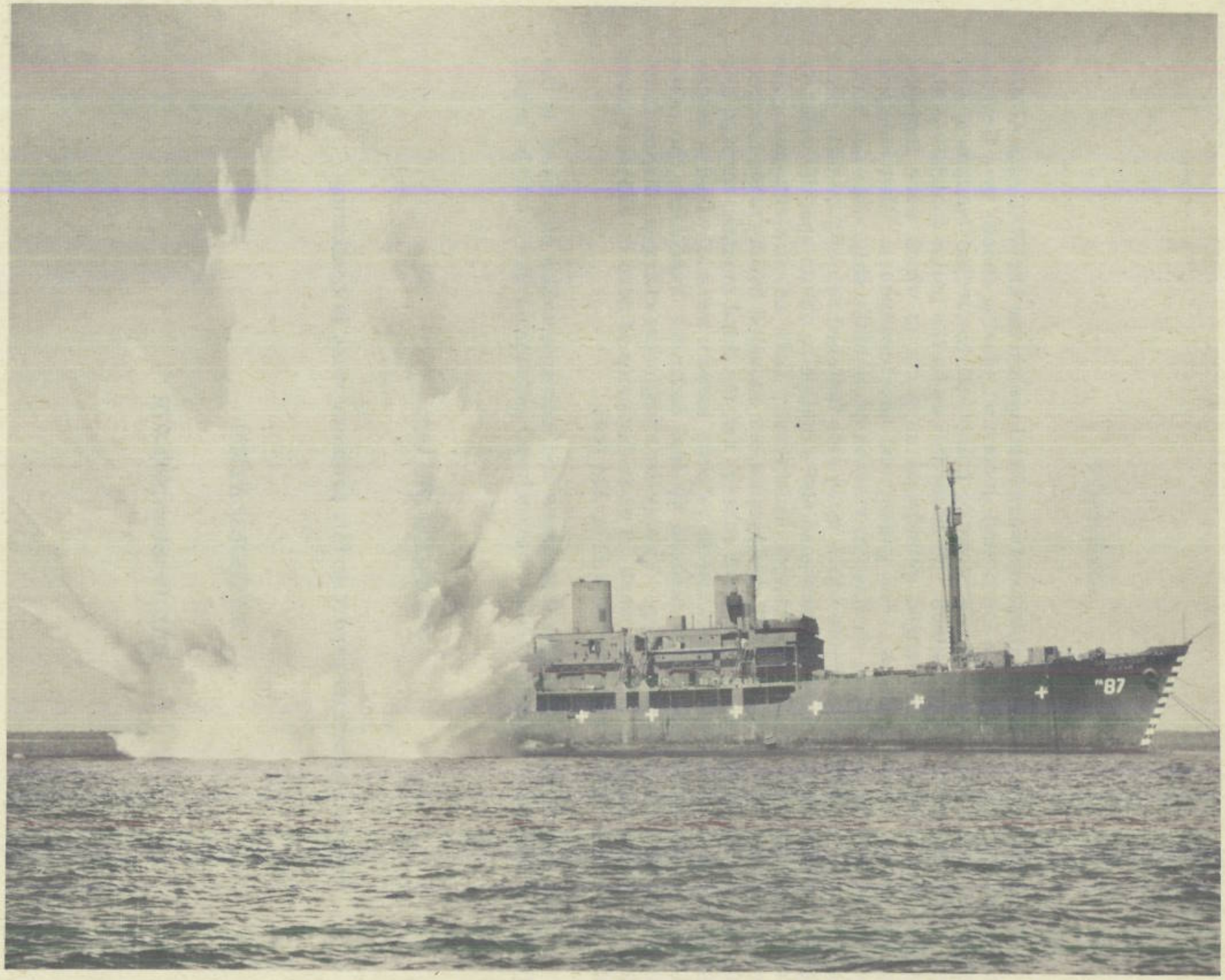

Frontispiece - Shot 12 - 1200 pounds of HBX-1,
70 feet down and 185 feet from the starboard beam

FULL SCALE SHOCK TESTS - USS NIAGARA APA87
PART I - TECHNIQUES AND INSTRUMENTATION

INTRODUCTION

During the summer of 1948 full scale underwater noncontact explosive shock tests were conducted against the USS NIAGARA APA87, in the Chesapeake Bay. The investigation was a joint undertaking of the David Taylor Model Basin, the Underwater Explosion Research Laboratory of Norfolk, the Naval Ordnance Laboratory, the Bureau of Ships, and the Naval Research Laboratory.

The Naval Research Laboratory was responsible for two phases of the investigation. The first problem was concerned with the determination of the forces on a foundation generated (during shock) by a flexible body such as a boiler. The second problem was the evaluation of the failures of shipboard electronic equipment under shock to the ship's structure together with the evaluation of the effectiveness of shock mounts.

This report describes the techniques and instrumentation employed by the Naval Research Laboratory group in the prosecution of the problem. Subsequent reports will present data obtained and results of the investigations.

BRIEF HISTORY OF PROBLEM

In January 1946, a letter[1] from the Bureau of Ships to the Director of the Laboratory stated that full scale shock tests on a naval vessel were being considered and that it was expected that the Naval Research Laboratory would carry a large share of the research activity. The Laboratory was requested to accelerate the program of shock instrument development.

On 27 May 1947 a letter[2] from the Bureau of Ships to the Director, requested the Laboratory to exert every effort toward arranging and carrying out necessary details for full scale shock tests to be started in the near future. To this request the Director answered[3] that the Laboratory was preparing to participate in the tests and a brief outline of what the Laboratory could undertake was submitted.

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[1] Letter from Navy Dept. Bureau of Ships Sec 911 S60-(2) (660-330) Section 911E-592 dated 15 January 1946 to Director, NRL.

[2] Letter from Bureau of Ships S60-(2) (660-6650911-332) Section 660E2 dated 27 May 1947 to Director, NRL.

[3] Letter from Director, NRL Ser. 401-47950 (402) dated 17 June 1947 to Bureau of Ships.

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On June 1947 a letter[4] from the Bureau of Ships to the Director stated that the USS NIAGARA APA87 had been allocated for full scale shock tests and a plan from the Laboratory for instrument locations was requested. The Director in a letter[5] dated July 1947 welcomed the apportunity to participate in the full scale shock tests and submitted a proposed program.

On 24 November 1947 a letter[6] from the Director to the Bureau of Ships contained a description of the scope of activity of the Laboratory in the full scale shock tests. A statement of the general purpose and description of the instrumentation to be used was also included. A reply[7] from the Bureau of Ships stated that the instrumentation plan submitted by the Laboratory was considered satisfactory. The Laboratory was directed to work with the Norfolk Naval Shipyard in outfitting the target vessel. A Bureau problem number SRD 1509-48 was designated for the work. This problem was incorporated into the Laboratory Problem number F03-07R.

On 28 November 1947, at a conference held at the Bureau of Ships[8] it was decided to coordinate the full scale shock tests against the NIAGARA with the full scale underbottom structural damage tests being conducted by the Underwater Explosion Research Laboratory at Norfolk. This was done to minimize the logistic support required for the two programs and to present to the Chief of Naval Operations a stronger request for support.

On 1 March 1948 the NIAGARA was towed to the Norfolk Naval Shipyard for outfitting with the test instrumentation. On 9 March the Mechanics Division instrumentation barge (YF570) was towed from the Naval Research Laboratory to the Norfolk yard for outfitting for sea. The yard work was completed approximately 10 April when both the target vessel and the instrumentation barge were towed to the test site in Chesapeake Bay. The first charge against the NIAGARA was fired on 21 May. The concluding charge was fired on 11 August. On 13 August, the NIAGARA was towed to the Norfolk yard, and the instrumentation barge was returned to Washington.

The USS NIAGARA APA87 was constructed by the Consolidated Steel Corp. at Los Angeles, Calif., and completed in March 1945. She was used as one of the target vessels in Operation Crossroads, but did not suffer damage during those tests. Shortly thereafter, the NIAGARA was decommissioned and allotted to the full scale shock investigation.

The NIAGARA has an overall length of 426 feet, an extreme beam of 58 feet, and full load gross displacement of 6800 tons with a mean draft of 16 feet. For the full scale shock tests, all fuel spaces in the inner bottom were filled with sea water. The draft was 9 feet 4 inches at the bow, and 16 feet 6 inches at the stern. The gross displacement was 5500 tons.

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[4] Letter from Bureau of Ships Sec 322 S60-(2) (332-440-660-665-911E-420) dated 9 June 1947 to Director, NRL.

[5] Letter from Director, NRL Ser. 401-47649 (402) dym dated 11 July 1947 to Bureau of Ships (Confidential).

[6] Letter from Director, NRL Ser. 401-562/47 (470) dated 24 November 1947 to Bureau of Ships.

[7] Letter from Bureau of Ships S60-(2) (332) dated 25 February 1948 to Director, NRL.

[8] Bureau of Ships Memorandum for Files Code 423 dated 28 November 1947.

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TEST SITE

The location of the test site for the full scale shock tests was determined by several factors.

a) The test area should be as near Washington as possible for convenience of participating agencies and supply of materials,

b) it was necessary to have water as deep as possible, and,

c) the area should be near a Naval activity.

Accordingly, an area in the Chesapeake Bay east of the mouth of the Patuxent River was selected as being most suitable. The area was bounded on the north by lat. 38°21′ N., on the south by lat. 38°19′30″N., on the east by long. 76°17′30″W., and, on the west by long 76°19′W. A chart of the test area, shown in Figure 1, is a section of H. O. 553. The target area was approximately 7 1/2 miles east of the Patuxent Naval Air Test Center Ferry landing, and approximately 9 miles from the Naval Ordnance Laboratory Test Facility at Point Patience on the Patuxent River.

The test area selected provided the deepest water in the Chesapeake Bay. Soundings taken in the immediate vicinity of the target vessel indicated a depth of water between 132 and 136 feet. It should be noted that approximately 1/2 mile east of the test site the depth of water decreased very rapidly to 15 feet which would be desirable in case a target required beaching.

The NIAGARA was moored at the bow to a telephone buoy, at the stern by a 5-ton anchor, and, in addition, four side anchors were used, two at the stern and two at the bow, all securing the ship so that the bow pointed due south. Since the prevailing winds and tides usually ran in a north-south direction, the motion of the target ship was at a minimum. However, during squalls when winds were in an easterly or westerly direction, the east-west motion of the APA was in several cases so great as to cause difficulty with the mooring of the NRL instrument barge which was alongside the target vessel.

The NRL instrument barge was moored on the port side of the APA by 4 diagonally opposed cables. Two pad eyes were welded on the APA at about frame 83 and frame 146, 5 feet above the water line. From these pad eyes, which were approximately 150 feet apart, 1 1/2 inch steel cables 70 feet long were run to the bits on the NRL instrument barge. Weights of 1600 pounds were suspended at the center of these cables to alleviate the sudden snubbing of the barge in rough weather. From the opposite side of the barge, 2 one-inch steel cables approximately 500 feet long were run to concrete clumps and anchors. Since the barge was only 50 feet from the APA, some protection was afforded the barge from the effects of the explosions as a result of shadowing. During the latter part of the tests when the severity of the shocks was increased, the barge was moved away from the APA by lengthening the cables. However, it was found that the shock intensity on the barge was not decreased by the relocation of the barge because the shadowing of the barge by the APA no longer existed. Figure 2 is a chart showing the mooring arrangement and Figure 3 shows the arrangement of all vessels during the operation.

Since no facilities were available at the test site for quartering and messing the scientific personnel, transportation to and from the Naval Air Test Center was provided in a number of small craft. Because of frequent storms and rough weather the transportation was never very satisfactory. Near the end of the tests a type APC boat was secured which made regular runs between the test site and the shore facility.

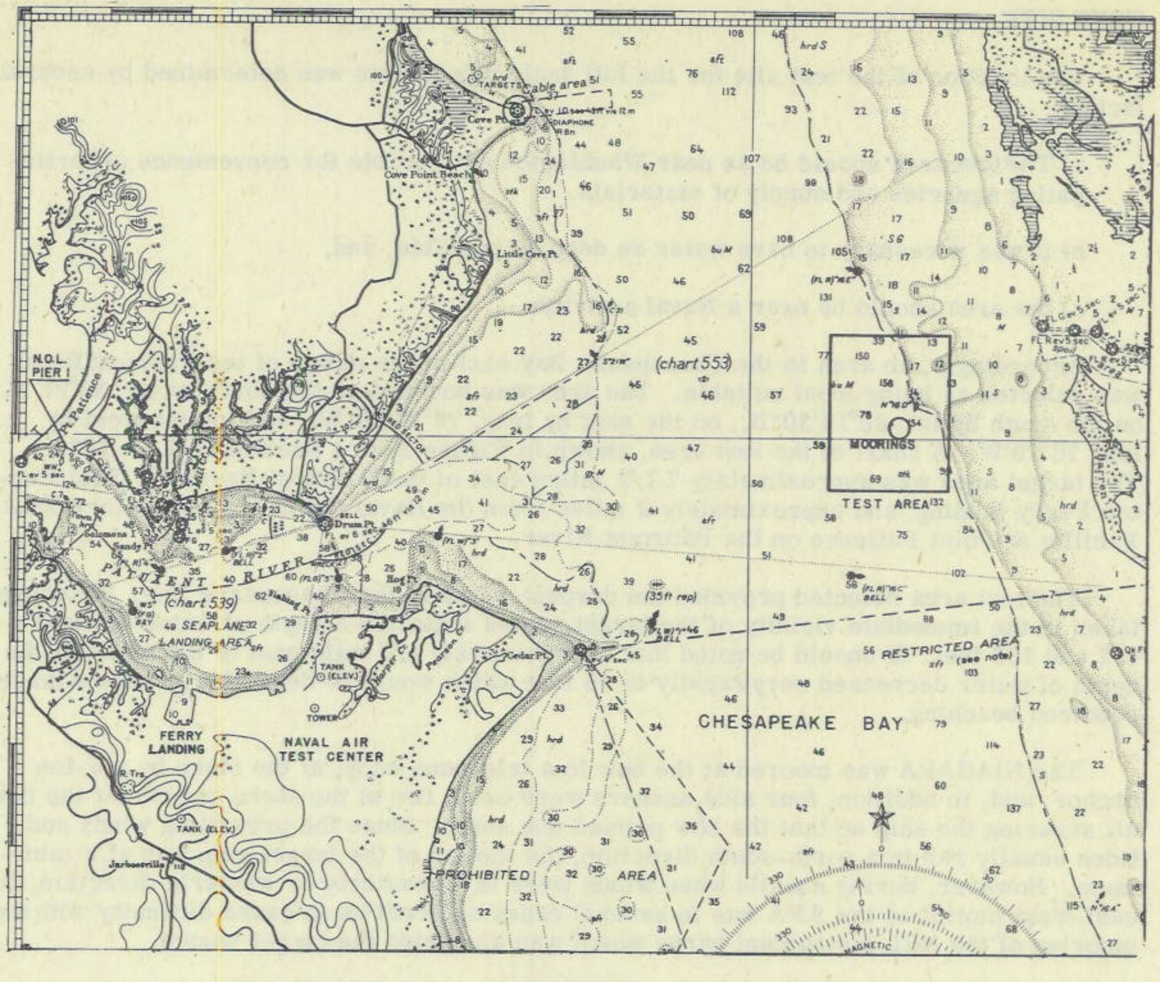

Fig. 1 - Map of test area
Long. - 76°17′30″ W. to 76°19′ W.
Lat. - 38°19′30″ N. to 38°21′ N.

FORCES ON THE BOILER FOUNDATION

To determine the magnitude of the forces on the boiler foundation, it was decided to measure the strains at the six boiler supports. Components of force in three directions and two components of bending moment (excluding the moment about a vertical axis) were measured at each of the six supports and separately recorded.

