THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Naval Architecture and Marine Engineering

Final Report

EXPERIMENTAL INVESTIGATION OF GREEN SEA LOADINGS ON DECKHOUSE GEOMETRY FOR A DESTROYER-TYPE MODEL

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ORA Project 08193

under contract with:

DEPARTMENT OF THE NAVY
NAVAL SHIP SYSTEMS COMMAND
NAVAL SHIP ENGINEERING CENTER
CONTRACT NO. NObs-94394
WASHINGTON, D. C.

administered through:

OFFICE OF RESEARCH ADMINISTRATION ANN ARBOR

December 1968

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INTRODUCTION

This report presents some of the test results obtained in a program conducted at The University of Michigan for the Naval Ship Systems Command under Contract No. NObs-94394. These results are intended to fulfill the requirements of that contract and this report is intended to serve as the final report specified in that contract.

The title of this report is more or less in keeping with the task described in that contract as follows: "The contractor shall undertake an experimental investigation to determine the load distribution generated by waves which break against a ship's deckhouse, deck, and side shell." This description is also reasonably consistent with that included in Proposal Request 440-60279 (S) and the proposal submitted by the writer in response to that request. The test results included, however, are not for as many conditions as was anticipated would be the case when the project was initiated. This stems from two considerations, both of which are to some extent test results in themselves.

The first consideration became apparent in early runs in the tank which clearly demonstrated that significant pressure readings could be obtained only when conditions were such that the waves the model met were able to break free relatively larger masses of water in chunks that could then collide with a vertical plane attached to the model. That is, the sharp bow and flare of the destroyer model used were such as to cause the water flow to progress aft on the model essentially clear of the deck except in the case of extremely high waves or at unrealistic drafts and forward trims. The second consideration is less significant and merely reflects the fact that realistic changes in the deckhouse geometry—longitudinal location of the front, and changes in the breadth and depth of the front—would not change the magnitudes of the maximum pressure readings obtained by one or more of the transducers appreciably, all else remaining constant.

That the tests results are not extensive, however, is indeed only symptomatic of the fact that this entire project was ill conceived and poorly executed from its inception. Measuring pressures generated by breaking waves is a difficult and complicated undertaking, requiring superior and hence expensive equipment, considerable patience, and, most important, the opportunity to repeat particular tests many times so as to modify procedures and/or equipment until a high degree of reliability can be insured. This assumes a reliable wavemaker, and sufficient funds and personnel to permit long periods of time in the towing tank gainfully used in improving all aspects of the program. In short, the proposal submitted was not realistic in regard to either the funds requested or the time suggested. The wavemaker was the major cause for most of the delays the project encountered, but not facing up to the realities of the situation continued to make the bad situation even worse and has made the writing of this final report extremely difficult. No one finds it easy to commit himself to such a task when that which is to be reported is inadequate and reflects poorly upon himself and upon his institution.

This section of this report is followed by a second describing the test program actually carried out, a third reviewing the results obtained, and a last section that enumerates such conclusions and recommendations as can be made. A page of references is also included.

All of the figures for this report are arranged in sequence at the end of the body of the report since some of them require several full pages and their insertion earlier would interrupt the text unduly.

DESCRIPTION OF TEST PROGRAM

The model used in this study as an existing wooden destroyer hull 12 feet long last used at The University of Michigan under Contract No. NObs 4485 with the Bureau of Ships for resistance studies in combination with several large bulbous bows, in 1962. The body plan is given in Figure 1. It was originally meant to model a destroyer 390 feet long at the design waterline, having a beam of 41 feet and a design draft of 13.5 feet, at a scale ratio of 32.5. The forward length of this existing model was built up with additional lifts back to station 7, and then two sections of wooden deck were put in place along the entire length of the model so that the forward part had the sheer shown in the figure. A generalized type of deckhouse was constructed of plywood and attached to the model as shown in Figures 1 and 2.

The deckhouse extended 6 inches above the deck at its forward end, about 46 inches back from the most forward point of the deck. It was centered transversely and just 10 inches wide. The box representing the deckhouse was some 12 inches long externally and its after end extended 9.5 inches above the top of the actual model, which was itself a constant 9.5 inches in height from station 7 aft. The top of this box was made removable so that weights could be placed inside the model to obtain the required drafts and so that transducers could be mounted in the forward end from inside. An additional box somewhat narrower but 18 inches long, also with a removable top, was constructed towards the stern of the model so that weights could also be placed inside the model (and removed from it) at that location.

The forward generalized type of deckhouse was intended to be only the first of a series of various configurations initially planned for this project. Seven pressure transducers were located in the front face, as shown in Figure 1, to obtain some early data as to how large the local pressures might become and how they might vary with location. The bottom three were centered relative to the upper four, the vertical distances from the deck of 2 inches and 3.5 inches having been selected arbitrarily.

The seven transducers were all Kistler Model 606L quartz pressure transducers, manufactured by the Kistler Instrument Corporation of Clarence, New York. They had a range of 30 psi, a resolution of 0.005 psi, and a normal sensitivity of 5 picocoulomb per psi. The manufacturers specify a resonant frequency of 60,000 cycles per second, a rise time of 6 microseconds, and a linearity of 1 percent. Sufficient miniature coaxial cable Teflon-sheathed low noise leads with Microdot connectors were used with the transducers.

Seven Kistler Model 503 or Model 504 charge amplifiers, specifically designed for use with the transducers to change the charge signals from the piezoelectric crystals to voltage outputs, were obtained. The specifications for these amplifiers are extensive, but they have a high frequency response consistent with the transducers (±5% from near dc to 100,000 cycles per second) and other features that made them seem quite suitable for this application. They were always set with the time constant selector in the "short" position to minimize zero drift even if this may have affected low frequency response to some slight degree.

It was originally planned to use 13 or 14 pressure transducers since two suitable seven-channel tape recorders were on hand and this seemed the most economical and versatile system to correlate simultaneous readings and obtain pressure distributions. Several days of testing with the outputs from seven charge amplifiers, connected to seven transducers mounted as has been described, going to one of the tape recorders produced hundreds of feet of tape that yielded mostly noise when played back. For this reason a Honeywell 906C Visicorder having 14 channels was connected directly to the seven charge amplifiers even though the photographic chart paper it uses requires special handling and records can be lost when exposed to light for too long a time. Seven Honeywell M1650 fluid damped galvanometers, having a frequency response of 1650 cycles per second, were used in the recorder.

All things considered, this instrumentation was reasonable satisfactory. The frequency response and the sensitivity were sufficient and records were obtained. One transducer or charge amplifier of the seven channels, that for the location indicated as 4 in Figure 1, was faulty on several occasions and no records from it are included in this report.

The wavemaker in The University of Michigan towing tank was a problem in several ways. It is a mechanical-wedge-type, and during the period when this project was active (and even as this is written) did not perform as intended when it was designed. Various bearings heated up rather drastically and the control system was not consistent. It was originally intended to select as many as eight regular waves of varying heights and periods and use these for a number of variations in the model orientation (mean draft, trim, and heel) and carriage speed. The wavemaker could generate waves up to 6 inches in height in a reasonable manner, and since these would correspond to waves higher than 16 feet at the scale ratio of 32.5, the initial familiarization runs were begun.

The model was rigidly attached to the towing carriage in the tank by four vertical rods constructed so as to permit their upper ends to fit into the brackets which normally hold the yaw guides used in regular resistance tests. The bottom ends mated with ball-and-socket joint fittings attached to the model. This arrangement permitted easy final adjustment of the model drafts fore and aft, and the angle of heel, and yet held the model firmly fixed relative to the carriage. Later these vertical rods were braced with wood pieces attached with C-clamps (see Figure 8) when very high waves were generated and the forces on the model were very large.

The intended test program was radically altered when it was found that breaking waves just did not reach the front of the deckhouse and the pressure transducers at normal drafts, reasonable forward trims, and realistic carriage speeds in conjunction with waves 6 inches high. It was then decided to generate much higher waves—up to 18 inches in height—and run the model at speeds of 5, 7.5, and 10 feet per second into these waves. These speeds, using Froude scaling, would correspond to approximately 17, 25, and 34 knots. With these speeds in such large waves the model drafts were found not to be very important over a reasonable range, but were generally kept at about 6 inches both fore and aft.

Under these conditions the waves did break over the bow of the ship quite regularly, wash back along the deck, and give some pressure readings on the lower three transducers as they struck the front of the deckhouse. But the significant readings came when water masses essentially broke free and impacted against the front of the deckhouse.

To illustrate how violent this process was, for this report, motion pictures were taken in two different ways. Figure 8 includes sixty still photographs from film shot with the camera just behind the wavemaker, looking down the tank as the carriage approached the end of the tank at which the wavemaker is installed. Figures 9, 10, and 11 include still photographs from film shot with the camera on the towing carriage, looking down on the top of the deckhouse and the deck just forward of it. (The wires coming out of the top of the deckhouse through a small pipe, sealed with a waterproof clay-like material, are the leads from the transducers and may be oriented by looking at the final photographs used in Figure 8.)

Figures 3 and 4 show typical wave records obtained during some of the runs. It is known which wave records were taken at the same time all of the pressure traces were and even which go along with the motion picture film frames used in this report. But the wave records were at a single location along the tank and only short lengths of the charts are included in Figures 3 and 4.

TEST PROGRAM RESULTS

The data from those runs in the towing tank which resulted in meaningful pressure charts are all in a form of which Figures 5, 6, and 7 are typical. That is, hundreds of feet of Visicorder chart were obtained and these three figures include only seven short, but typical, lengths. Figure 5 includes two records having six pressure traces from transducers 1, 2, 3, 5, 6, and 7 (see Figure 1 for locations on front of deckhouse), including zero settings at the left edge The actual chart photographic paper (Kodak Linagraph Direct Print Paper, Type 1855) is 6 inches wide, and 5 inches between the major (heavy) lines closest to each edge. The zero settings were in all cases originally set on the heavy lines 1/2 inch apart, in order, from these edge lines in. Transducers 1, 2, 3, and 4 were connected so as to deflect toward the center of the chart (down the pages as Figures 5, 6, and 7 are made up), and transducers 5, 6, and 7 were also but from the other edge in (up Figures 5, 6, and 7). The zeros drifted considerably with hours of running up and down the tank, as can be seen from the charts in the figures, but the order was always maintained and the drift did not affect the calibration. Thus in Figure 5 the uppermost trace at the left edge is from transducer 1, the next from 2, and the lowest of the upper three from 3. The uppermost of the lower three traces is from transducer 5, the next lowest from 6, and the bottom from 7.

