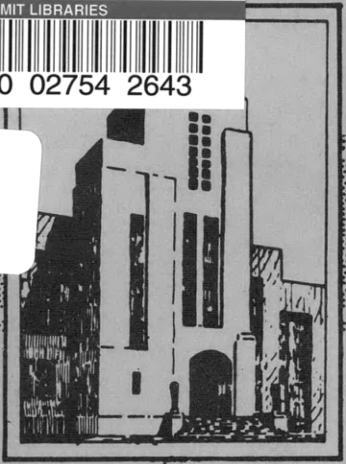

DEPARTMENT OF THE NAVY
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EXPERIMENTS ON ROTATIONAL IMPACT

by

Margaret D. Bledsoe and Frank M. Schwartz

HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

October 1961

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EXPERIMENTS ON ROTATIONAL IMPACT

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ABSTRACT

This report presents the results of an experimental investigation to determine the pressures produced on the bottom of a slamming ship when impact with the smooth water surface results from simple rotation in the plane of symmetry. The effect of forward speed of advance is not included. The primary purpose of the work was to secure data for comparison with theoretical results obtained previously.

Graphs are included which show pressure dependence on time and on shape for a particular transverse section. A comparison of experimental and theoretical average pressures for this station shows good agreement in magnitudes for the theoretical computations available. The agreement between the time histories is within the experimental accuracy of the tests.

The highest pressures measured are found to be located at or near the keel. For a meaningful comparison of the experimental results with theory, however, it is necessary to consider only those pressures which occur a short time after the keel contacts the water surface. Thus the proper application of the theory requires that the immersion be small, but greater than zero. With this restriction an examination of maximum pressures over the forward 22.5 percent of the ship's length shows that the region experiencing the highest pressures is located approximately at 9 percent of the ship's length aft of the forward perpendicular. This result is in close agreement with theory. However, the magnitude of the peak pressures obtained theoretically was found to be unrealistic.

INTRODUCTION

A theoretical investigation was made to determine the pressure distribution over the bottom of the five members of Series 60 when impact with the water surface results from simple rotation.[1] The investigation was based on the method described in Reference 2. The study indicated that the highest pressures are produced at the keel at the instant the vessel first contacts the surface. Then, with increasing immersion, the maximum instantaneous pressure at a station decreases with time, and its position shifts outboard rapidly. Although the theory cannot predict the magnitude of the pressures at the keel, it was used to determine the transverse location of maximum pressure a short time after the ship penetrated the water surface. The present experimental study was initiated to obtain information regarding the magnitudes of pressures actually developed at the keel and to attempt verification of the theoretical pressure distribution over the hull. Accordingly, a model of the 0.80 block coefficient member of the series was tested, with the conditions established for the computations duplicated in the tests. The most critical condition which had to be met was the duplication of the velocity-time and acceleration time relations used in the theoretical study. This was necessary to ensure a meaningful comparison of the theoretical and experimental results.

DESCRIPTION OF TESTS

A 10-ft model of the Series 60 parent form of 0.80 block coefficient was used for the tests. The characteristics of a 400-ft ship, which this model represents, are listed in Table 1, and the lines are shown in Figure 1. To duplicate the conditions for which the theoretical calculations were made, the model was pivoted about a fixed point 3.02 ft forward of the aft perpendicular. The pivot point was located 4.6 in. above the water surface.

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[1] References are listed on page 8

Weights were located in the model to obtain a moment of inertia and a moment, due to the model's weight, which would produce the desired acceleration-time relation. A Statham accelerometer of ± 15-g range and 200-cps natural frequency was located 1.02 ft aft of the forward perpendicular. The output was recorded by a Consolidated string oscillograph. A schematic diagram of the arrangement of the model is shown in Figure 2.

The TMB 140- by 10-ft basin was used for conducting these tests. The tests were made at zero forward speed and consisted of dropping the bow of the model from an elevated position and recording the pressures resulting from impact with the smooth-water surface. This necessitated the construction of a rigid frame consisting of I-beams spanning the basin to serve as a support for the fixed pivot. The model was attached to this structure by means of a strut and frame. A bearing pivot in the model, to which the strut was attached, allowed the model to rotate in a vertical plane. Figure 3 is a photograph showing this arrangement.

The releasing mechanism consisted of a solenoid attached to the I-beams in the same longitudinal plane as the strut and frame. This solenoid was equipped with a pin which was inserted into a bracket on the bow of the model. When the solenoid was activated, the pin was instantaneously released from the bracket and the model was free to fall until it struck the water surface. Figure 4 shows the model at this stage.