The existing supports of the boiler were unsuitable for the direct application of metalectric strain gages because the shape of the supports did not permit assumption of a simple stress and strain distribution. It was necessary to modify the foundation slightly so that cylindrical tubes could be inserted between the boiler and its foundation, upon which

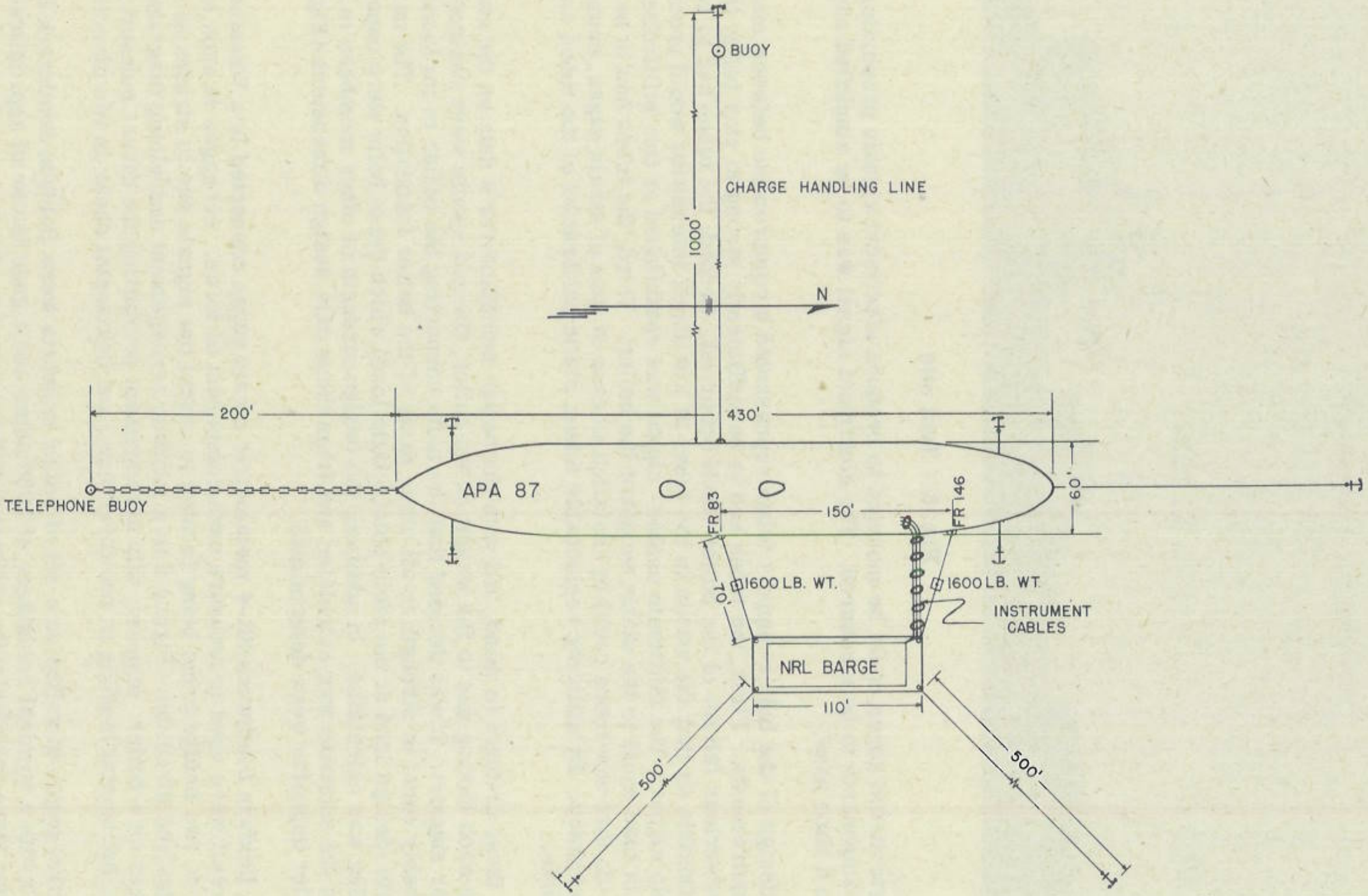

Fig. 2 - Mooring arrangement

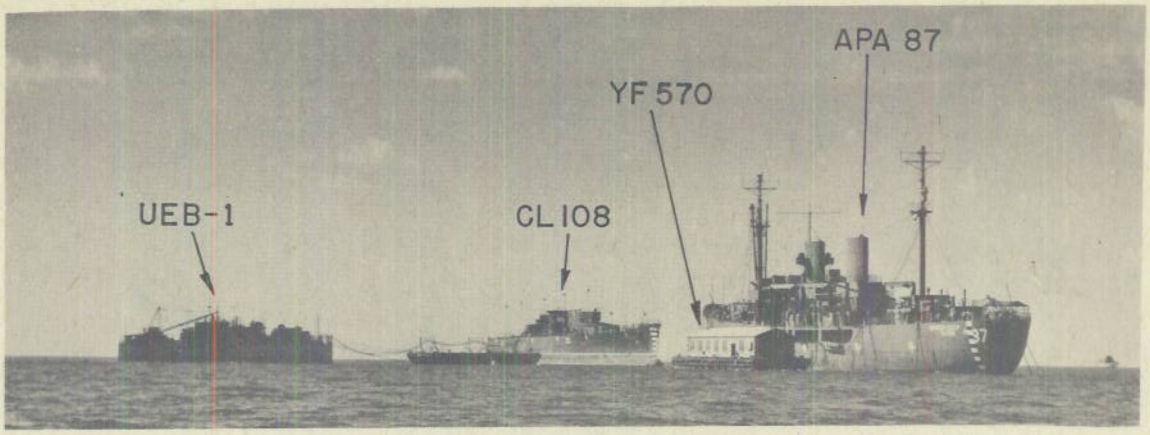

Fig. 3 - Test site

metalectric strain gages could be mounted to produce electrical signals proportional to the five components to be measured. The electrical signal was to be amplified and recorded on a time base.

The design of the boiler support tubes represented a compromise between many different requirements. First, the tubes had to be sufficiently strong to stay below the yield point until serious failure of the boiler itself occurred. Second, the tubes had to be sufficiently flexible so that the strain in the tubes at low shock intensities would produce a discernible signal. The minimum usable signal was established at five millivolts for a change in load equal to the static weight of the boiler. Third, the tubes had to be replaceable so that new tubes could be installed in case of loss of strain gages, damage or other emergency. By utilizing replaceable tubes, static calibration of the tubes and gages was possible.

With these criteria in mind, and with the boiler manufacturer's data on the static loading on each footing due to the weight of the boiler, flanged spools were designed for each boiler support. It was decided that the bolts connecting the boiler to its foundation were probably equal in strength to all other parts of the boiler foundation. The number of "g" units (design load at the yield point/static load) which these bolts were capable of withstanding was calculated. In addition, the design strength of other members in the vicinity of the supports was calculated and from these data design dimensions (Figure 4) of the boiler supports were determined.

Four Baldwin Southwark SR-4 metalectric strain gages connected in a Wheatstone bridge circuit were used to measure each component of force. All gages in each bridge were active, two bridge arms being located to cancel out signals due to strains in other than the desired direction. Figure 5 is a location arrangement and wiring diagram of the strain gages on a boiler support, this arrangement permitting the direct measurement of tension, horizontal bending in two directions, and horizontal shear in two directions.

The first gages installed on a set of boiler supports were Baldwin Southwark SR-4 Type C-10 with a nominal resistance of 1000 ohms and a gage factor of approximately 3. These gages were satisfactorily calibrated and the agreement between calculated output voltages and measured output voltages with strain was remarkably good. However, approximately a month after the boiler supports were installed under the boiler, it was found that approximately 40 percent of the gages had open-circuited within the gage.

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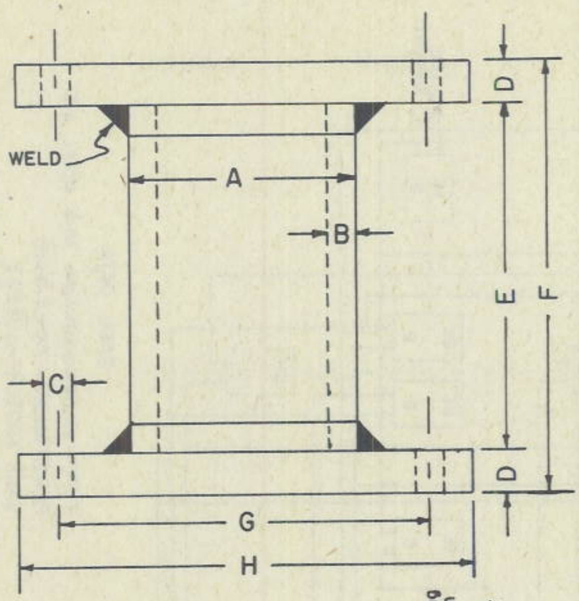

SUPPORT	A	B	C	D	E	F	G	H	No. of mounting holes on each flange	Mounting bolt diameter	Weld	Tube Material
ECONOMIZER	2.875	0.203	$\frac{25}{32}$	$1\frac{1}{2}$	6	9	5.281	$7\frac{17}{32}$	8	$\frac{3}{4}$	$\frac{7}{32}$	SAE 1045
WATERWALL HEADER	4.609	0.337	$1\frac{5}{32}$	$1\frac{1}{2}$	9	12	8.688	$12\frac{1}{8}$	8	$1\frac{1}{8}$	$\frac{11}{32}$	SAE 1045
WATER DRUM	5.375	0.750	$1\frac{17}{32}$	$1\frac{1}{2}$	11	14	11.063	$15\frac{9}{16}$	10	$1\frac{1}{2}$	$\frac{3}{4}$	SAE 6150

Heat treat to 60000 psi yield

Fig. 4 - Boiler support dimensions

After consultation with the Baldwin Southwark people, it was learned that the Type C-10 gage wire was made of a steel alloy which was unusually sensitive to corrosion and moisture. The waterproofing was considered inadequate because of the high humidity which existed under the boiler. Accordingly, the Type C-10 gages were replaced with Type A-15 gages whose resistance element was a manganin alloy which provided greater corrosion and moisture resistance. In addition, the entire cylindrical section of each support was covered with a one-quarter-inch layer of waterproof wax. Only three gage failures were observed with the Type A-15 gage, two of which were due to mechanical damage when a wrench slipped and crushed a gage lead. The improved resistance to humidity was obtained at a sacrifice of sensitivity, as the Type A-15 gages had a resistance of 750 ohms, and a gage factor of approximately 2. These two features reduced the sensitivity by a factor of 2. The insulation resistance between all gages connected in parallel and ground exceeded 1/2 megohm for the duration of the tests which extended over about three months.

The four arms of each gage bridge were connected at the boiler support spool. Four leads were brought from each bridge on the spool to a terminal board, alongside the boiler. Since there were five bridges on each spool, a total of 120 leads was required for the complete installation. However, one lead from each bridge was a ground lead so that thirty

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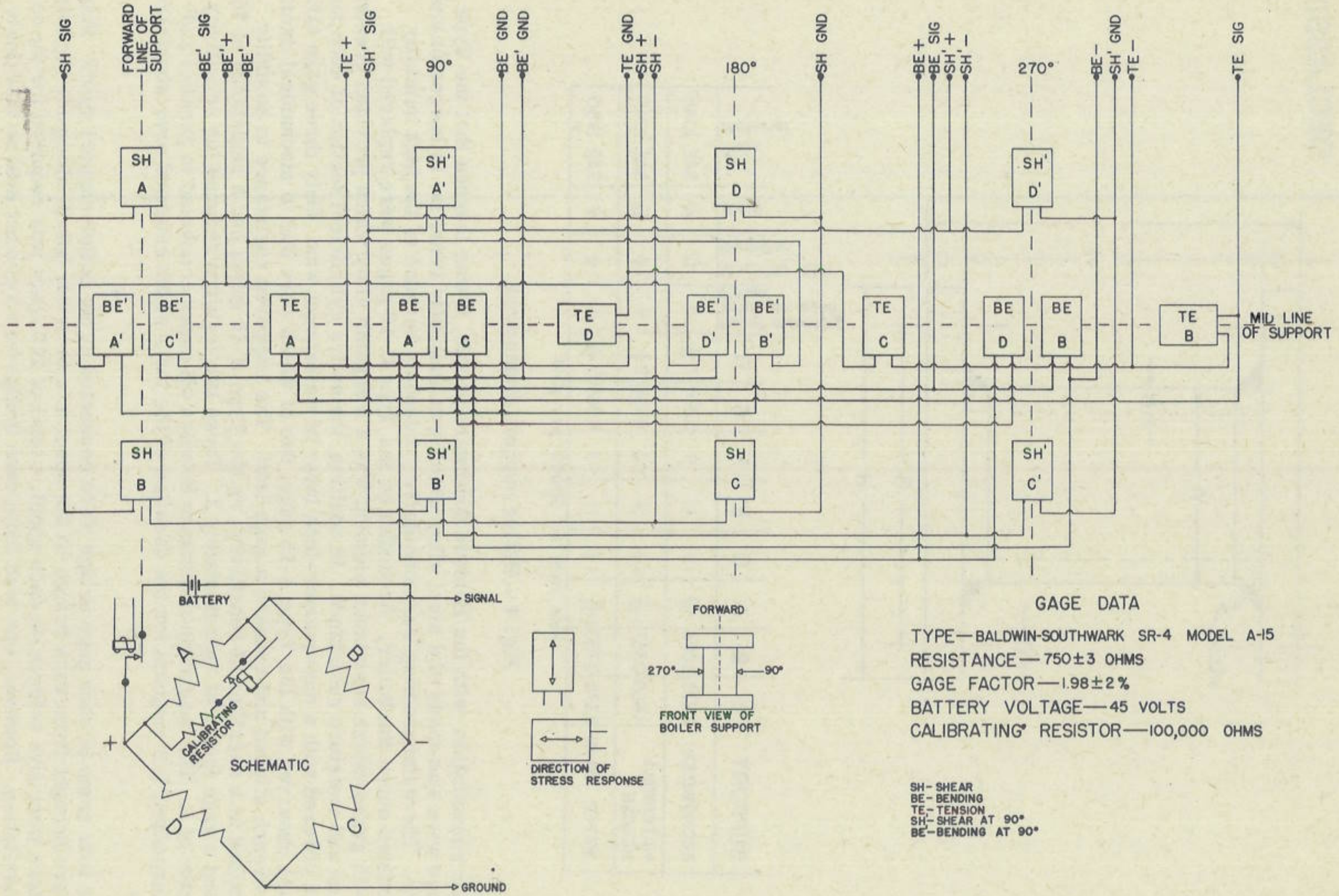

Fig. 5 - Wiring diagram of strain gages on boiler support

ground leads were tied together at the terminal board and carried from the target vessel to the recording barge as one lead. Thus, a total of 91 leads was required for the strain gage circuits; thirty for the signal leads, thirty for the battery positive leads, thirty for the negative leads, and a common ground. A representative single strain gage circuit is shown in Figure 6.

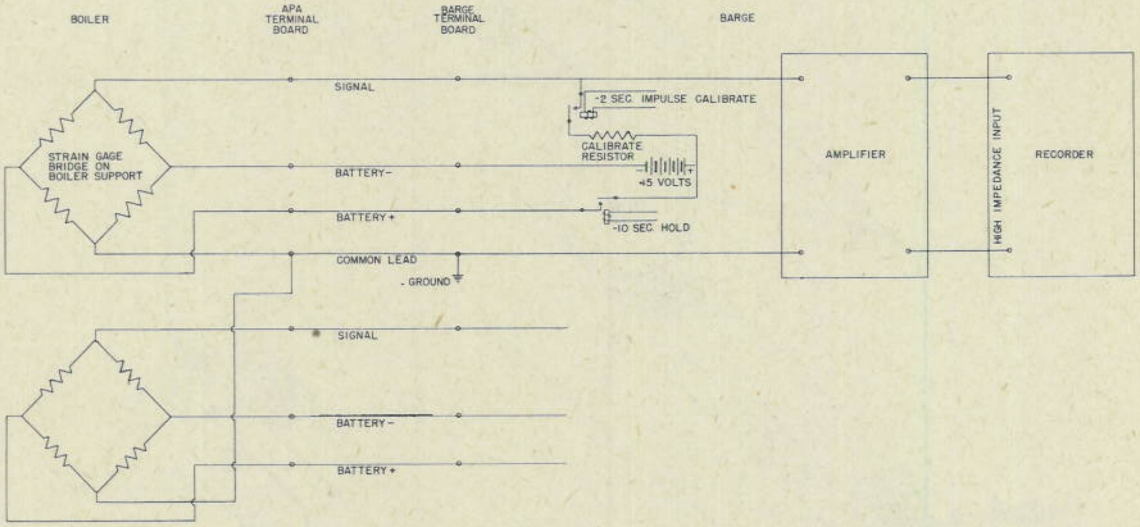

Fig. 6 - Typical strain gage circuit

The installation of the supports under the boiler presented a problem, as it was desired to minimize the bending and shear forces on individual supports from errors in alignment and elevation. The boiler was held in place by web sections welded to the boiler and the foundation. Approximately one-half-inch spacing was allowed between the boiler and the top of the support. The gap was very carefully measured, and shims were made so that the loading would be equal over the entire area of the upper flange of each boiler support. The signal produced by each bridge as the boiler was lowered on the supports and as the bolts were tightened was observed to determine if any static stresses exceeded the design limits.

