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HYDRODYNAMIC SLAMMING ON A LARGE SONAR DOME FITTED ON A DL-2 DE--ETC(U)
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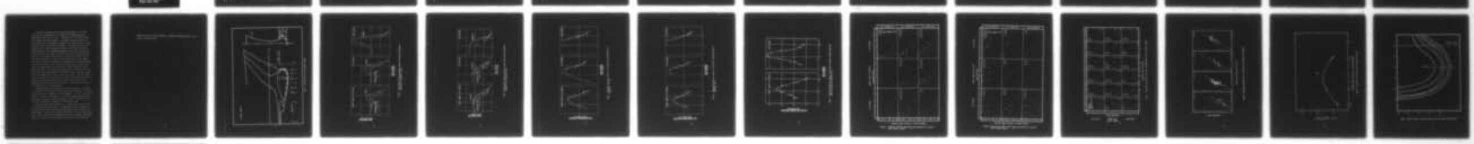

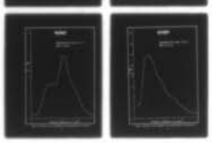

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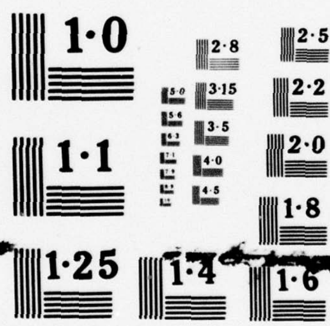
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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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HYDRODYNAMIC SLAMMING ON A LARGE SONAR DOME FITTED ON A DL-2 DESTROYER

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HYDROMECHANICS LABORATORY

TEST AND EVALUATION REPORT

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NOTATION

$k = \frac{\text{peak pressure}}{V^2}$

V = Relative velocity between bow and water surface at moment of impact.

T_w = Wave period.

ADMINISTRATIVE INFORMATION

This work was sponsored by the Sonar Systems Office of NAVSHIPS, Technical Code 00V1 under Sub Project SF 11121203, Task 8722 (formerly SF 1010317, Task 8139).

INTRODUCTION

To obtain data on hydrodynamic slamming on the bottom of a large sonar dome of a DL-2 destroyer, a 20-ft model of the ship was tested in the Harold E. Saunders Maneuvering and Seakeeping Facility of the Naval Ship Research and Development Center. Both the probability of occurrence of slamming and the magnitude of the associated pressures were investigated.

EXPERIMENTAL PROCEDURE

The tests were conducted on a model of the DL-2 fitted with a sonar dome of the SQS 26 type. The main particulars of the ship and model are given below.

TABLE I

CHARACTERISTICS OF SHIP AND MODEL

	Ship	Model 4051-2
Length on waterline	476 ft	20 ft
Length between perpendiculars	476 ft	20 ft
Draft	14 ft	0.59 ft
Beam	48 ft	2.02 ft
Displacement in salt water	4650 l. tons	
Displacement in fresh water		760 lbs
Longitudinal gyradius	0.26 L	0.26 L
Natural pitch period	5.6 sec	1.15 sec
Natural heave period	5.8 sec	1.19 sec

The model was tested in regular and in long-crested irregular head waves. It was self-propelled and free to move in all six degrees of freedom.

The model irregular seas represented approximately a fully developed Sea State 4 and a more severe Sea State 6 (high) or Sea State 7 (low). The latter with a significant wave height corresponding to 20.5 feet, was the most severe irregular sea that could be generated for a scale ratio of 23.8. Most of the tests were conducted in regular waves with a ship length-wave length ratio between 0.4 and 1.2. To induce slamming on the rather deeply submerged sonar dome the waves had to be steep. In most cases the wave height-wave length ratio varied between 1/20 and 1/25. The investigated speeds corresponded to 25, 30 and 40 knots for the prototype. The measured quantities were heave, pitch, relative bow motions and vertical accelerations at Stations 3/4 and 1½, and the pressures at the nine locations indicated in Figure 1. Pitch and heave were measured with potentiometers, the accelerations with accelerometers. The relative bow motion transducers consisted of resistance wires extending to a distance 10 inches below the dome. One transducer was located on the starboard side of the model at Station 3/4 during part of the tests and at Station 1 during the remainder of the tests. The other transducer was located on the port side of the model at Stations 1½ and 1¼. Pressure gages which make use of strain gages were used for the pressure measurements. Some further remarks on the instrumentation are made in the Appendix.

PRESENTATION OF RESULTS

The data on heave, pitch and vertical bow acceleration* measured in regular waves are given in non-dimensional form in Figures 2, 3, 4 and 5. The relative bow motion was derived from the tests in irregular waves and these results are given in non-dimensional form in Figure 6.

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*The presented accelerations do not include the high frequency accelerations caused by slamming impact.

During the tests in regular waves slams generally occurred with each wave encounter resulting in eight or more slams during one pass in the towing tank. During any given run the measured peak pressures varied from one wave encounter to the next. In Figures 7a, 7b and 8 the average of six consecutive slams is given. In addition, for each occurrence of a slam the peak pressure and the relative velocity at the moment of impact are given in Figure 9. From this graph the factor k was determined using the relationship, peak pressure = $k \times V^2$, in which V is the relative velocity at the moment of impact. The values of k so obtained are plotted in Figure 10. All pressure data obtained in regular waves are presented for model scale.

The spectra of the seas in which the irregular wave tests were conducted are given in Figures 12 and 13. Of the measured motions the significant values were determined and presented in Tables 2 and 3. They were derived from the spectra and represent the average of the one-third highest values measured from trough to crest. All results in irregular seas are given for the prototype. The effective draft indicated in the tables is defined as the draft at the subject station corrected for the measured average relative bow motion due to trim, sinkage and bow wave of the model.

TABLE 2

TEST RESULTS IN SEA STATE 4

Duration of the test: 30 minutes

Observed number of slams: 0

Effective draft at Station 3/4: 26.5 ft

	Significant Value
Wave Height	6.1 ft
Pitch Angle	1.4 deg
Heave Motion	1.5 ft
Relative Bow Motion at Station 3/4	9.8 ft
Relative Bow Velocity at Station 3/4	15.4 ft sec
Vertical Acceleration at Station 3/4	0.28 g
Absolute Vertical Motion at Station 3/4	8.7 ft

TABLE 3

TEST RESULTS IN HIGH SEA STATE 6 OR LOW SEA STATE 7

Ship Speed: 30 knots

Duration of the Test: 8.3 minutes

Observed Number of Slams: 5

Maximum Slamming Pressure Measured at Station ½: 95 psi

Maximum Slamming Pressure Measured at Station 3/4: 88 psi

Maximum Slamming Pressure Measured at Station 1: 31 psi

Effective Draft at Station 3/4: 28.4 ft

	Significant Value
Wave Height	20.5 ft
Pitch Angle	6.2 deg
Heave Motion	14.4 ft
Relative Bow Motion at Station 3/4	50.1 ft
Relative Bow Velocity at Station 3/4	65.7 ft sec^{-1}
Vertical Acceleration at Station 3/4	1.13 g
Absolute Vertical Motion at Station 3/4	38.3 ft

DISCUSSION OF RESULTS

Tests in Regular Waves

Pitch and Heave - In Figures 2 and 3 measured heave and pitch responses are given together with the calculated response curve and an experimental curve as established from earlier tests with the same model in less steep waves. The earlier tests were conducted in waves with a steepness of about 1/40 while the present tests were conducted in wave steepness of 1/20 to 1/25. The difference between the two sets of results suggests that non-linear effects are present in the very severe waves in which the present (slamming) tests were conducted. For the calculations, computer program ZK11 was used. A description of this program is given in Reference [1]*. The results of the calculations are in agreement with earlier experiences that the procedure used tends to give results which are high at the rather high Froude numbers investigated here.

Bow Accelerations - As could be expected, the differences between the vertical accelerations measured at Station 3/4 and those measured at Station 1½ are small; see Figures 4 and 5.

Pressures Along the Keel of the Sonar Dome - The highest pressures apparently may be expected between Stations 1 and ½ (see Figures 7a and 7b). The maximum value of k is obtained in the region of Station 1, see Figure 10. This result is in agreement with the expectation that the highest k value will occur on that part of the sonar dome with the smallest curvature, see Figure 11. The highest measured pressure was about 4 psi for the model or 96 psi for the ship. This pressure was obtained in very severe conditions; regular waves of about ship length with a height of about 1/20 the wave length.