Although it is difficult to follow the various traces on the charts in Figure 5 (and recall that these are only short lengths from many feet of chart representing just these two runs down the tank), it was clear along the whole length of these two charts that the pressure peaks never went full scale (5 inches) as all six traces were on the charts at their ends. Thus the pressures measured were at most several psi since full scale was set to be 5 psi.

The nature of the peaks varied greatly throughout most of the charts obtained. The rise times were sometimes rather short, and on other occasions very sharp, presumably depending upon whether the water mass built up in front of the particular transducers relatively gradually as the front of the deckhouse was immersed in a breaking wave or a mass of water broke free from the wave and impacted against one or more of the transducers. Chart speed, of course, has a lot to do with how the peaks appear and care should be exercised in examining Figures 5, 6, and 7 to note the chart speed that is indicated for each record. Figure 7, which includes records having three different chart speeds, shows this particularly well. But also please note that the impulses shown in that figure are from three different runs and not the same run with three different chart speeds. Also note that the cutting away of some of the 6—inch original widths of the charts included in Figure 7, to make it possible to get all three on the same page, does not cause any problems since the zero settings are included and none of the pressure peaks in that figure reach even 0.5 psi (0.5 inch—the original distance between two adjacent heavy lines—equals just 0.1 psi on these three charts).

CONCLUSIONS AND RECOMMENDATIONS

The results of the test program actually carried out on this project are not extensive enough to warrant many very positive conclusions, but it is true that the pressures recorded were surprisingly small, despite the severity of the conditions generated. Placing model gun turrets or other equipment forward of the deckhouse or curving the surfaces of the deckhouse, for example, could well result in even lower pressures. Moving the deckhouse forward could result in somewhat higher pressures, but not necessarily so. Thus one is forced to conclude that these model tests show that the face of the deckhouse on a destroyer-type hull heading directly into very extreme seas at even nearly full speed would not be subjected to loading equivalent to more than several (2 to 4) pounds per square inch on the model.

If one scales this up to full size on the basis of Froude scaling, the equivalent loading would be over thirty-three times as large (32.5, the geometric scale ratio, multiplied by the ratio of the densities of salt water to fresh water) and on the order of one hundred pounds per square inch and thousands of pounds per square foot. But there is ample reason to believe this is not a proper procedure, as drop tests conducted to better understand slamming have indicated.

There is also the question of how much air, which can be compressed, is trapped when either a breaking wave crest or a separate mass of water broken free from the crest impact against the front of the model (or the prototype) deckhouse. This, of course, has also been a problem in the drop tests mentioned above, and has not been fully resolved at present. The one recommendation, therefore, that would seem most pertinent is to suggest that instrumentation of the type used in these model tests be installed on an actual destroyer. It is difficult to imagine that any ship's commanding officer would willingly subject his vessel to conditions as extreme as were generated for the model tests, but he may on occasion encounter very bad situations which he would be unable to avoid or to alleviate. If a correlation between model scale measurements and full scale measurements could be established, even for significantly less severe conditions, it would permit at least rough evaluation of all of the model measurements and allow design loadings to be specified on a reasonably rational basis.

REFERENCES

1. K. M. Ochi and M. D. Bledsoe, "Hydrodynamic Impact with Application to Ship Slamming," 4th Symposium on Naval Hydrodynamics, Office of Naval Research, August 1962.

2. S. L. Chuang, "Experimental Investigation of Rigid Flat—Bottom Body Slamming," DTMB Report 2041, September 1965.

3. S. L. Chuang, "Slamming of Rigid Wedge—Shaped Bodies with Various Deadrise Angles," DTMB Report 2268, October 1966.

4. S. L. Chuang, "Experiments on Flat—Bottom Slamming," Journal of Ship Research, pp. 10-17, March 1966.

FIGURES

The eleven figures which are included in this report are arranged in order on the following pages. The first two are drawings that describe the model used and show the location of the pressure transducers. The next two indicate the characteristics of the waves generated, while the following three are examples of the pressures measured. The last four figures are sequences of photographs (all but one requiring several pages) taken from motion picture films to illustrate the type of water loading to which the pressure transducers were subjected.

In the reproduction process the records (and the drawings, too) included among these figures were not printed at exactly true size and scales normally in inches or millimeters are thus somewhat distorted. For this reason care should be exercised in reading values from the records, even though it is anticipated that the individual captions explain this matter satisfactorily.

The figure titles for all figures on right pages are on the facing left pages.

Figure 1. Body Plan of Destroyer Model Showing Front of Deckhouse and Locations of Seven Pressure Transducers

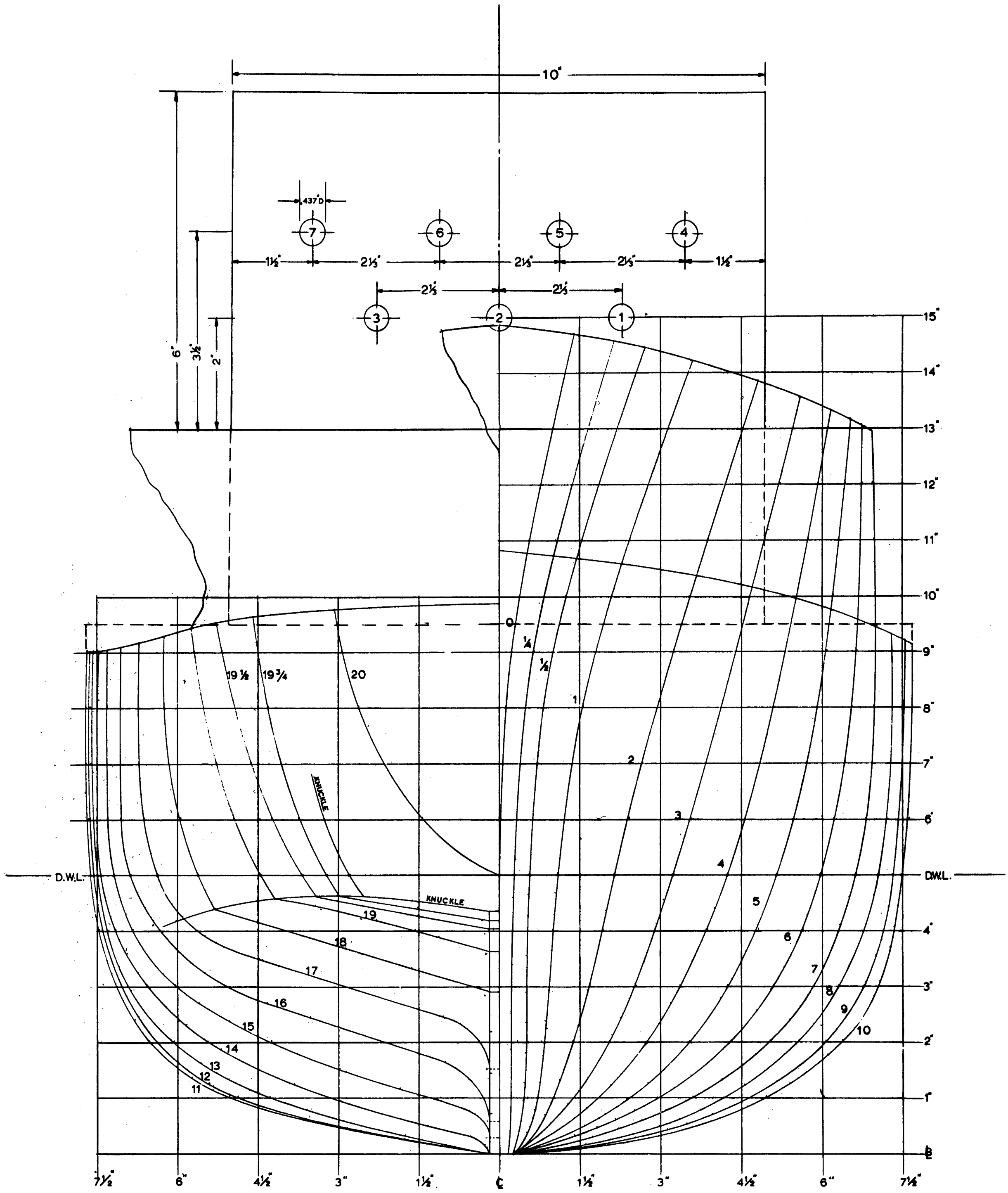

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Figure 2. View of Destroyer Model Showing Deck-house Configuration and Location

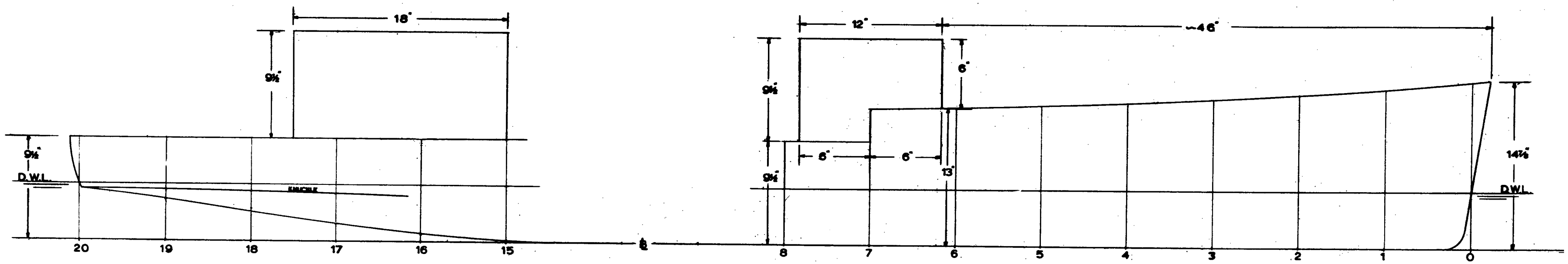
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Figure 3. Typical Wave Records Taken During Various Runs in Towing Tank

(All records were obtained at the same fixed location about midway along the length of the tank using a variable capacitance transducer and a Sanborn recorder. Crests are towards the top of the page and each major division (originally 5 millimeters) is equivalent to 2 inches of wave height. Chart speeds were all 5 millimeters per second. The top record illustrates a reasonably regular wave with a height of about 11 inches and a period of about 6 seconds. This next two records illustrate how irregular waves of greater height often became, and the bottom one shows the height varying from over 18 inches down to perhaps 2 inches in just a few cycles.)

