SSC-202

MIDSHIP WAVE BENDING MOMENTS IN A MODEL OF THE MARINER-CLASS CARGO SHIP "CALIFORNIA BEAR" RUNNING AT OBLIQUE HEADINGS IN REGULAR WAVES

SHIP STRUCTURE COMMITTEE

NOVEMBER 1969

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SECRETARY
SHIP STRUCTURE COMMITTEE
U.S. COAST GUARD HEADQUARTE
WASHINGTON, D.C. 20591

November 1969

Dear Sir:

The Ship Structure Committee has sponsored a series of studies relating bending moments and strains on towing-tank models to those on actual ships. The enclosed report presents towing-tank data on the *California Bear* for which full-scale data has been previously obtained.

This report is being distributed to persons interested in the Ship Structure Committee's work. Your comments would be appreciated.

Sincerely,

C. P. Murphy
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

SSC-202

Technical Report

on

Project SR-165

"Bending Moment Determination"

to the

Ship Structure Committee

MIDSHIP WAVE BENDING MOMENTS IN A MODEL OF THE MARINER-CLASS CARGO SHIP *CALIFORNIA BEAR* RUNNING AT OBLIQUE HEADINGS IN REGULAR WAVES

by

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Stevens Institute of Technology
Hoboken, New Jersey

under

Department of the Navy
NAVSEC Contract N00024-67-C-5218

U. S. Coast Guard Headquarters
Washington, D. C.

November 1969

ABSTRACT

Vertical and lateral wave bending moments were measured at the midship section of a 1/96-scale model of the C4-S-1A MARINER-class cargo ship CALIFORNIA BEAR. The model was self propelled through a ship speed-range of 10 to 22 knots at seven headings to regular waves of lengths between 0.2 and 2.0 times the length between perpendiculars; moderate wave heights not exceeding 1/50 of the model length were used. Results are presented in charts of bending-moment-amplitude/wave-amplitude versus ship speed, with wave length as the parameter. Two ship loading conditions, representative of actual westbound and eastbound trans-Pacific voyages are covered.

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INTRODUCTION

In 1960 the Ship Structure Committee authorized Davidson Laboratory to initiate a research program entitled "Bending Moment Determination," using ship-model tests to investigate hull bending moments in regular and irregular waves.

The initial phase of this program, Project SR-157, covered investigations of trends of midship bending moment as a function of wave steepness in models of (1) a MARINER-class cargo ship with variations in freeboard and weight distribution, (2) a destroyer, and (3) a tanker. Dalzell[1,2] concluded that, within practical operational and design limits, no dramatic upper limit of wave bending moments at amidships is to be expected as the ratio of wave height to wave length increases to a value of about 1:9.

Since this conclusion was limited to midship bending moments, and it was known that maximum moments under certain circumstances could occur elsewhere, the next phase of the study, Project SR-165, examined the longitudinal distribution of bending moments in a MARINER-class cargo-ship model in regular waves of extreme steepness. Maniar[3,4] concluded that, within practical operational limits of speed for the MARINER, maximum wave bending moments would occur in the region from amidships to 0.125L aft of amidships. Thus the practice of concentrating on midship bending moments both in design studies and in full-scale measurements appears to be justified.

Another part of the investigation involved the testing of the MARINER model in high irregular waves to obtain time history records of wave bending moment and wave elevation. Wave and bending moment energy-spectra were computed and used to derive equivalent regular-wave bending-moment "response operators" which were shown to be in reasonable agreement with response results obtained from model tests in regular waves.

Such favorable agreement inspires confidence in the alternate procedure of using a "response operator" from tests in regular waves to predict the energy spectrum of bending-moment response of either a ship model in a known wave-spectrum or a ship in a real seaway the energy spectrum of which can be determined. Before taking this latter step, however, it is necessary to demonstrate satisfactory correlation between model and ship bending-moment responses.

Over a period of years, full-scale statistical data on midship bending-moment responses have been collected by the Teledyne Materials Research Company (under Project SR-153), on several vessels including (1) the MARINER-class cargo ship CALIFORNIA BEAR operated by the Pacific Far East Line in trans-Pacific service between San Francisco and Yokohama and (2) the cargo ship WOLVERINE STATE operating on the United States-Northern Europe route in the North Atlantic Ocean. Davidson Laboratory proposed the conduct of scale-model tests of these vessels at various speeds and headings in regular waves, to obtain bending-moment response operators. Webb Institute of Naval Architecture, in a parallel effort, proposed an analysis of statistical data for the ships and the prediction of ship bending-moment statistics from Davidson Laboratory's model-test results. The tests of the WOLVERINE STATE model have been reported in Reference 5.

This report describes the tests of the CALIFORNIA BEAR model at Davidson Laboratory, under Project SR-165, and presents the wave-bending-moment results which have been used by Webb Institute in their model-ship correlation program under Project SR-177.

Two ship loading conditions were used in this experiment. Both were taken from the reported cargo and tankage distributions for actual trans-Pacific voyages of the CALIFORNIA BEAR, on which the Teledyne Research Corporation had installed instruments to collect strain data on ship bending moments.

DESCRIPTION OF THE EXPERIMENT

Model

The tests were conducted on a 65-inch (1/96-scale) fiberglass model of a standard MARINER-class cargo vessel. This model was originally built for the tests reported in Reference 3. Figure 1 shows the body plan. The model was cut at a point corresponding to 260 feet aft of the ship's fore perpendicular. The two halves of the model were connected by the standard Davidson Laboratory two-component bending-moment balance, illustrated in Fig. 2. This balance consists of two pedestals with an integral flexure beam of cruciform cross-section milled from a single block of aluminum alloy. The componental deflections of the beam in its vertical and lateral planes of symmetry are mechanically amplified by linkages and sensed by linear variable differential transformers. Figure 3 is a photograph of the model in profile and a photograph of the setup of the bending-moment balance across the model cut. The midships cut was sealed with a thin sheet of rubber fixed to the hull with vinyl-plastic electrical tape.

An electric propulsion motor was installed to turn a stock four-bladed propeller of approximately the desired scale diameter. The rudder was built to scale and was operated by a servomotor which formed part of an automatically controlled steering system.

Loading Conditions

Pacific Far East Line made available complete records of cargo and tankage distributions for nine voyages covering two years of instrumented operation between January 1966 and December 1967.

Two representative loading conditions were used for ballasting the model. For the first condition, representing a full load of cargo typical of a westbound voyage (San Francisco to Yokohama) of the CALIFORNIA BEAR, the loading condition chosen was that of westbound voyage number 33 of October 1967. The mean draft on this voyage was nearly identical to the average of the mean drafts of nine westbound voyages, numbers 25 through 33. Figure 4 is a weight distribution diagram for westbound voyage 33, and shows a displacement of 16,840 tons at a mean draft, at mid-voyage, of 24.6 feet with a trim of 1.8 feet by the stern.

The second condition was meant to represent a low-density, dry-cargo loading typical of an eastbound voyage from Yokohama to San Francisco. The average of the displacements of the nine sample eastbound voyages was 12,000 tons. This value was too low to be simulated on the model. To facilitate proper ballasting of the model, the cargo-loading of eastbound voyage 25 of March 1966 was chosen. Figure 5 is the weight distribution diagram for this voyage and shows a displacement of 13,900 tons at a mean draft, at mid-voyage, of 20.9 feet with a trim of 3.29 feet by the stern.

Reported cargo and tankage distributions were used to simulate each loading condition on model scale. Each half of the model was ballasted to the desired scaled values of weight, LCG, and pitch gyradius. Gyradius was checked by suspending each model-half from a knife edge, oscillating it as a compound pendulum, and measuring its natural period. The gyradius was calculated from this period and the distance from the knife-edge to the CG. Tare weights were substituted for the bending-moment balance to permit separate ballasting of the model-halves. The vertical center of gravity of each half was adjusted to a common value based