Pressures Along the Girth of Station 3/4 - Figures 7a, 7b and 8 indicate that the impact pressures are much higher at the keel than at the other locations investigated along the girth of Station 3/4.

Tests In Irregular Seas

In addition to the test results given in Tables 2 and 3, some calculations have been made on the number of slams and highest pressures that may be expected. For this purpose the procedures outlined in Reference [2] have been followed. The tests and the calculations indicate that when the ship proceeds with a speed of 25 knots in a Sea State 4, dome emergence is most unlikely to occur and so is slamming. The model was also tested in a much more severe condition, namely, Sea States 6 to 7 at 30 knots. The number of slams observed during these tests and the expected number based on the calculations are given in Table 4.

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*References are listed on page 7.

TABLE 4

OCCURRENCE OF SLAMMING IN SEA STATE 6 - 7, SHIP SPEED 30 KNOTS

Duration of The Test Full Scale	Number of Slams Expected	 Observed
8.3 minutes	6.8	5
60 minutes	49	

The most probable maximum pressure and the maximum value which is exceeded in 5 per cent of the number of tests if the test is repeated many times were calculated for Station 3/4 using $k = 0.1$. The results are presented in Table 5.

TABLE 5

MAXIMUM SLAMMING PRESSURES IN SEA STATE 6 - 7, SHIP SPEED 30 KNOTS

Station 3/4 (Full Scale Values)	Duration of The Test 8.3 Minutes	 20 Hours
Calculated most probable maximum pressure	113 psi	382 psi
Calculated maximum, not to be exceeded with probability 0.95	276 psi	543 psi
Measured maximum pressure	88 psi	

Since the number of slams observed during the tests is very small, the discrepancy between the measured and expected maximum pressures is not surprising.

It is to be noted again that to induce slamming on the bottom of the sonar dome, the model had to be tested in extreme conditions which were more severe than the conditions which a vessel generally experiences during slamming.

REFERENCES

1. Salvesen, N., "Manual Ship Motion Computer Program ZK11", David Taylor Model Basin, Hydromechanics Laboratory, Technical Note 65, January 1967.

2. Ochi, Michel K., and Lewis E. Motter, "Prediction of Extreme Values of Impact Pressure Associated With Ship Slamming", Naval Ship Research and Development Center, Hydromechanics Laboratory, Technical Note 106, July 1968.

APPENDIX

NOTES ON THE INSTRUMENTS USED

During the tests some difficulties were encountered which were caused primarily by the very severe conditions to which the model was subjected. The greatest problem was associated with the pressure gages - STATHAM PM222TC pressure gages with ranges of $\pm$ 5 and $\pm$ 10 psi were used. Very soon after the beginning of the tests the zero level of the electrical output of these gages started to drift. Some time later these gages became extremely noisy making it impossible to discern the slamming pressures properly. These difficulties are attributed to moisture that had penetrated the gages notwithstanding the measures taken to prevent this. After completion of the test program these gages were thoroughly inspected and subjected to some tests together with a set of new gages. The conclusions from these tests were:

1. When the membrane of a gage whose temperature is that of the air is brought into contact with water 10° F colder or warmer than air, a signal corresponding to 0.1 to 0.3 psi was produced. During slamming tests, however, the gage will be in the water for some time, emerge into the air for less than a second and re-enter the water. In this case the output due to the change in temperature is negligible.

2. When subjected to accelerations of about 8 g, the signal produced by "dry" gages corresponded to about 0.4 psi. If the gage has been affected by moisture this signal is many times higher. Accelerations due to slamming are of the order of 1 g.

3. Contrary to the "dry" gages, the "wet" ones produced a sizeable signal when their cables were shaken. The reason for this is not clear.

The above findings confirm that pressure gages of the type used meet the requirements for a reasonable slamming pressure measurement when they are "dry". When used in a humid environment these gages deteriorate rapidly. Attempts to keep the water out of the model were unsuccessful because of the large amounts of water shipped on deck and the generated spray. In addition, some water leaked into the model through the adapters which held the gages. Waterproofing of each individual gage had to be more rigorous than anticipated since the gages could also be affected by the humidity of the air. The best solution was to seal off the channel for the differential pressure. During the second series of tests, gages were used for which this channel was extended with a flexible plastic tube and closed at the end. Another tube was used to protect the cable, the extended air channel and the location where the cable enters the gage. This waterproofing proved to be sufficient for the duration of the second series of tests which was considered necessary for an assessment of the value of the first tests. From the experience thus obtained it was decided to reject a part of the results obtained during the first part of the tests. The scatter in the remaining pressures from the first series of tests was about equal to that obtained in the second series.

Problems were also encountered with the transducers to measure the relative motion between the hull and the water surface. Two types of transducers were available for this purpose. The one, sonic wave probe, could not be used because of the heavy spray generated during the tests. The other, probes consisting of wires between which the electrical resistance is measured, was therefore used.

When the model speed exceeded 3 or 4 knots these probes tended to loose some of their accuracy. During the tests in irregular seas the relative bow motion was in the range that could be measured by these probes. During the tests in regular waves, in many cases, this motion was so large that the amplitude could not always be determined. However, in these cases the relative bow velocity at the moment of impact could still be determined by graphical differentiation of the relative motion record.