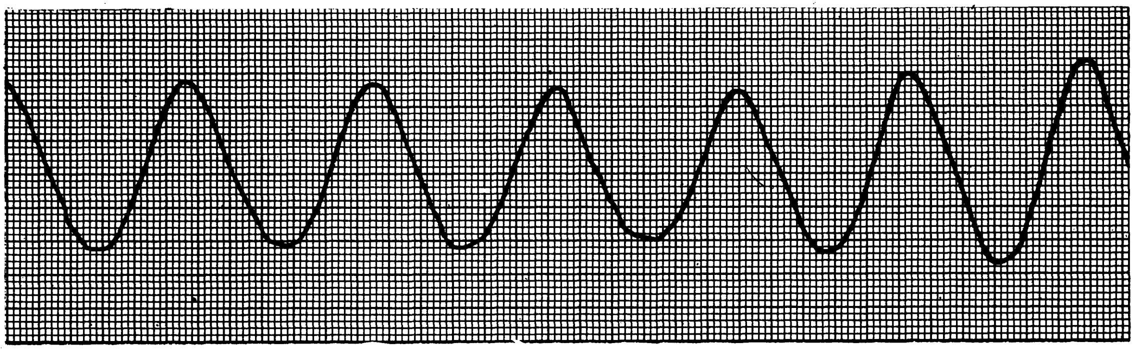
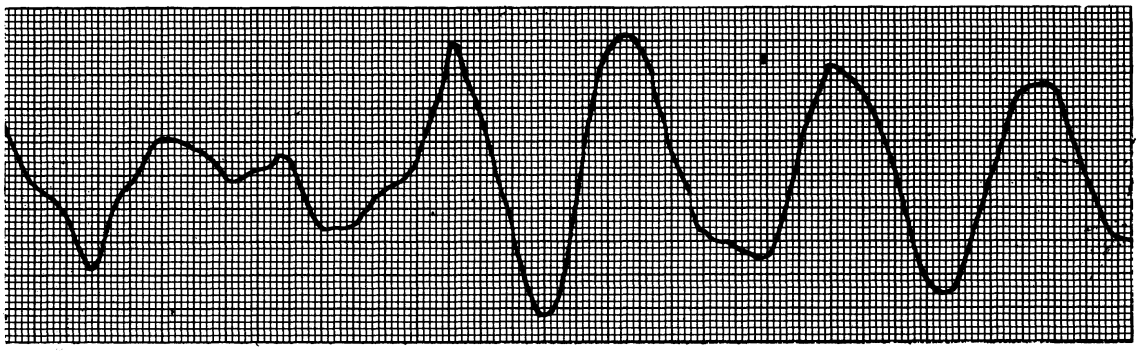
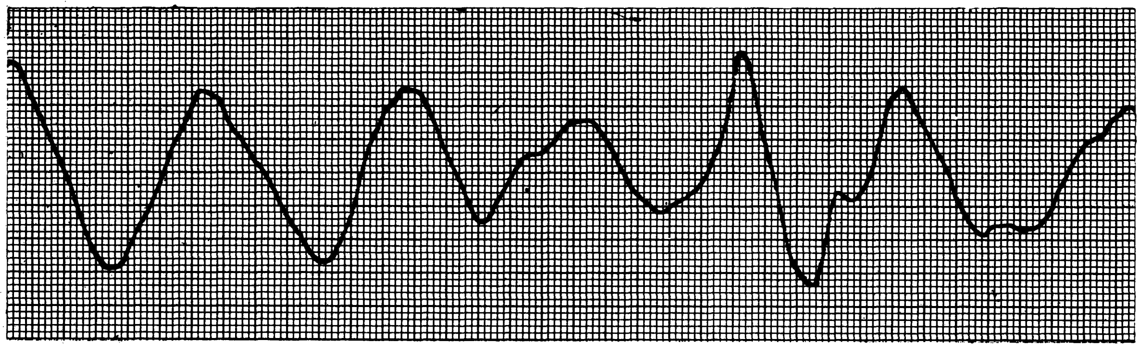
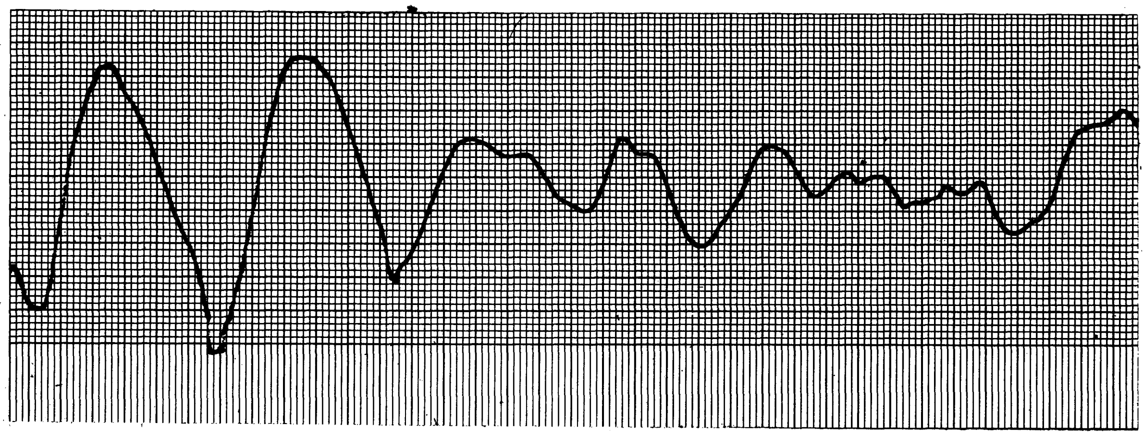
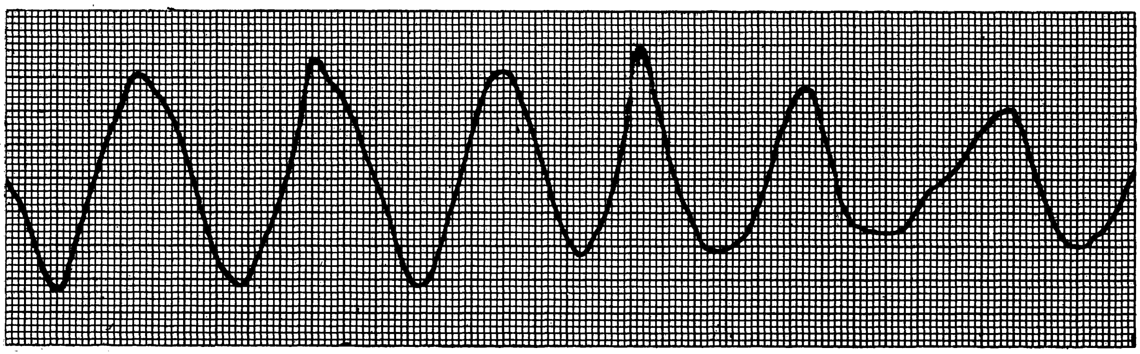
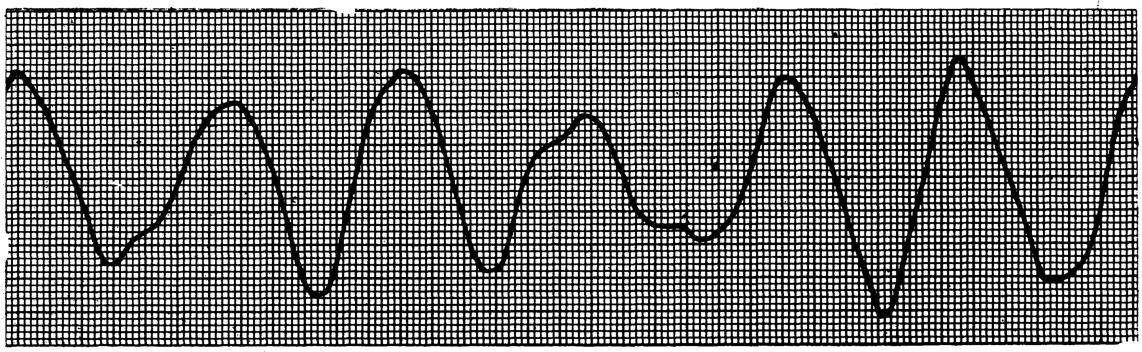





Figure 4. Additional Wave Records Taken During Various Runs in Towing Tank

(Scales are the same as indicated for Figure 3, and the chart speeds for the top three records are again 5 millimeters per second. This bottom record was obtained with a chart speed of 1 millimeter per second. The top record indicates about as regular a wave as could be generated with a height well above 12 inches. The other records illustrate how irregular the higher waves could be, the bottom record indicating a maximum height of 20 inches adjacent to heights as small as 3 inches.)





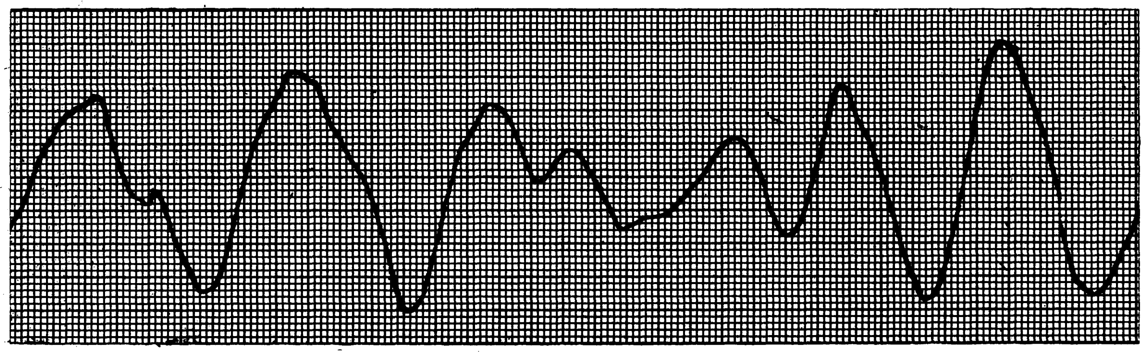
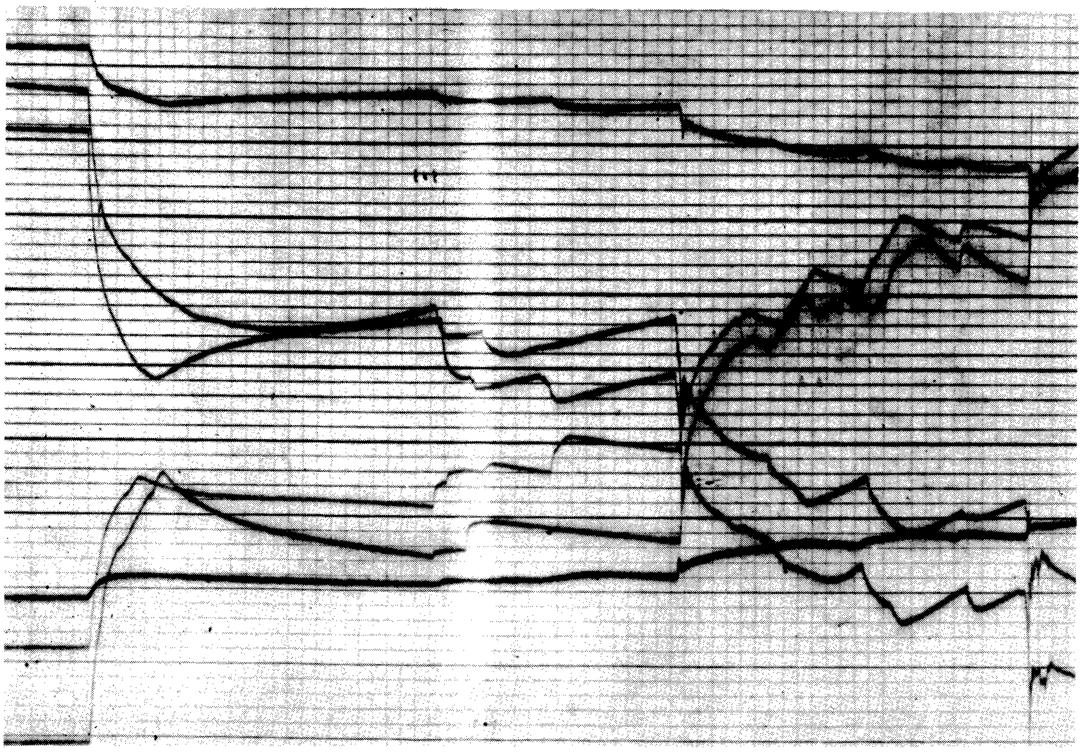