The history of linear acceleration used in the theoretical study of Reference 1 is shown by the solid line in Figure 5. The maximum deceleration was 12.6 g at the instant of slamming. To reproduce the theoretical time-dependence of the acceleration as well as the maximum value, weights were suitably placed in the forward portion of the model. The desired acceleration was obtained with 37 lb of added weight located 2.44 ft aft of the forward perpendicular, with the model inclined at an initial angle of 15.2 deg. Figure 6 shows the model in this inclined position. The acceleration varied somewhat from test to test; for example, the peak acceleration varied from 11.3 g to 14.8 g. Average values were obtained for all the tests, and this curve is shown as the broken line in Figure 5.

Commercial Dynisco transducers were used for the pressure measurements. These are diaphragm-type instruments, 0.5 in. in diameter, in which the sensing device consists of unbonded strain gages connected in a four-arm bridge. The displacement of the diaphragm produced by the pressure results in an unbalance of the bridge. The output of the gages was fed through a 20-kc carrier amplifier and recorded on a Consolidated string oscillograph.

Fourteen gages, with capacities ranging from 15 to 100 psi, were mounted over the forward quarter of the model length. The response characteristics varied with the rated capacities, but the natural frequencies were all sufficiently high to provide very satisfactory recordings of short-duration phenomena. The location of the gages was governed largely by the results of the theoretical study of Reference 1. In the theoretical study pressures were computed for immersions equal to or greater than 0.02 in. Therefore, where only one gage was placed at a section, the location chosen corresponded to the pressure peak, as determined from the computation, when the keel at that section was immersed 0.02 in. This immersion corresponds to 0.01 in. for the model used in the tests.

On one particular station (Station 3) the pressures were also measured at the keel and at three additional locations in order to provide a mapping of the pressure distribution over the section. There is no significance to the port or starboard location of the gages, since it was assumed that the pressures were symmetric with respect to the keel. Figure 7 shows the location of the pressure gages in the model.

DISCUSSION OF RESULTS

An example of the pressure traces as recorded by the string oscillograph is shown in Figure 8 along with the acceleration trace. From such records, the magnitudes as well as the time-dependence of the pressure could be determined.

Data obtained from the gages located along Station 3 were used to prepare Figure 9. This figure shows the pressure distribution across the station for a particular instant during slamming. It also shows the theoretical curve established by appropriately scaling the values obtained in Reference 1. The time for which Figure 9 was prepared was that indicated by the theory for maximum pressure at a location of 6.35 in. outboard on Station 3. The actual location of the gage in the experiments was 6.2 in. outboard. The magnitude of the theoretical pressure at a location of 6.2 in. agrees well with the highest pressure measured on the station at this time; however, in the tests the highest pressure was observed at a more inboard location of 4.5 in. from the keel. This discrepancy between experiment and theory in the location of highest pressure may be due to the theory which always predicts the maximum pressure in or near the region where the spray is formed. However, the discrepancy could have resulted from the time lag existing between the experimental and theoretical deceleration curves shown in Figure 5. To reproduce experimentally the proper deceleration-time relation presented great practical difficulties. The best approximation, shown in the figure, was obtained only after many repeated trials involving variations in the weight distribution and initial angle of drop. In the tests, the time for maximum deceleration actually lagged that of the theoretical study by about 0.001 sec. Such a time difference in the study of impulses whose duration is of the order of only 0.002 to 0.003 sec can have a significant effect on the pressure magnitude at a particular instant of time.

From a series of plots such as Figure 9, Figure 10 was prepared. This figure shows the average pressure over Station 3 during slamming. The theoretical curve is again included. A comparison of the experimental and theoretical average pressures over the station shows close agreement for the time interval for which values were computed.

The theory showed that the peak pressure developed for a particular station at a particular time is a function of only the instantaneous velocity and slope of the section at the instantaneous waterline; that is

$$P_{max} \approx \frac{\rho v^2}{2} \left[1 + \frac{1}{u^2(c)} \right] \qquad [1]$$

where v is the instaneous vertical velocity

ρ is the density of the fluid, and

$u(c)$ is the slope of the modified transverse section at the instantaneous waterline, and is a function of the slope of the section at the waterline.

Now, during the time interval critical for slamming for Station 3 ($0.215 < t < 0.217$ sec), the velocity decreased by about 15 percent. This can be shown by integration of the acceleration curve in Figure 5. However, during this same time the slope of the section at the instantaneous waterline increased from zero (flat bottom) to 0.277. Thus it can be seen from Equation [1] that the effect of change in slope has a much larger effect on the pressure than does the relatively small change in velocity. We may therefore neglect the velocity change during this time interval without introducing an appreciable error, and express the maximum pressures measured on Station 3 as a function of section slope only. For this purpose, the slope of the transverse section of the model at the pressure gage locations was calculated from an analytical curve approximating the section. These slopes were then plotted versus the peak pressures measured at these locations, and the results are shown in Figure 11. The pressure dependence on slope indicated in this figure is in agreement with the trend established from the theoretical results; namely, that an increase in pressure occurs with the decreasing slope of the sections.