MOTION OF THE BOILER FOUNDATION

To determine the effect of a flexible body on its foundation during shock, it is necessary to measure both the forces generated on the foundation and the motions which produced those forces. Accordingly, the foundation of the boiler was instrumented to determine the absolute motion of the foundation during shock.

The boiler foundation is essentially two large rectangular pedestals, running in a fore and aft direction. The starboard pedestal supports the water wall of the boiler, and the more massive port pedestal supports the water drum and economizer. For practical purposes the boiler foundation supports the boiler at each of the boiler's four corners (Figure 7) and it was at these corners that a complete set of instruments was installed to measure the shock motion. Each set consisted of three British-type velocity meters measuring velocity along three mutually perpendicular axes, three multifrequency reed gages which recorded the motions in three mutually perpendicular axes, and six peak reading putty accelerometers which recorded peak acceleration in two opposite directions along each of three mutually

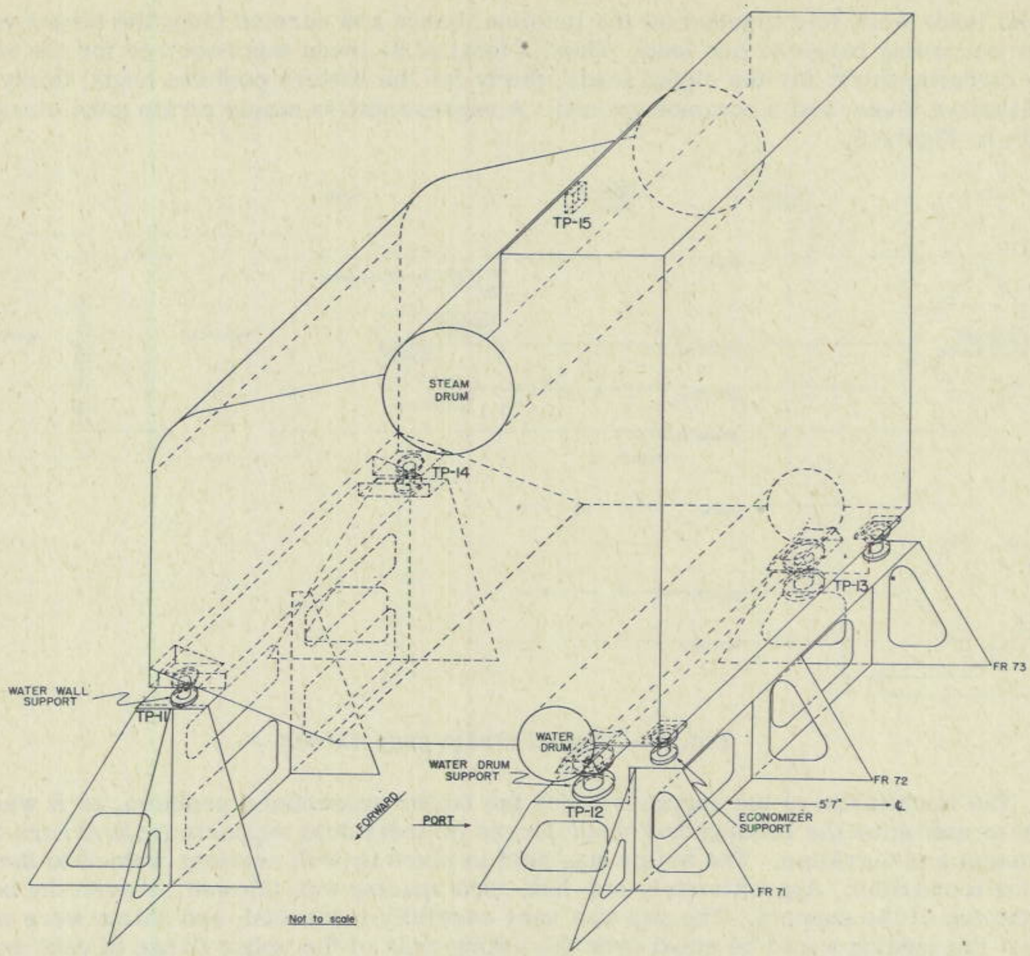

Fig. 7 - Supports for forward boiler USS NIAGARA APA87

perpendicular axes. The peak reading accelerometers and multifrequency reed gages were self recording. The British velocity meter output consisted of an electrical signal which was proportional to velocity and which was carried to the recording barge where it was recorded as a function of time.

It was necessary to make certain that the instruments were mounted on stiff sections of the foundation, so that the recorded motions would be truly representative of the actual motion of the foundation. The photographs of Test Position 11, Figure 8, under the forward starboard corner of the boiler clearly show the boiler supports, the British-type velocity meters, the multifrequency reed gages, and the peak reading accelerometers.

TESTS ON ELECTRONIC EQUIPMENT

Identical units of electronic equipment were installed at ten different locations on the ship to determine the effect of shock on electronic equipment, and to evaluate the effectiveness of shock mounts. At each of the ten test positions, three identical units of electronic equipment were mounted, each with a different mounting arrangement. One unit was solidly fastened to a mounting bracket, details of which will be described in a subsequent report. The second unit was supported on mounts which provided one inch of rubber for resilient support. The third unit was supported on mounts which provided 3/8 inch of rubber which corresponds to the method of mounting extensively used on Naval vessels. The mounting bracket, with three units of equipment is shown in Figure 9, which is a photograph of Test Position 2.

Selected for these tests was the Navy Type BN IFF Equipment, consisting of a transmitter, receiver, and a common power supply, considered representative of mechanically good Naval construction. In 1943 this equipment was subjected to shock and vibration tests at the Laboratory to determine compliance with specifications; results were submitted to the Bureau of Ships.[9],[10] The units were checked for operation before and after each shock.

To determine the motions at each of the ten test positions of the electronic equipment, various shock measuring instruments were secured to the equipment mounting bracket. A British-type velocity meter responding to vertical motion was secured to one end of the mounting bracket. The signal from the meter was transmitted to the recording barge where it was recorded on a time base. Two self-recording multifrequency reed gages registered motions in the vertical and thwartship directions, and two peak reading accelerometers registered accelerations in the vertical and thwartship directions. Lead deflection gages were installed around each of the resiliently mounted units to record the maximum relative motion of the unit with respect to the mounting bracket (Figure 10). From the measured excursions and the load deflection characteristics of the mountings it was hoped to calculate the maximum forces on the electronic equipments.

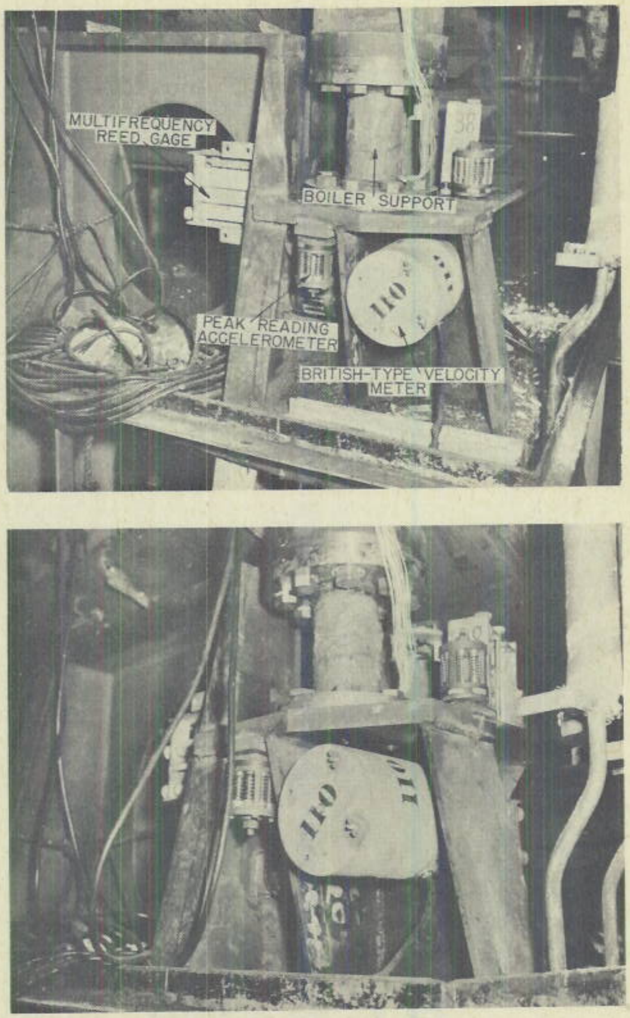

Fig. 8 - Test position 11

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[9] Letter from Director, NRL C-S67/89 MK III (380-GBG) dated 20 November 1943 to BuShips.

[10] Letter from Director, NRL S67/30 (1253C:EDF) Ser. 1250-355/46 dated 8 August 1946 to BuShips.

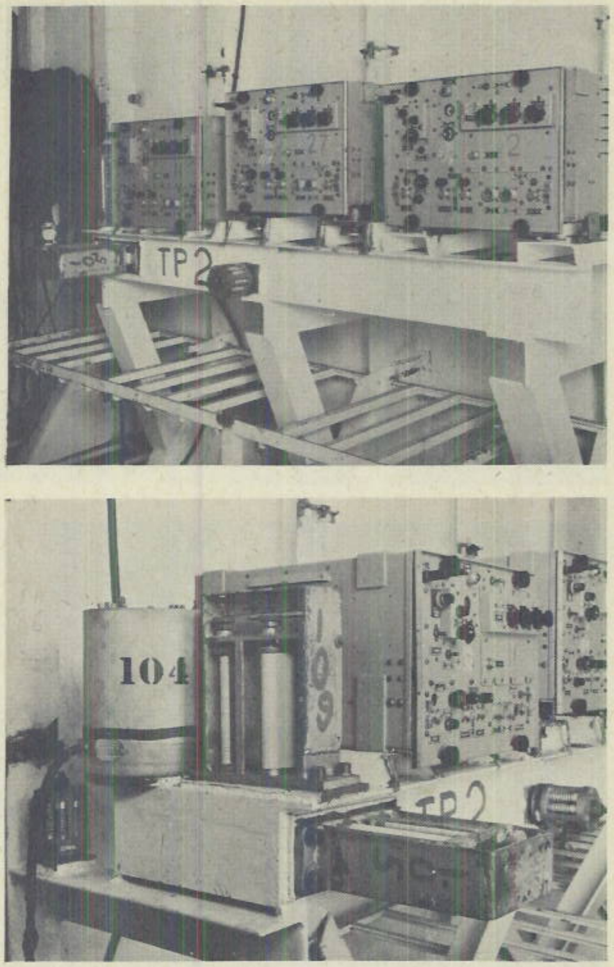

Fig. 9 - Test position 2

Fig. 10 - Electronic equipment mounting

SHOCK MOTION INSTRUMENTATION

Four basic types of shock motion instruments were employed during the full scale shock tests; the British-type velocity meter, the multifrequency reed gage, the peak reading accelerometer, and the lead displacement gage.

The British-Type Velocity Meter

This meter, (Figure 11) is composed of a fixed pickup coil firmly secured to a base, and a movable, essentially seismic electromagnetic field coil, whose motion is restricted by rollers to a direction perpendicular to the base.[11] The voltage generated in the pickup coil is proportional to the rate of cutting the flux of the field coil, and is therefore proportional to the relative velocity between the base of the instrument and the seismic element. Figure 12 is a representative circuit of the British-type velocity meter electrical connections.

The velocity meters used in the NIAGARA tests were modified from the British design by the addition of a steel stop welded to the top of the field coil so that upon contact between the movable field coil and the frame of the instrument, a more elastic rebound would occur. It was hoped that the records from the meter would be valid but of course with a reversal in algebraic sign even after the meter moving element contacted the limits.

The velocity meter was calibrated by removing the coil supporting springs and recording the output from the meter when the coil was allowed to fall by gravity. From the known height of fall and the time of fall, the calibration constants could be calculated. With the field current in the meter adjusted

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[11] For a complete description see British Admiralty Report BR 1314 Shock Effects from Underwater Explosions: Sect. 13- Instrumentation and Velocity Meter Trials, Nov. 1945.

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to 0.5 amperes, the constant of the modified velocity meter was found to be 0.397 volts per foot per second and was linear with displacement over the total permissible travel between stops of 1.755 inches. The natural frequency of the seismic element was measured to 3.3 cycles per second with the meter mounted so that the direction of response was vertical. For horizontal response, two additional springs were added to center the seismic element, and the natural frequency was increased to 5.1 cps.

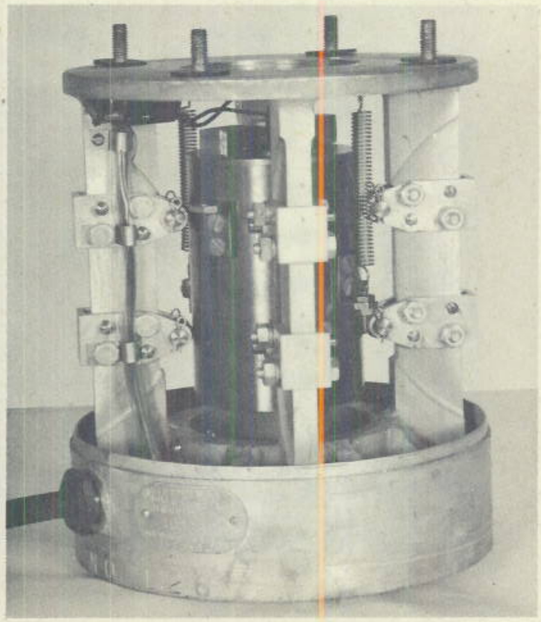

Fig. 11 - British velocity meter

The Multifrequency Reed Gage

This gage, (Figure 13) is composed of a series of cantilevers with masses at their free ends. Each cantilever has a different natural frequency in the first mode. The maximum motion of the reed with respect to the frame of the instrument is scribed on waxed paper. Blake and Walsh[12] show that the "shock spectrum" derived from the reed gage record provides design conditions for "Shockproof" equipment in the form of equivalent static accelerations of the shock motion, and a rational method for comparing the severity of different shock motions.

Eight different cantilevers were used on the multifrequency reed gages employed in the NIAGARA tests. The natural frequencies of the reeds in the first mode were 20, 40, 100, 198, 345, 430, 570, and 920 cps.

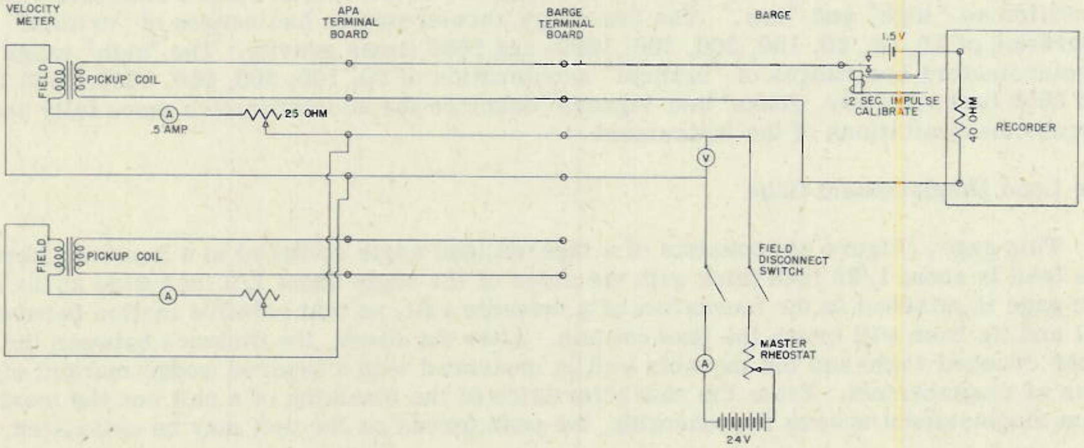

Fig. 12 - Typical velocity meter circuit

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[12] Walsh, J. P. and Blake, R. E., "The Equivalent Static Accelerations of Shock Motions," NRL Report No. F-3302, June 1948.