Figure 5. Two Typical Visicorder Records of Pressures on Face of Deckhouse During Typical Runs in Towing Tank

(The upper chart speed was 1 inch per second and the bottom one 5 inches per second, each horizontal division representing one-tenth of a second. The six traces on each chart are from transducers 1, 2, 3, 5, 6, and 7, successively from the top of each chart. Full scale is 5 inches (10 major divisions) for each trace and is equivalent to 5 psi, all traces indicating towards the center of the chart from the zero recorded at the left edge. The towing carriage speed for both records was 10 feet per second.)



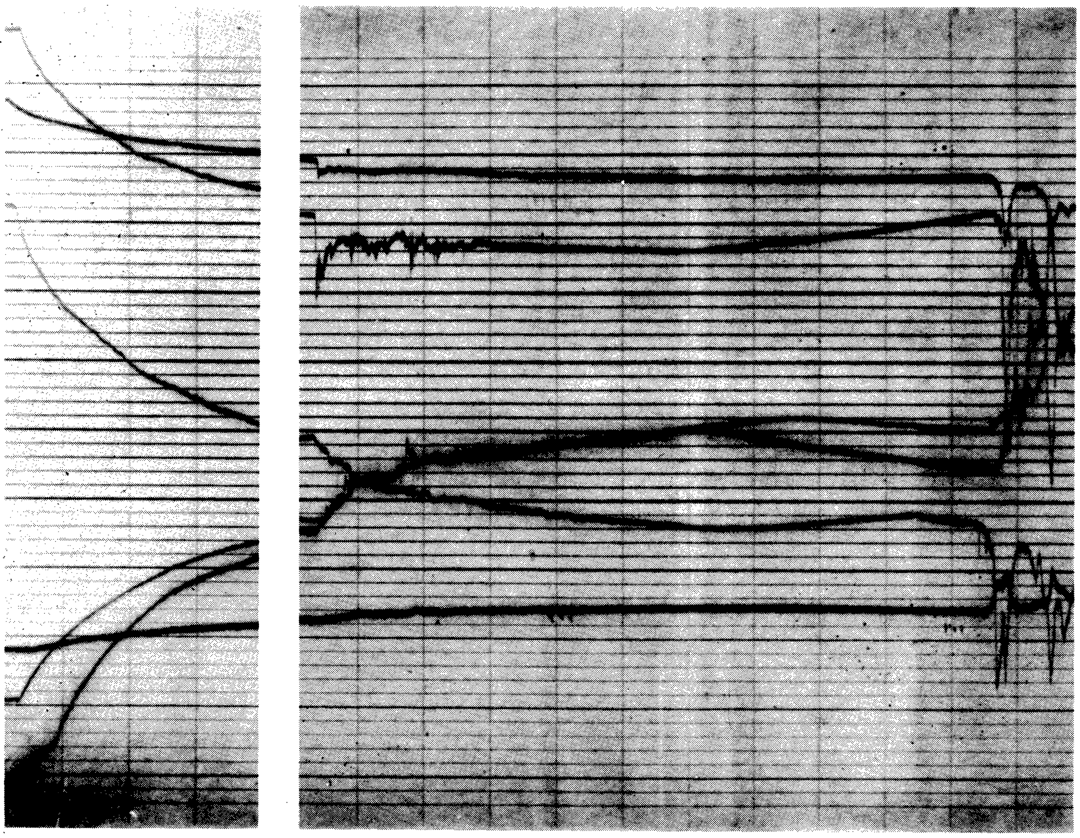


Figure 6. Two More Typical Visicorder Records of Pressures on Face of Deckhouse During Typical Runs in Towing Tank

(Both chart speeds were 1 inch per second. The four traces on each chart are from transducers 2, 3, 5, and 6, successively from the top of each chart. Full scale is again 5 inches (10 major divisions) for each trace and is equivalent to 5 psi, all traces indicating towards the center of the chart from the zero recorded at the left dege. The towing carriage speed for the upper record was 7.5 feet per second while that for the lower one was 10.)