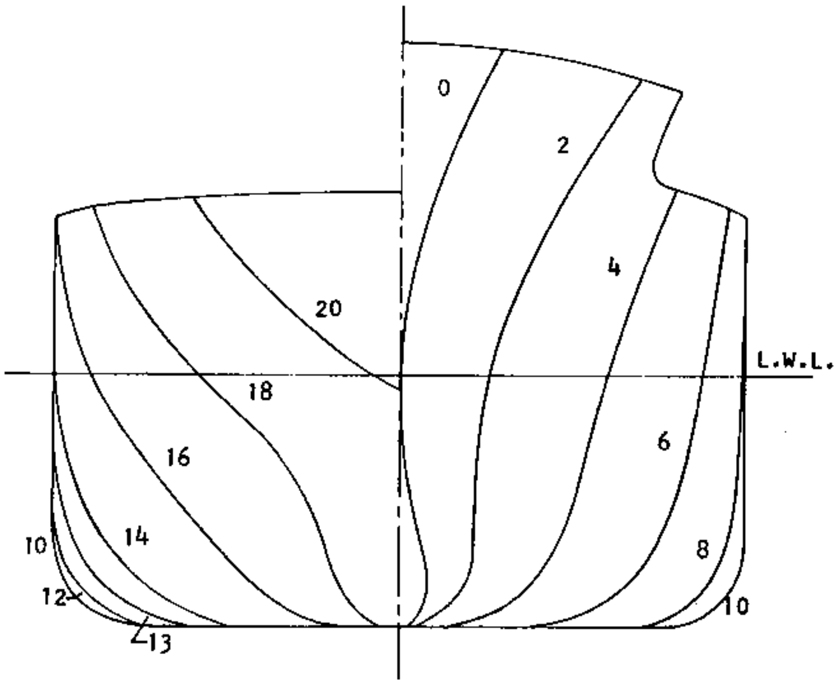

Fig. 1. Body Plan of CALIFORNIA BEAR

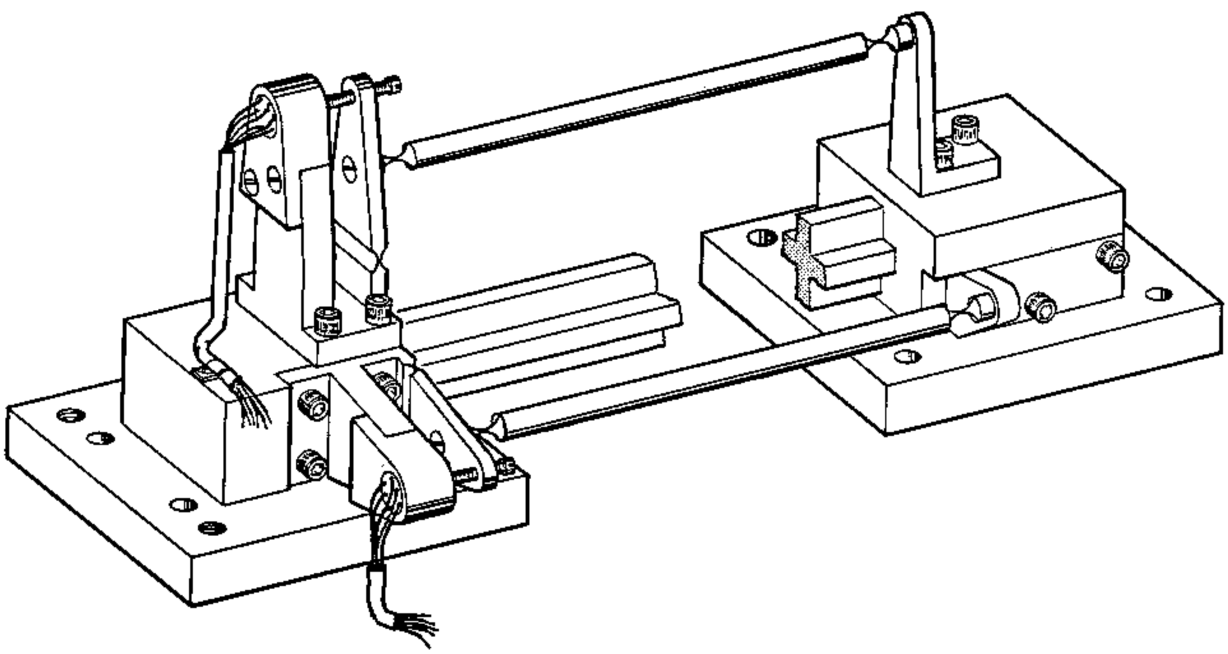

Fig. 2. Vertical and Lateral Bending Moment Balance

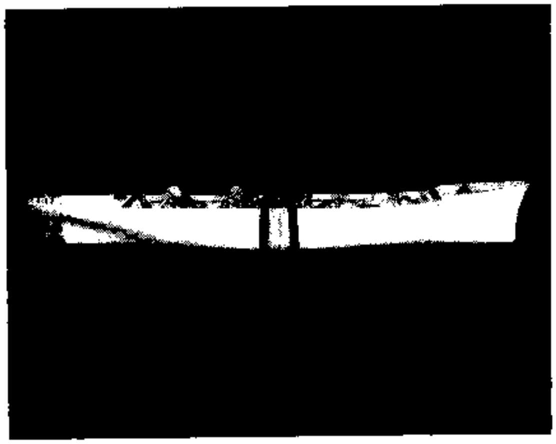

Fig. 3. Profile of CALIFORNIA BEAR

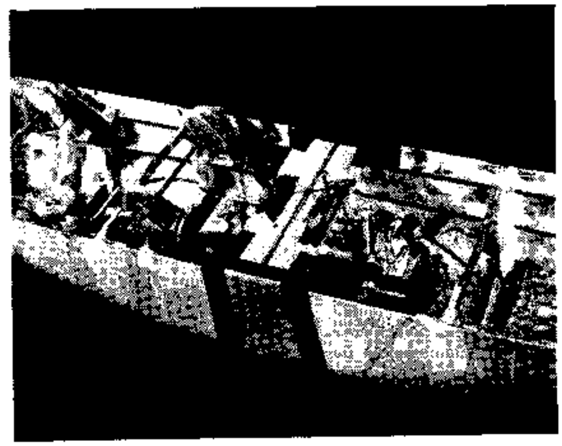

Fig. 3. Bending Moment Balance in Position Across Model Cut

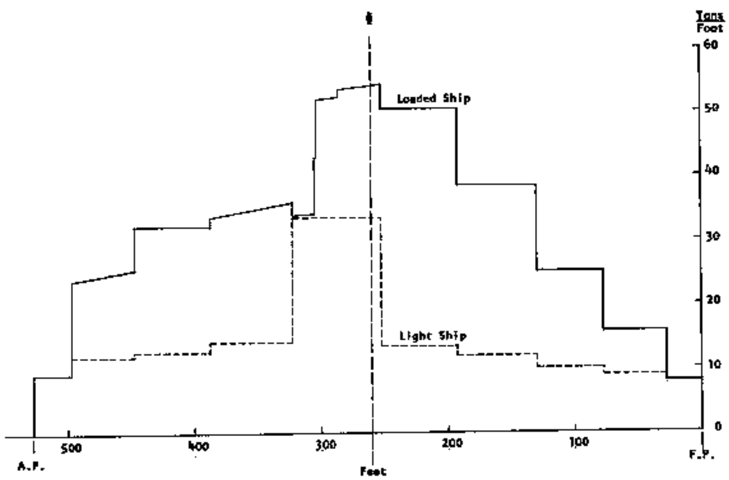

Fig. 4. Weight Distribution Diagram Displacement: 16,840 Tons Drafts: 23.70' Fwd, 25.55' Aft

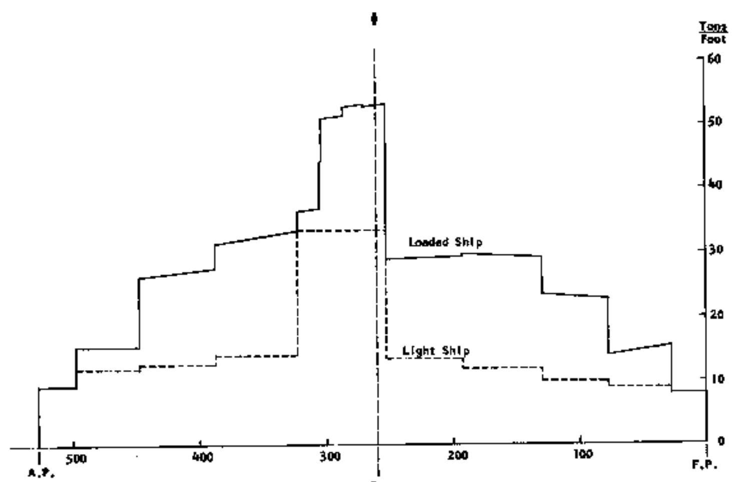

Fig. 5. Weight Distribution Diagram Displacement: 13,900 Tons Drafts: 19.25' Fwd, 22.55' Aft

on the reported loading. Ballast was adjusted laterally to obtain the scaled value of the natural rolling period of the complete model. The ship characteristics for the two loading conditions are tabulated below.

TABLE OF SHIP CHARACTERISTICS

Length Between Perpendiculars, ft . . . 528.0
Beam, ft 76.0

	Eastbound	Westbound
Displacement, long tons	13,900	16,840
Draft		
Fore perpendicular, ft	19.25	23.70
Aft perpendicular, ft	22.55	25.55
Mean, ft	20.90	24.62
LCG aft of amidships, ft	9.9	8.8
Pitch radius of gyration, ft	123.0	123.6
Natural rolling period, sec	14.4	16.7
Forebody		
Displacement, long tons	6,129	8,073
LCG forward of amidships, ft	105.0	98.2
Pitch gyradius, ft	68.9	66.5
VCG above baseline, ft	24.0	27.0
Afterbody		
Displacement, long tons	7,771	8,767
LCG aft of amidships, ft	100.5	107.2
Pitch gyradius, ft	70.3	71.4
VCG above baseline, ft	24.0	27.0

Apparatus

The experiment was conducted in Davidson Laboratory's Tank 2 (75' x 75' x 4.5'). This facility includes a wavemaker along one 75-foot side of the tank, a wave absorber along the opposite side, and a movable bridge spanning the tank. The bridge supports a monorail carriage driven by a servo-controlled motor.

Suspended from the carriage is a six-degree-of-freedom motions apparatus which is servo-driven to follow a self-propelled, automatically steered model in waves. A vertical heave rod rides in bearings on the apparatus and is attached to the model through a three-degree-of-freedom gimbal. Power and control wires for the rudder and propulsion motors, as well as signal cables from the bending-moment balance, are led upward to the carriage and thence to a recording and control station at tankside. The moment-balance output signals were fed through a Sanborn 350-1100 Series carrier amplifier system, and then through Krohn-Hite Model 335 low-pass active filters to minimize high-frequency noise in the records. The signals were then displayed by a visicorder Model 1108 as time histories on oscillograph chart paper.

The heights of all regular waves were calibrated before model tests, by traversing the "reading" section of carriage travel with a resistance-type wave probe at the model location. The resulting records of wave-elevation time history were reduced to obtain the average wave height for each wave length at each bridge heading. During each test of the model, the wavemaker speed-control was adjusted to maintain the wave period used during the wave calibrations. This procedure was preferred to the measuring of the wave elevation during each model run, because it is known that model-generated waves can influence wave-probe readings.

Test Procedure

The bridge was positioned for model headings of 180 degrees (head seas), 150 degrees, 120 degrees, 60 degrees, 30 degrees, and zero degrees. At each heading angle, at least eight wave lengths were tested and a minimum of three speeds in the range of 10-22 knots, full scale. A nominal wave height of 1/50 of the model length was used for all waves except the relatively short ones, for which a reduced height was substituted. The mean speed of the model was averaged over a distance of about four model lengths (20 feet).

The bending moment balance was calibrated periodically by applying known moments to the model while it was afloat.

Data Reduction and Presentation

Time histories of vertical and lateral bending moments were reduced to obtain the average range of moment during the 20-foot interval of model travel. The phase between the two moments was also determined.

The moment data are presented in dimensional form (bending-moment-amplitude/wave-amplitude in ft-tons/ft) as trends versus ship speed for all wave-length/ship-length ratios at a given heading angle; separate charts are presented for vertical and lateral moments. Figures A-1 through A-25 of the Appendix contain the results for the 20.9-ft mean draft condition; Figures A-26 through A-45 present the results at 24.6-ft mean draft. The reported bending moments are due solely to wave-induced loads and are measured with respect to a still-water datum. Still-water hogging moments were 86,000 ft-tons at 20.9-ft mean draft and 70,000 ft-tons at 24.6-ft mean draft; these are calculated values.

Phase is presented as the lag of lateral moment behind vertical moment for a given wave-length/ship-length ratio. The phase results are consistent with a heading-angle convention of representing head seas by 180 degrees and following seas by zero degrees. At intermediate heading angles, the waves approach the port bow (150 degrees, 120 degrees), the port beam (90 degrees), or the port quarter (60 degrees, 30 degrees). Each phase angle is the lag of starboard lateral moment behind hogging vertical moment, with a starboard lateral moment corresponding to a hull-deflection curve which is concave to starboard. The phase results are presented in tabular form in Tables A-1 and A-2 of the Appendix; a single phase value is given for each combination of heading angle and wave-length/ship-length ratio.

DISCUSSION

The object of this investigation was to obtain wave-bending-moment response data from model tests and reduce them to a form usable by Webb Institute in their prediction-and-correlation project. The moment curves and phase results in the Appendix are convenient and practicable for the purpose. Sample response-curves for the average Pacific crossing-speed of 20 knots have been constructed from the charts in the Appendix and are shown in Figs. 6-13.

The double peaks in some of the vertical-moment curves, Figs. 6, 7, 10, and 11, have been documented by investigators at the St. Albans Tank in England (most recently by Murdey[6]), but only for head seas. Murdey, with the help of analytical predictions of the inertial and hydrodynamic components of vertical moment, explains why the peaks occur. He shows that each component contributes one peak to the total vertical moment. Fukuda,[7] using an analytical prediction technique, has found double peaks in vertical-moment response curves for other heading angles.