The highest pressures measured over the bottom of the hull were found to occur at locations where the bottom was essentially flat. These were measured on Station 3 at the keel (zero slope) and 3 in. from the keel where the slope of the transverse section was 0.0004.

The maximum pressures recorded at those gage locations at which the theory predicted peak pressures for 0.01-in. immersion have been plotted in Figure 12 as a function of their time of occurrence and location along the half-breadth. The time scale is measured from the instant at which the model had obtained zero acceleration; see Figure 8. A faired curve through these pressures shows that the region experiencing the highest pressure occurs at approximately Station 1 3/4 or 9 percent of the ship's length aft of the forward perpendicular. This is in close agreement with the theoretical results which indicate highest pressures at 10 percent of the length aft of the forward perpendicular (Figure 13 of Reference 1). The pressure measured on Station 3 presents the only radical deviation from the faired curve. However, while a peak pressure of 35 psi was recorded at 5.4 in. from the keel for this station, at the same time a peak pressure of only 11 psi was recorded at 6.2 in. from the keel. As mentioned earlier, these experiments were designed to check the theory which is not applicable when the keel first contacts the water surface. Therefore, the pressures in Figure 12 do not apply on the flat portion, but are the maxima which exist after the keel at each station has obtained an immersion of 0.01 in. (0.4 in. full scale). The pressures on the flat bottom can be expected to be somewhat higher. For instance, at the instant the keel of Station 3 contacted the water surface, a maximum pressure of almost 50 psi was measured at the keel and at a location of 3 in. outboard where the bottom was still flat. When the section had obtained an immersion of 0.01 in. however, a pressure of only 35 psi was measured at a more outboard location where the bottom has a small curvature.

The data in Figure 12 should not be used quantitatively in a practical application, since the pressure magnitude depends on the time history of the deceleration during each impact. However, the figure does show the longitudinal position where the highest pressures may be expected during slamming.

CONCLUSIONS

In this experimental study pressures have been measured at fourteen locations over the forward quarter length of a vessel when slamming results from simple rotation. The largest pressures were measured at or near the keel, a result which was suggested by the theoretical calculations. A comparison of the experimental results with the theoretical results indicates that the theory can be used to determine adequately the regions of highest pressure and trends, such as pressure-dependence on time and shape of section. Although the magnitudes of the pressure peaks as determined theoretically appear to have little realistic value, a comparison of the average pressures over a section with the experimental pressures indicates that the theory does provide reasonable results regarding magnitude and time variation of the average pressure sustained by any section during slamming.

A comparison of the theoretical and experimental pressure distribution over one station for a particular instant shows a discrepancy in the transverse location of the highest pressure. Possibly this discrepancy resulted from the time differential for obtaining maximum deceleration between the theory and experiment. However, further attention should be given to this problem in future slamming studies.

REFERENCES

1. Bledsoe, M. D., "Series Investigation of Slamming Pressures," David Taylor Model Basin Report 1043 (Dec 1956).

2. Todd, M. A., "Slamming Due to Pure Pitching Motion," David Taylor Model Basin Report 883 (Jan 1955).

TABLE 1

Ship Characteristics of Series 60, 0.80 Block Coefficients

L_{BP} ft	400
B, ft	61.54
H, ft	24.59
Δ, tons	13,859
W. S., sq ft	37,200
C_b	0.800
C_x	0.994
C_p	0.805
C_{pv}	0.920
C_w	0.871