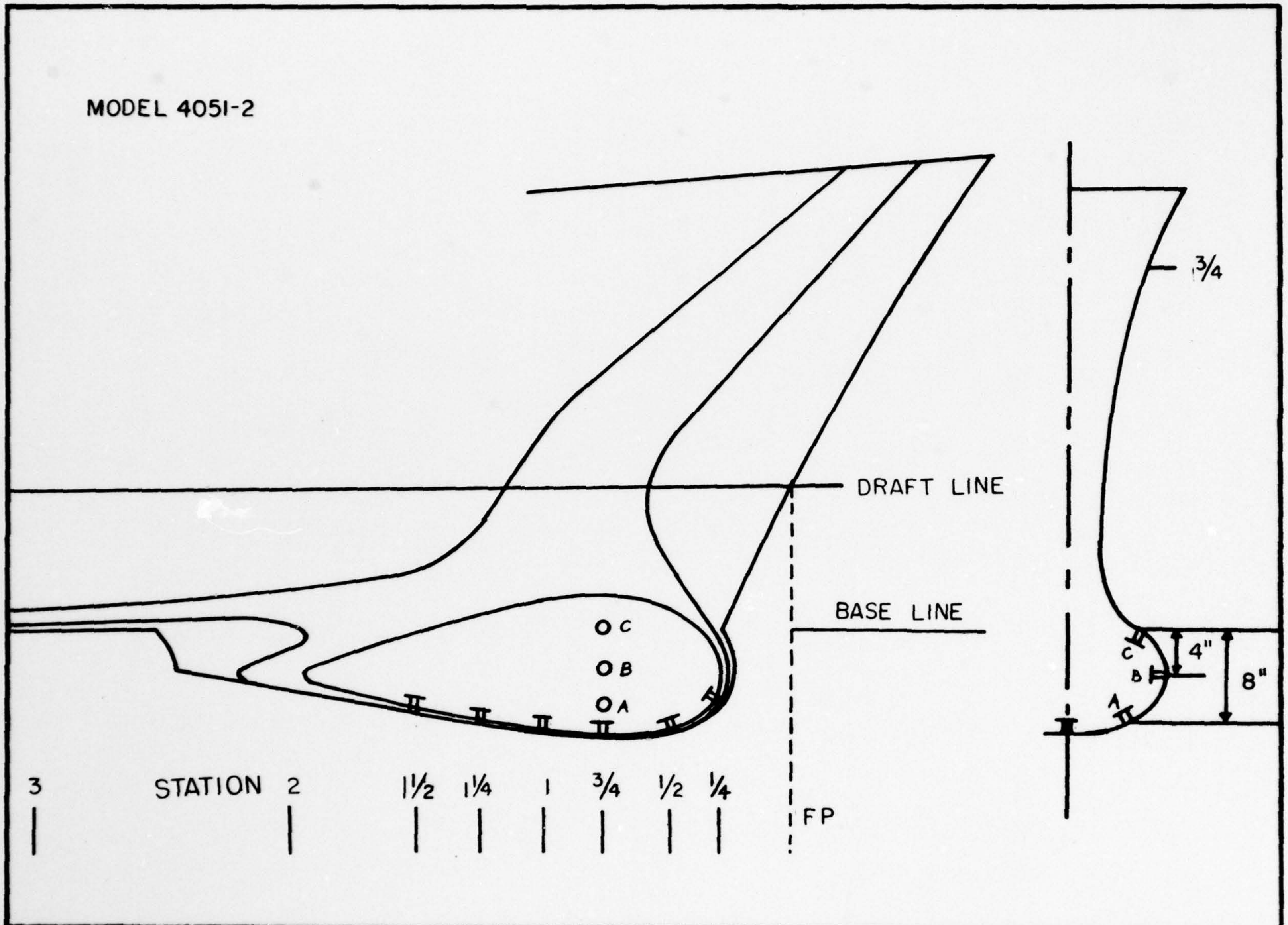

Fig.1 Location of the pressure gages

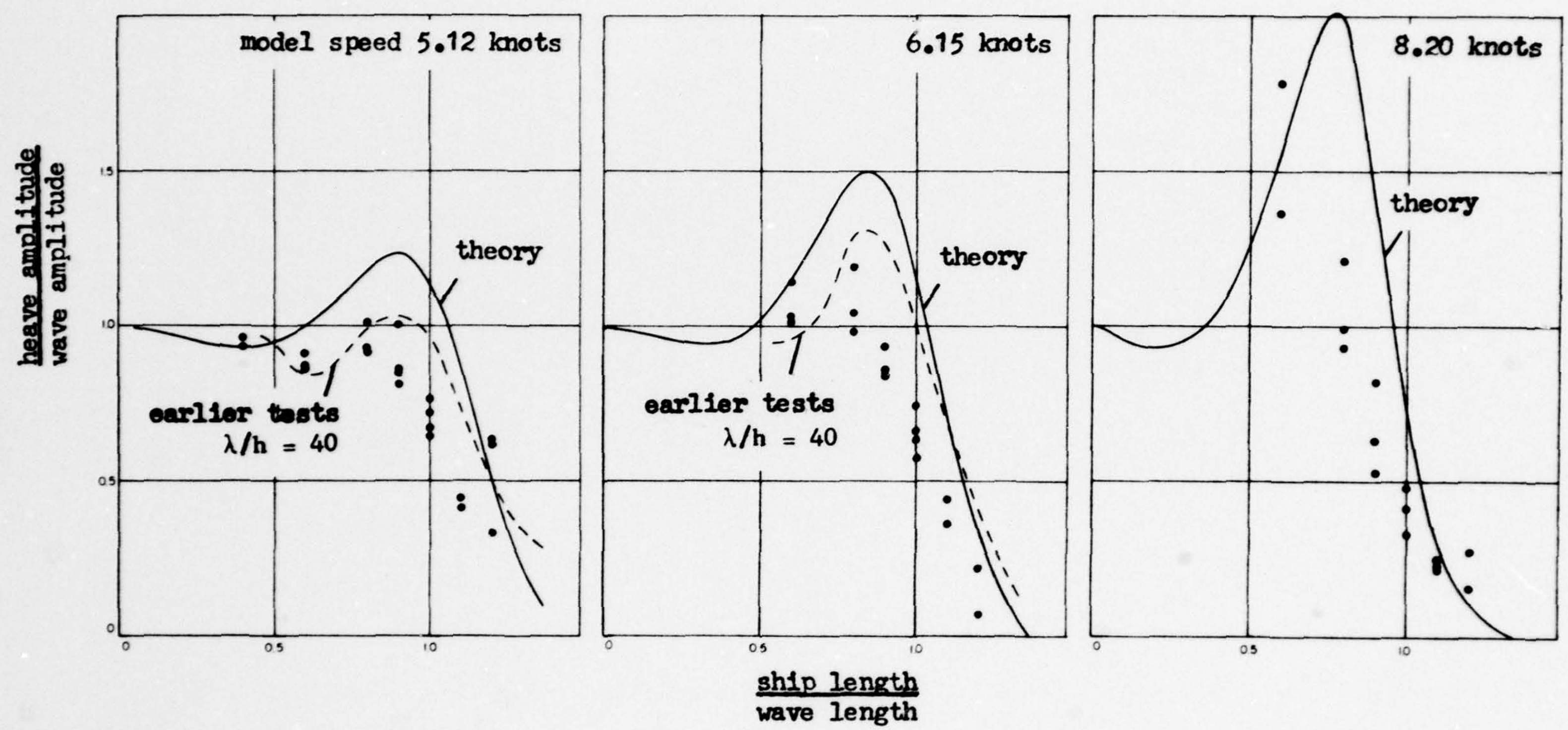

Fig.2 Calculated heave response curves and heave response measured in regular waves

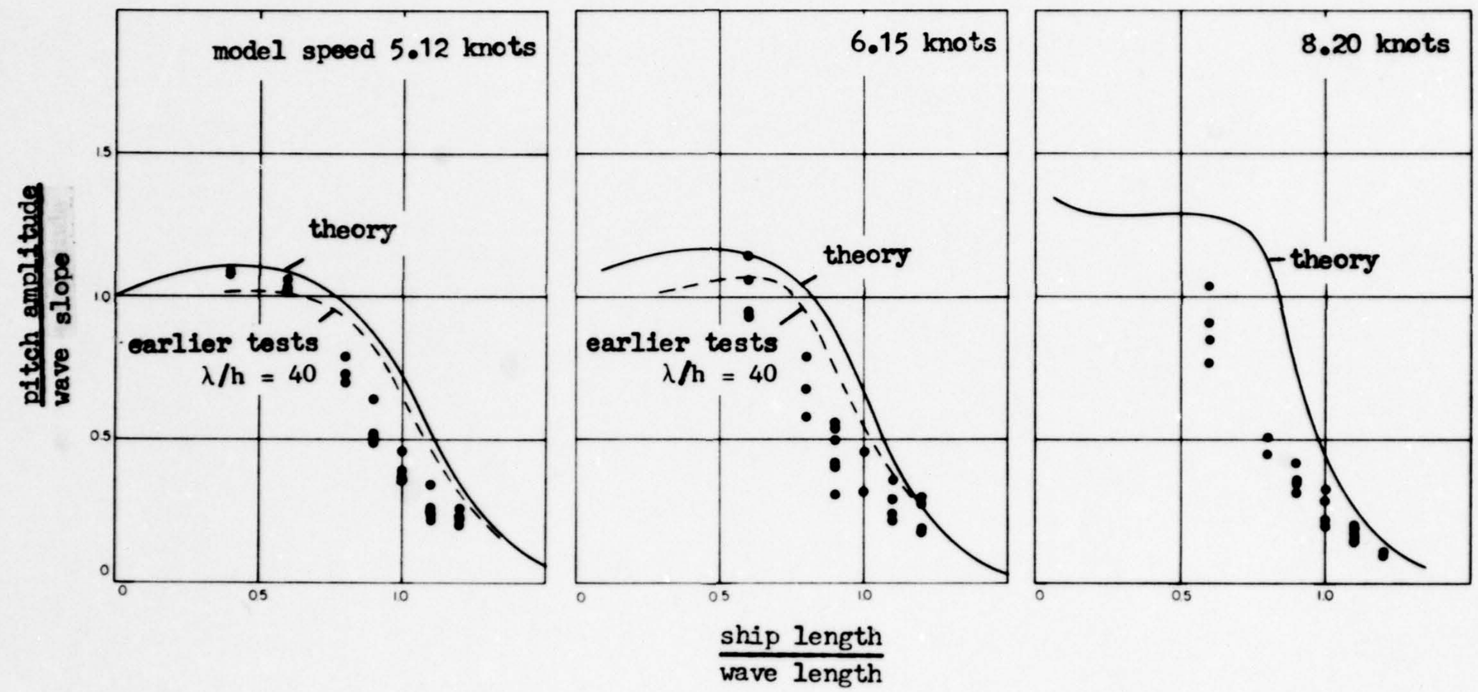

Fig. 3 Calculated pitch response curves and pitch response measured in regular waves