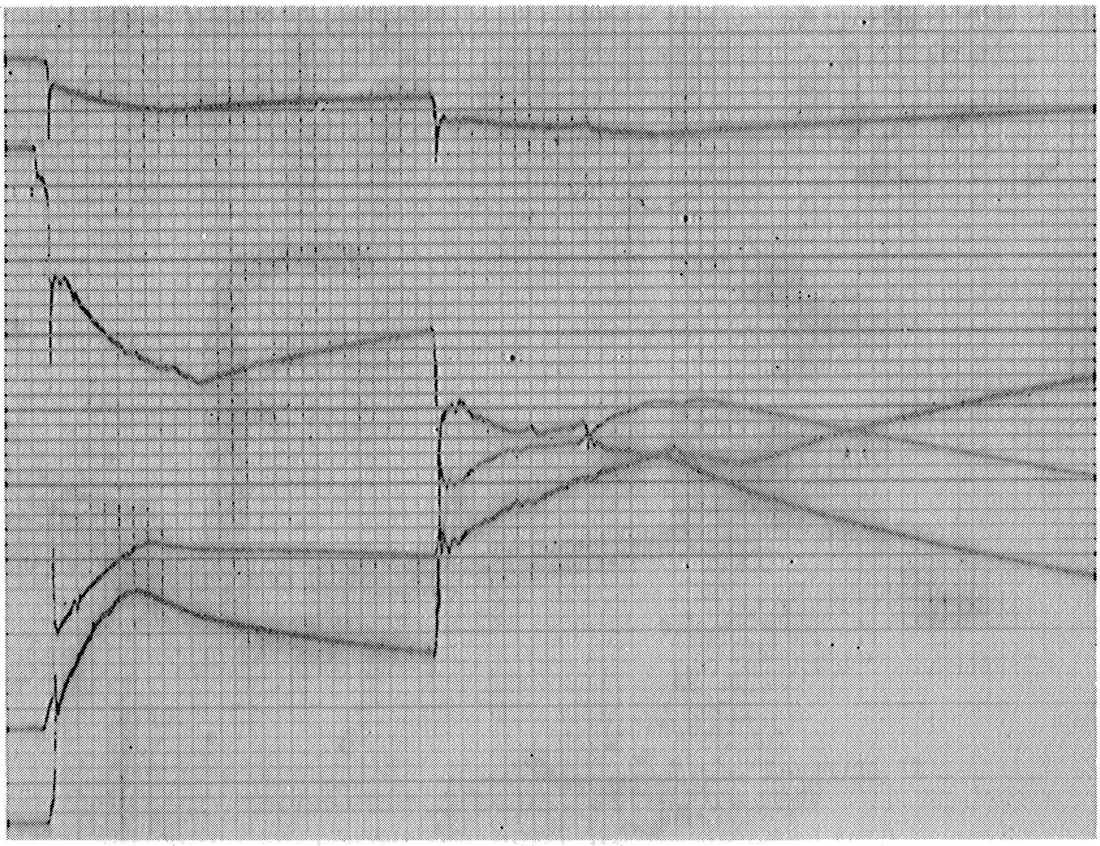
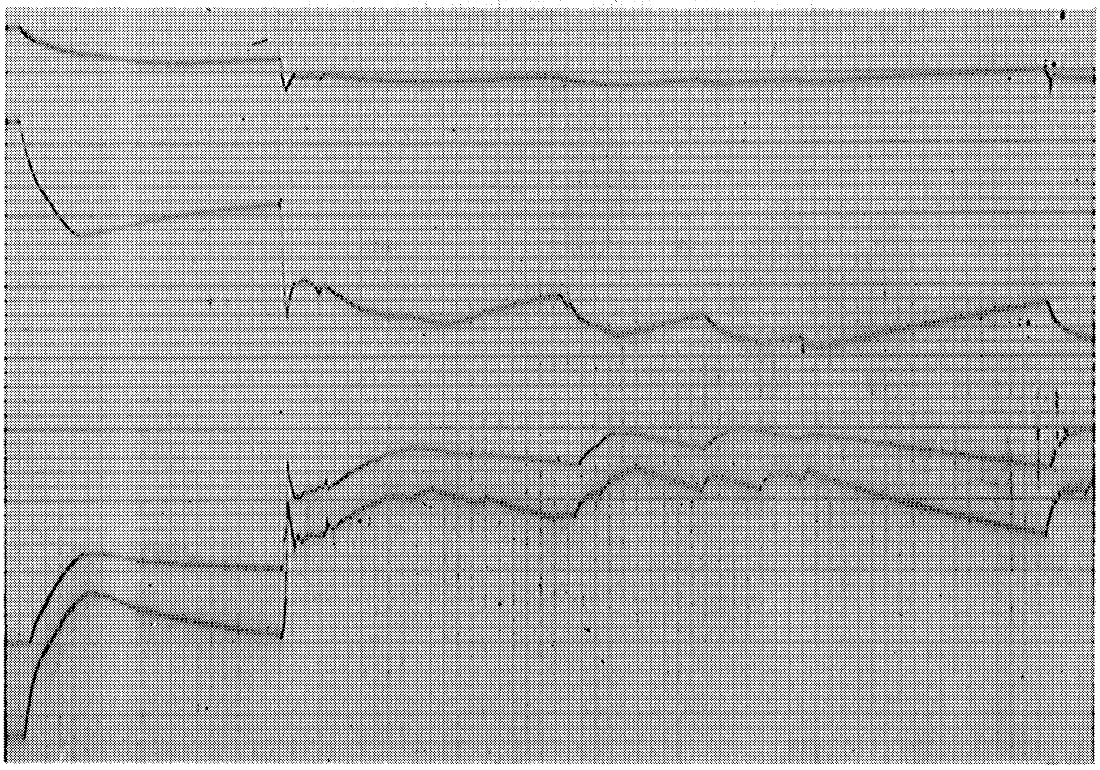
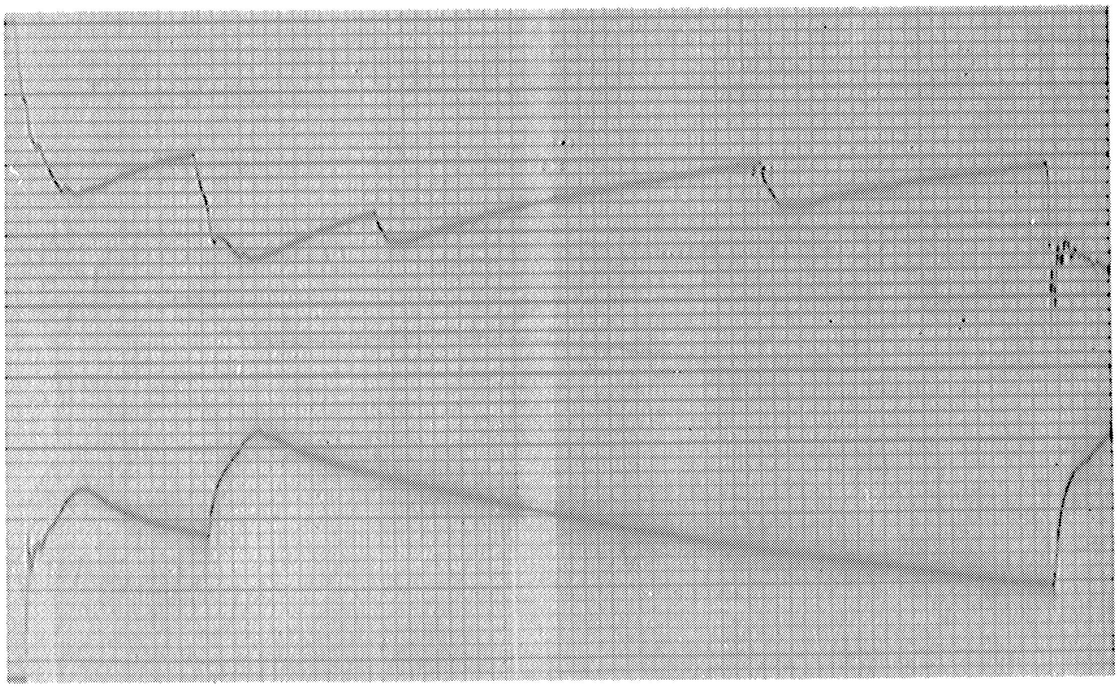
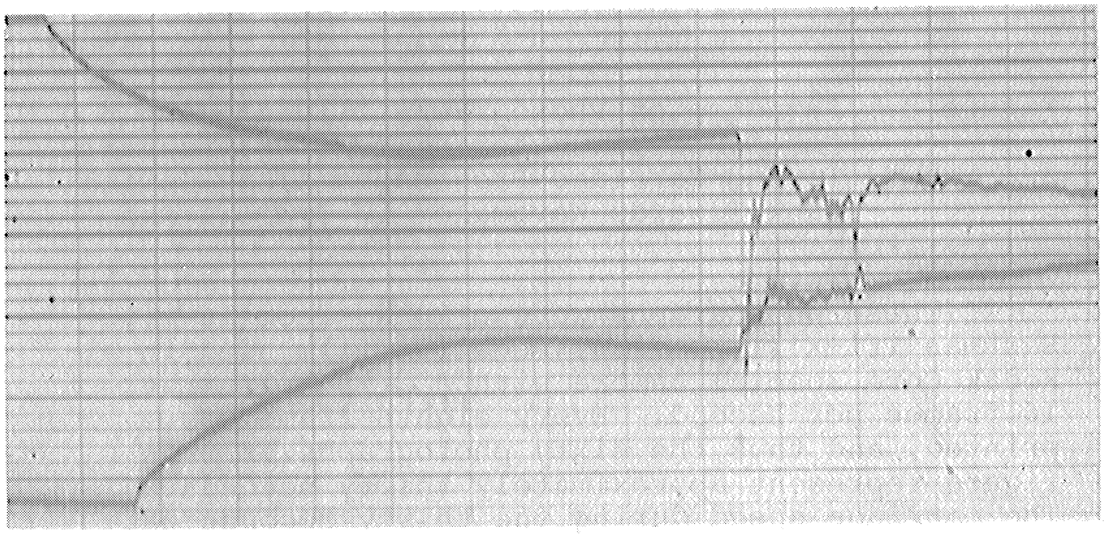



Figure 7. Three Typical Visicorder Records of Pressures on Face of Deckhouse During Typical Runs in Towing Tank

(The chart speeds for these three records were 1, 5, and 25 inches, respectively, each horizontal interval representing one-tenth of a second. The upper trace in all cases is from transducer 3, the bottom from transducer 5. Full scale for both traces in all cases is 5 inches and is equivalent to 1 psi. The towing carriage speed for both the upper and the lower records was 7.5 feet per second while that for the middle record was 10.)





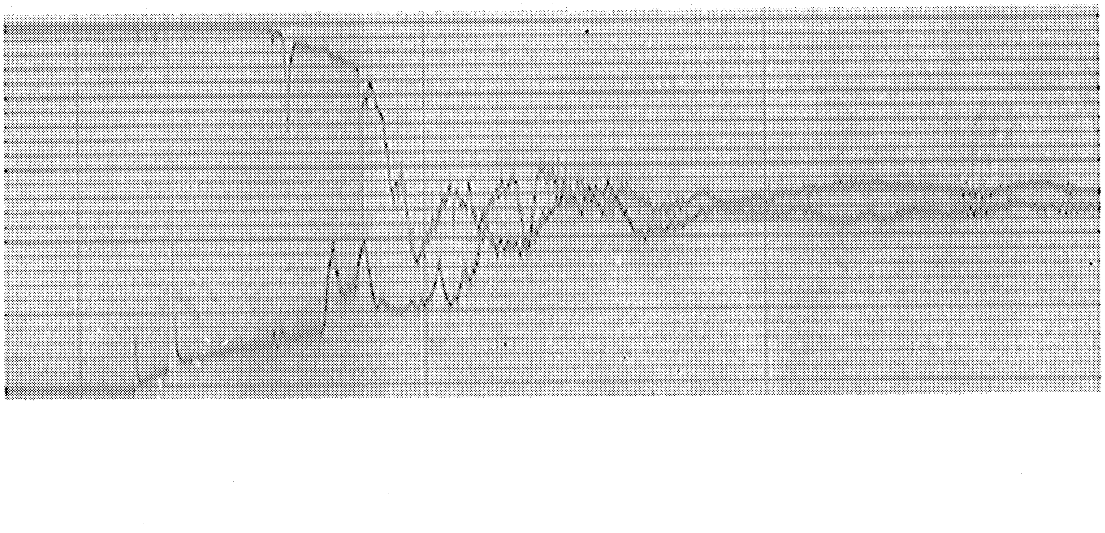
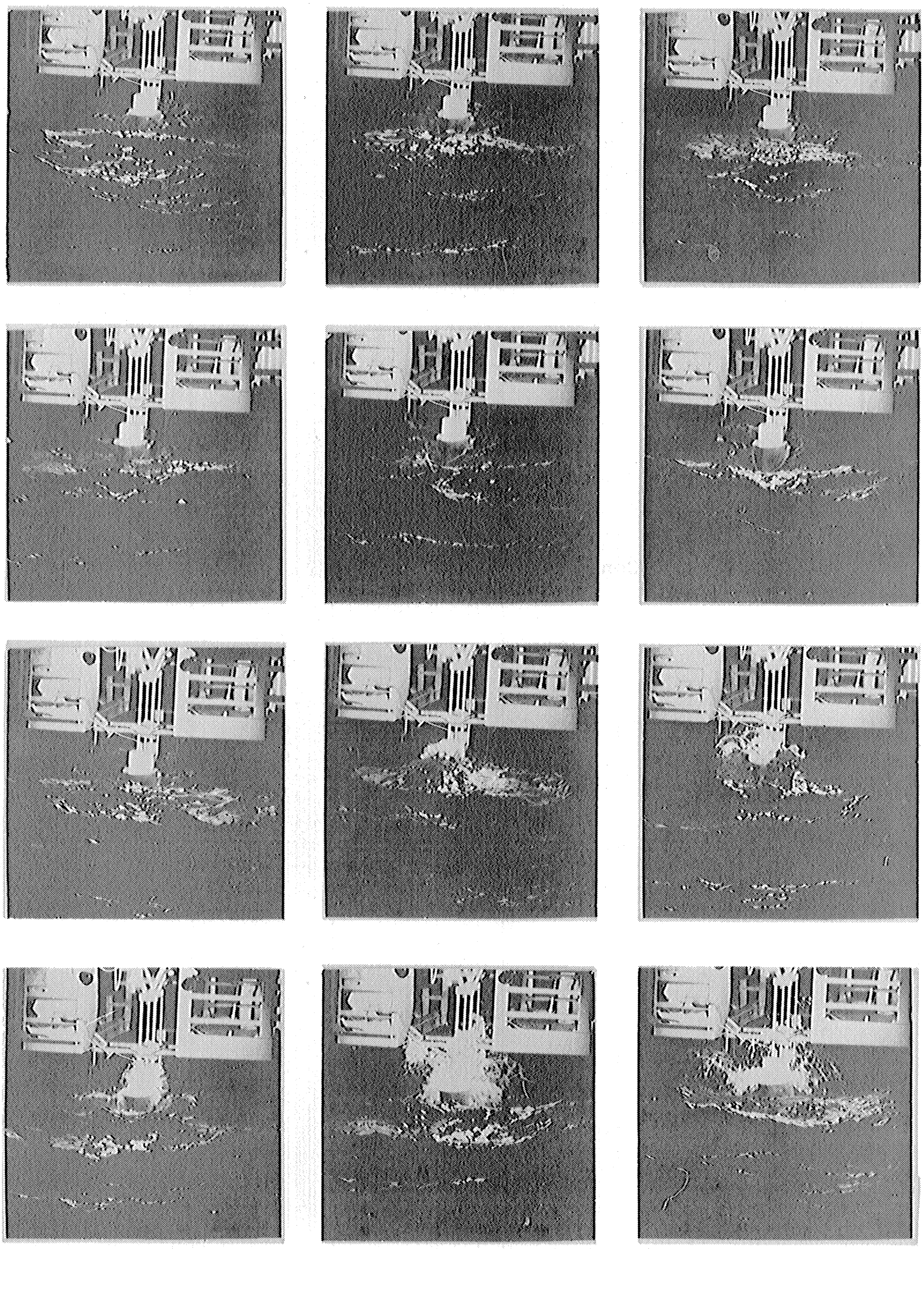