A typical set of vertical-moment response curves, Figs. 6 and 7 for example, shows a consistent tendency for the moment peaks to shift to shorter wave lengths as the heading angle changes from 0 or 180 degrees to 90 degrees. In 180-deg head seas the peak moment occurs in a wave length about equal to the ship length. Thus it may be visualized that maximum sagging moment occurs when the trough of such a wave is at amidships with wave crests near each perpendicular. To obtain a similar wave-ship geometry, at a 120-deg heading, the wave length should be about equal to the <u>effective</u> ship length (i.e. , $L \cos \mu_w$) where L is ship length and μ_w is heading angle.

Figures 14-17 show trends of wave bending moments versus wave length/$L \cos \mu_w$ for the various heading angles at a ship speed of 20 knots. This method of plotting shows that the moment peaks generally occur at a constant value of wave length / $L \cos \mu_w$ of about 0.9.

Figures 18 and 19 show cross-plots of moments versus heading angle at a value of wave length / $L \cos \mu_w$ of 0.9; with certain exceptions, noted by asterisks, these are curves of peak values. Data were taken at too few headings to permit definition of the angles at which maximum moments occur. However, the general headings at which highest values occur are head seas for vertical moment and bow seas (about 130 degrees) for lateral moment. Both moments exhibit secondary peaks in quartering seas (about 50 degrees). These trends are in general agreement with analytical predictions for a ship of similar fineness, by Fukuda.[7]

CONCLUDING REMARKS

The primary objective of this experimental model investigation was to obtain wave-bending-moment data and to reduce them to a form usable by Webb Institute for correlation with full-scale measurements. This has been accomplished and the general trends of the results appear reasonable when compared with published data.

Analysis of the results shows that peak moments tend to occur--

(a) At a constant value of wave length/effective ship length, and
(b) In head seas for vertical moment and in bow seas for lateral moment.

In view of the self-sufficient nature of these results, it is recommended that no further model testing be conducted in connection with the CALIFORNIA BEAR project.

ACKNOWLEDGEMENTS

The authors wish to thank two persons who made significant contributions to this investigation: Mr. V. J. Bahorich, Superintending Engineer, Pacific Far East Line, for furnishing an extensive amount of information on the loading statistics of the CALIFORNIA BEAR; and Mr. M. J. Chiocco, for conducting the model investigation of the westbound loading condition.

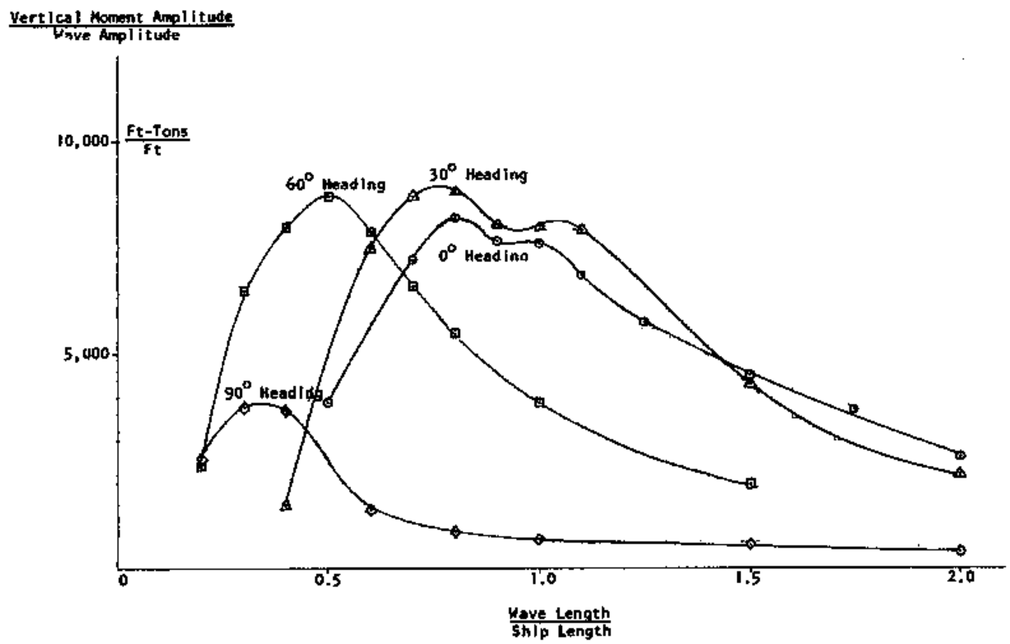

Fig. 6. Vertical Wave Bending Moments
Drafts: 19.25' Fwd, 22.55' Aft Speed:
20 Knots

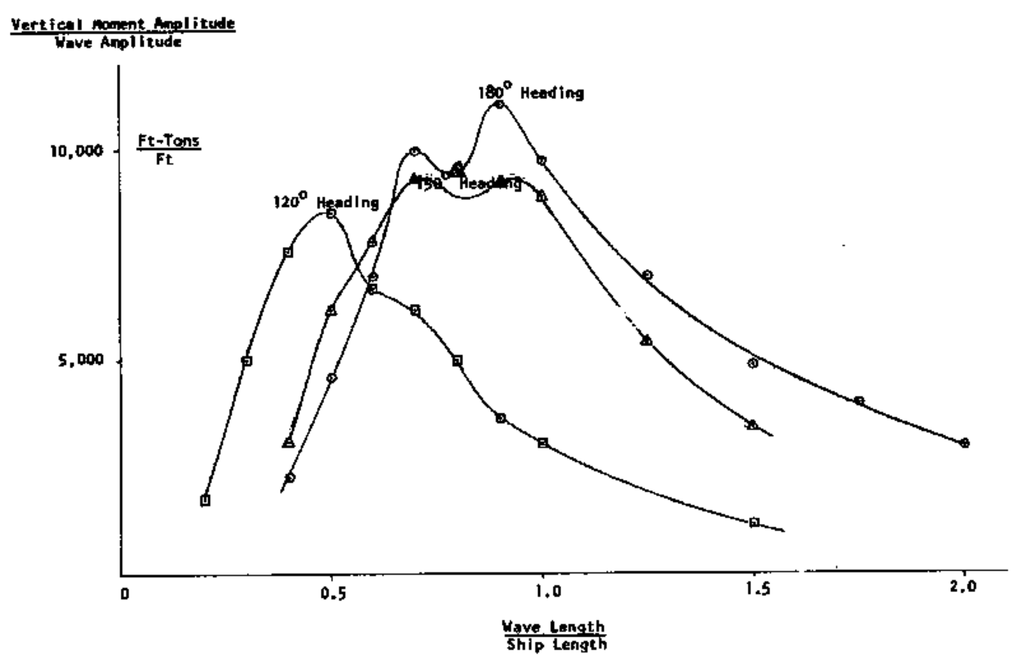

Fig. 7. Vertical Wave Bending Moments
Drafts: 19.25' Fwd, 22.55' Aft Speed:
20 Knots

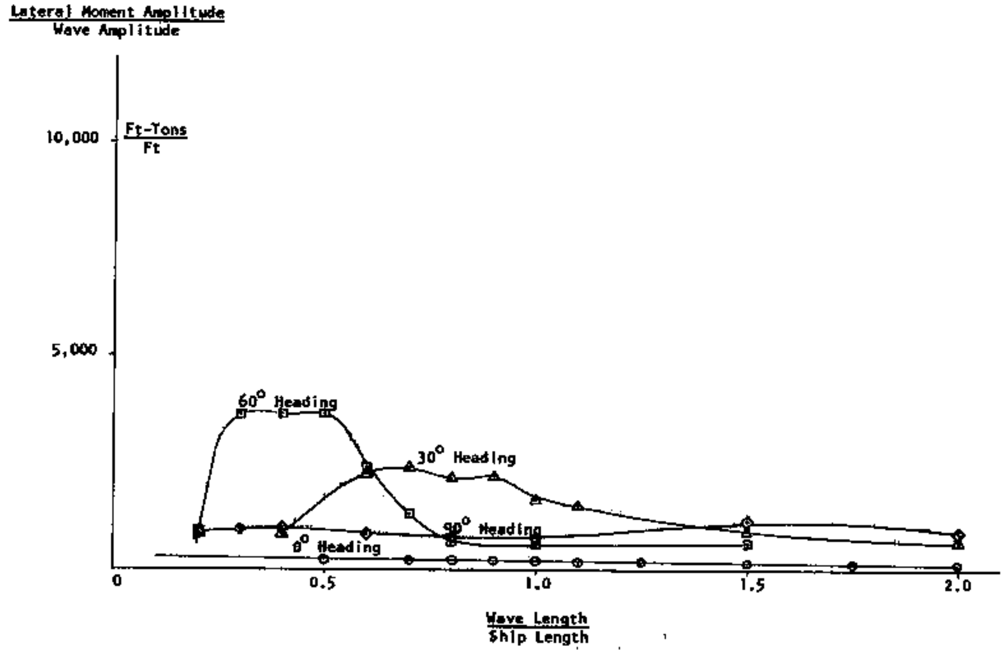

Fig. 8. Lateral Wave Bending Moments
Drafts: 19.25' Fwd, 22.55' Aft Speed:
20 Knots

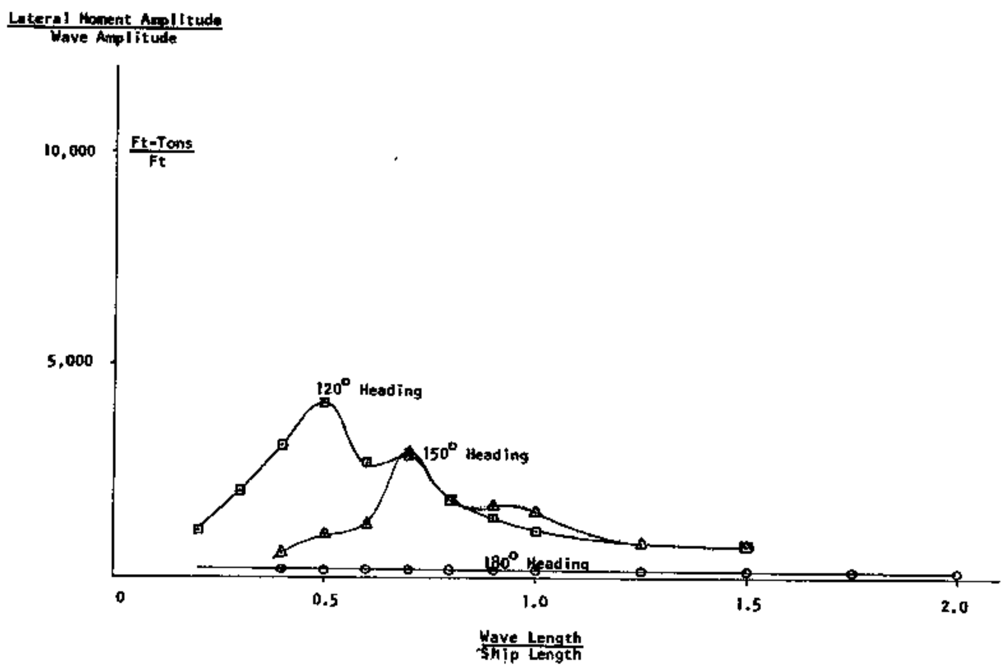

Fig. 9. Lateral Wave Bending Moments
Drafts: 19.25' Fwd, 22.55' Aft Speed:
20 Knots