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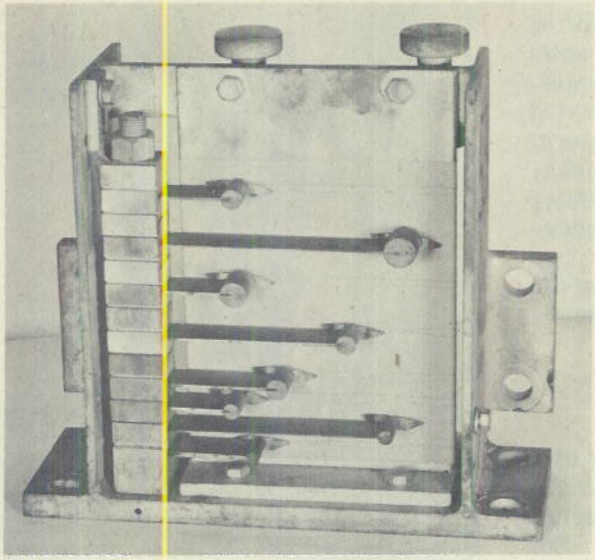

Fig. 13 - Multifrequency reed gage

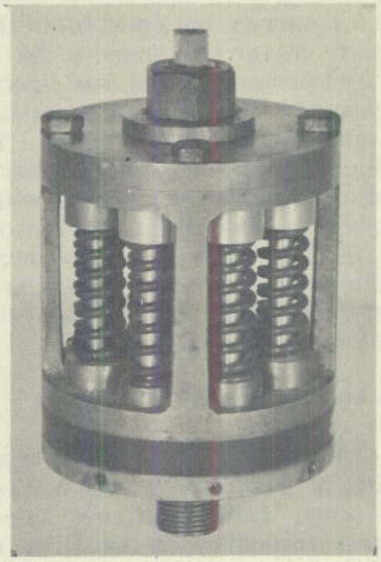

Fig. 14 - Peak reading accelerometer

The Peak Reading Accelerometer

This meter (Figure 14), sometimes called a "Putty Accelerometer," is a mechanical self-recording instrument designed to measure the maximum value of acceleration to which it is subjected. A mass with a plunger is held in place with a precompressed spring. When the forces on the mass overcome the spring forces as a result of an applied acceleration, the plunger indents a plastic clay. A series of eight different spring and mass combinations are assembled in each accelerometer, so that the peak acceleration is "bracketed" between two values. For the NIAGARA tests, two ranges of accelerometers were used and were identified as "high" and "low." The low range accelerometer had ranges of "critical" acceleration of 20, 50, 90, 150, 300, 700, 1200, and 1800 times gravity. The "high" range accelerometers had ranges of "critical" acceleration of 50, 100, 300, 650, 1000, 1500, 2000, and 2500 times gravity. Blake[13] and Vigness[14] describe the accelerometer more fully and discuss the limitations of the instrument.

The Lead Displacement Gage

This gage, (Figure 15) consists of a tapered lead angle soldered to a mounting base. The lead is about 1/32 inch thick with the sides of the angle about 1/2 inch wide at the base. The gage is attached to the foundation of a movable unit, so that relative motion between the unit and its base will crush the lead column. After the shock, the distance between the top of the crushed angle and the movable unit is measured with a tapered wedge marked off in units of displacement. From the characteristics of the mounting of a unit and the maximum displacement across the mounting, the peak forces on the unit may be calculated.

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[13] Blake, R. E., "Peak Reading Accelerometers," NRL Report, Shock and Vibration Bulletin, No. 8, March 1948

[14] Vigness, I, Kammer, E.W., and Holt, S.G., "Shock and Vibration Instrumentation and Measurements (Second Partial Report)," NRL Report O-2645, September 1945.

AMPLIFIERS AND RECORDERS

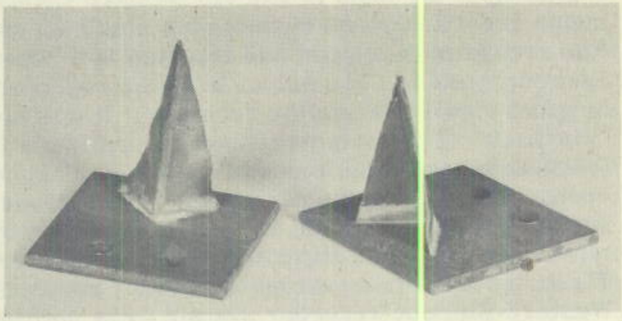


Fig. 15 - Lead displacement gages

The signals from the strain gage bridges on the boiler supports were too small to be recorded directly, so a high-gain linear amplifier was employed to raise the signal level to a satisfactory value. The Waterman Products Co., Model A-10-A-A thirteen-channel amplifier was used to amplify the incoming strain gage bridge signals and drive the recording system. Each amplifier unit contained thirteen individual independent amplifiers so that with four units, a total of 52 channels could be employed. Actually, the maximum number of channels employed on any particular test shot was 42; 30 for the strain gage bridges, and 12 for the velocity meters under the boiler. It was later found that the signals from the velocity meter were sufficiently large to permit direct recording without the use of amplifiers. Figure 16 shows an amplifier and recorder set up on the instrument barge.

Four types of recorders were employed to record the velocity meter and strain gage signals; the Consolidated Engineering Co. Type 5-101B, the Hathaway Type S8B, the Hathaway Type RS9, and the Western Electric Type RA-1132-C. It was planned at the

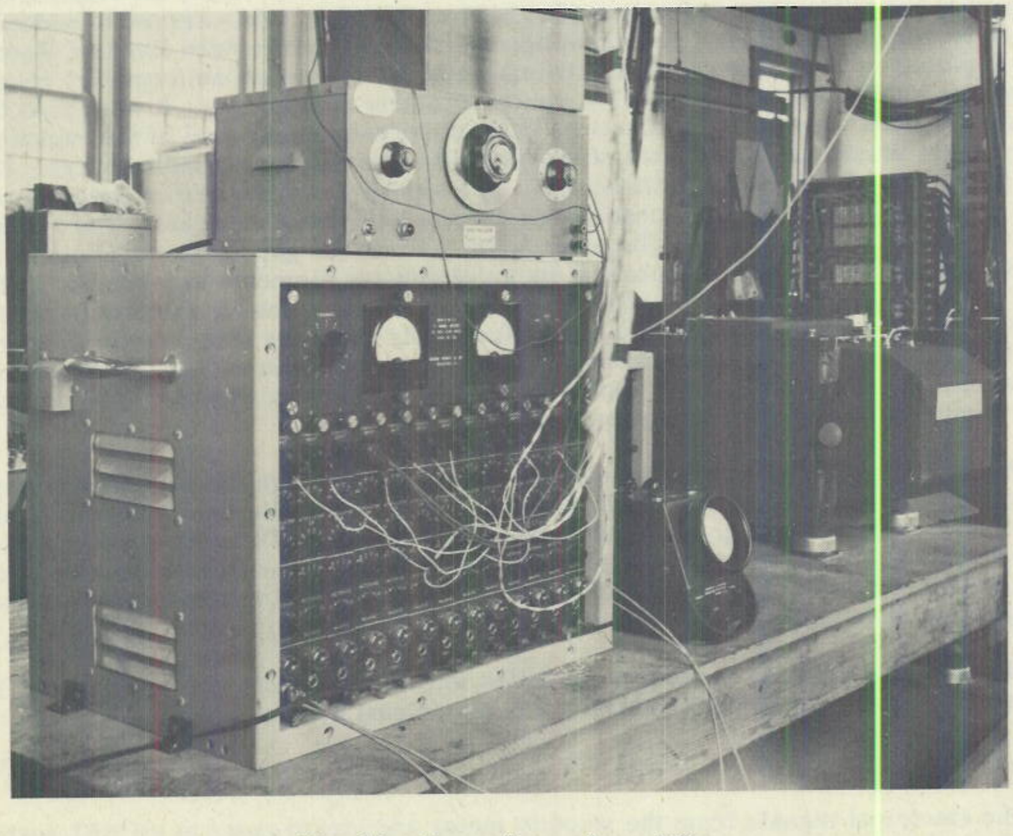


Fig. 16 - Recorder and amplifier

beginning of the tests to use the Western Electric recorders exclusively. These instruments record thirteen signals on a single 35-mm sound motion picture film negative. The record is developed and inserted in a reproducing unit which is a part of the Western Electric system. The output from the reproducer is an electric signal identical to the original signal fed into the recorder. It was hoped that this system would permit the "playback" of the original shock record into a transient analyzer for the determination of frequencies and amplitudes of motion during the shock transient. Serious difficulties were encountered during the early shots which caused a temporary abandonment of the Western Electric system in favor of electromagnetic string recorders of the more conventional type. The principal difficulties with the Western Electric system arose from two sources. First, the amplitude-versus-frequency response characteristics of the Waterman amplifier – Western Electric recorder system were not linear. It was discovered that the response was fairly uniform from 6 to 1000 cps, but above 1000 cps the sensitivity of the recorder radically increased so that at 8000 cps, which was the resonant frequency of the mechanical elements in the recorder, the sensitivity was approximately 12 db greater than the sensitivity at 1000 cps. The effect of this was that any steep wave fronts exciting the recorder were greatly overemphasized. To prevent over-modulation of the trace with these steep wave fronts, the amplifier gain had to be lowered to a point where the low frequency components were obscured in the general noise. The second difficulty arose from the fact that the acoustic noise produced by the explosion wave striking the bottom of the recording barge produced large "microphonic" signals from the Waterman amplifiers. These microphonic noises, along with their attendant steep wave fronts, completely obscured the signals from the shock recording instruments.

A partial remedial solution to this problem was twofold. First, the amplifiers were wrapped in heavy blankets and well padded before each shot. This served to reduce, but not eleminate, the acoustic noise-produced signals. Second, the Western Electric Recorders were replaced by the conventional electromagnetic recorders whose frequency response was uniform up to 1000 cps, but greatly attenuated at higher frequencies. It was found that the recorded signals were valid for the time interval between the arrival of the explosion wave at the target vessel and the arrival of the explosion wave at the recording barge. This was usually of the order of 30-40 milliseconds. The signals from the British velocity meters were recorded directly by the Consolidated and the Hathaway recorders. The output signal from the velocity meters was sufficiently large to drive the galvanometer elements directly without amplification. The response of the galvanometer elements was linear with frequency from zero to slightly above 1000 cps. This was satisfactory for all velocity meters mounted above the inner bottom. However, a higher frequency response with a faster film travel would have been desirable for all meters mounted on the inner bottom at Test Positions 1, 2, 11, 12, 13, and 14. A typical strain gage recording circuit is shown in Figure 6 and a typical velocity meter recording circuit is shown in Figure 12.

It was found that the writing speed of the trace was too high for satisfactory recording on photographic paper for the Consolidated recorders. Accordingly, the feed and take-up spools were modified to accommodate seven-inch Super Aero film. No further difficulty was encountered from lack of writing speed. The voltage on the light bulbs was increased above normal on the Hathaway recorders to obtain higher writing speeds with adequate photographic density, so that photographic paper could be used.

Because photographic developing facilities were not available on the recording barge, the records were returned to Washington for processing after each shot.

CABLES

The electrical signals from the velocity meter and strain gages at all NRL test positions throughout the ship were terminated at a shock-mounted terminal board adjacent to the boiler in the forward machinery space. From this terminal board, multiconductor cables were run to the weather deck where a second terminal and dis-connect board was installed. The cables from the Taylor Model Basin instrumentation were also connected to this second board. From this point, multiconductor cables were run to the after part of the target vessel and then to the recording barge. To support the large number of cables between the target vessel and the barge, a cargo-handling boom was lowered over the port side of the vessel, to which was attached a sling loop to keep the cables out of the water. Under certain conditions the cables did get in the water, but no great number of conductor faults occurred.

Multiconnector cable connectors were installed at the target vessel dis-connect board on the weather deck, and on the terminal board on the recording barge to facilitate the release of the cables should it become necessary because of storms or accident. These JAN connectors were not satisfactory as they were exposed to the saline atmosphere and internal shorts or opens occurred over a period of time. Near the end of the tests, additional 30-conductor cables were run directly from the terminal board at the boiler to the recording barge, bypassing the dis-connect boards. This proved more satisfactory.

In addition to the signal cables, 115-volt power for emergency lighting, 24 volts dc for velocity meter fields, and miscellaneous timing, warning, and firing circuits were also run from the target vessel to the recording barge. All these cables were grouped in one large bundle with a 1/2-inch steel messenger. Figure 17 is a schematic of the instrument cable distribution system.

TEST POSITIONS

The motions produced by the underwater explosions were measured at twenty locations throughout the ship. Test Positions 1 to 10 were associated with the electronic equipment

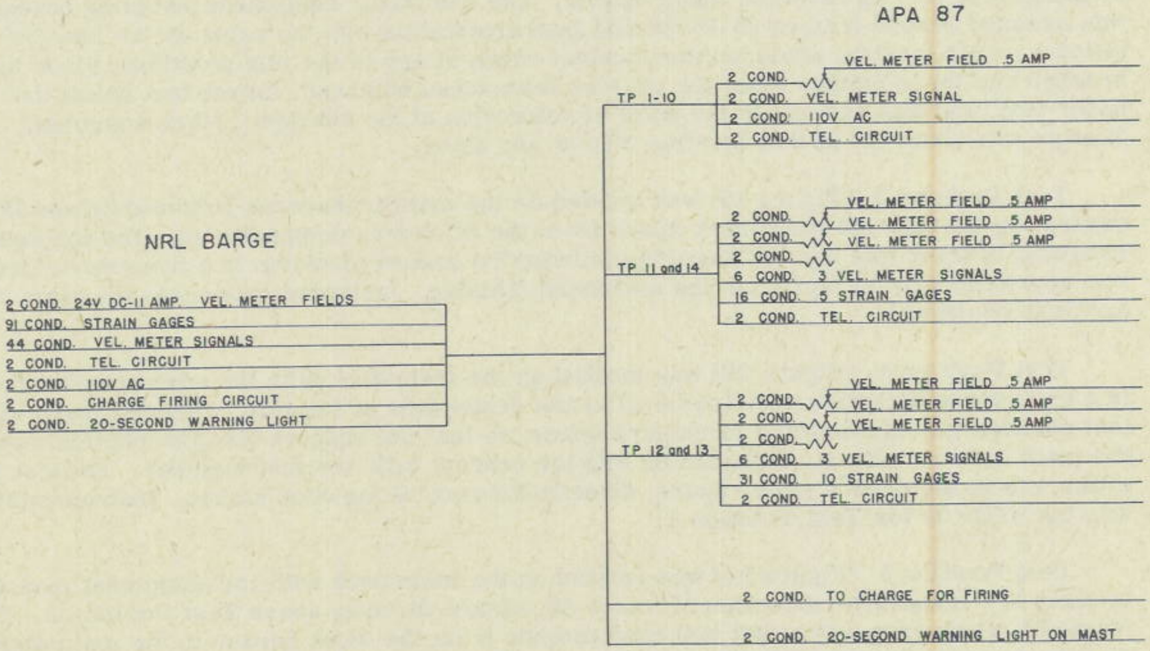


Fig. 17 - NRL instrument cables

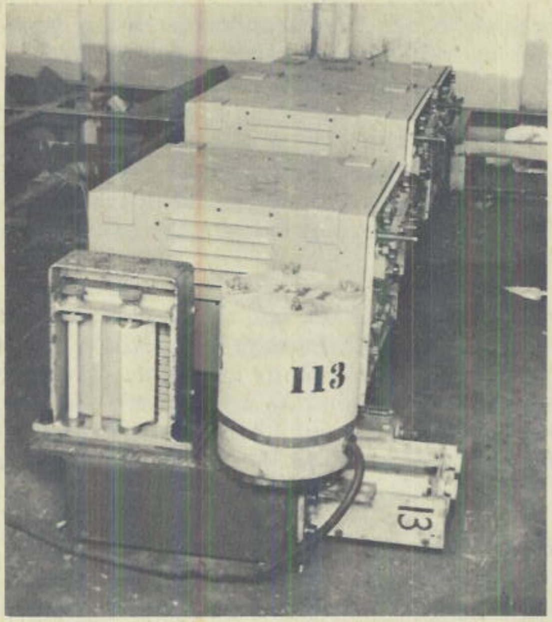


Fig. 18 - Test position 1

investigation. Test Positions 11 to 15 were associated with the forces on the boiler foundation; and Test Positions 16 to 20 were miscellaneous locations used for obtaining data on shock motions to be compared with the information obtained from positions 1 to 10. It is believed that a short description of each test position will be of interest.