Figure 8. Sequence of Photographs Illustrating the Model Encountering Wave Crests As Towing Carriage Progresses Along Towing Tank Towards Wavemaker in Typical Run

(These photographs were printed from 16-mm. Eastman Tri-X (Type 7233) negative film used in a Kodak Curé Special camera with a 2-inch lens at 16 frames per second. Every eighth frame was printed, and thus the sixty photographs of this figure represent approximately thirty seconds. The carriage speed during the thirty seconds was kept constant at 10 feet per second, so approximately 300 feet of tank length travel is illustrated. The order of the sequence is across each row from left to right, starting with the photograph in the upper left corner on each page.)



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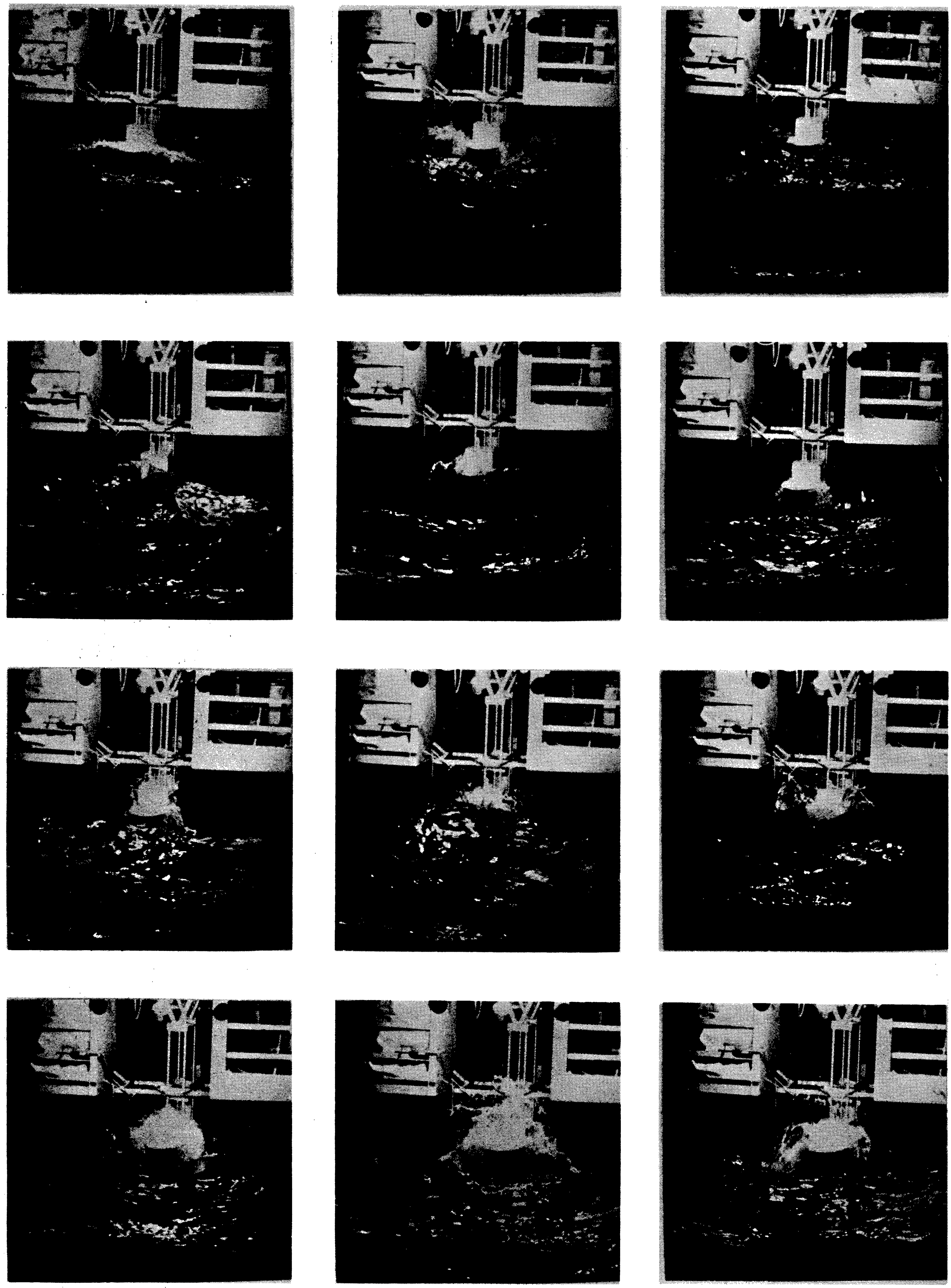

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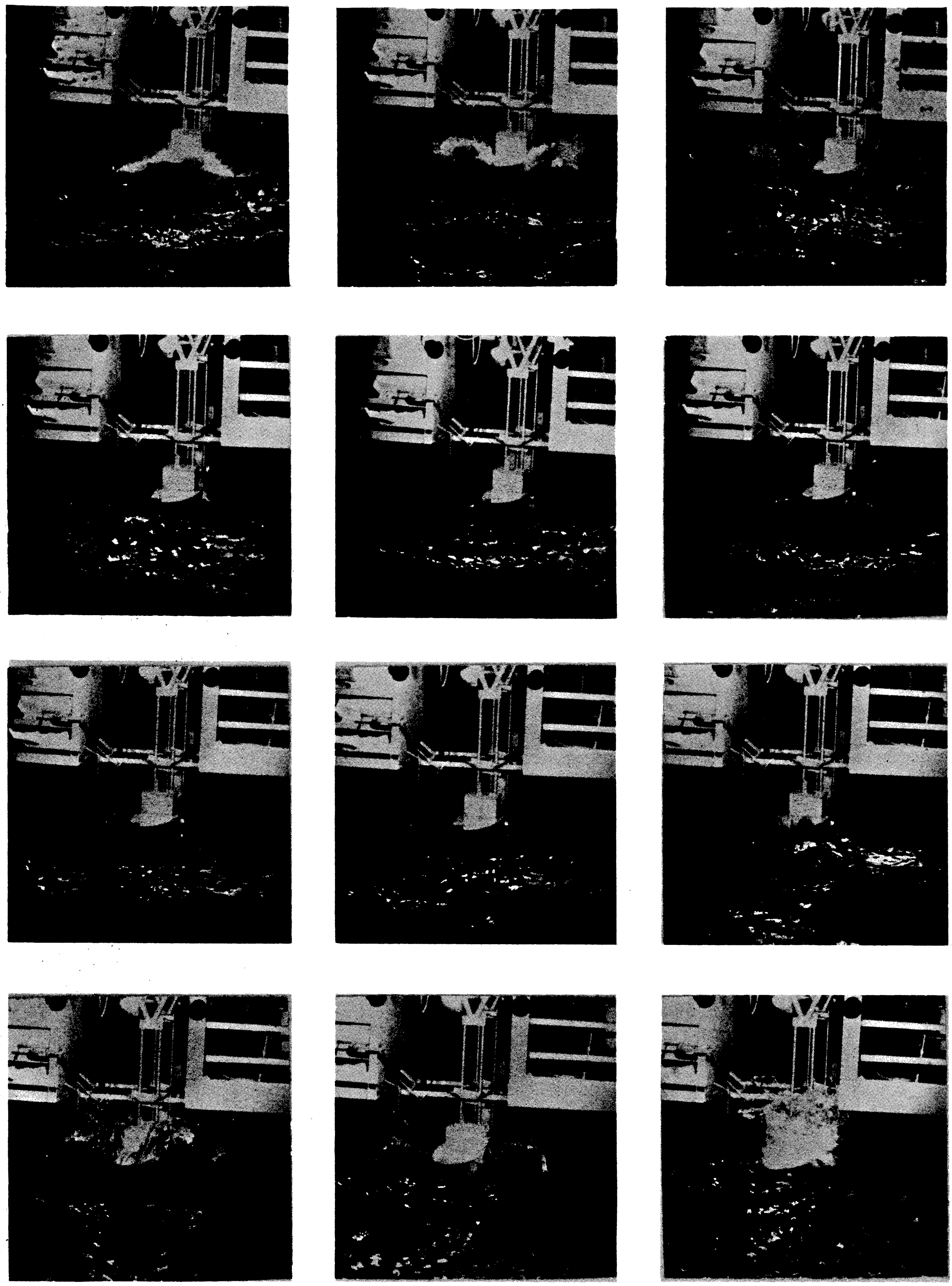