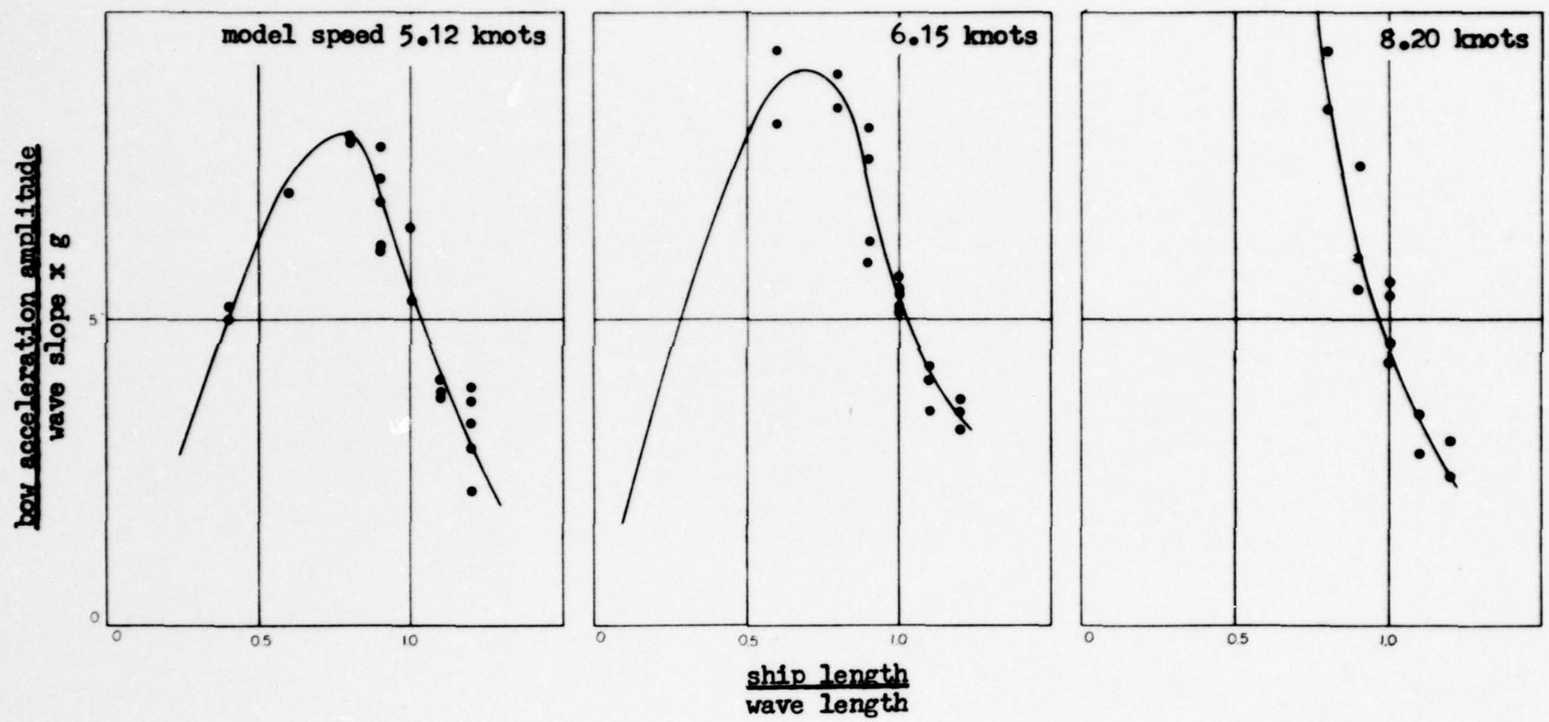

Fig.4 Measured response curve of vertical acceleration at station 1 1/2.

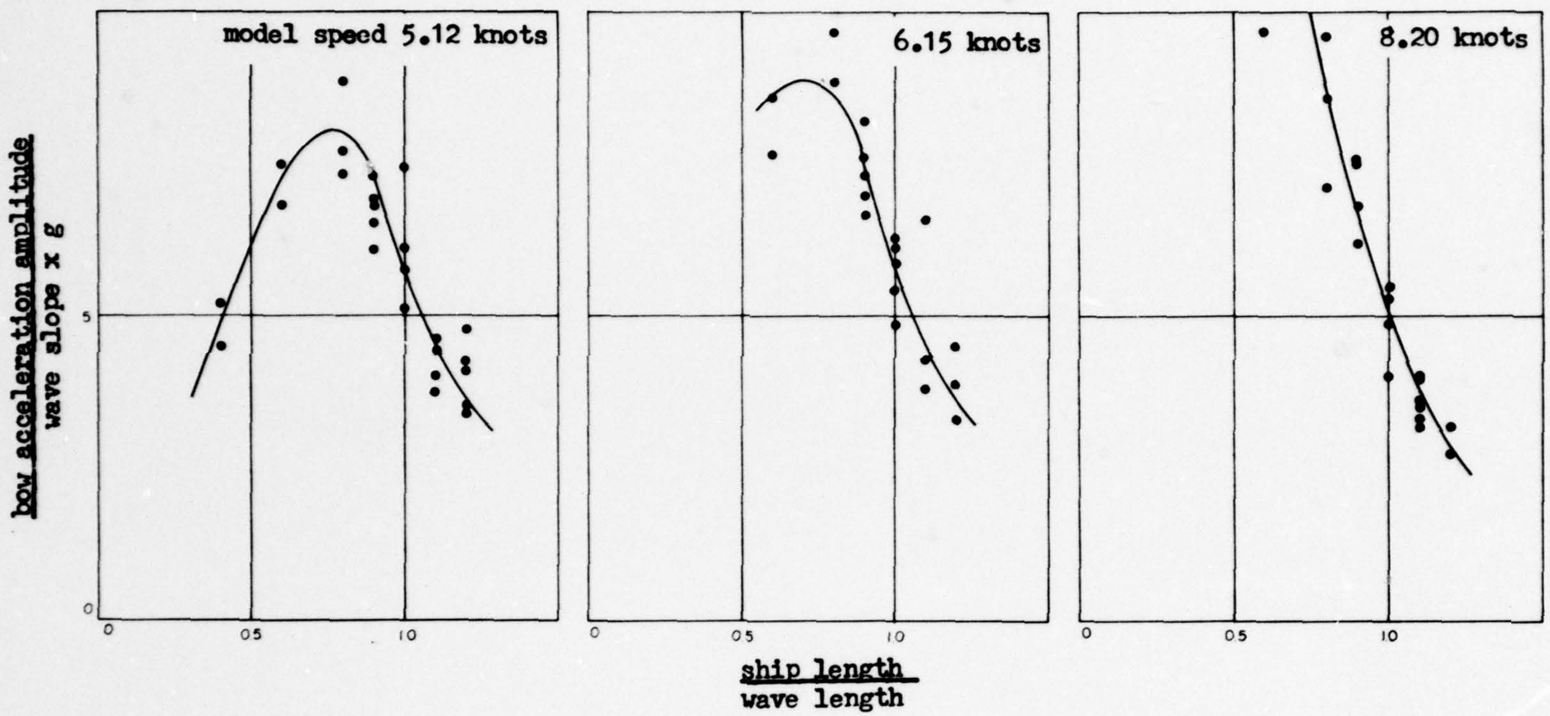

Fig.5 Measured response curve of vertical acceleration at station 3/4 .