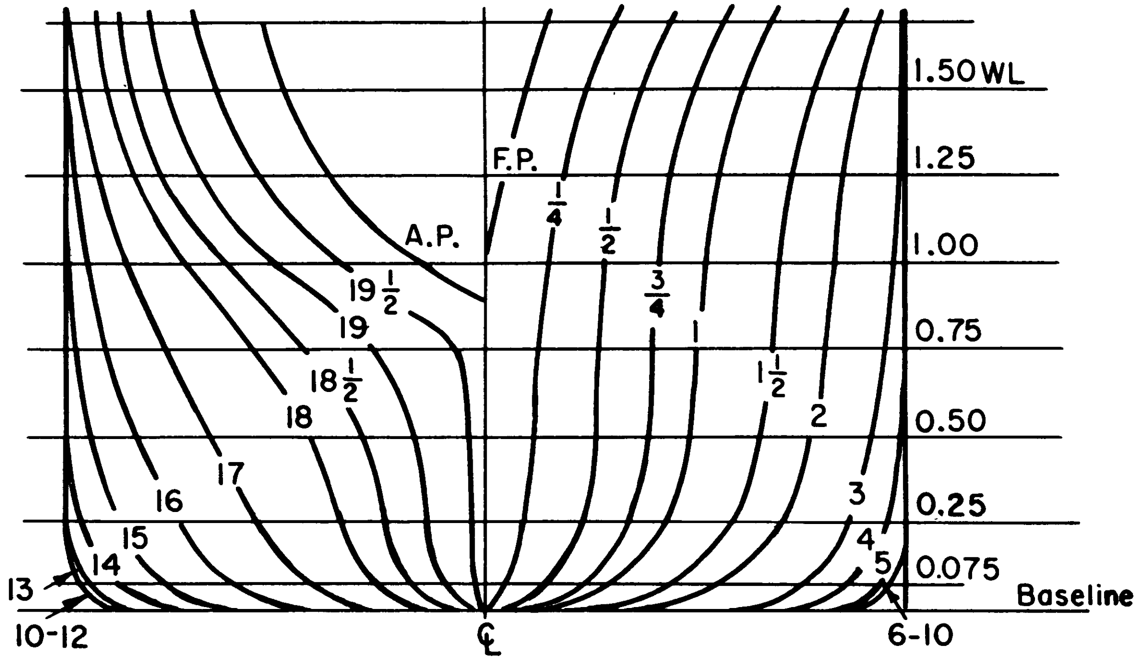

Figure 1 - Body Plan for Series 60, C_b = 0.80

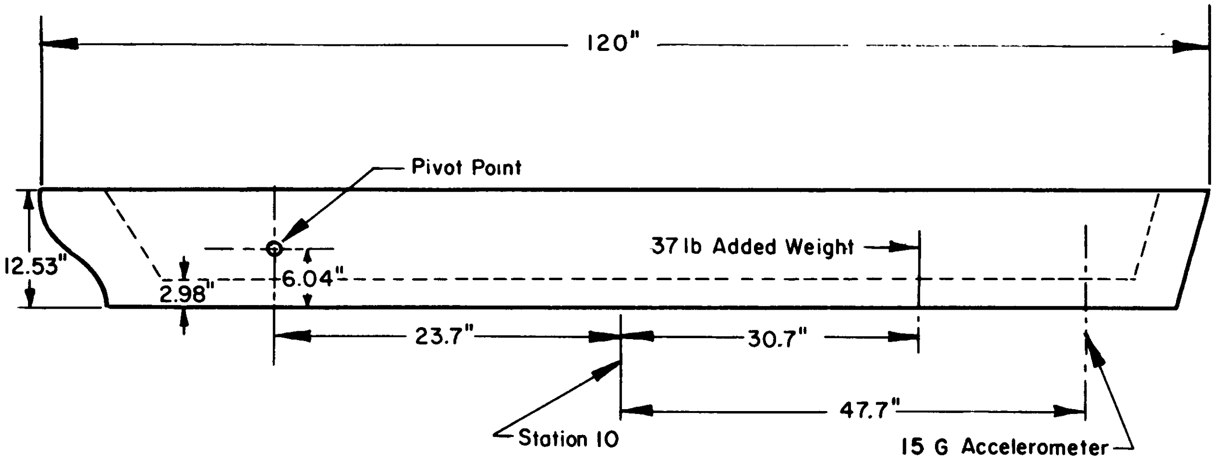

Figure 2 - Schematic Diagram of 10-foot Model of Series 60, 0.80 Block Coefficient