Test Position 1 (Figure 18) was located in the SD stores compartment on the inner bottom over a fuel tank. The electronic equipment mounting bracket was secured to the deck in a fore and aft direction across frames 89-90-91, approximately 5 feet inboard from the starboard plating. Three type BN equipments, a velocity meter, two reed gages, and two peak reading accelerometers completed the installation. The velocity meter was oriented to produce a signal for vertical motion; the multifrequency reed gages were oriented to record vertical and thwartship motions; and the peak reading accelerometers were oriented to record vertical and thwartship motions. Lead displacement gages were also installed adjacent to the two shock mounted electronic equipments and oriented to measure maximum downward and side-to-side motions across the mounts.

Test Position 2 (Figure 9) was located in the SD stores compartment on the starboard framing, four feet up from the inner bottom. The electronic equipment mounting bracket was secured across frames 86-87-88 and instrumentation was the same as for Test Position 1. This location provided the greatest shock of any of the test positions, since the bracket was three frames from the nearest transverse bulkhead, eleven feet below the water line, and was nearest to the point of detonation of the charges. More equipment damage was observed at this location than at any other.

Test Position 3 (Figure 19) was located on the main transverse bulkhead (frame 83) separating the forward machinery space from the SD stores compartment. The equipment mounting bracket was located four feet up from the second platform in a transverse direction approximately 14 feet from the starboard framing. Instrumentation was the same as for Test Position 1.

Test Position 4 (Figure 20) was located on the main deck with the equipment bracket in a transverse direction over frame 87 at the center line of the ship. Directly under this test position was the forward machinery space, so that the support for this location was only the main deck members. Bulkhead 83 was the nearest stiff vertical member. The test position was in the crew's galley space, directly forward of the cook stoves. Instrumentation was the same as for Test Position 1.

Test Position 5 (Figure 21) was located on the main deck with the equipment mounting bracket in a transverse direction of frame 83, almost directly above Test Position 3. The frame 83 transverse watertight bulkhead extends from the inner bottom to the main deck, so that the structural support for this position was the same as for Test Position 3. Instrumentation was the same as for Test Position 1.

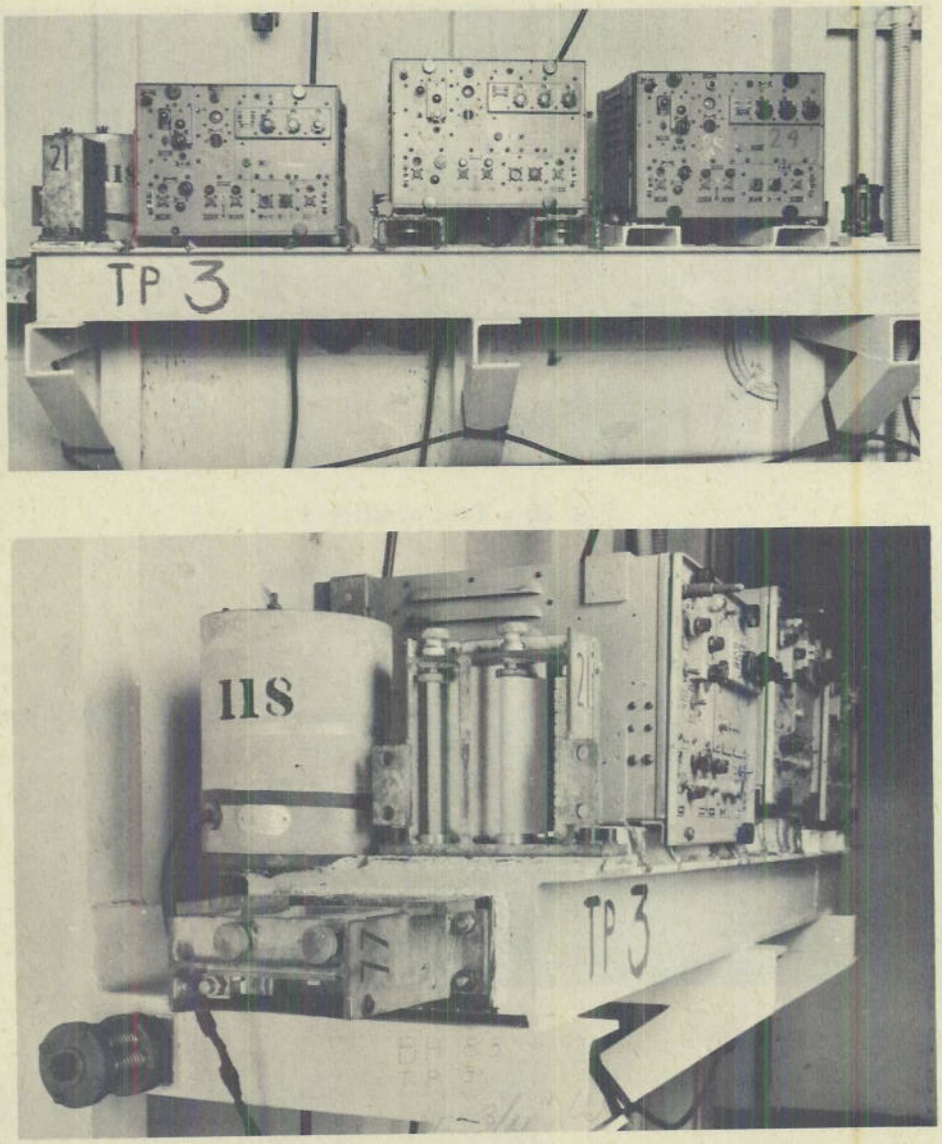


Fig. 19 - Test position 3

Test Position 6 (Figure 22) was located on the navigation deck, three decks above the main deck on the transverse bulkhead at frame 83. This test position was almost directly above Test Positions 3 and 5. Instrumentation was the same as for Test Position 1.

Test Position 7 (Figure 23) was located on the navigation deck in the same compartment as Test Position 6, with the equipment mounting bracket secured to the deck midway between the four bulkheads. Instrumentation was the same as for Test Position 1.

Test Position 8 (Figure 24) was also located in the same compartment as Test Position 6 and Test Position 7, with the equipment mounting bracket secured to the starboard outer framing. Instrumentation was the same as for Test Position 1. It was desired to determine the difference in performance for equipments mounted on transverse bulkheads,

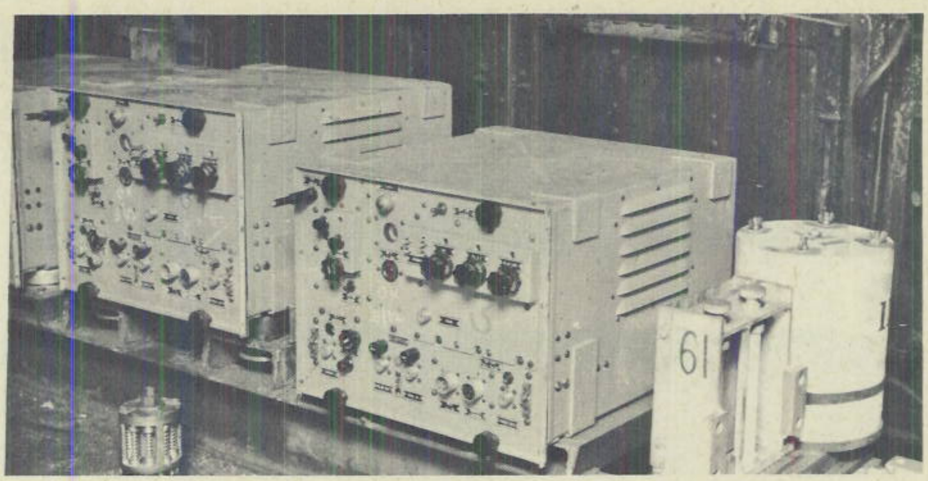


Fig. 20 - Test position 4

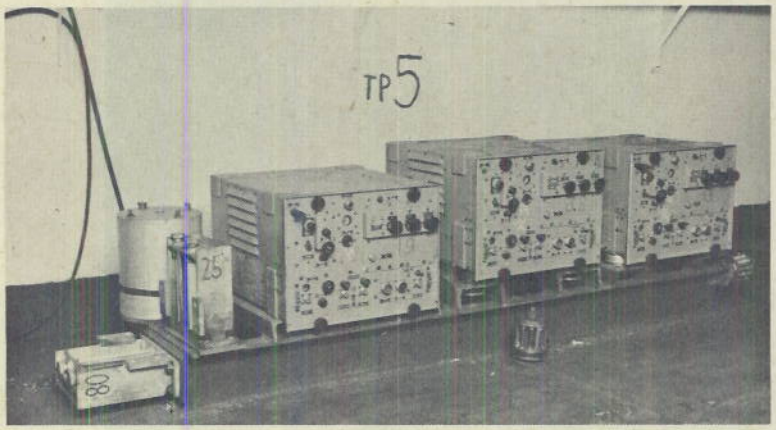
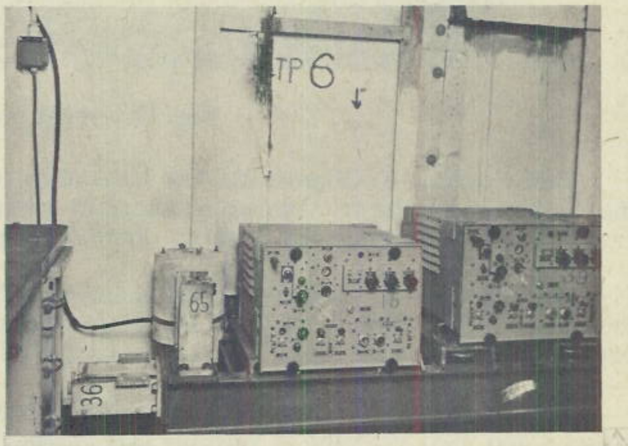


Fig. 21 - Test position 5

Fig. 22 - Test position 6



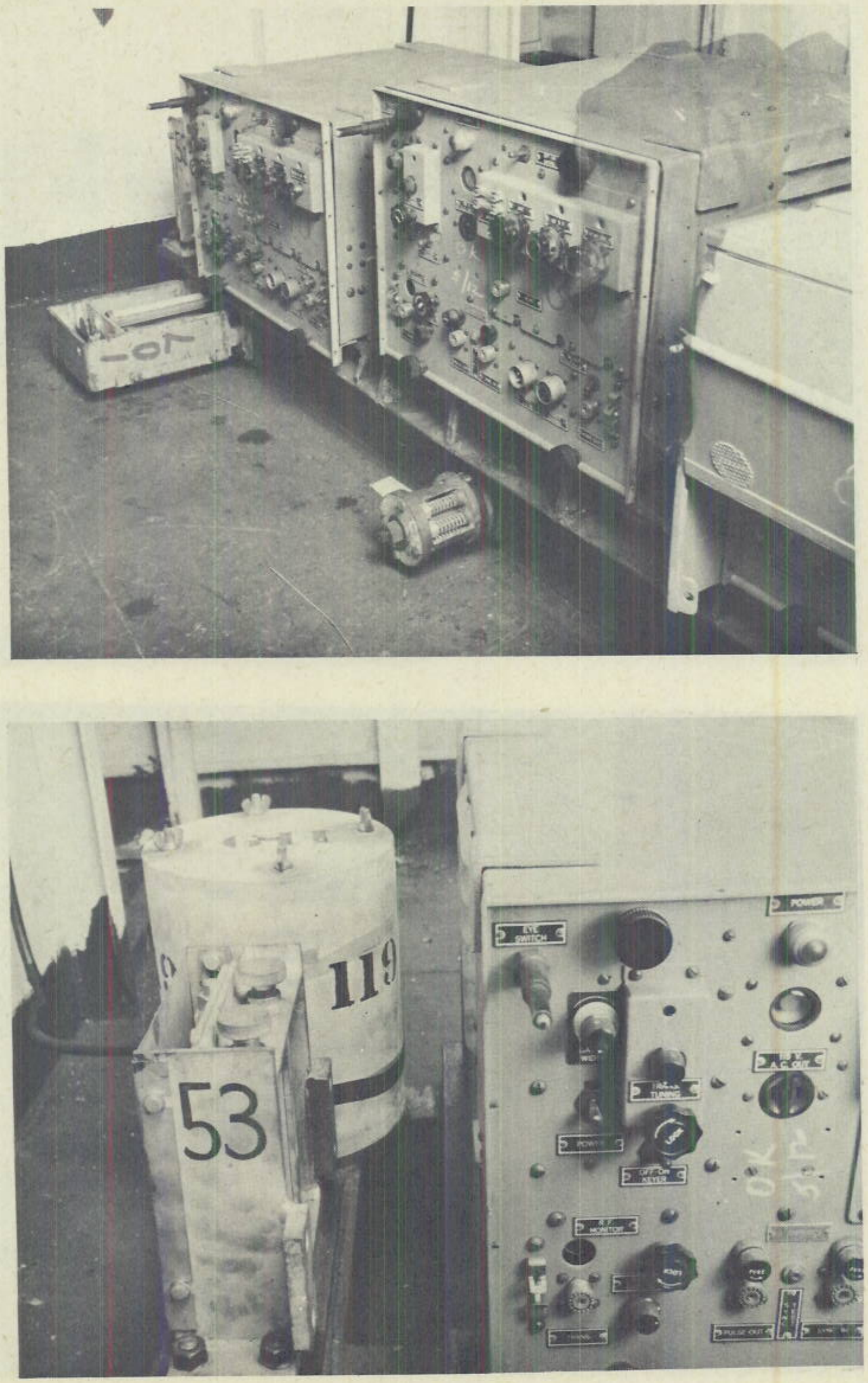


Fig. 23 - Test position 7

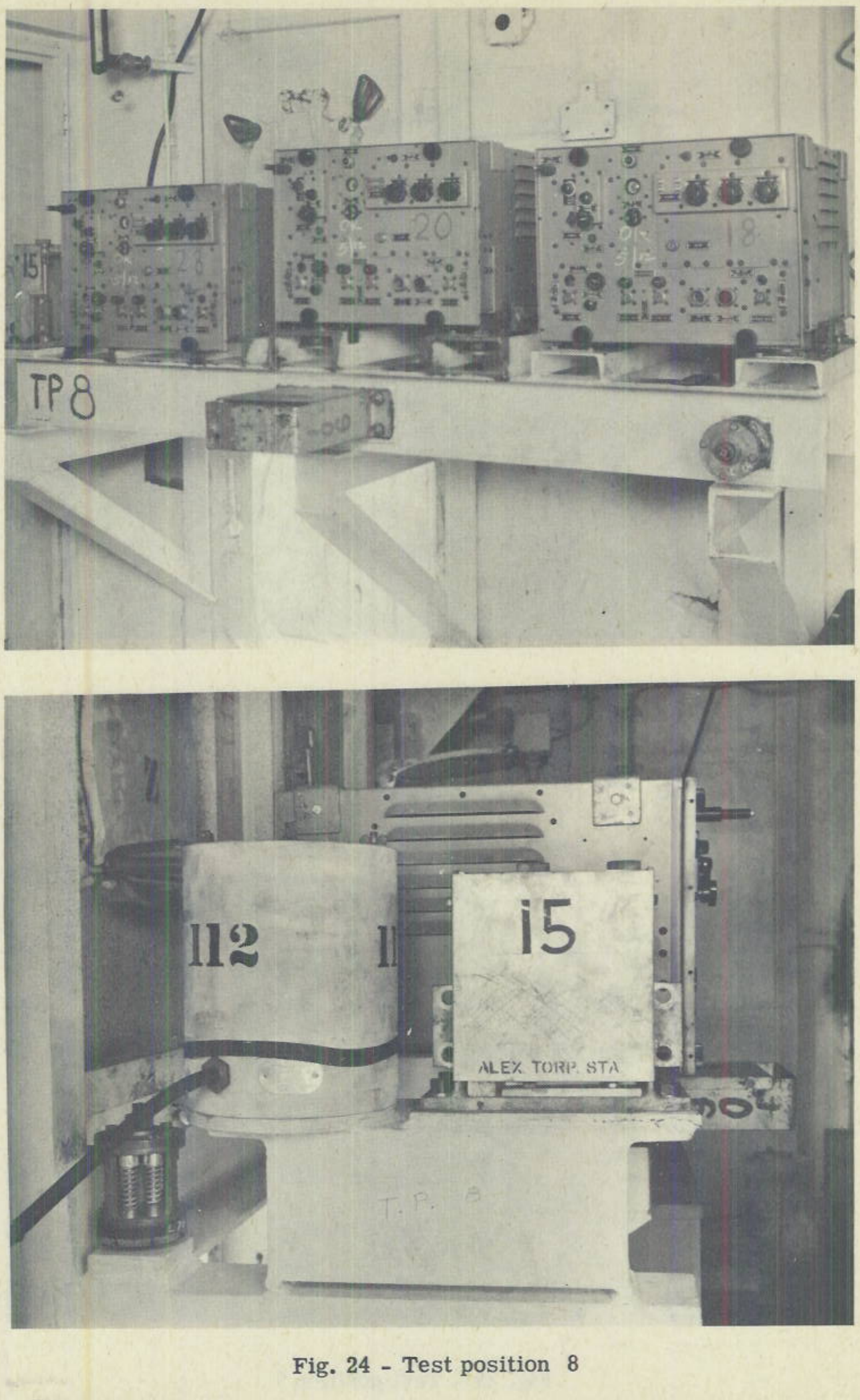


Fig. 24 - Test position 8

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center of decks, or on outer framing for a given compartment. The area chosen for Test Positions 6, 7, and 8 was the Coding Room which is a part of the main communication section of the ship.