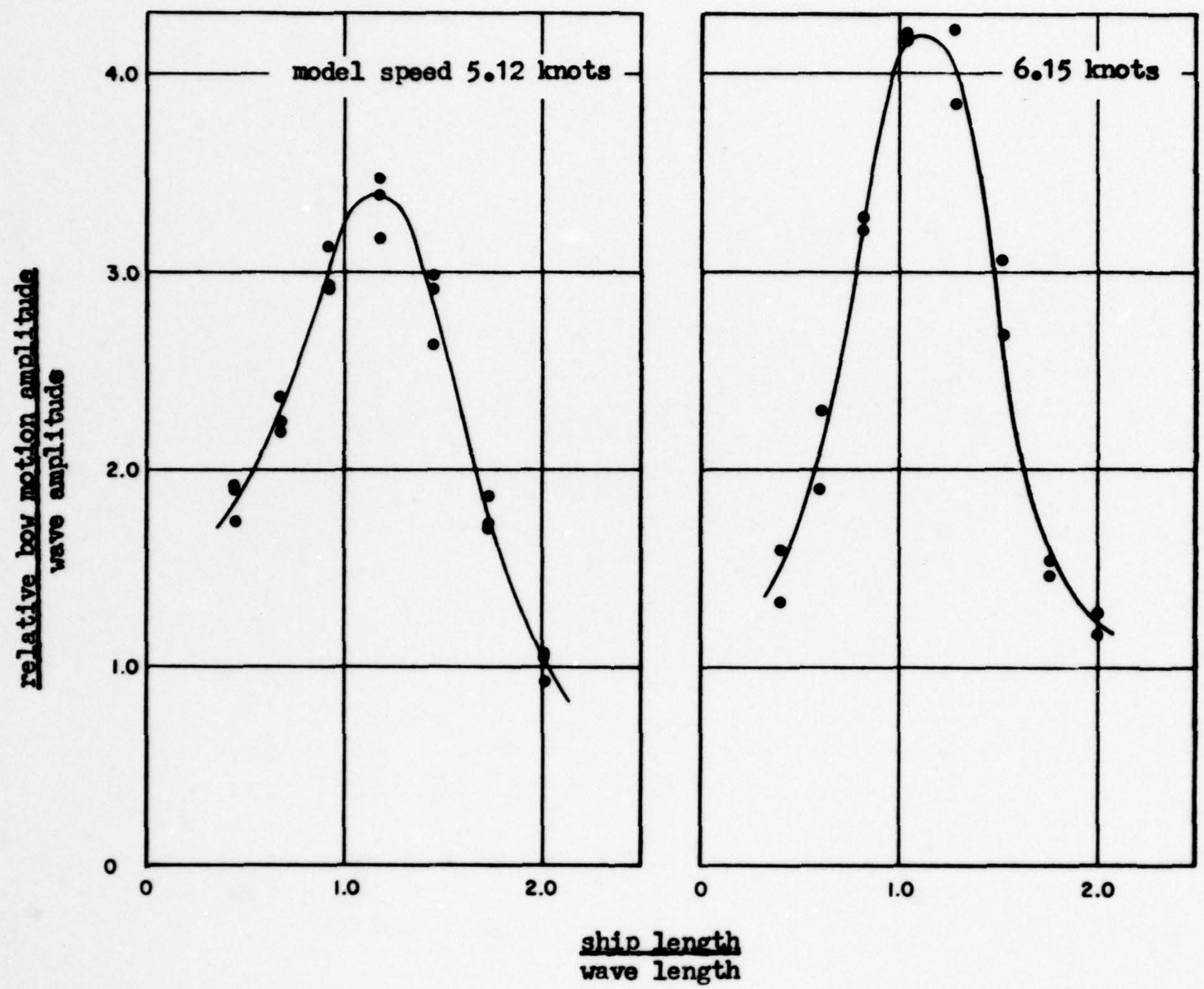

Fig.6 Measured response curve of relative motion between bow and water surface at Station 3/4.

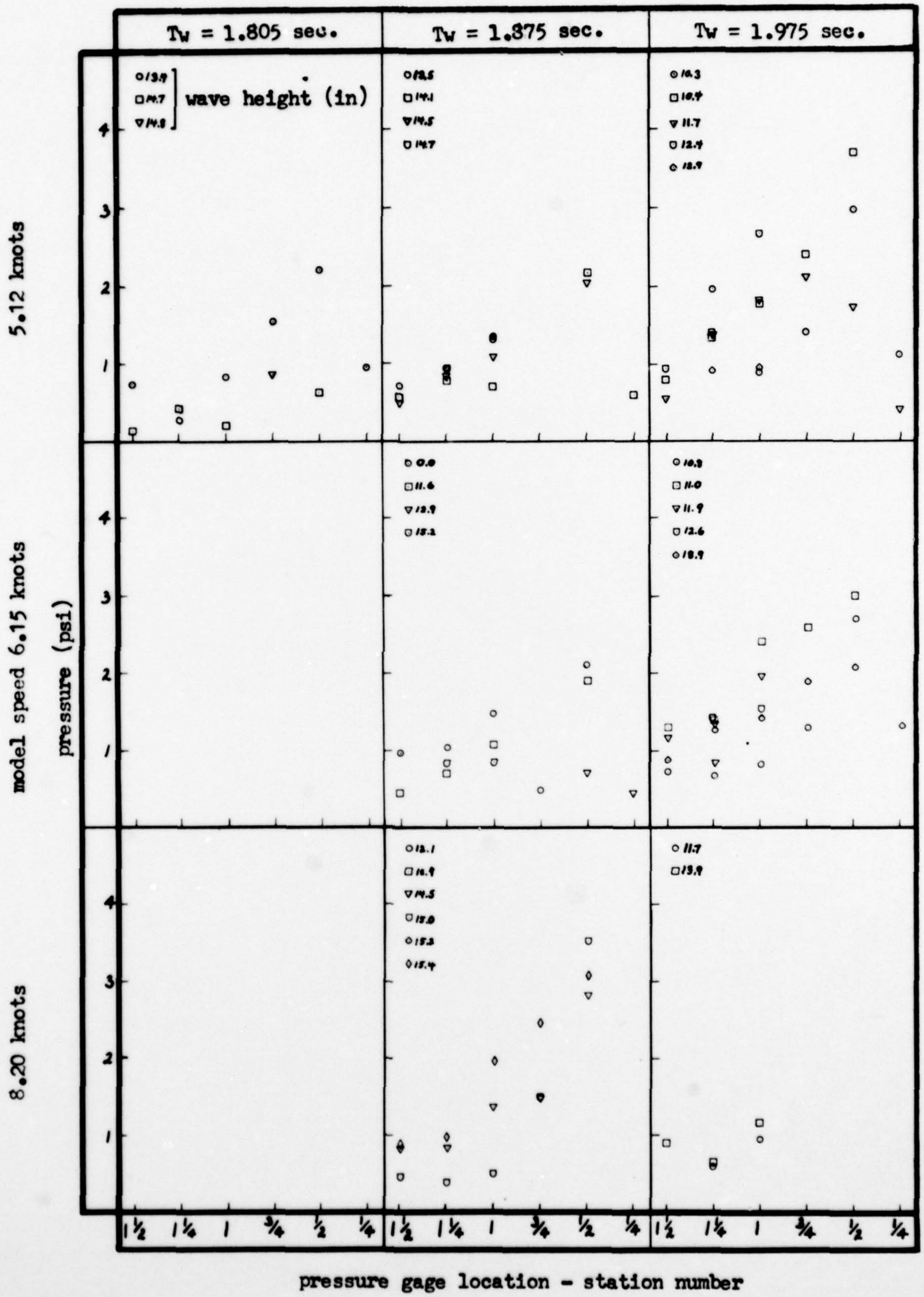

Fig.7a Slamming pressure along the keel,measured in regular waves (model scale).