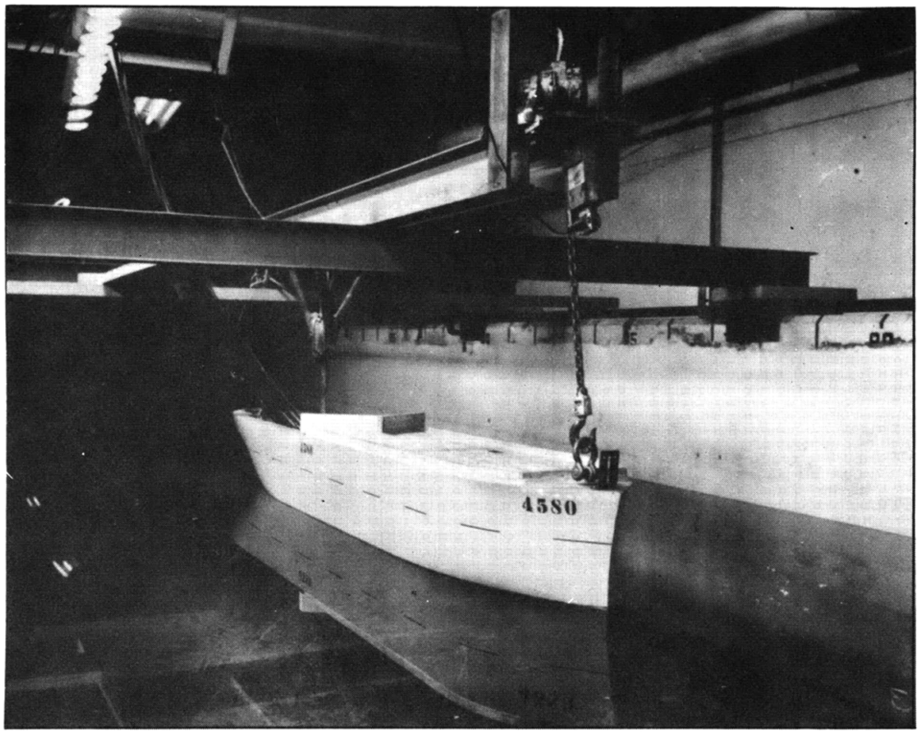

Figure 3 - Photograph Showing Testing Apparatus

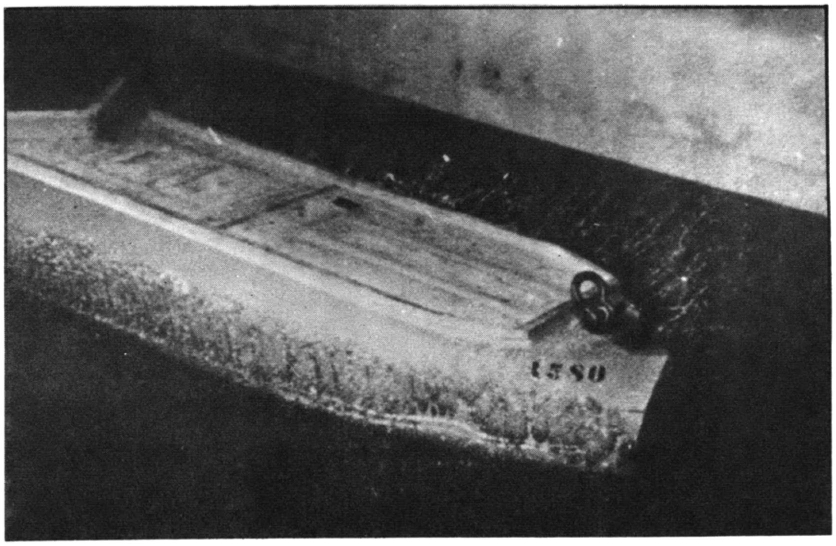

Figure 4 - Photograph Showing Model Striking Water Surface

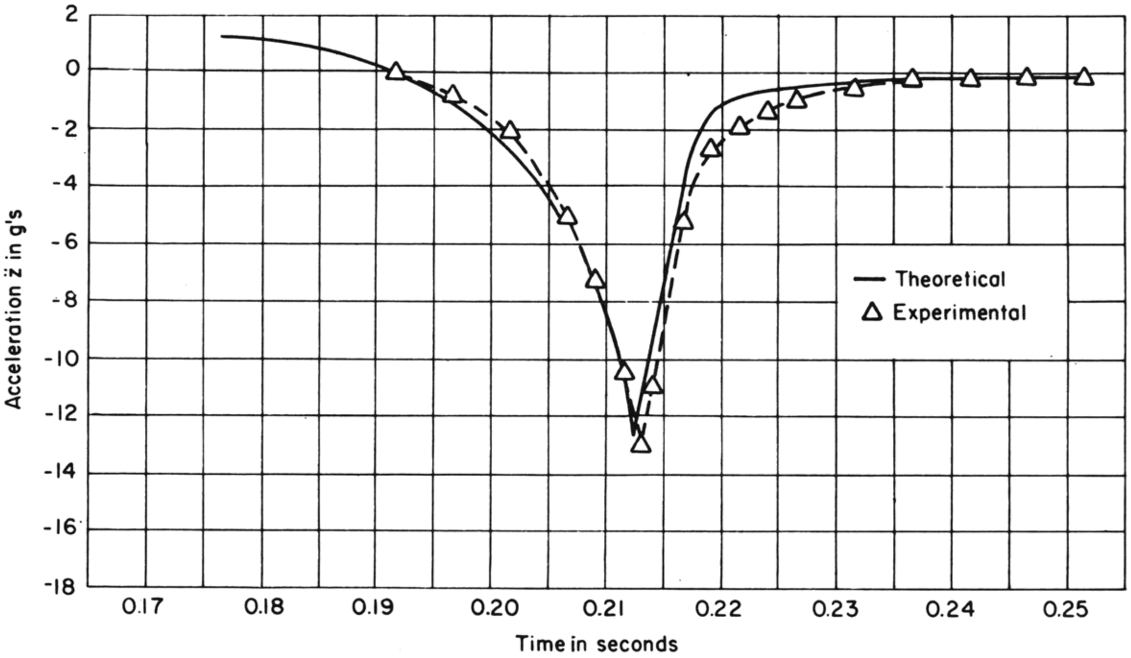

Figure 5 - Comparison of Theoretical and Experimental Acceleration Curves