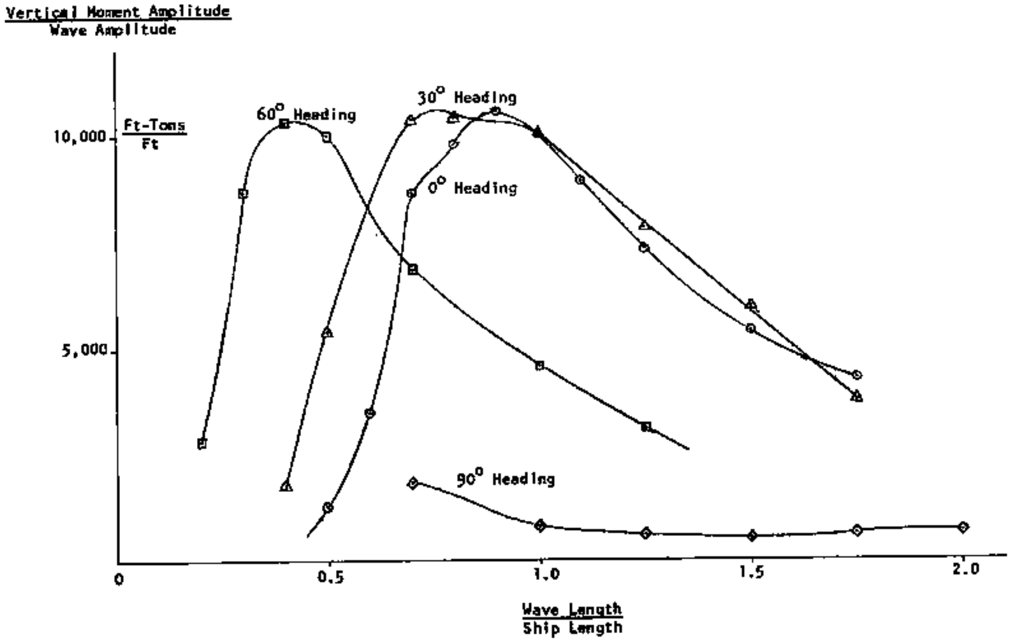

Fig. 10. Vertical Wave Bending Moments
Drafts: 23.70' Fwd, 25.55' Aft Speed:
20 Knots

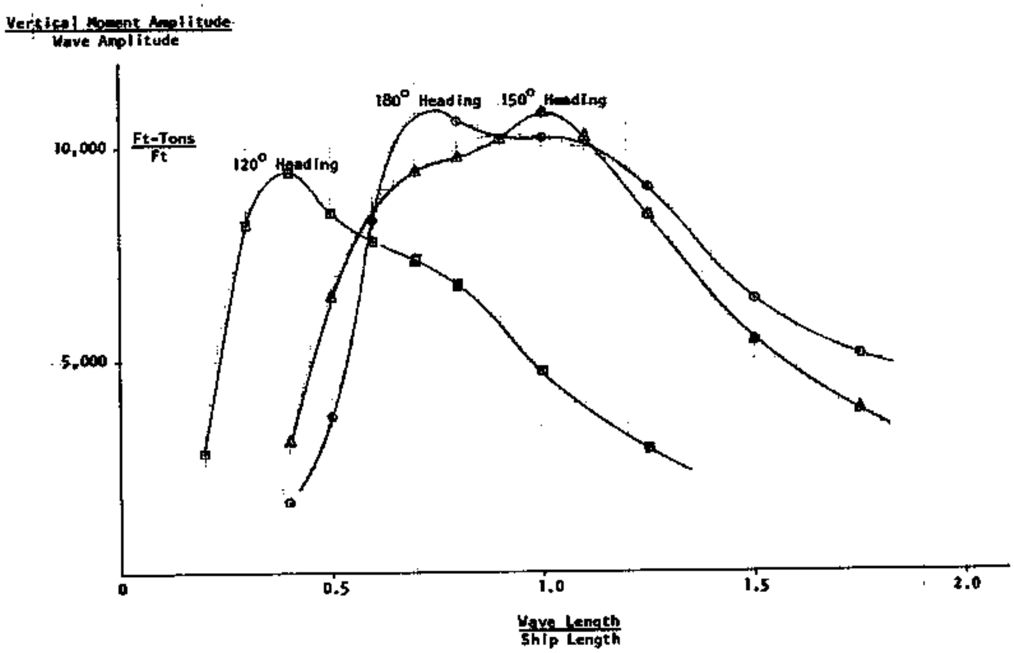

Fig. 11. Vertical Wave Bending Moments
Drafts: 23.70' Fwd, 25.55' Aft Speed:
20 Knots

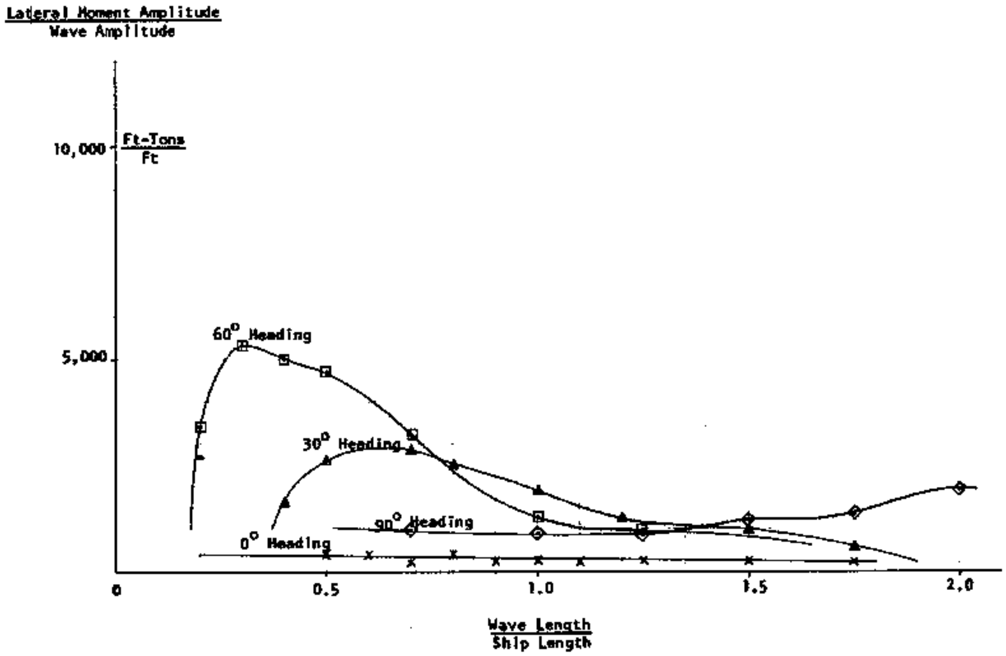

Fig. 12. Lateral Wave Bending Moments
Drafts: 23.70' Fwd, 25.55' Aft Speed:
20 Knots

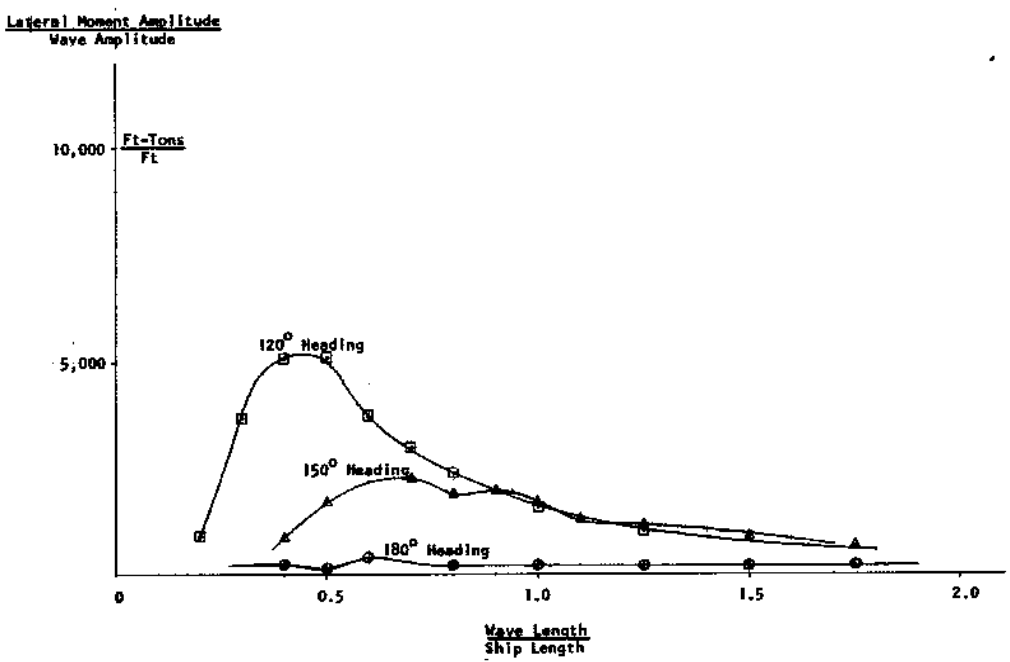

Fig. 13. Lateral Wave Bending Moments
Drafts: 23.70' Fwd, 25.55' Aft Speed:
20 Knots