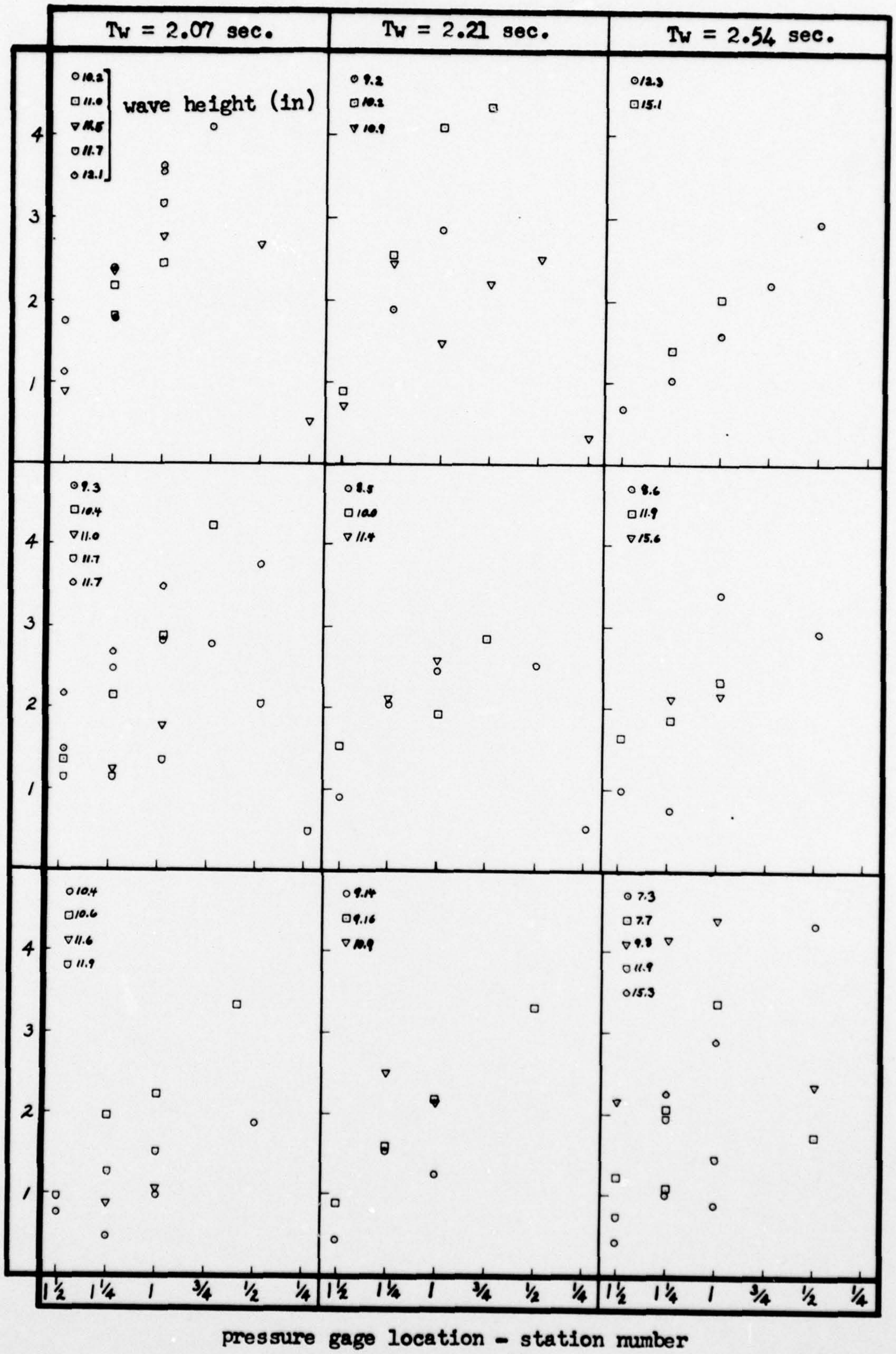

Fig.7b Slamming pressure along the keel,measured in regular waves (model scale)

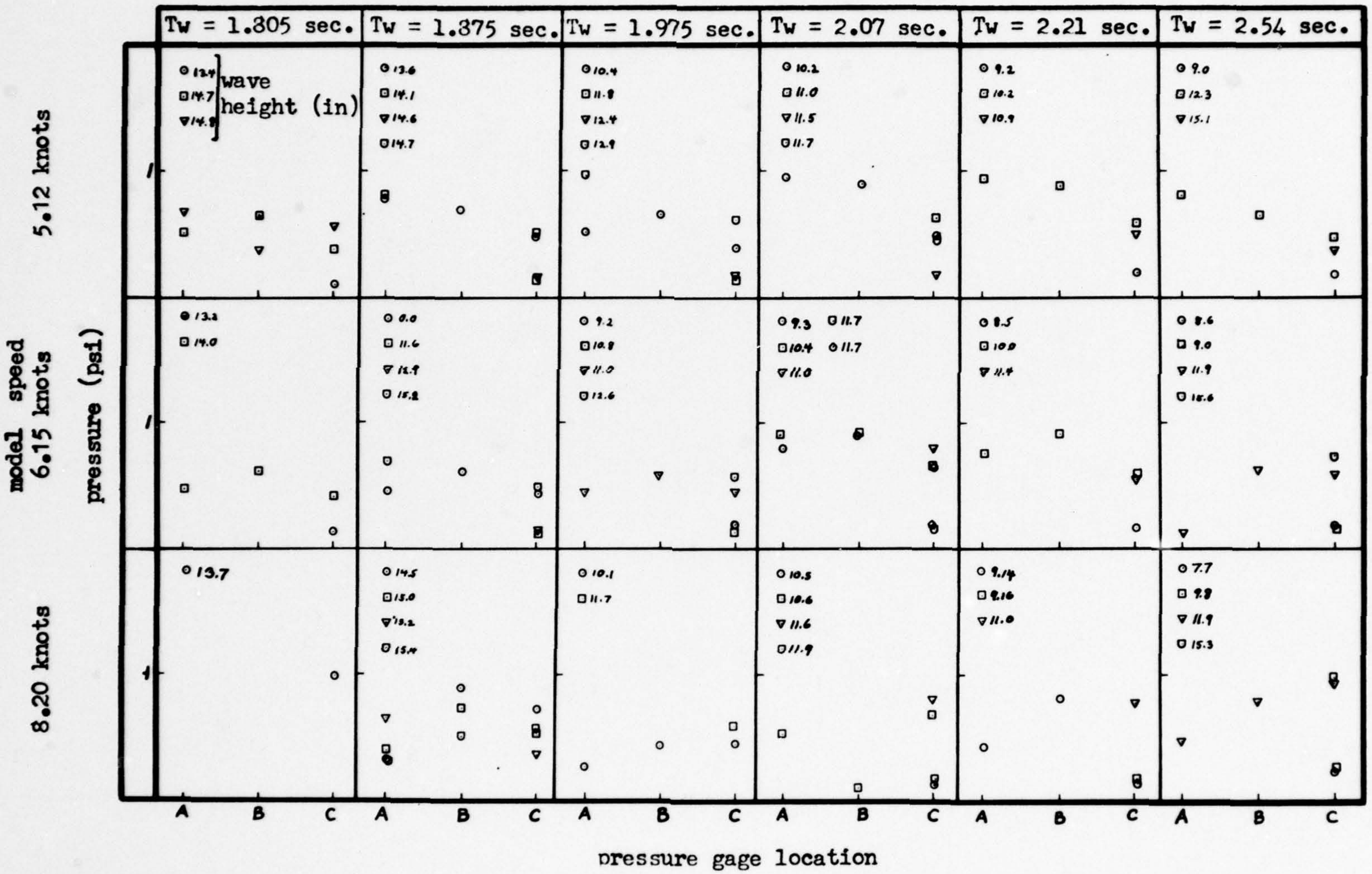

Fig.8 Slamming pressure along the girth, station 3/4 (model scale)