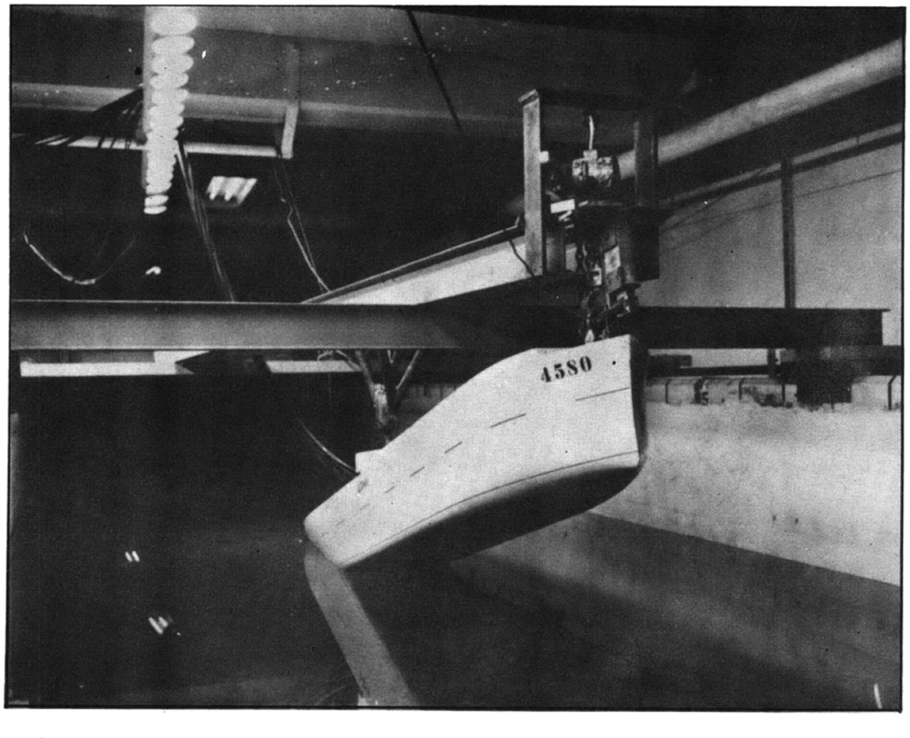

Figure 6 - Photograph Showing Model Inclined at an Initial Angle of 15.2 Degrees

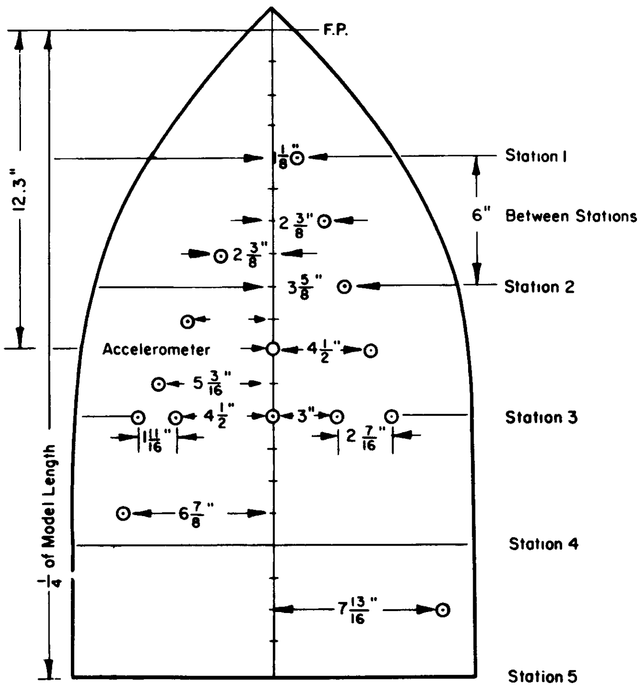

Figure 7 - Schematic Diagram Showing Locations of Pressures Gages and Accelerometer