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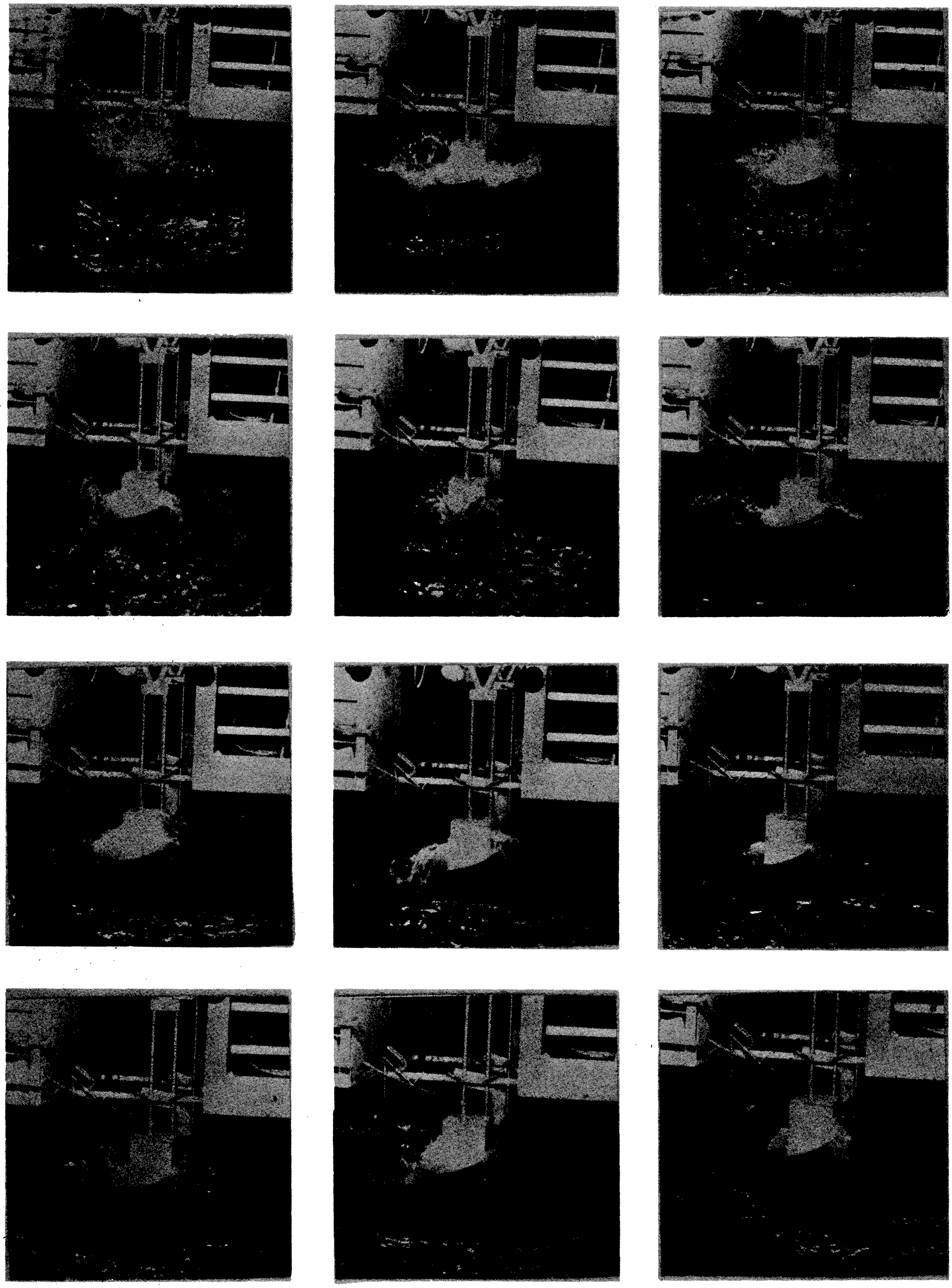


Figure 8. (Continued)

Figure 9. Sequence of Photographs Illustrating Rather Mild Wash Along Deck Striking Front of Deckhouse, As Viewed from Above

(These photographs were printed from 16-mm. Eastman Tri-X (Type 7233) negative film used in a Wollensak Fast-Air camera with a 75-mm. lens at 100 frames per second. Only every fifth frame was printed, and thus the time interval between two successive photographs of the twelve included in this figure is one-twentieth of a second. The order of the sequence is across each row from left to right, starting with the photograph in the upper left corner of the page.)

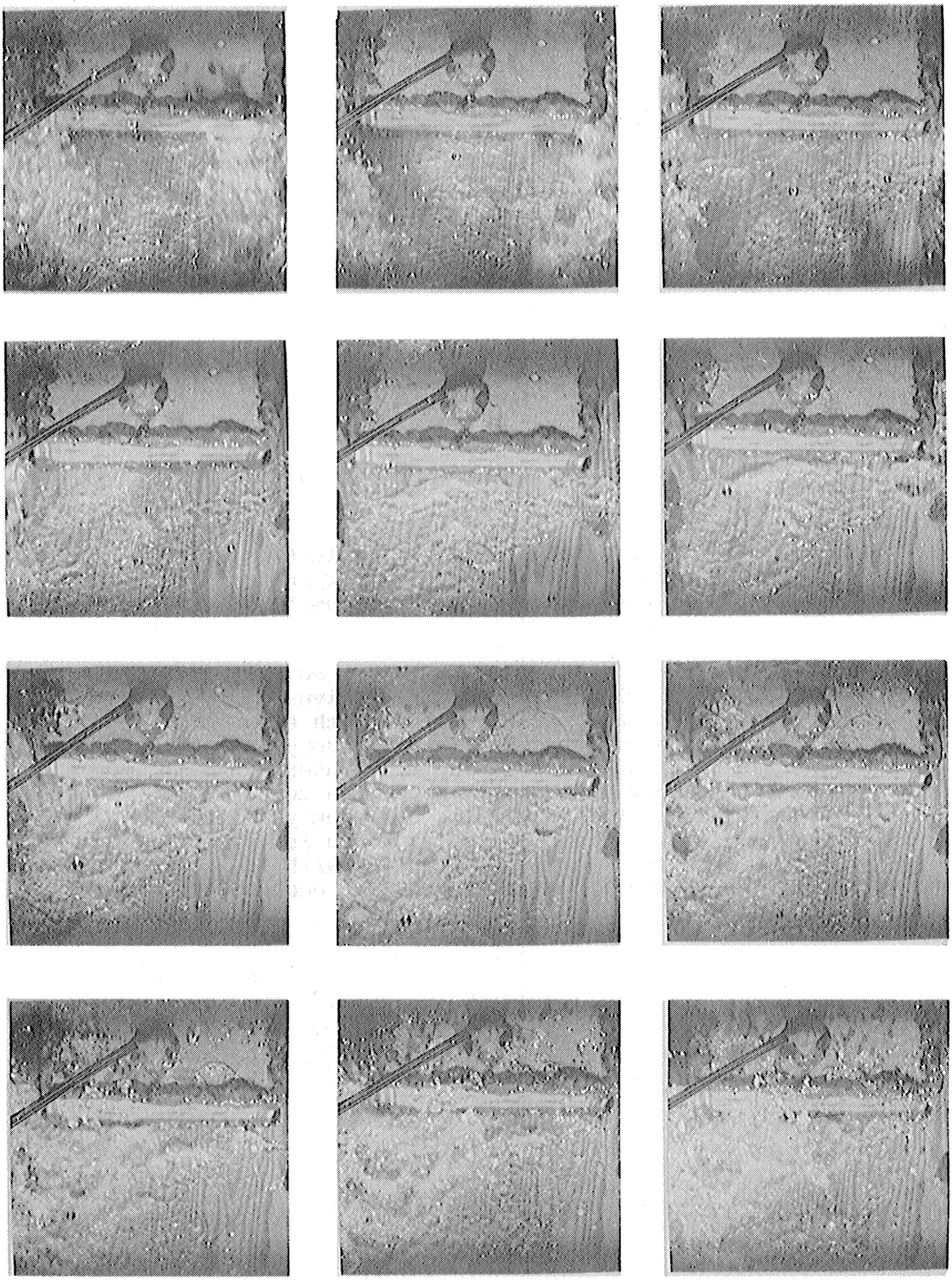


Figure 10. Sequence of Photographs Illustrating More Severe Impact of Water on Front of Deckhouse, As Viewed from Above

(These photographs were also printed from 16-mm. Eastman Tri-X (Type 7233) negative film used in a Wollensak Fast-Air camera with a 75-mm. lens at 100 frames per second. Only every fourth frame was printed, and thus the time interval between two successive photographs of the twenty-four included in this figure is one twenty-fifth of a second. The order of the sequence is across each row from left to right, starting with the photograph in the upper left corner on each page.)

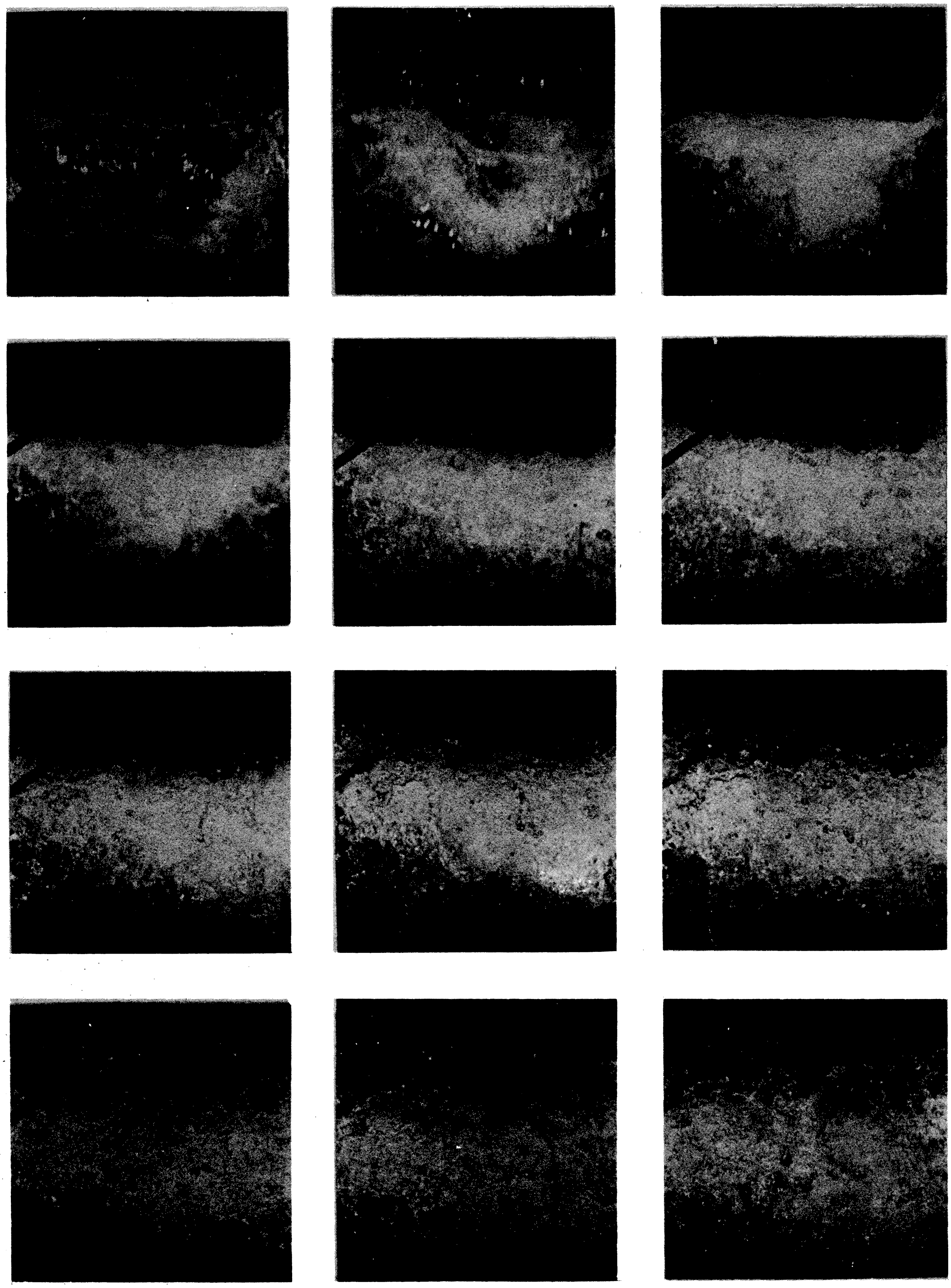


Figure 10. (Continued)