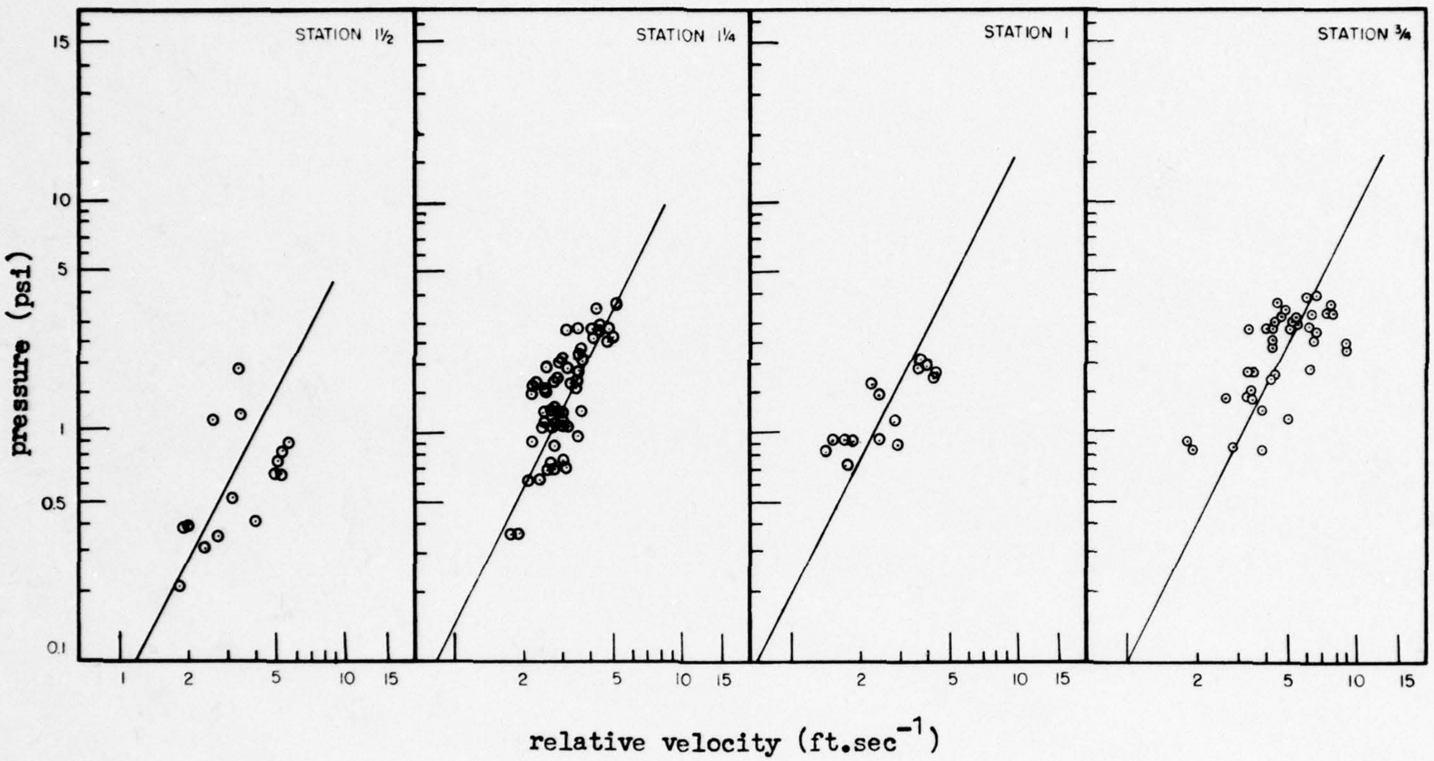

Fig.9 Slamming pressure as a function of relative velocity

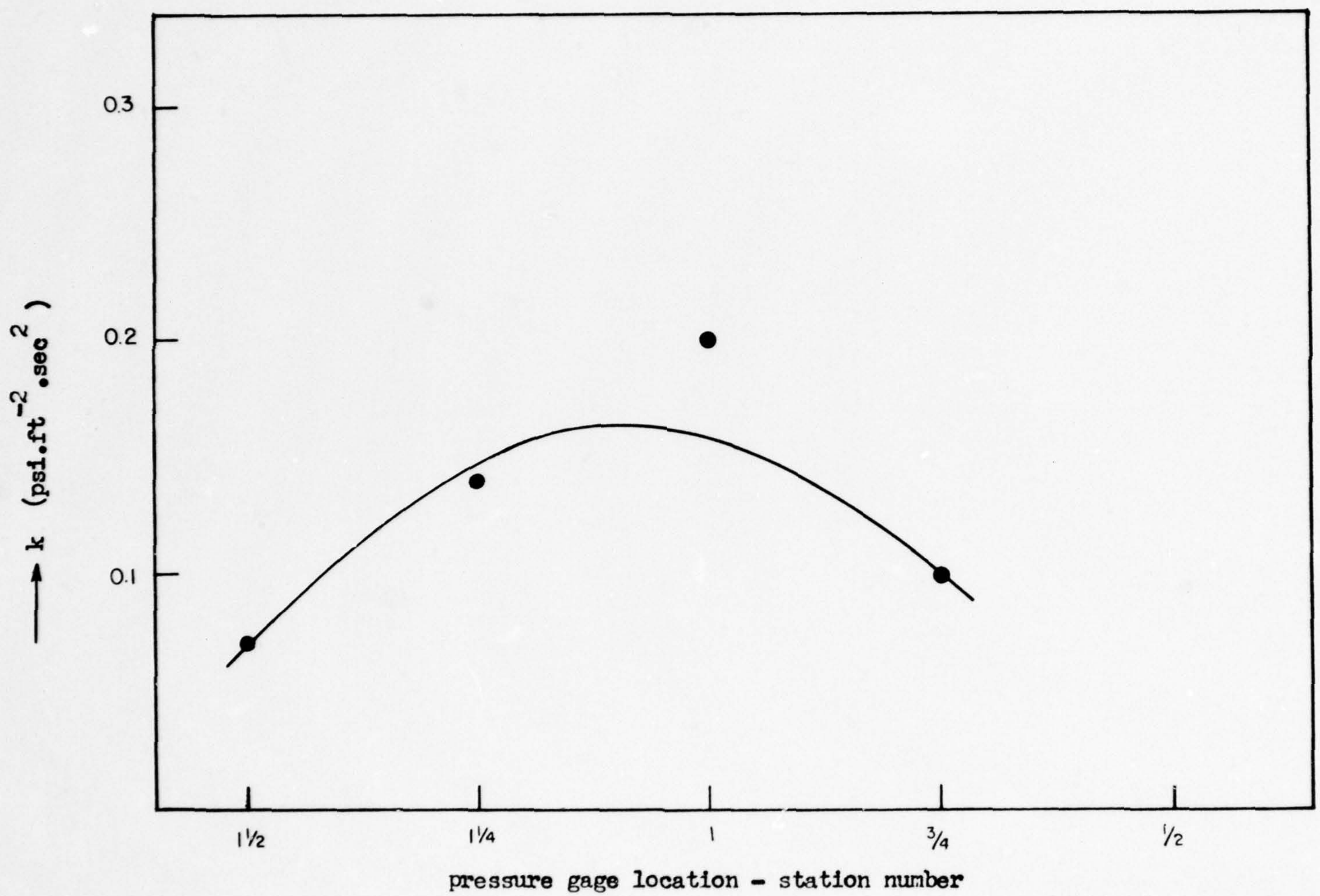

Fig.10 Variation of the k-factor along the keel

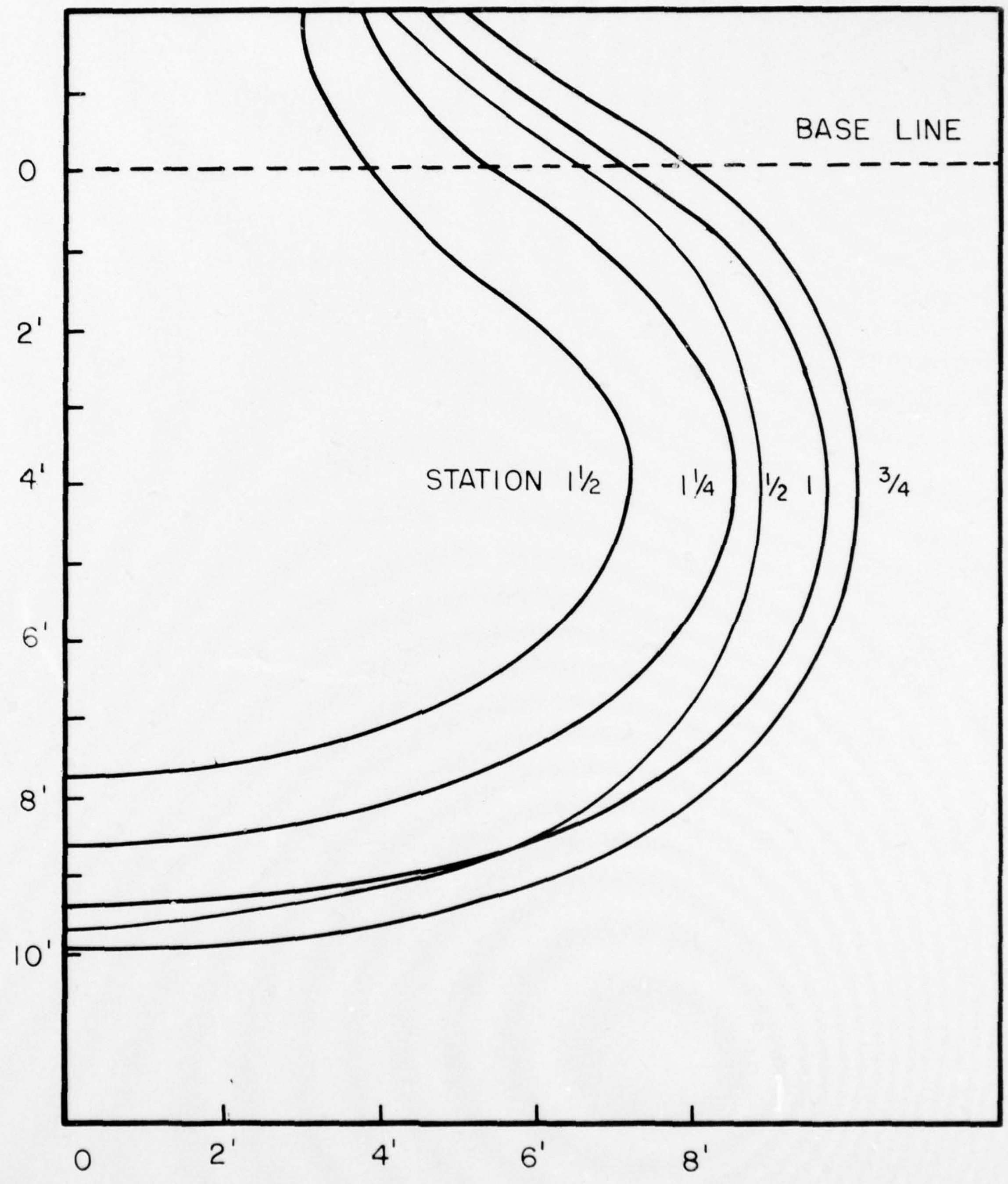