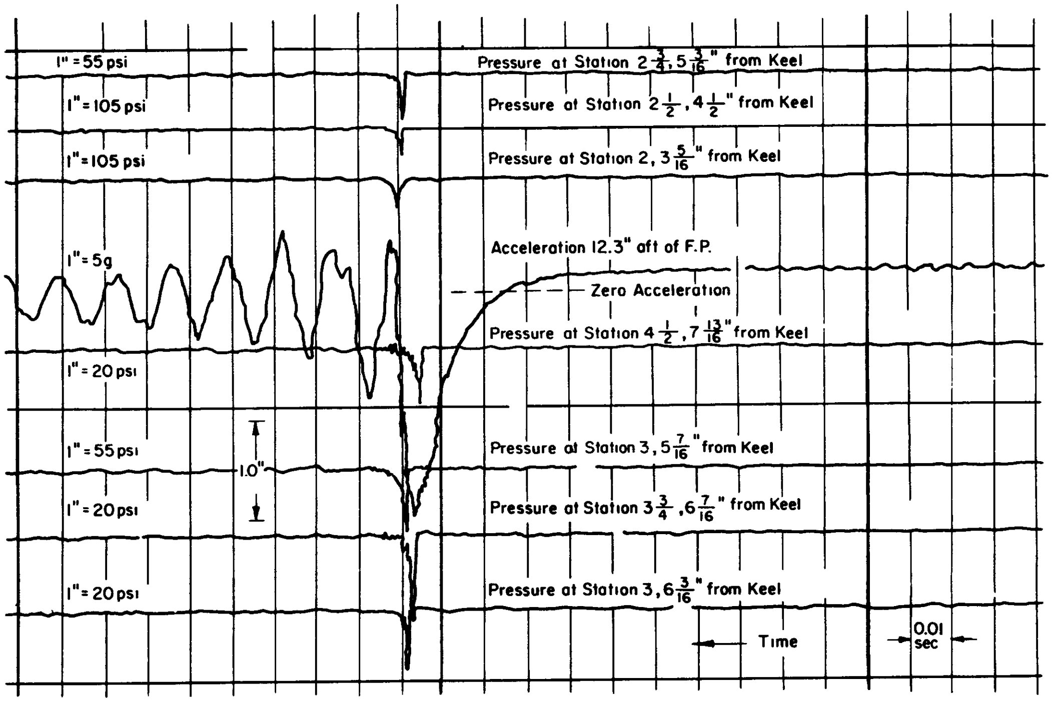

Figure 8 - Representative Example of Oscillograph Record Showing Pressures and Vertical Acceleration

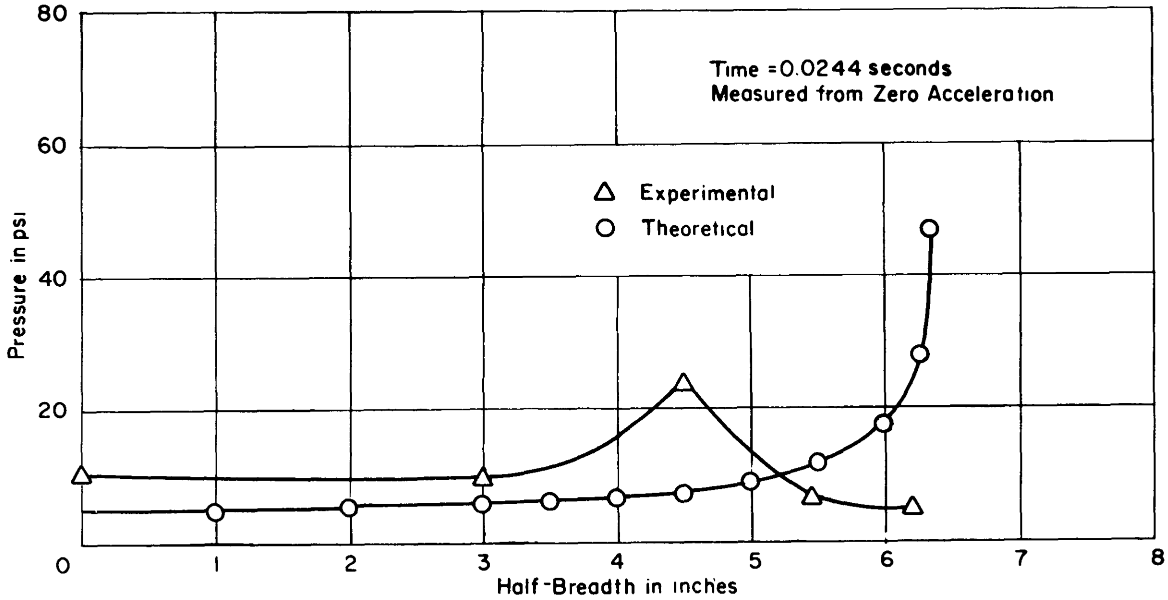

Figure 9 - Comparison of Experimental and Theoretical Pressure Distribution across Station 3 for a Particular Instant during Slamming