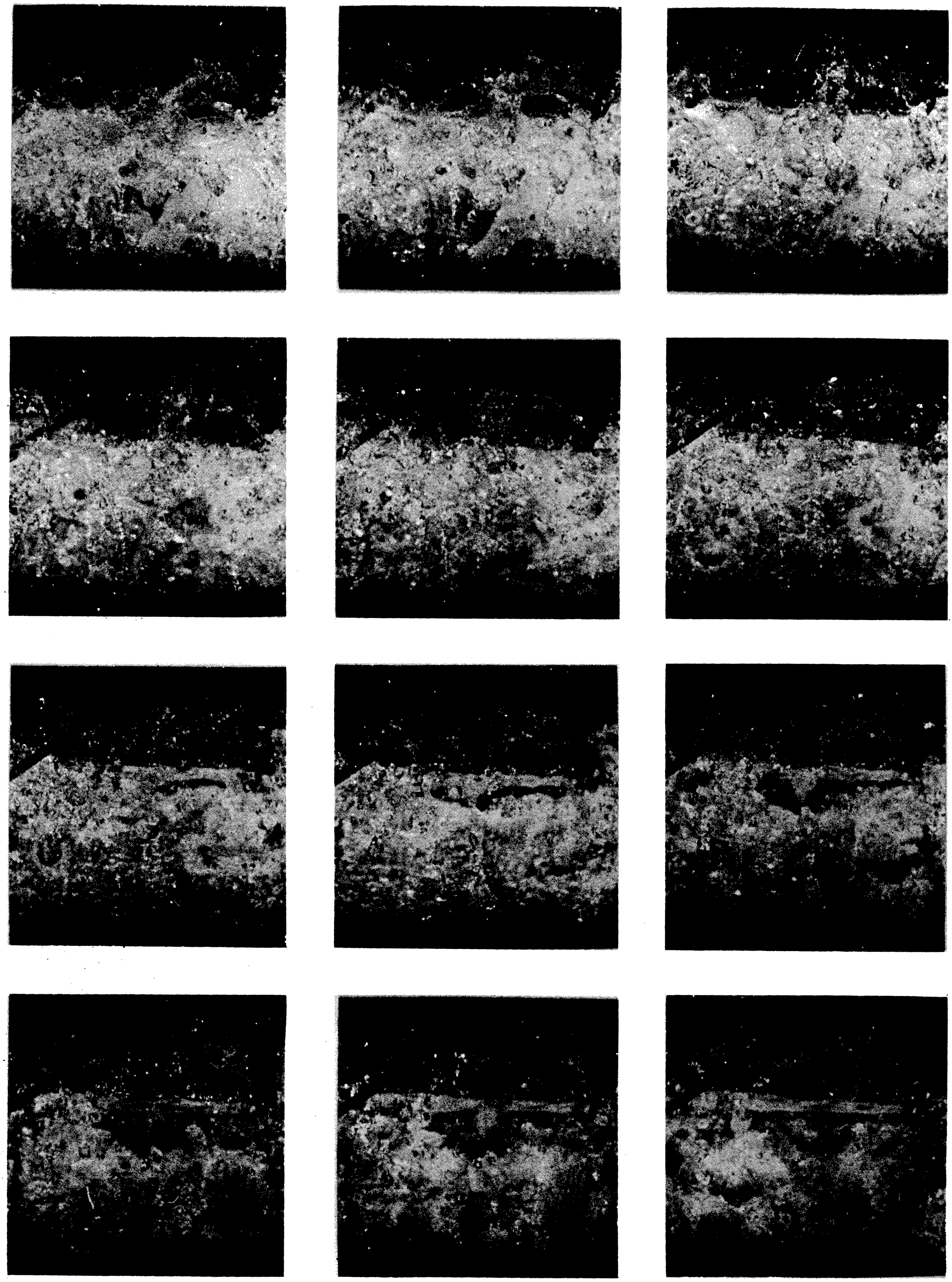
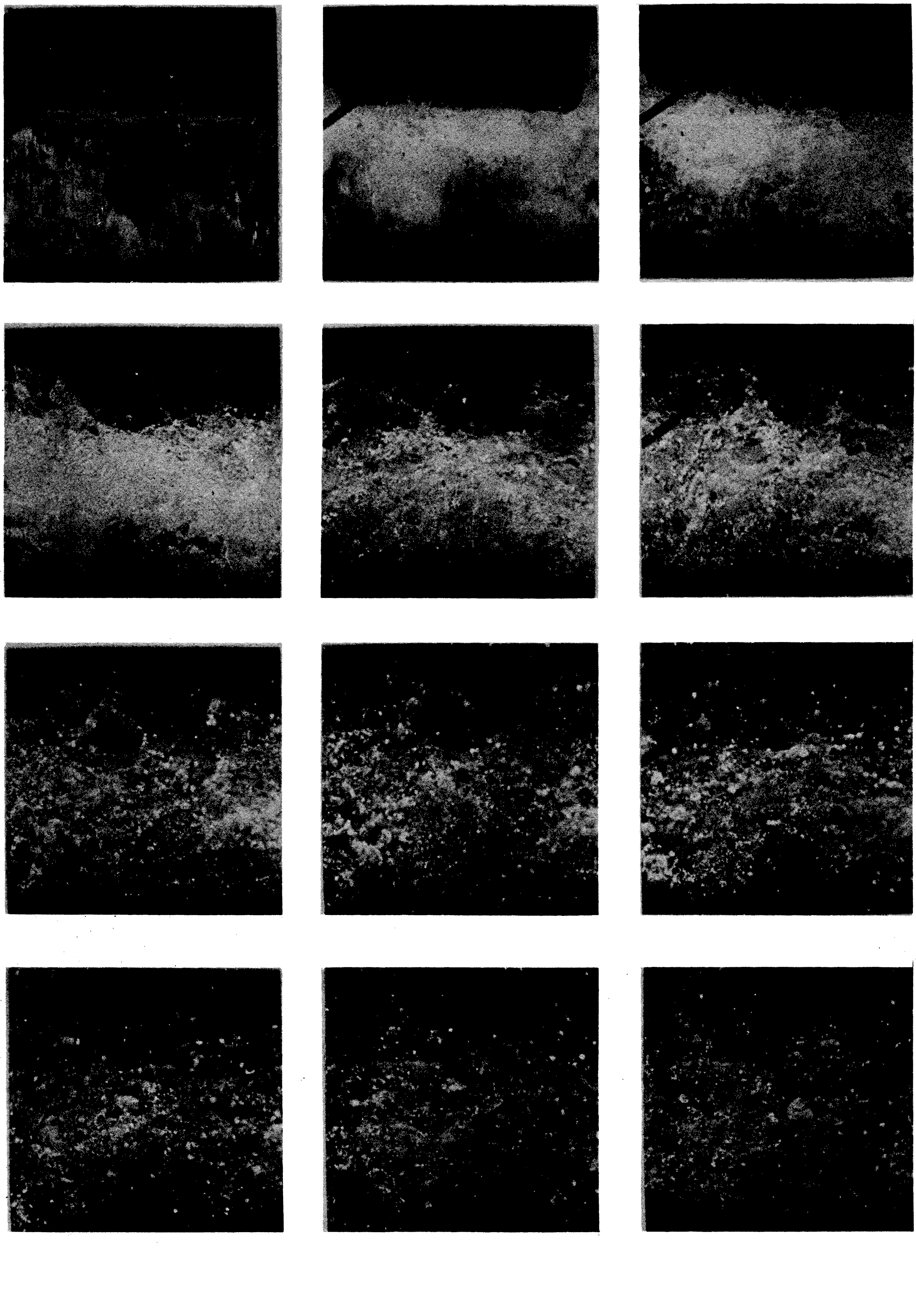


Figure 11. Another Sequence of Photographs Illustrating Severe Impact of Water on Front of Deckhouse, As Viewed from Above

(These photographs were also printed from 16-mm. Eastman Tri-X (Type 7233) negative film used in a Wollensak Fast-Air camera with a 75-mm. lens at 100 frames per second. Only every tenth frame was printed, and thus the time interval between two successive photographs of the twelve included in this figure is one-tenth of a second. The order of the sequence is across each row from left to right, starting with the photograph in the upper left corner of the page.)



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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Regents of The University of Michigan Ann Arbor, Michigan	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

Experimental Investigation of Green Sea Loadings on Deckhouse Geometry for a Destroyer-Type Model

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

Raymond A. Yagle

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1968	46	4

8a. CONTRACT ~~OR GRANT NO.~~ NObs-94394 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 08193-1-F 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Initial distribution of this report is being made as specifically required by the contract.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy Naval Ship Systems Command Naval Ship Engineering Center

13. ABSTRACT

A test program to determine the impact pressures generated on the front of a generalized type of deckhouse by breaking heavy seas was carried out in The University of Michigan towing tank. Pressures of several (2 to 4) psi were measured, but only under extreme sea conditions at relatively high model speeds, using quartz pressure transducers. Typical charts recorded are presented, along with sequential still photographs taken from motion pictures illustrating how violent the impact process was. All results were obtained with the model clamped in a fixed position relative to the towing carriage.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hydrodynamic impact						
Deckhouse loading						
Sea loading						