Fig.11 Shape of some of the sections where pressure was measured

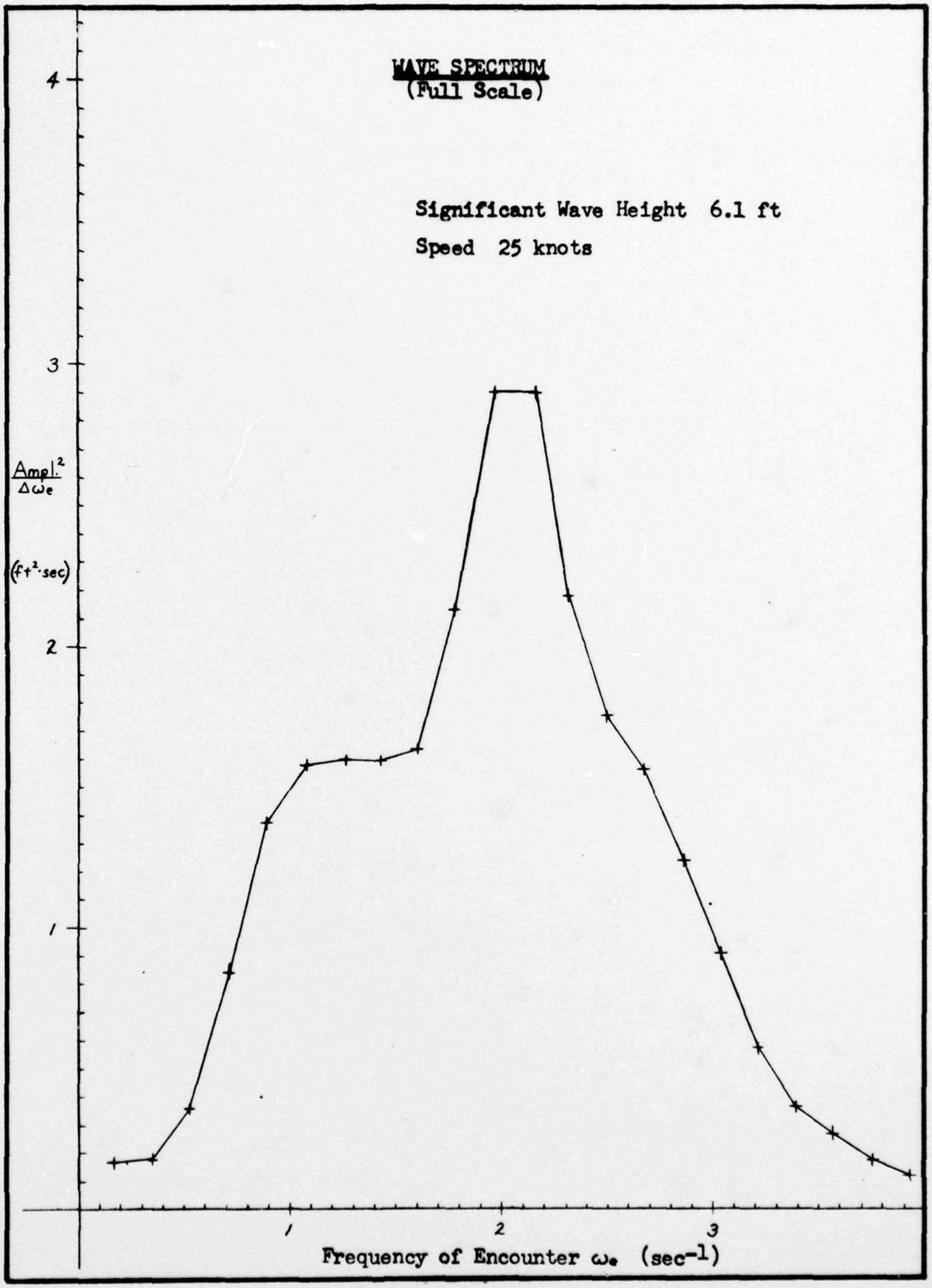

Fig.12 Spectrum of the irregular sea corresponding to Sea State 4

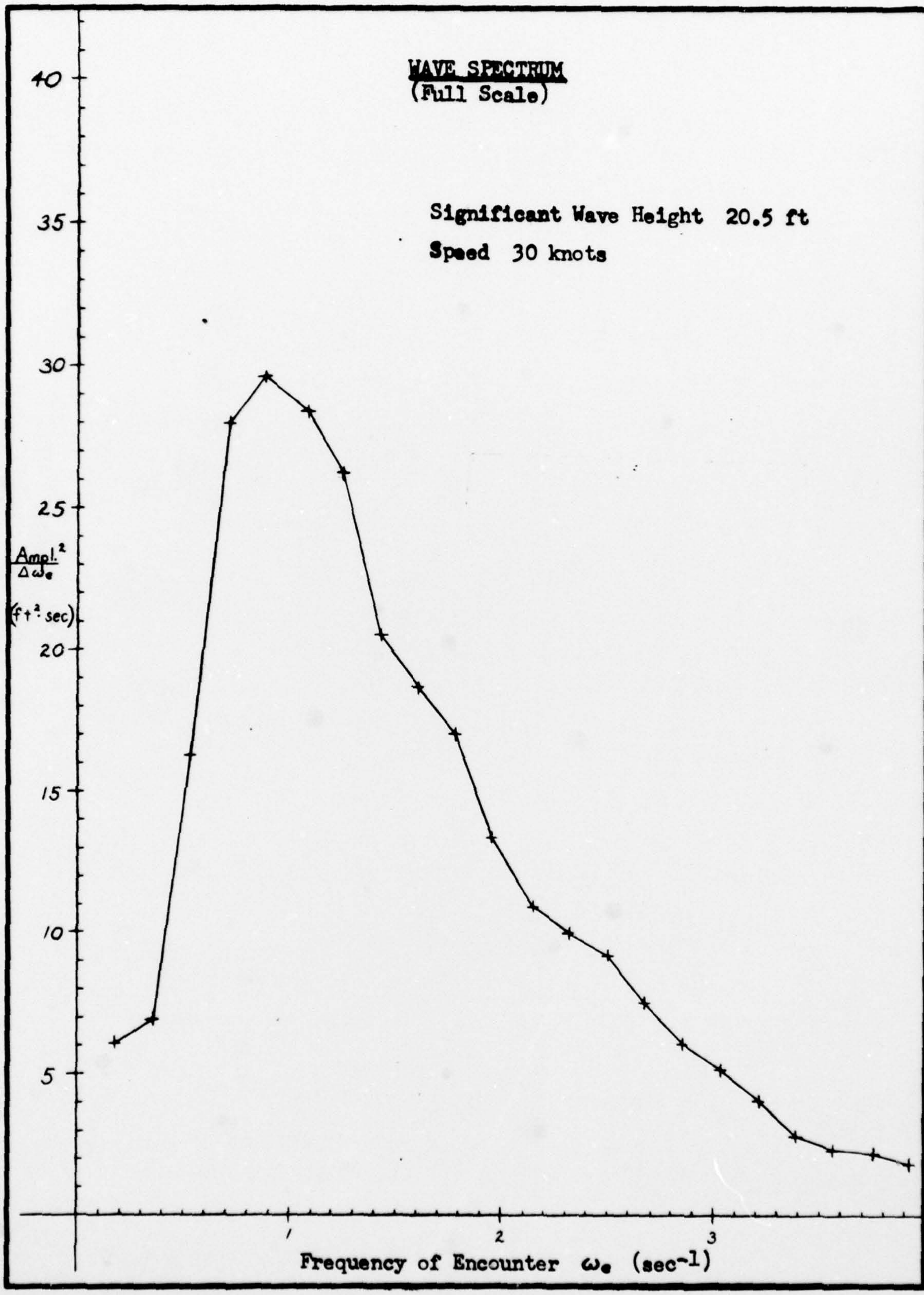

Fig.13 Spectrum of the irregular sea corresponding to Sea State 6-7