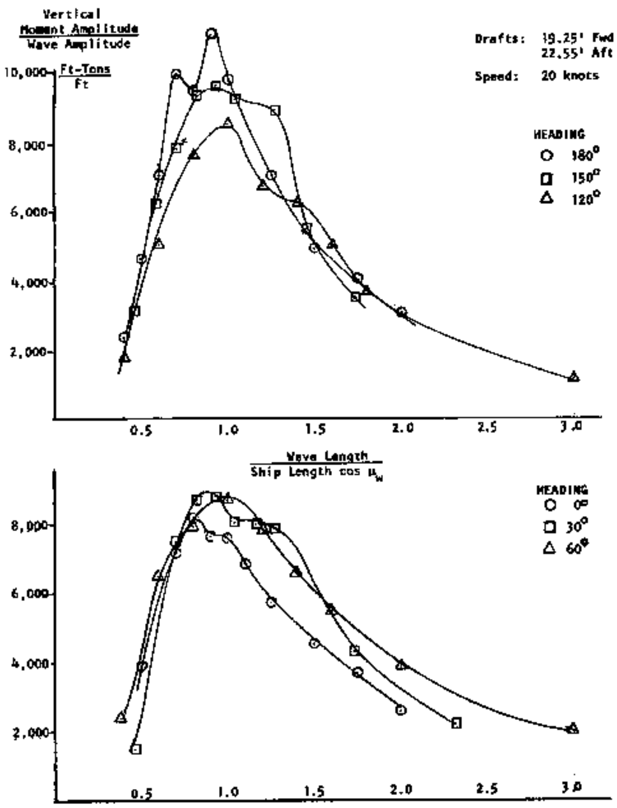

Fig. 14. Vertical Wave Bending Moments

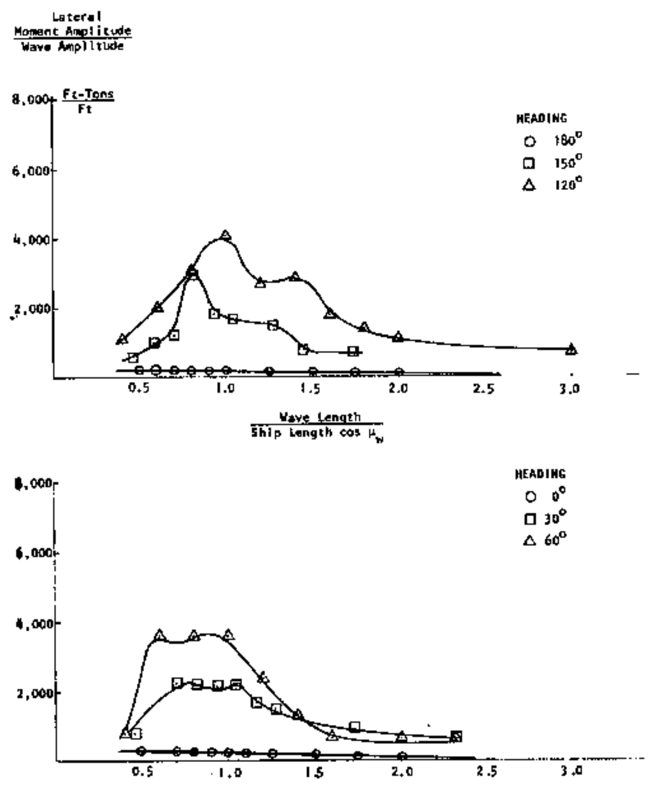

Fig. 15. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft Speed: 20 Knots

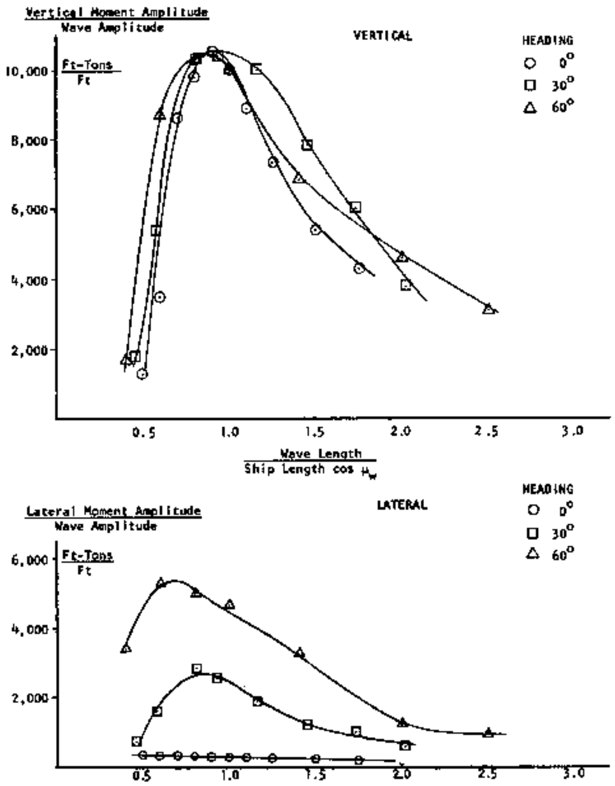

Fig. 16. Vertical and Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft Speed: 20 Knots

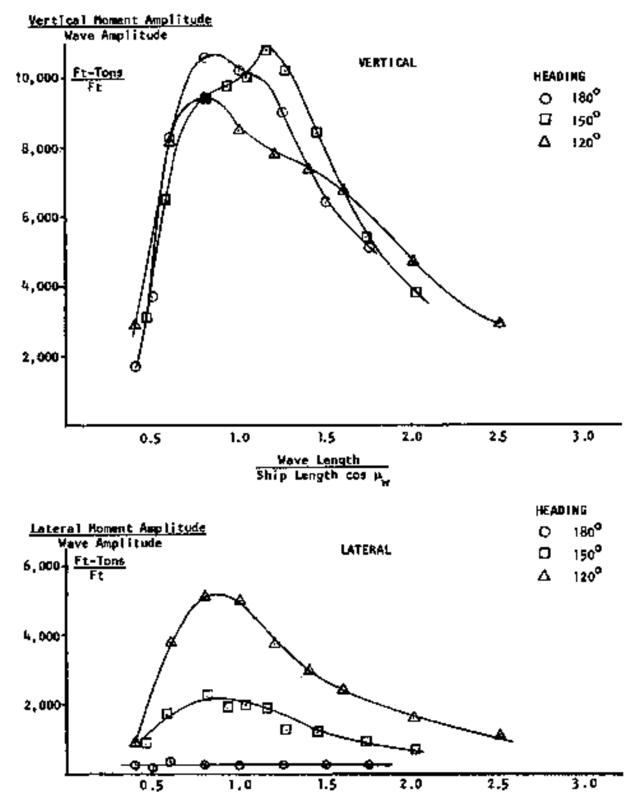

Fig. 17. Vertical and Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft Speed: 20 Knots

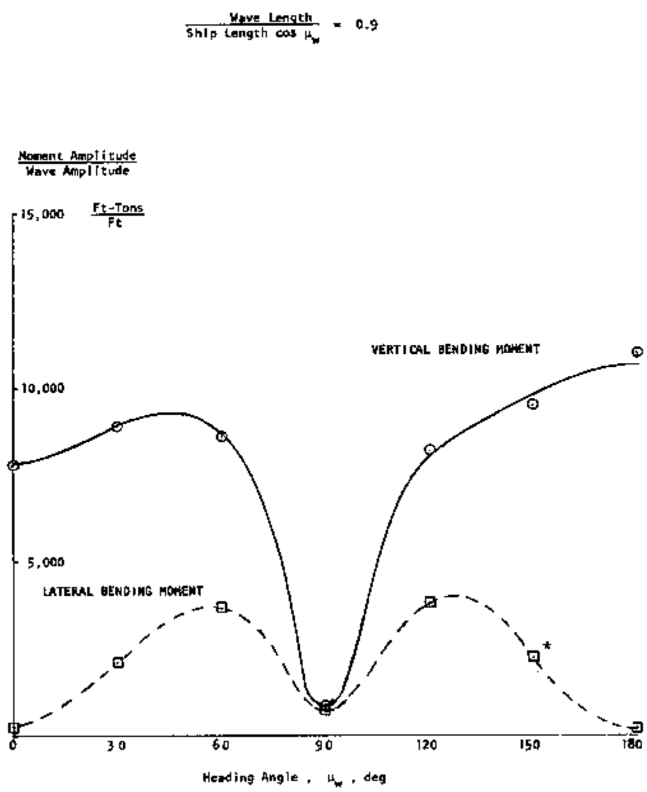

Fig. 18. Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft Speed: 20 Knots

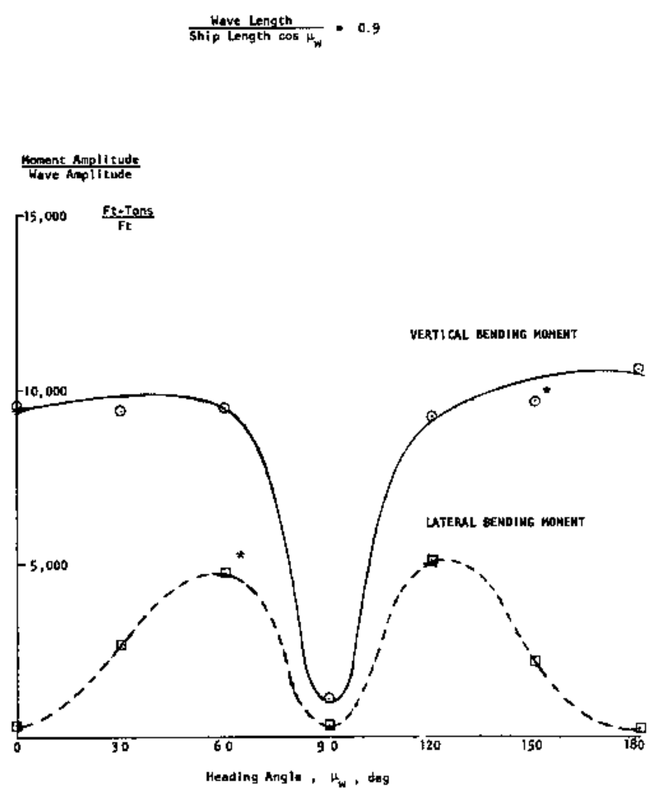

Fig. 19. Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft Speed: 20 Knots

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APPENDIX

TABLE A-1. MOMENT PHASE ANGLES

Drafts: 19.25' Fwd, 22.55' Aft

Wave Length / Ship Length	Headings				
	30°	60°	90°	120°	150°
0.20	-	200	-140	175	-
0.30	-	175	- 80	160	-
0.40	165	150	- 55	170	135
0.50	-	140	-	170	160
0.60	170	135	80	155	155
0.70	180	90	-	150	155
0.80	175	95	165	145	155
0.90	190	-	-	145	150
1.00	200	40	200	145	145
1.10	200	-	-	-	-
1.25	-	-	-	-	145
1.50	205	-65	190	120	150
1.75	-	-	-	-	-
2.00	220	-	140	-	-

Lateral moment after vertical moment.

Phases constant with speed from 10 to 20 knots.

TABLE A-2. MOMENT PHASE ANGLES

Drafts: 23.70' Fwd, 25.55' Aft

Wave Length / Ship Length	Headings				
	30°	60°	90°	120°	150°
0.20	-	85	-	140	-
0.30	-	165	-	150	-
0.40	190	160	-	160	130
0.50	180	155	-	150	145
0.60	-	-	-	145	-
0.70	195	145	55	145	150
0.80	180	-	-	140	140
0.90	-	-	-	-	135
1.00	180	90	130	140	135
1.10	-	-	-	-	140
1.25	185	-	185	135	145
1.50	185	75	175	-	145
1.75	200	-	155	-	135
2.00	-	-	-	-	-

Lateral moment after vertical moment.

Phases constant with speed from 10 to 20 knots.