Test Position 9 (Figure 25) was located on the first platform with the equipment mounting bracket in a fore and aft direction over frames 63-64-65 on the center line of the ship. The bracket was near the center of the dry-provisions issue room and represented an unloaded deck. Instrumentation was the same as for Test Position 1 except for the addition of an extra peak reading accelerometer recording acceleration in a longitudinal direction.

Test Position 10 (Figure 26) was located on the open or weather deck with the equipment mounting bracket in a fore and aft direction over frames 36-37-38, approximately 18 feet starboard of the center line. This location was near a forward cargo hold winch which represented a considerable mass loading of the deck. Instrumentation was the same as for Test Position 1.

Test Position 11 (Figure 8) was located under the forward starboard corner of the boiler in the forward machinery space. Test Position 14 (Figure 27) was located under the after starboard corner of the boiler. The instrumentation for each test position was the same and is detailed earlier in this report.

Test Position 12 (Figure 28) was located under the forward port corner of the boiler and Test Position 13 was located under the after port corner of the boiler. Test Position 12 included both the forward water drum and economizer boiler supports, while Test Position 13 included the after water drum and economizer boiler supports.

Test Position 15 (Figure 29) consisted of a single multifrequency reed gage mounted at the top center of the steam drum of the forward boiler to record vertical motions of the steam drum. It was desired to compare the motions of the steam drum with those of the water drum almost directly below at Test Positions 12 and 13.

Test Position 16 (Figure 30) consisted of a single multifrequency reed gage mounted to record thwartship motion of the starboard framing at frame 97 four feet from the inner bottom. It was desired to compare the motion of comparatively unloaded framing at this location with the motion of loaded framing at Test Position 2.

Test Position 17 (Figure 31) consisted of a single multifrequency reed gage mounted to record vertical motion of the inner bottom at frame 95 in the after machinery space approximately 5 feet inboard of the starboard plating. It was desired to compare the motion of the inner bottom at this location with the recorded motion at Test Position 1.

Test Position 18 (Figure 32) consisted of two gages: (a) a multifrequency reed gage mounted to record thwartship motion of the starboard framing at frame 90, four feet above the inner bottom, and (b) a peak reading accelerometer mounted to record vertical motion at the same location. This test position is two frames aft of Test Position 2 and represents an unloaded frame adjacent to a loaded frame.

Test Position 19 (Figure 33) was located on the inner bottom at frame 86 approximately 5 feet from the starboard plating. A single multifrequency reed gage was mounted at this location which was three frames forward of Test Position 1. It was desired to compare the motions of the unloaded tank top at this location with the motions at Test Position 1.

Test Position 20 (Figure 34) was located on the port plating four feet above the navigation deck level at frame 80. Two multifrequency reed gages recording motions in a vertical

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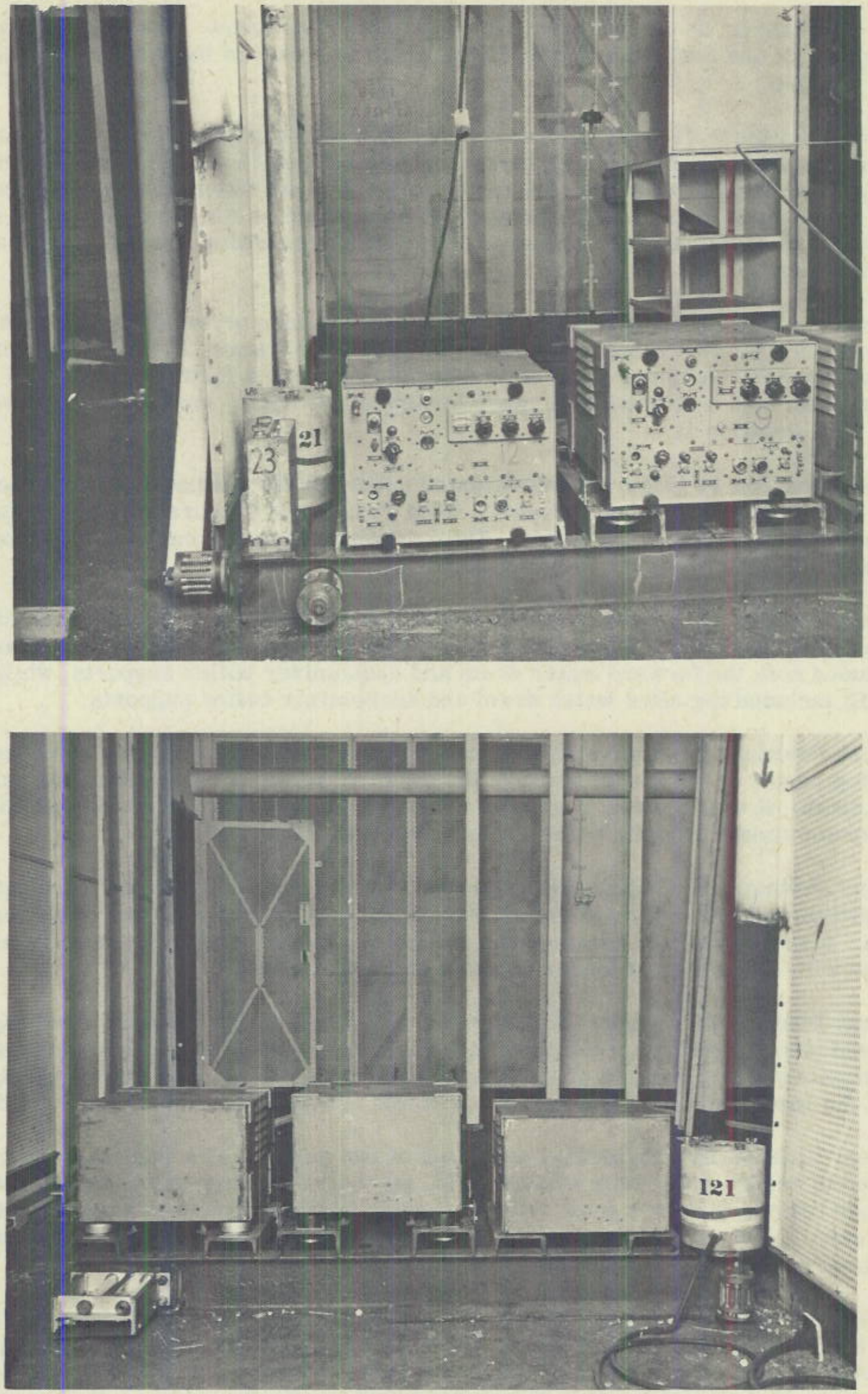