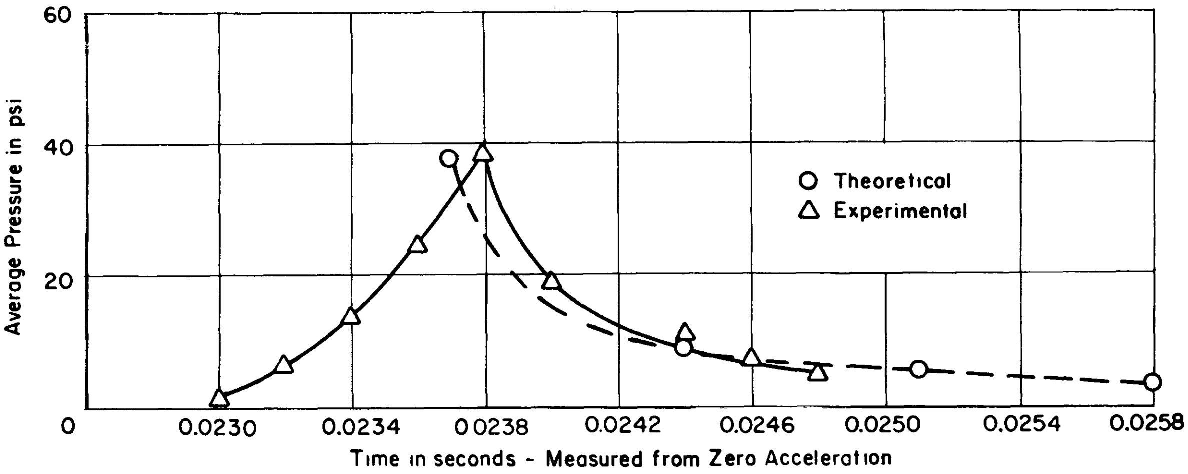

Figure 10 - Comparison of Theoretical and Experimental Average Pressures on Station 3 during Slamming

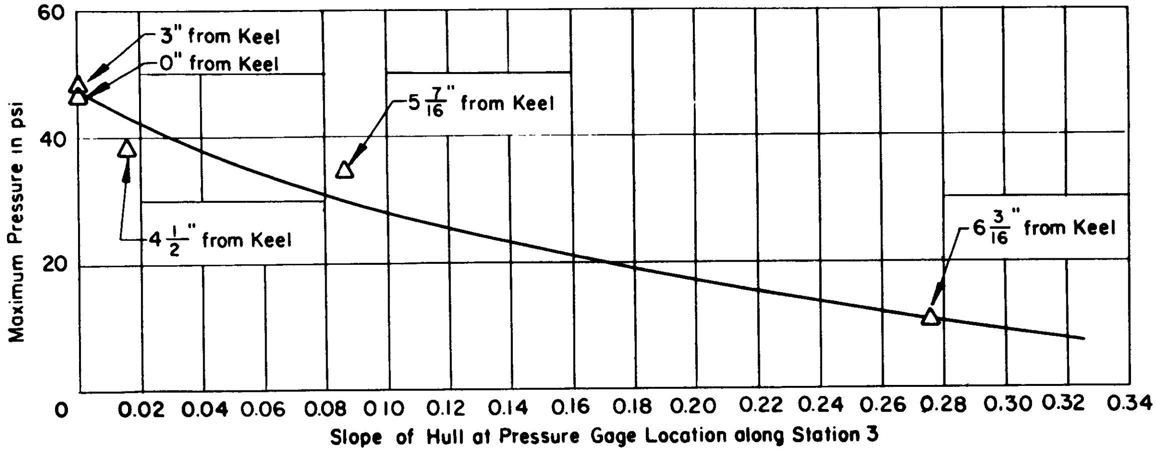

Figure 11 - Variation of Maximum Pressure with Slope of Transverse Section at Gage Locations for Station 3

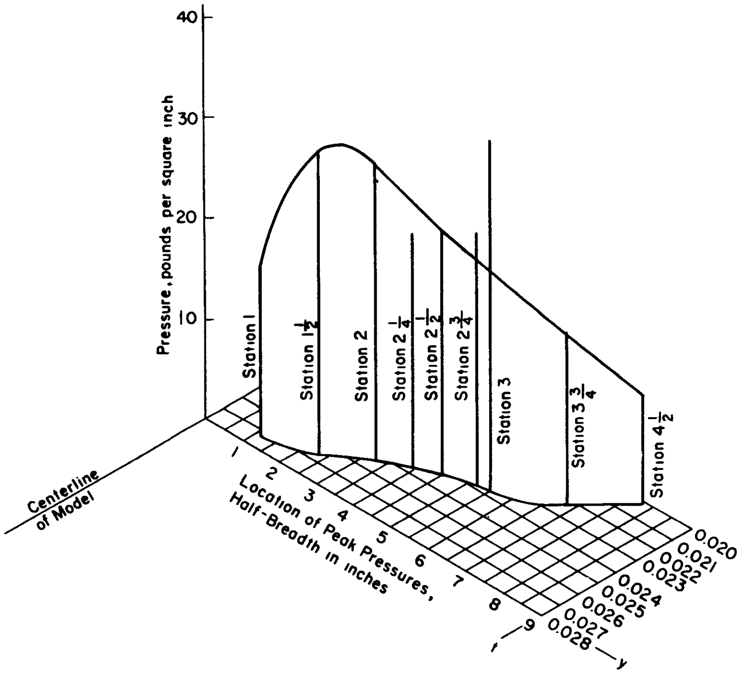

Figure 12 - Maximum Pressures Measured over Forward 22.5 Percent of Series 60, 0.80 Block Model (Exclusive of Keel)

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