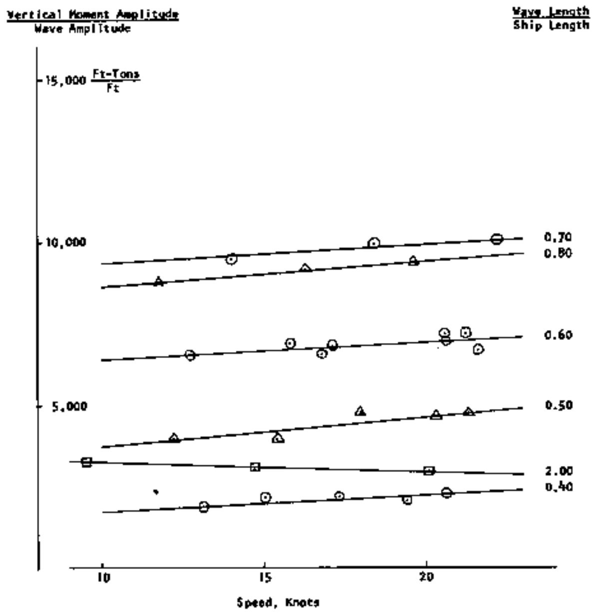

Fig. A-1. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 180° Heading

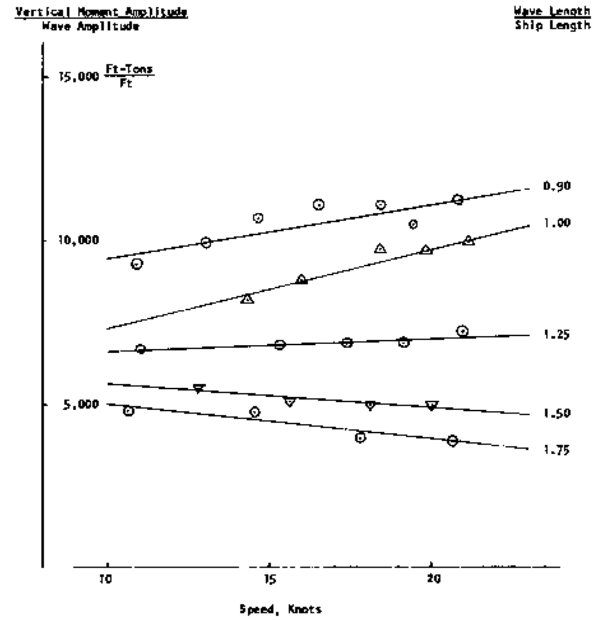

Fig. A-2. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 180° Heading

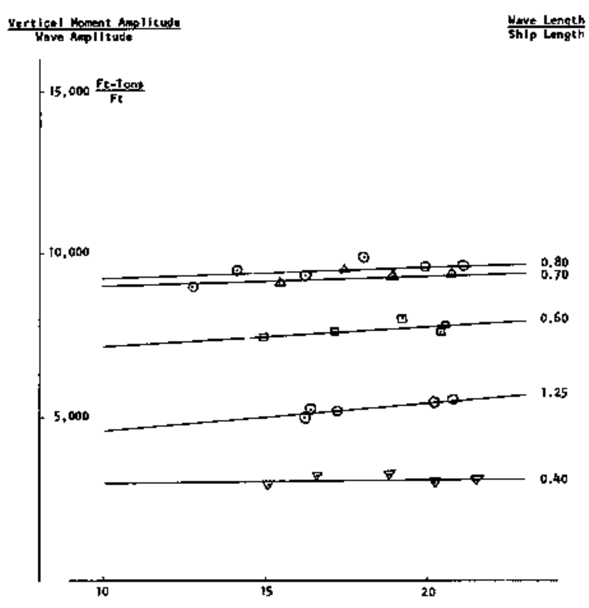

Fig. A-3. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 150° Heading

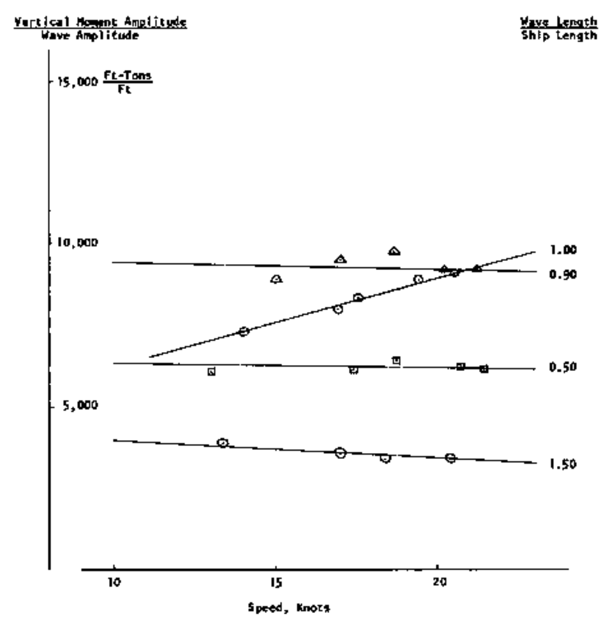

Fig. A-4. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 150° Heading

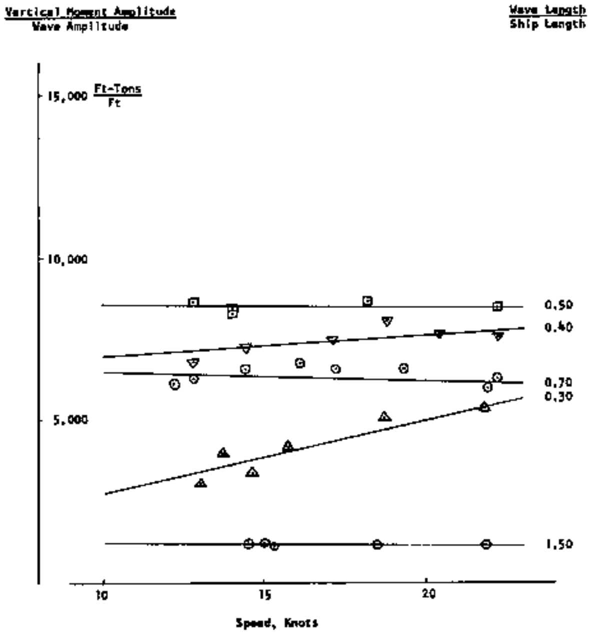

Fig. A-5. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 120° Heading

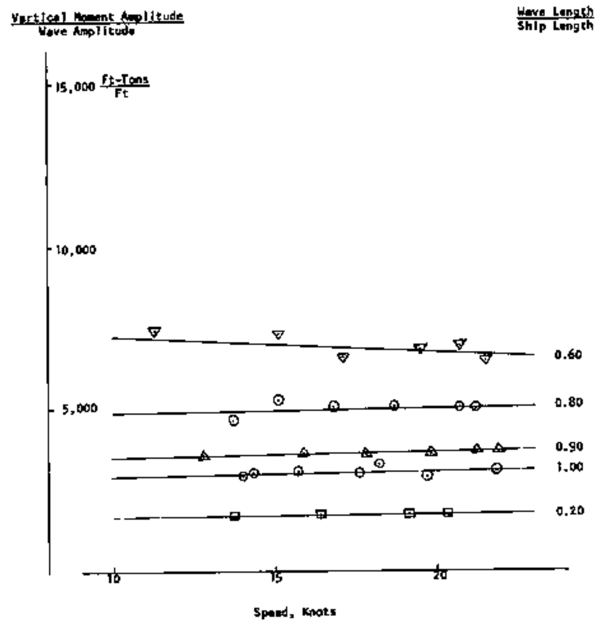

Fig. A-6. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 120° Heading

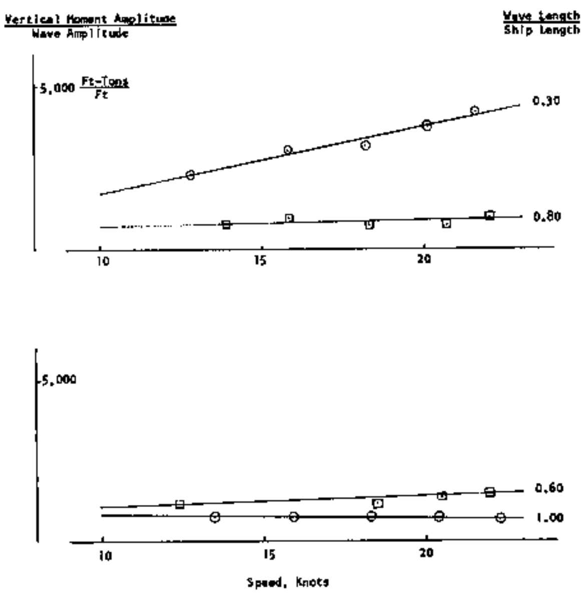

Fig. A-7. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55'Aft 90° Heading