Fig. 25 - Test position 9

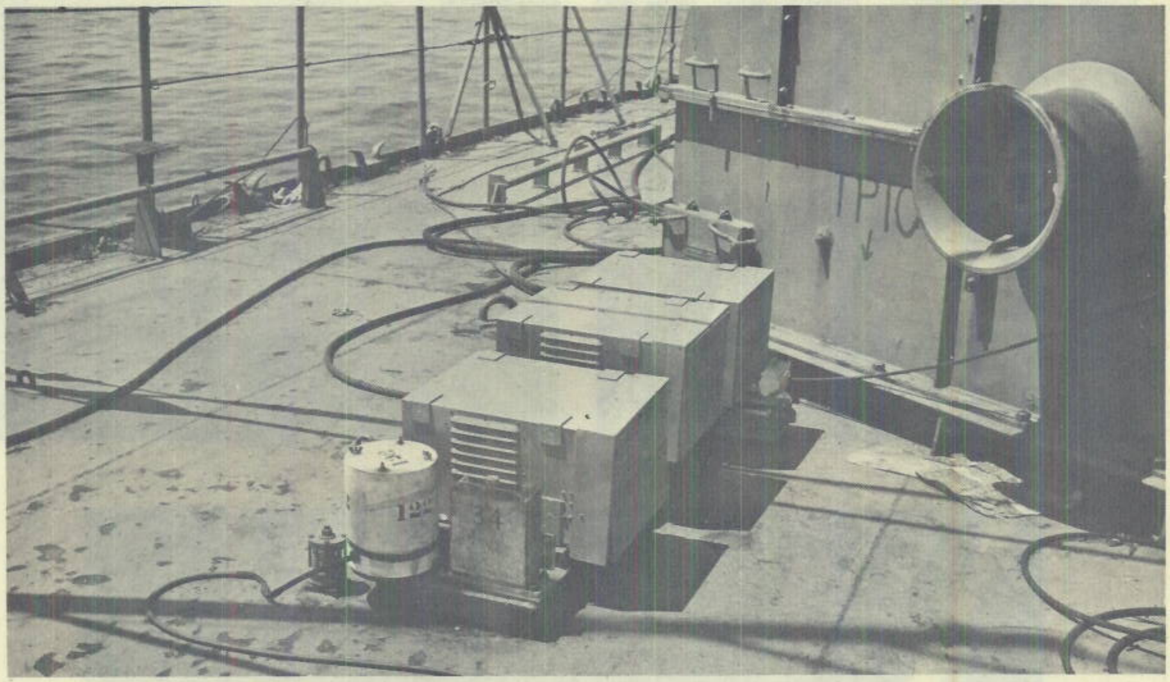

Fig. 26 - Test position 10

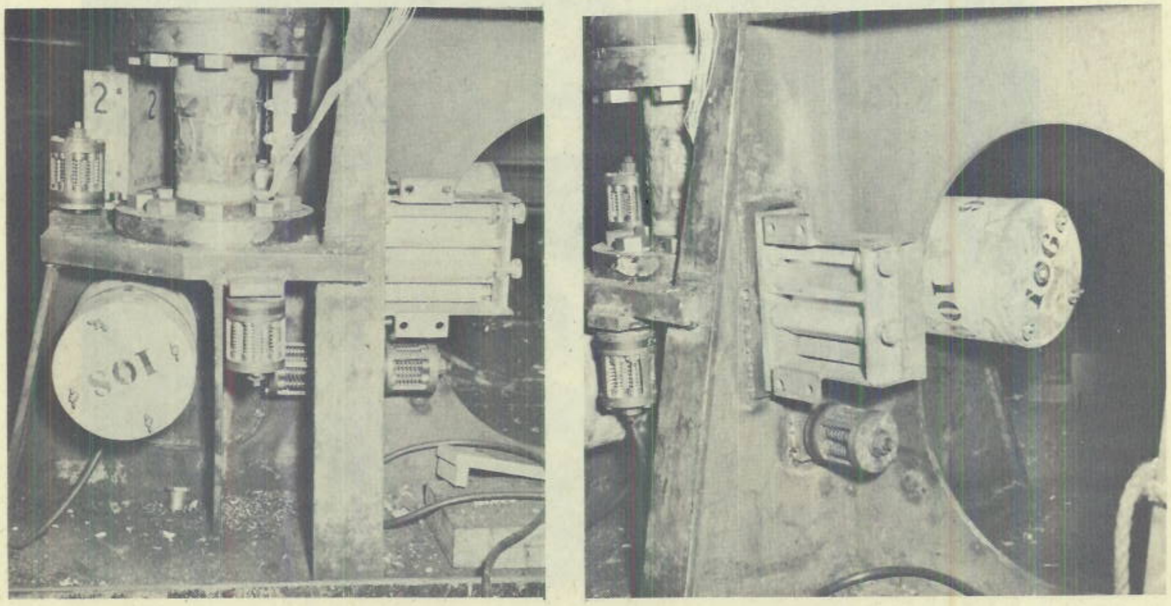

Fig. 27 - Test position 14

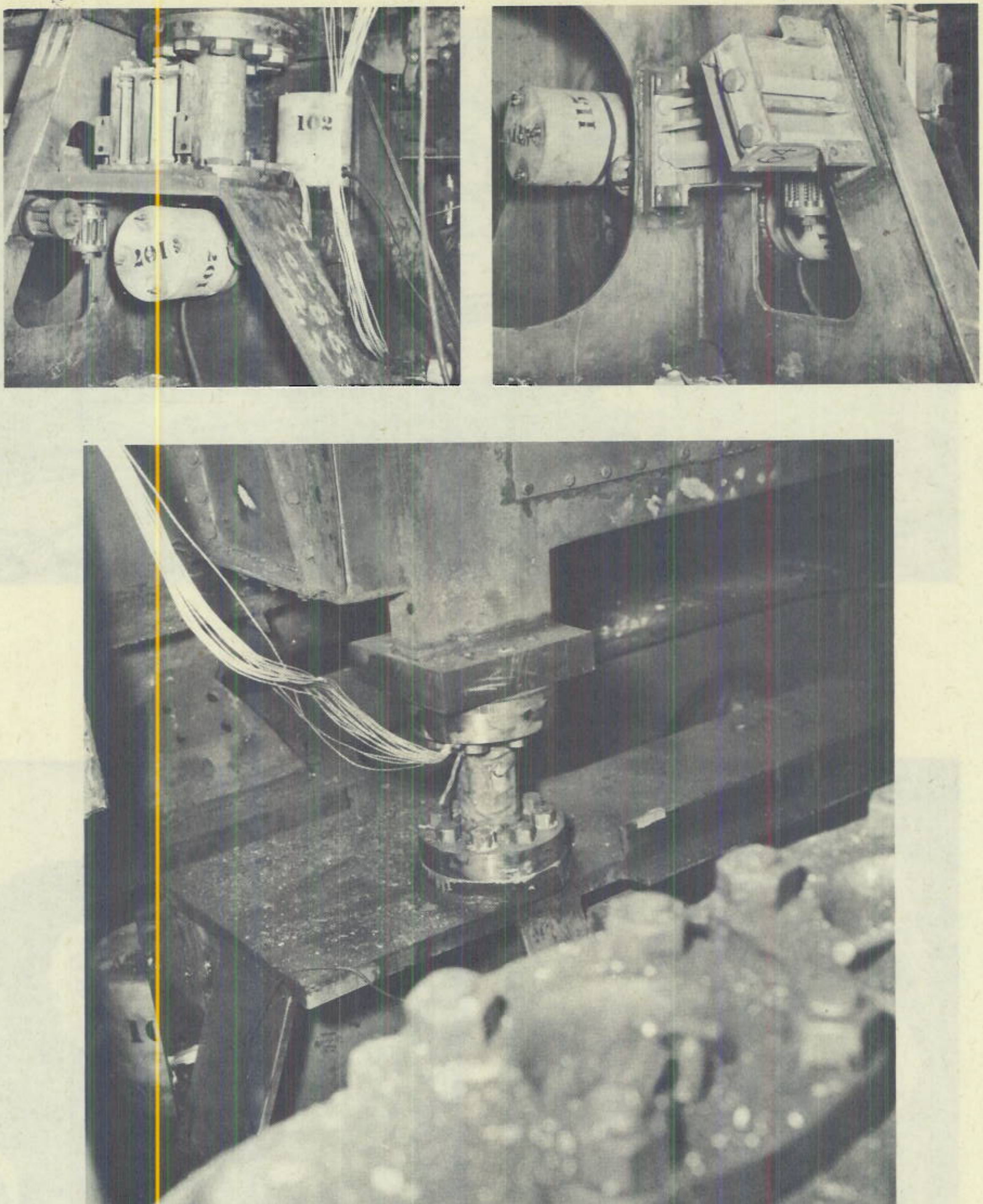

Fig. 28 - Test position 12

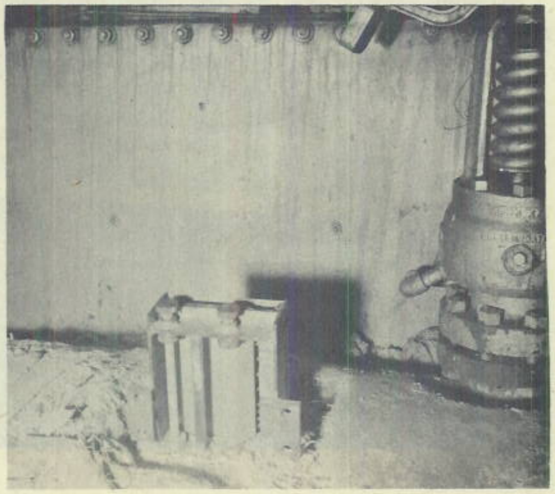

Fig. 29 - Test position 15

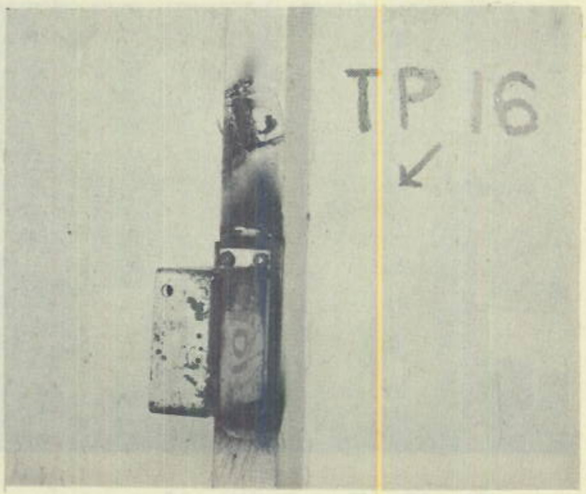

Fig. 30 - Test position 16

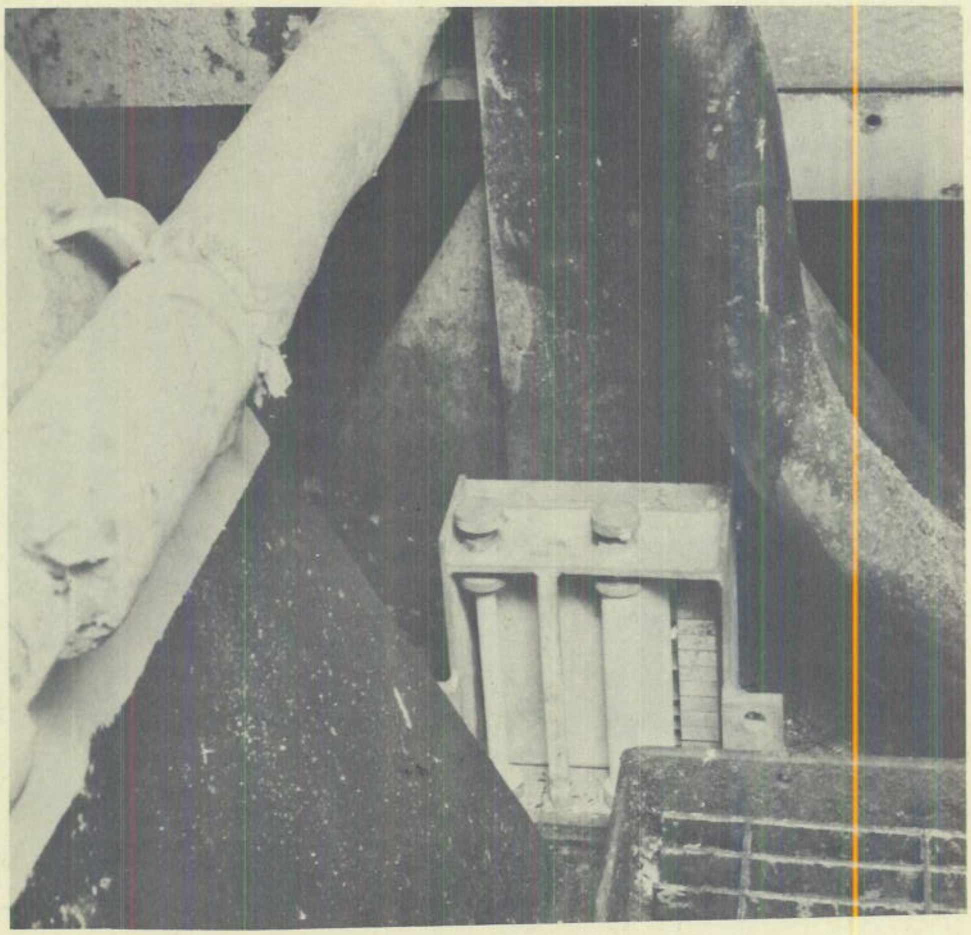

Fig. 31 - Test position 17

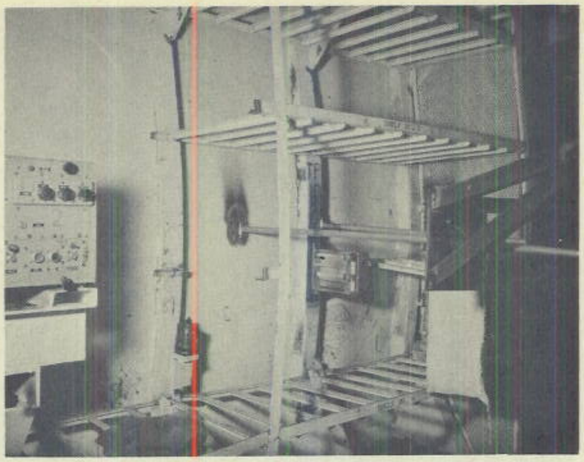

Fig. 32 - Test position 18 showing deformation of starboard framing

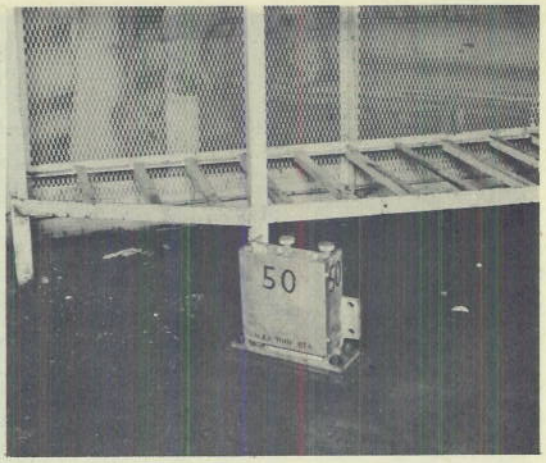

Fig. 33 - Test position 19

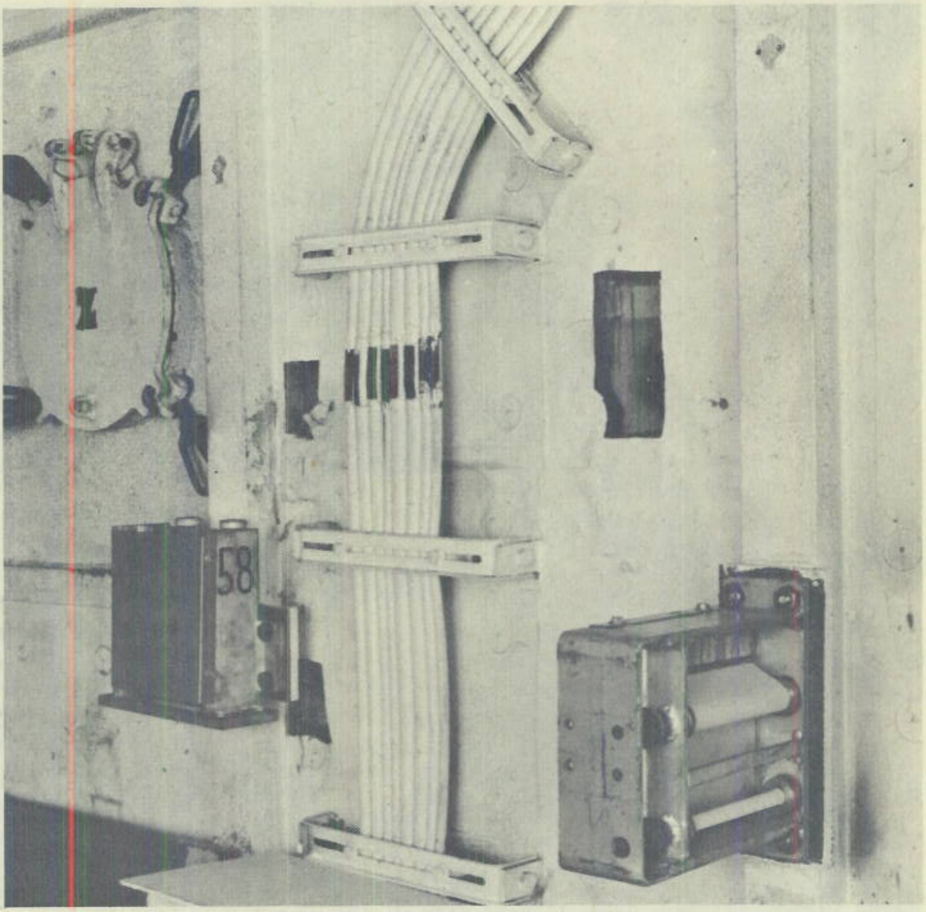

Fig. 34 - Test position 20

and thwartship direction were installed at this location. It was desired to compare the motion of an unloaded framing at this location with the motion of a loaded framing of similar construction such as at Test Position 8.

Table 1 lists the test positions, the locations, and the serial numbers of the various instruments mounted at each test position.

CHARGE DATA

A total of 24 charges were actually fired against the NIAGARA. Table 2 lists the sequence, charge weight, distance, depth, and the date fired. Charge 13A was a repeat shot used to determine whether instrumentation difficulties previously encountered had been eliminated and it also provided a check on the consistency of results. After an inspection by hull experts from the Norfolk Naval Shipyard immediately after shot 16, it was decided that any greater shock would probably cause hull failure and therefore charge 17, originally scheduled to be 1200 pounds 70 feet down and 88 feet from the side of the target vessel, was cancelled. Shot 21 was a low-order detonation which produced no shock. Due to lack of time, a repeat charge was not fired. The explosive HBX-1 charge was brought out from the magazine located at the Patuxent Naval Air Test Center by small boat and was rigged for firing (Figure 35) by an Underwater Demolition Team responsible for the proper location of the charge and the installation of the electric firing cable from the charge to the weather deck of the target vessel. The Naval Research Laboratory was responsible for the firing cable from the target vessel to the recording barge and for the firing circuit. The firing cable was kept shorted until minus one minute, when the master firing switch was thrown for automatic control by the sequence timer. A 45-volt heavy duty radio "B" battery was used to fire the charge.

Three firing failures occurred. The first occurred when the cable between the charge and the target vessel parted in rough weather. The charge was not recovered, but towed to a safe area and dumped. The second failure occurred when the master firing switch was not thrown to the automatic position. The cameras and recorders were reloaded, and the charge successfully fired. The third failure was a low-order detonation of one of the small charges. This was attributed to an improper booster charge used to detonate the main charge.

SEQUENCE TIMER

The sequence timer (Figure 36) provided automatic remote control of the switching, calibrating, and de-energizing of all recording, warning, and firing circuits for each explosion. A synchronous-motor-driven cam wheel provided normally open, normally closed, and impulse closed or open contacts at various intervals from minus ten minutes to plus ten minutes from the explosion time. While only one set of contacts was provided in the sequence timer for each sequence interval, an additional panel of relays was provided for operation of more than one circuit simultaneously. The following sequence intervals were provided.

- 10 min
- 2 min
- 1.5 min
- 20 sec
- 15 sec
- 10 sec
- 9 sec
- 8 sec
- 7 sec
- 6 sec
- 5 sec
- 4 sec
- 3 sec
- 2 sec
- 1 sec
- 0 sec
+ 5 sec
+ 30 sec
+ 1 min
+ 1.5 min
+ 2 min
+ 2.5 min
+ 3 min
+ 3.5 min
+ 4 min
+ 4.5 min
+ 5 min
+ 10 min

[redacted]

TABLE 1

APA Test Position Descriptions

TEST POSITION NUMBER	DECK LEVEL	FRAME NUMBER	DISTANCE OFF CENTER LINE	HEIGHT ABOVE DECK LEVEL	BN EQUIPMENT NUMBERS			BRITISH VELOCITY METER NUMBERS			REED GAGE NUMBERS			PUTTY ACCELEROMETER NUMBERS					
					MOUNTING A	MOUNTING B	MOUNTING C	VERTICAL	TRANS.	LONG.	VERTICAL	TRANS.	LONG.	VERTICAL UP	VERTICAL DOWN	TRANS. PORT	TRANS. STBD	LONG. FWD	LONG. AFT
1	HOLD	89-90-91	24' TO STBD	ON DECK	23	5	36	113	—	—	104	13	—	L-61	—	L-71	—	—	—
2	HOLD	86-87-88	STBD FRAMING	4'	11-21	27	2	104	—	—	109	105	—	A-39	—	H-21	—	—	—
3	SECOND PLATFORM	83	15' TO STBD	4'	15	33	24	118	—	—	21	77	—	L-40	—	L-19	—	—	—
4	MAIN DECK	87	ON CL	ON DECK	7-39	34	3	117	—	—	61	33	—	L-60	—	L-121	—	—	—
5	MAIN DECK	83	9' TO STBD	ON DECK	19	38	13	126	—	—	25	80	—	L-101	—	L-26	—	—	—
6	NAVIGATION DECK	83	5' TO STBD	1.5'	16	39-29	25	123	—	—	65	36	—	L-38	—	L-69	—	—	—
7	NAVIGATION DECK	79-80-81	6' TO STBD	ON DECK	40	30	35-14	119	—	—	53	107	—	L-66	—	L-3	—	—	—
8	NAVIGATION DECK	79-80-81	10' TO STBD	4	28	20	18	118	—	—	15	106	—	L-76	—	L-124	—	—	—
9	FIRST PLATFORM	63-64-65	ON CL	ON DECK	12	9	22	121	—	—	23	102	—	L-51	—	L-102	—	L-43	—
10	UPPER DECK	36-37-38	18' TO STBD	ON DECK	10	26	6	122	—	—	34	3	—	L-21	—	L-130	—	—	—
11	FWD MACH SPACE	FWD SIDE OF BOILER	STBD SIDE OF BOILER	BOILER FOUNDATION	—	—	—	111	110	116	38	82	59	L-12	L-116	L-72	L-14	L-103	L-106
12	FWD MACH SPACE	FWD SIDE OF BOILER	PORT SIDE OF BOILER	BOILER FOUNDATION	—	—	—	125	107	115	99	68	64	L-84	L-110	L-68	L-119	L-115	L-29
13	FWD MACH SPACE	AFTER SIDE OF BOILER	PORT SIDE OF BOILER	BOILER FOUNDATION	—	—	—	124	103	109	16	83	40	L-123	L-59	L-57	L-37	L-47	L-126
14	FWD MACH SPACE	AFTER SIDE OF BOILER	STBD SIDE OF BOILER	BOILER FOUNDATION	—	—	—	102	108	106	2	91	14	L-5	L-45	L-108	L-128	L-109	L-112
15	FWD MACH SPACE	TOP OF BOILER	CENTER OF STEAM DRUM	ON STEAM DRUM	—	—	—	—	—	—	27	—	—	—	—	—	—	—	—
16	AFT MACH SPACE	97	STBD FRAMING	4'	—	—	—	—	—	—	—	101	—	—	—	—	—	—	—
17	AFT MACH SPACE	95	18' TO STBD	ON DECK	—	—	—	—	—	—	22	—	—	—	—	—	—	—	—
18	HOLD	90	STBD FRAMING	4'	—	—	—	—	—	—	—	108	—	H-103	—	—	—	—	—
19	HOLD	86	24' TO STBD	ON DECK	—	—	—	—	—	—	50	—	—	—	—	—	—	—	—
20	NAVIGATION DECK	80	10' TO PORT	4'	—	—	—	—	—	—	58	103	—	—	—	—	—	—	—

[redacted]

TABLE 2

Firing Data

BuShips No.	Firing Sequence	Distance (ft)	Depth (ft)	Charge Weight (lb)	Date Fired
1	1	325	70	250	5/21/48
2	2	325	70	600	5/27/48
3	3	325	70	1200	6/1/48
4	4	325	70	600	6/11/48
5	5	325	70	1200	6/18/48
6	6	185	70	600	6/23/48
7	7	185	17	600	6/25/48
8	8	185	70	600	7/1/48
9	9	325	17	600	7/2/48
10	10	185	70	250	7/7/48
11	11	220	70	1200	7/8/48
12	12	185	70	1200	7/12/48
13	13	185	70	640	7/19/48
13A	13A	185	70	640	7/20/48
14	14	155	70	1200	7/26/48
15	15	124	70	1200	7/27/48
16	16	110	70	1200	7/29/48
17	Not fired - Cancelled				
18	17	131	53	250	7/30/48
19	18	170	110	1200	8/3/48
20	19	120	134	1200	8/4/48
21		105	110	250	8/5/48
22	20	65	134	320	8/6/48
23	21	0	134	250	8/9/48
24	22	46	119	250	8/10/48
25	23	0	65	250	8/11/48

Notes:

1. Distance measured from starboard plating.
2. Depth measured from surface of water.
3. Charge 21 failed to detonate - No records.
4. Depth of water - 134 ft.
5. BuShips Charge No. to be used in all reports and correspondence.