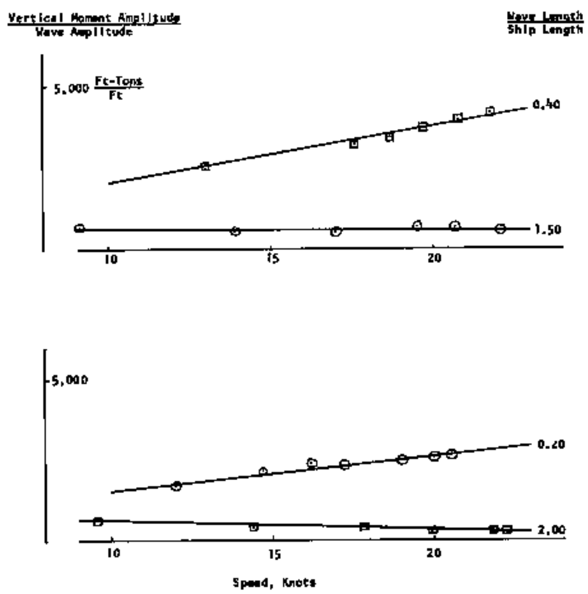

Fig. A-8. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55'Aft 90° Heading

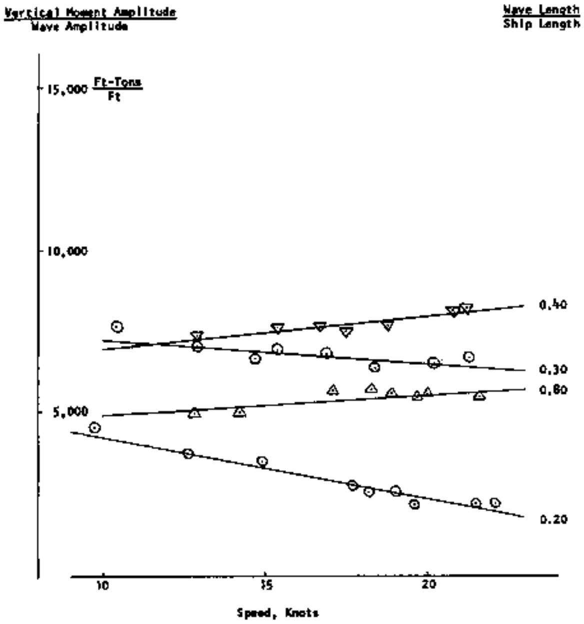

Fig. A-9. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 60° Heading

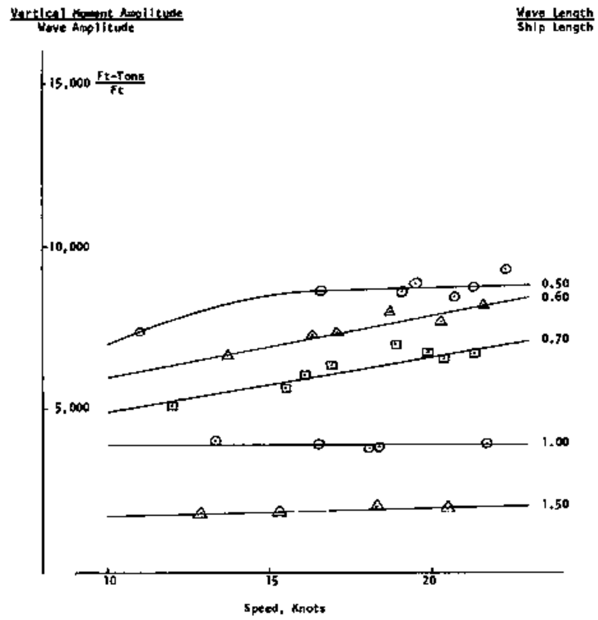

Fig. A-10. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 60° Heading

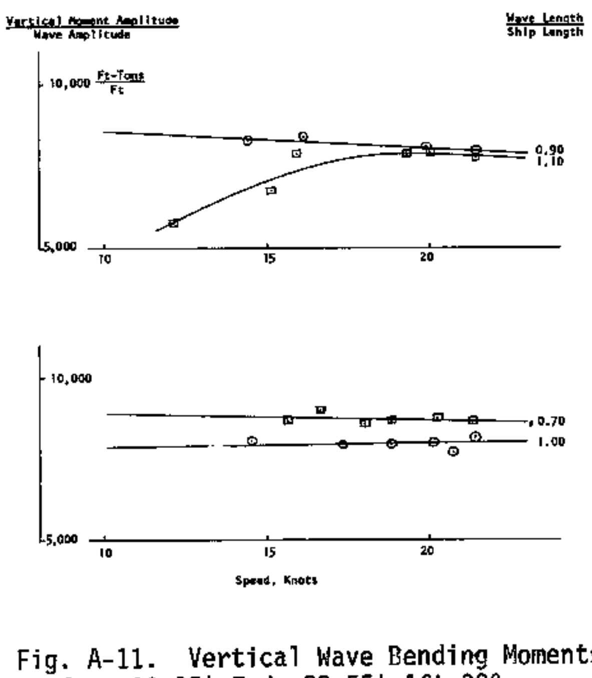

Fig. A-11. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 30° Heading

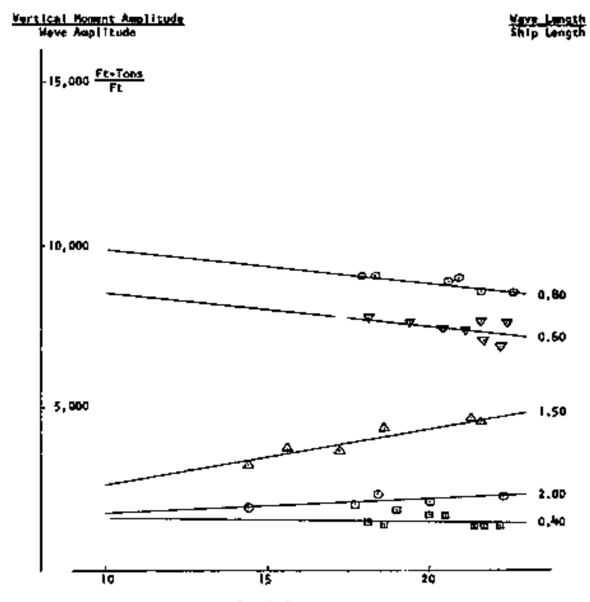

Fig. A-12. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 30° Heading

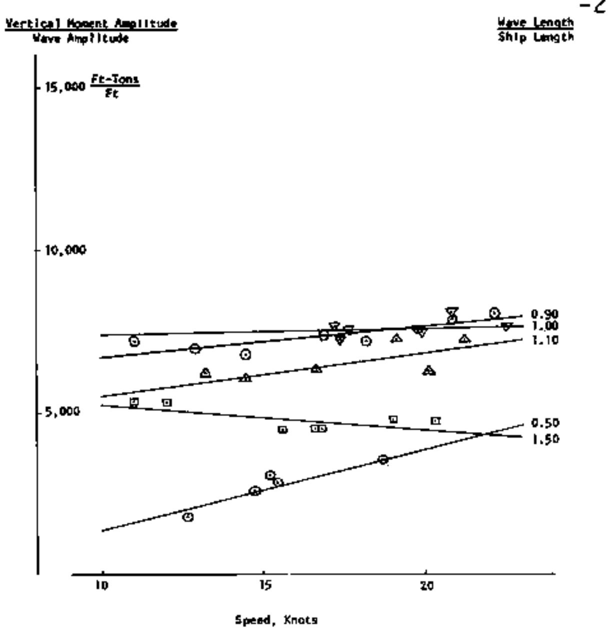

Fig. A-13. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 0° Heading

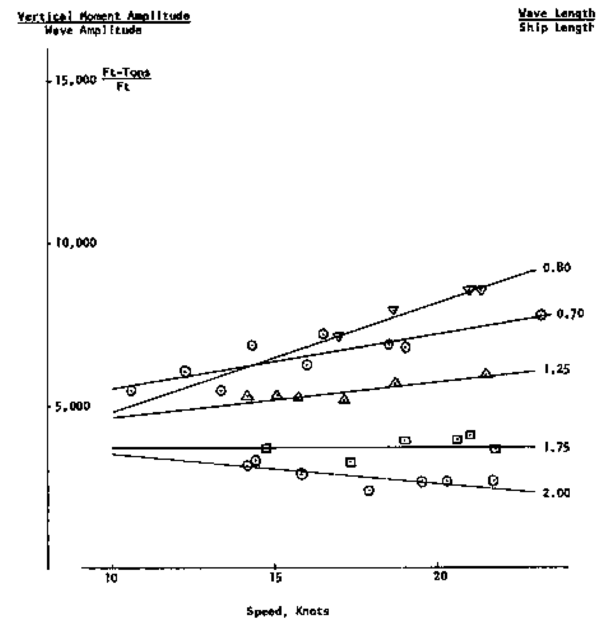

Fig. A-14. Vertical Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 0° Heading