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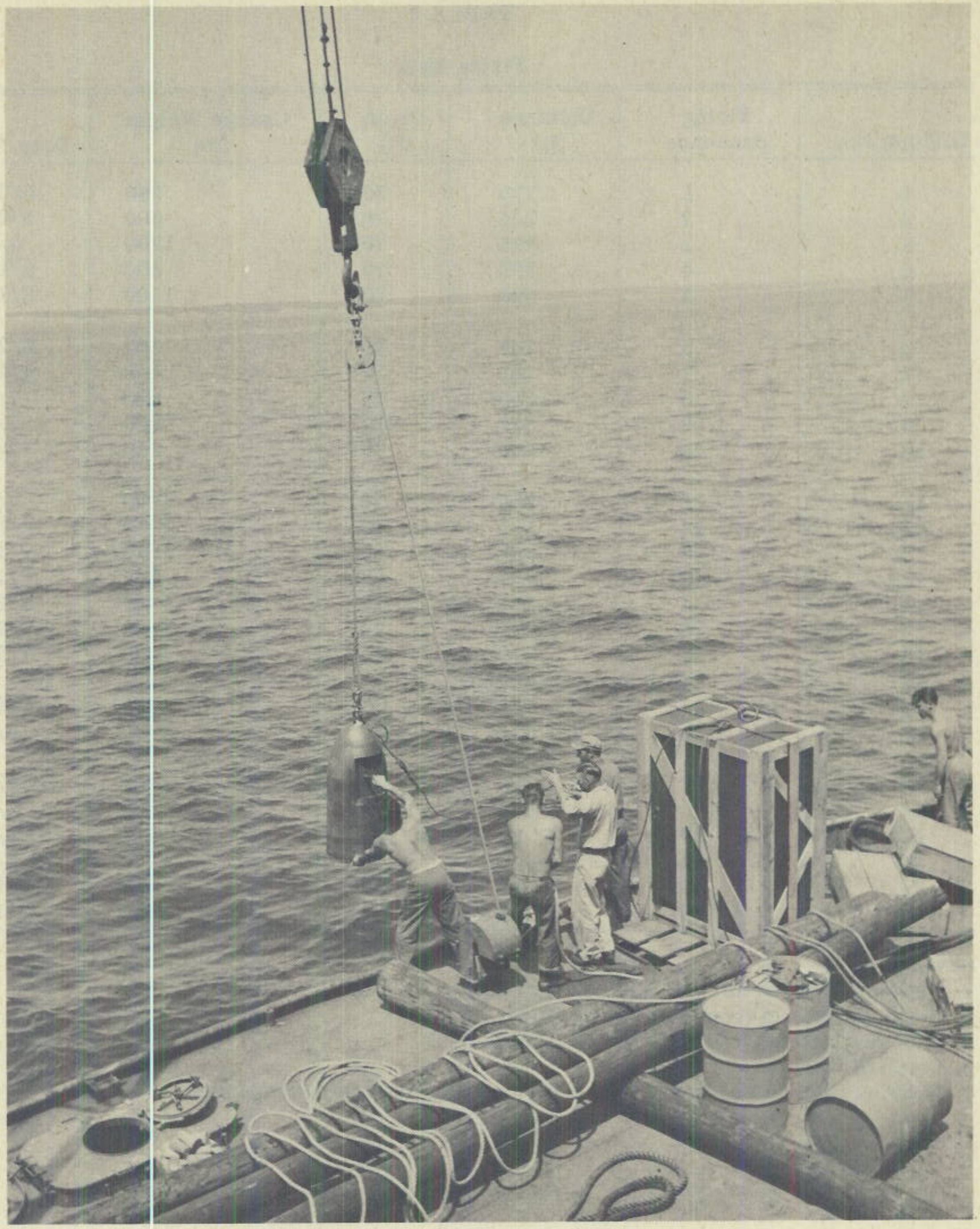

Fig. 35 - Rigging of 640-lb charge

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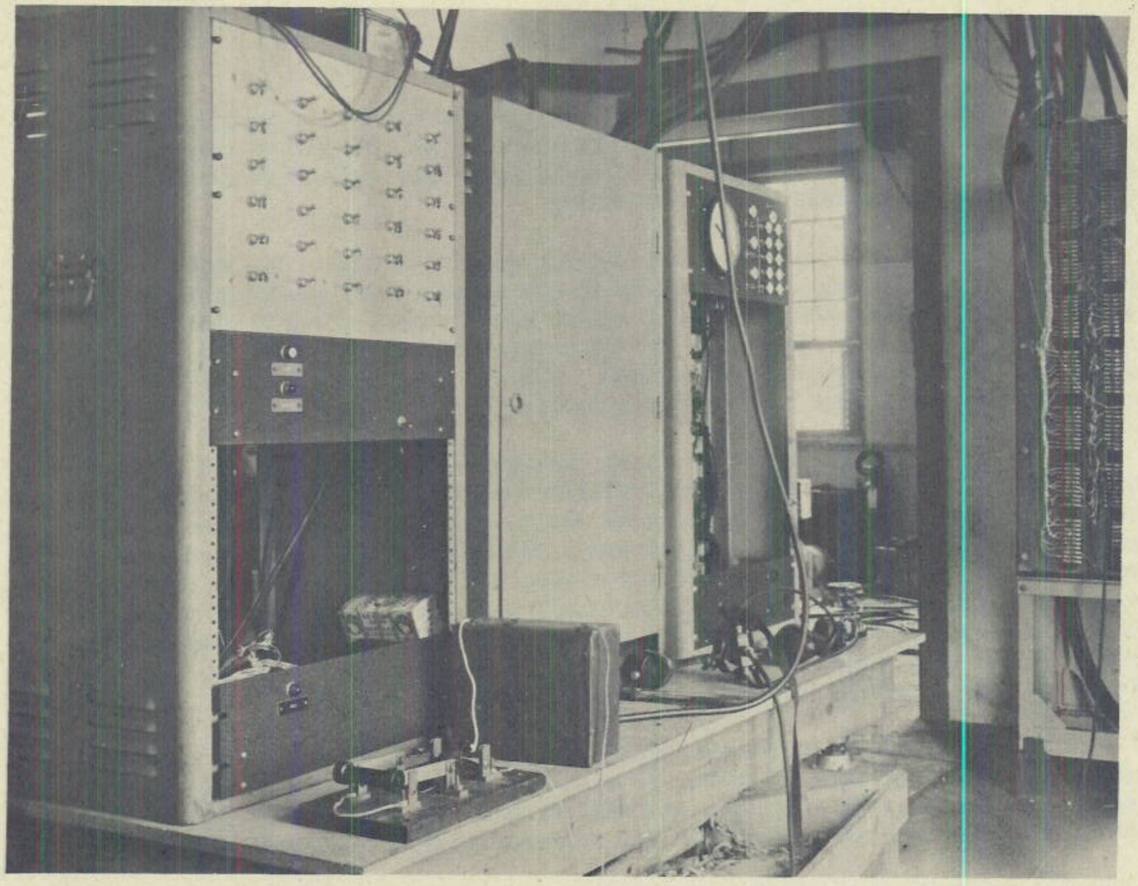

Fig. 36 - Sequence timer

The following firing sequence was used on one shot and is representative of all shots.

- 10 min	Warning siren ON to warn small boats in area to stand clear. All amplifiers energized, velocity meter field energized.
- 2 min	Warning siren on for 20 seconds.
- 20 sec	Warning light on stack of target vessel ON.
- 10 sec	Warning siren on for one sec. Strain gage circuits energized.
- 5 sec	All recorders ON.
- 2 sec	Strain gage and velocity meter circuits calibrated (momentary impulse).
- 1 sec	Pressure gage recorder located on UEB-1 ON. DTMB recording circuit calibrator ON.
0 sec	Firing circuit closed. Flash bulb on target vessel fired.
+ 5 sec	Velocity meter circuits calibrated (momentary impulse).
+ 10 sec	All circuits de-energized.

RECOMMENDATIONS FOR FUTURE SHOCK TESTS

This report has described the instrumentation and techniques used during the full scale shock tests against the NIAGARA. In the hope that difficulties encountered in the current operation will be avoided in any future shock tests against combatant vessels, the following recommendations are submitted:

(1) One of the most troublesome problems was the weather. The Chesapeake Bay is subject to frequent and violent squalls so that all schedules were contingent on the weather. Often it was possible to work on the target vessel or the recording barge in preparation for a shot, only to have the schedule disrupted by high waves which made small boat operation extremely hazardous. It is believed that any future tests should allow more time for tests because of this factor.

(2) From an examination of the charge firing dates in Table 2, it will be seen that three charges were fired in one week on three separate occasions. The physical work of preparing for three firings in one week was tremendous. Any future schedule should call for not more than two shots in one week. Monday is not satisfactory because travel orders, transportation, assembling of special gear at the home base, and the necessary reports of progress to supervisors usually require the first part of a day. Friday is not satisfactory for the same reasons. One day should be allowed between shots to check instruments, develop records, and prepare for the next shot, which means that Tuesdays and Thursdays are the most favorable days.

(3) The photographic developing facilities were unsatisfactory. It is believed that complete developing facilities should be available on the recording barge for developing the records immediately after each shot so that instrumentation and recording difficulties can be detected immediately and remedial procedures initiated.

(4) A complete and reliable communication network is an absolute necessity for such an operation. The "Ballpark" circuit (Figure 37) operating on 2076 kilocycles was fairly satisfactory, providing a radio link between Washington, the test site, and Norfolk. However during thunderstorms or periods when strong static was prevalent, communication was somewhat difficult. A low-frequency circuit such as the "Ballpark" circuit plus a VHF radio circuit for interunit use would be desirable. Particularly, several portable walkie-talkie outfits could be very useful for the photographers stationed on small boats, as well as for miscellaneous operations around the test site requiring communication with the recording barge.

(5) Instrumentation that has not been thoroughly tried and tested in the laboratory should be avoided in field tests if at all possible. The personnel of this Laboratory were confronted with the problem of learning the operation and limitations of new and untried equipment for recording the signals from the instruments on the target vessel. The problem of obtaining reliable data was made that much more difficult. A good rule of thumb is that instruments which have not been in use in the laboratory for at least a year should be employed sparingly in field tests.

ACKNOWLEDGMENTS

A number of Laboratory personnel were involved in various phases of the shock test program. Messrs. R. C. Cowan, J. H. Bachman, S. J. Siegel, R. C. Nowak, A. H. Hausrath and R. S. Ravinsky, with the help of J. M. Sonnar and W. E. Duquette were responsible for

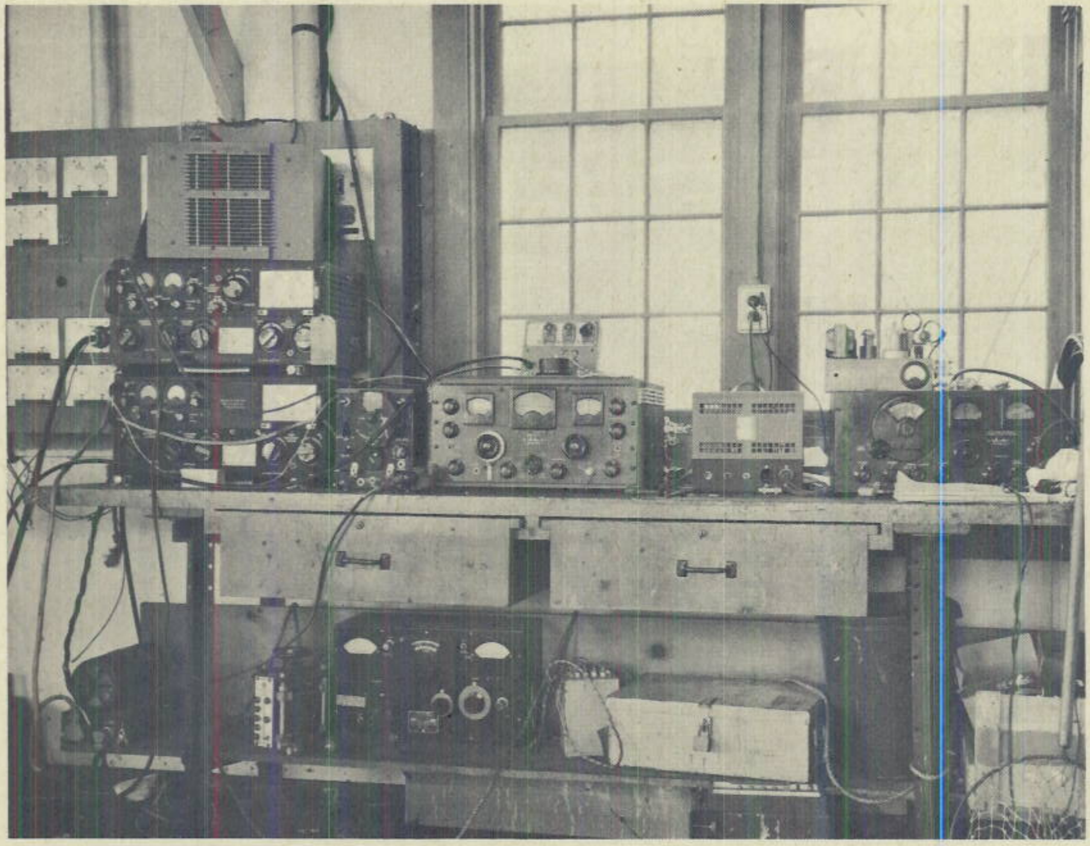

Fig. 37 - Communication equipment

the installation of mechanical instruments and collection of data. Mr. F. J. Hartz supervised the installation of instruments on the NIAGARA at the Norfolk Naval Shipyard. Messrs. E. E. Bissell and M. W. Oleson observed failures of the electronic equipments and the operation of the amplifiers and recorders. Mr. L. H. Feher was responsible for the processing and preliminary analysis of all photographic records. Messrs. J. P. Walsh and R. E. Blake were responsible for the design of the boiler supports. Messrs. H. L. Wuerffel and T. P. McCullough designed and installed the firing sequence timer. Mr. C. C. Hauver took the photographs.

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