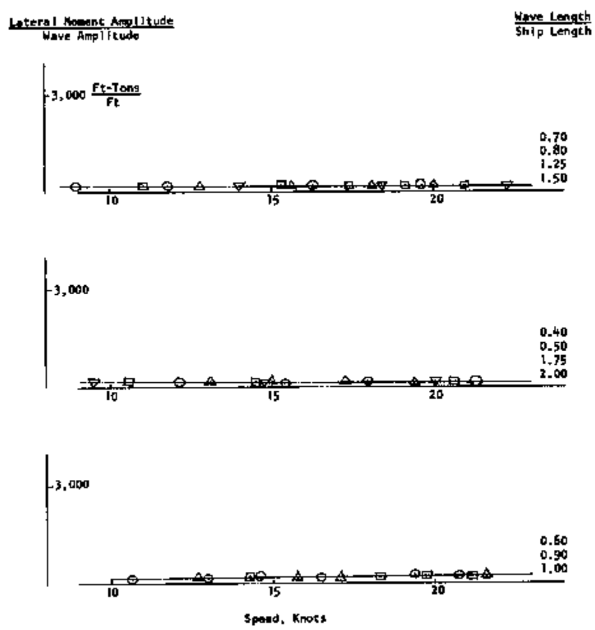

Fig. A-15. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 150° Heading

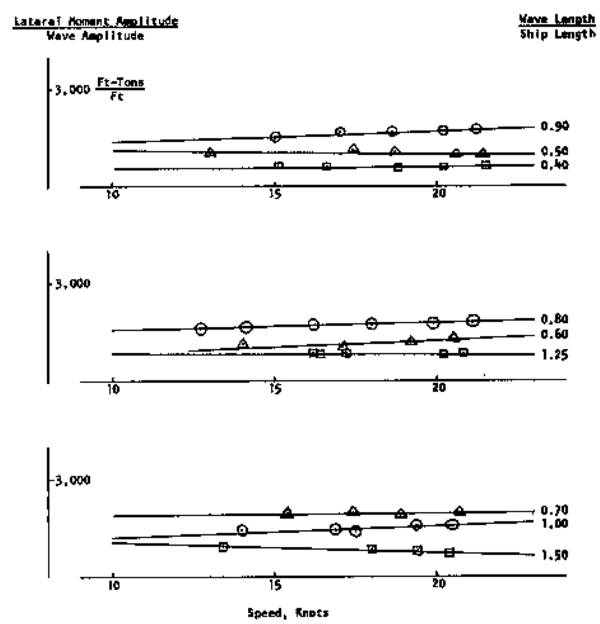

Fig. A-16. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 150° Heading

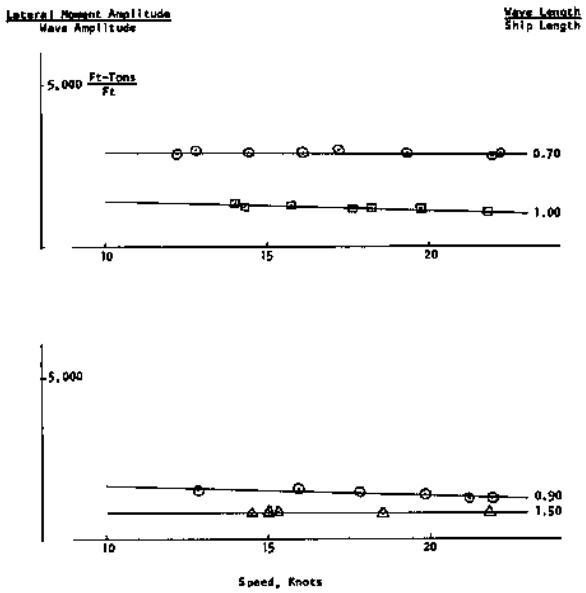

Fig. A-17. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 120° Heading

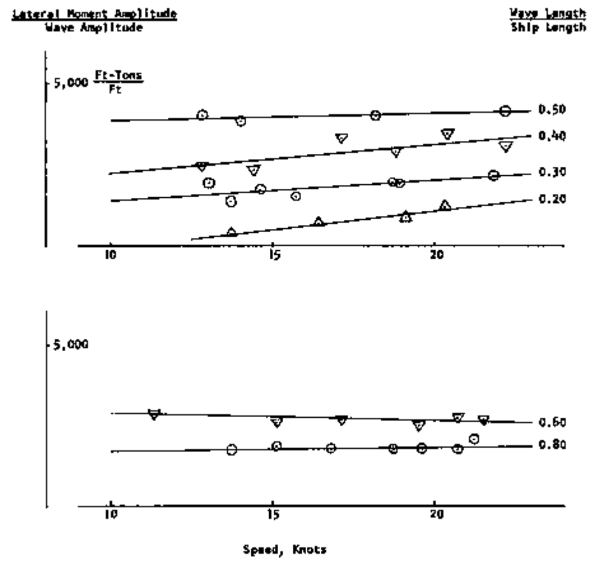

Fig. A-18. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 120° Heading

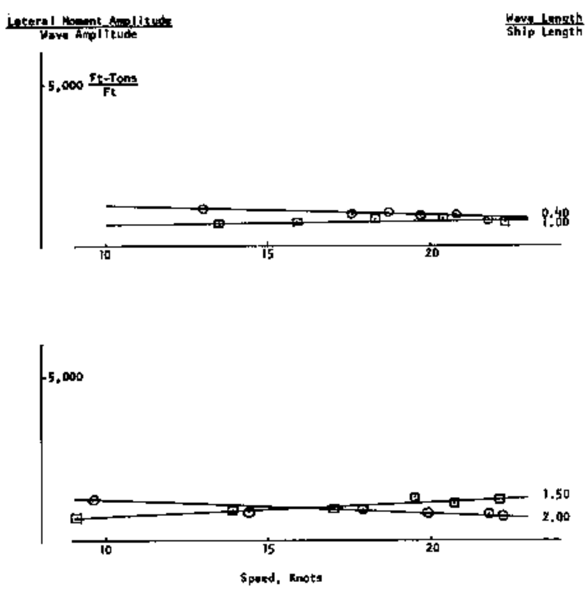

Fig. A-19. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 90° Heading

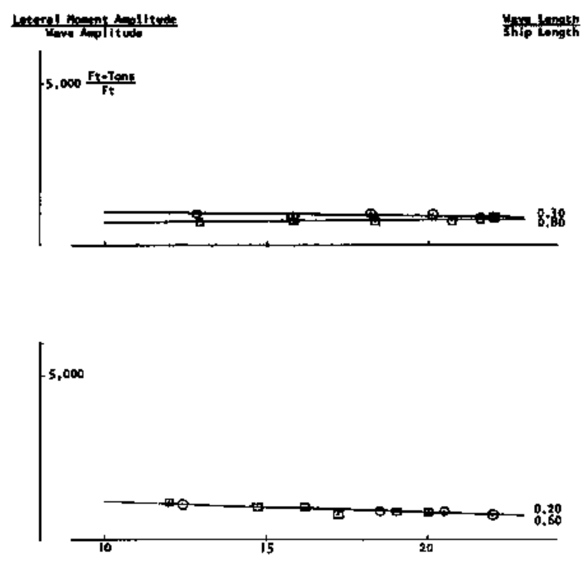

Fig. A-20. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 90° Heading

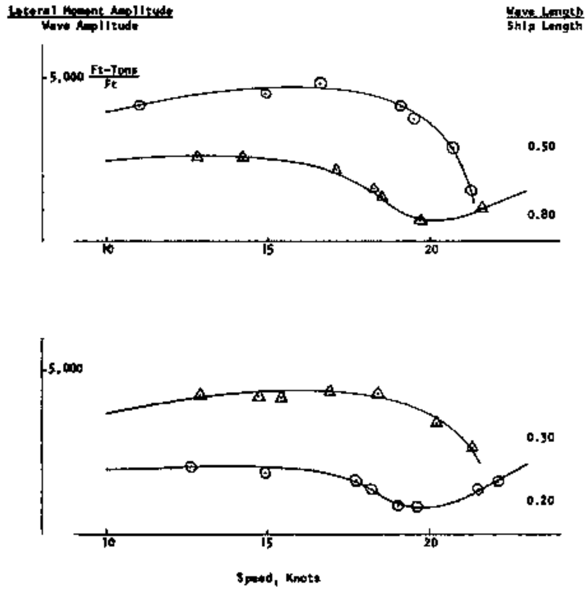

Fig. A-21. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 60° Heading

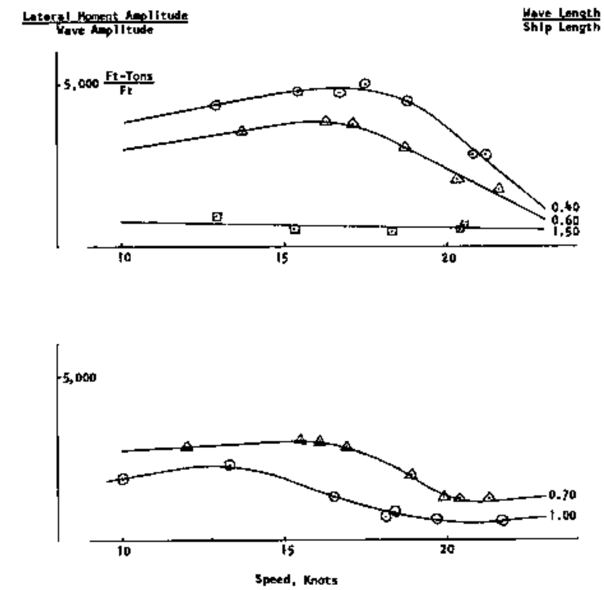

Fig. A-22. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 60° Heading

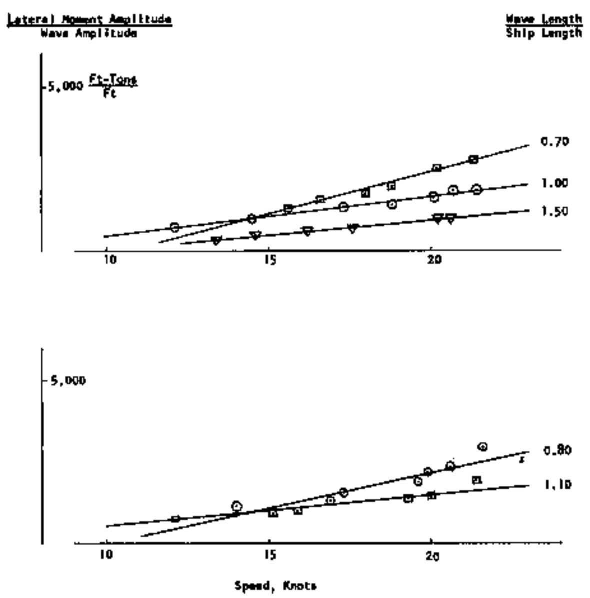

Fig. A-23. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 30° Heading

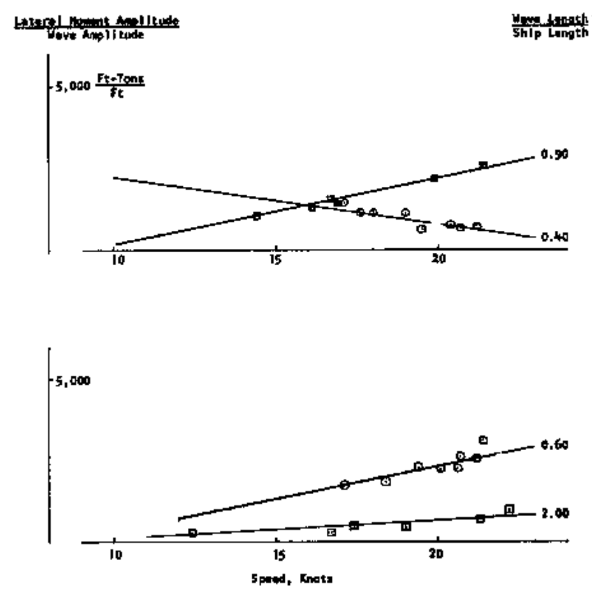

Fig. A-24. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 30° Heading

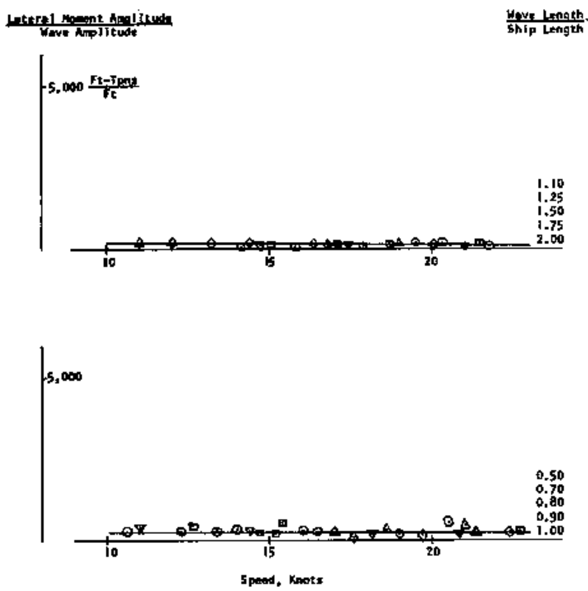

Fig. A-25. Lateral Wave Bending Moments Drafts: 19.25' Fwd, 22.55' Aft 0° Heading

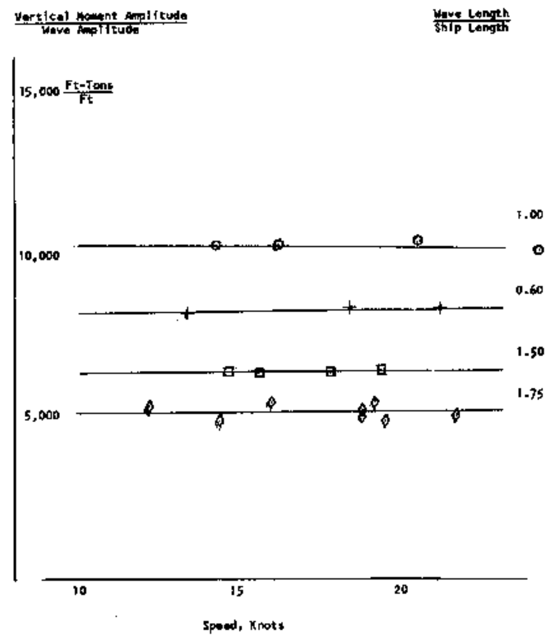

Fig. A-26. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 180° Heading

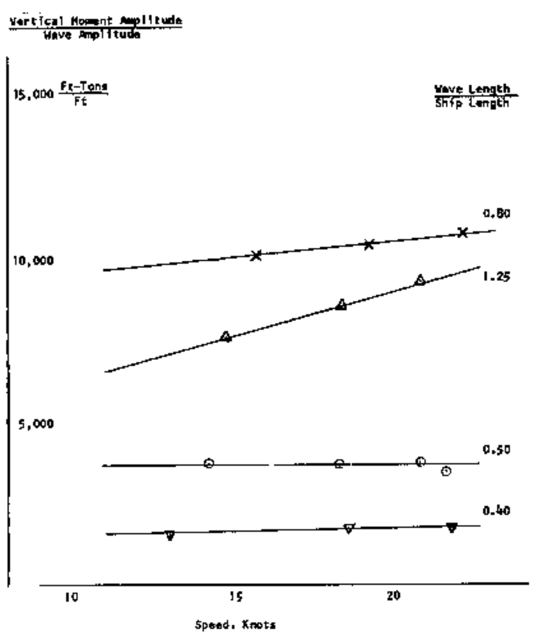

Fig. A-27. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 180° Heading

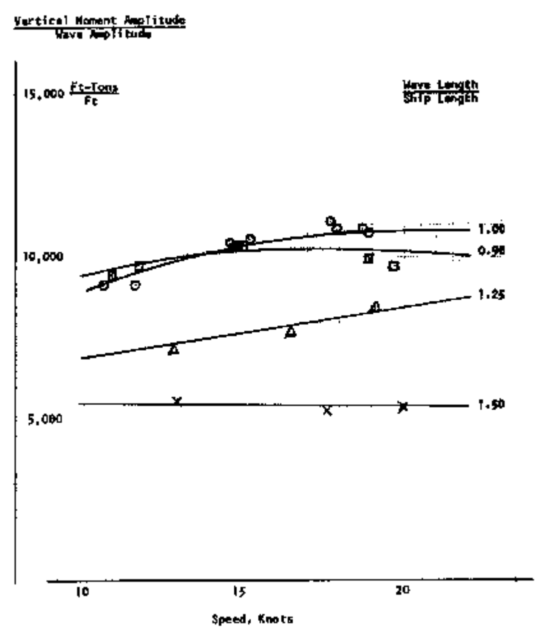

Fig. A-28. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 150° Heading

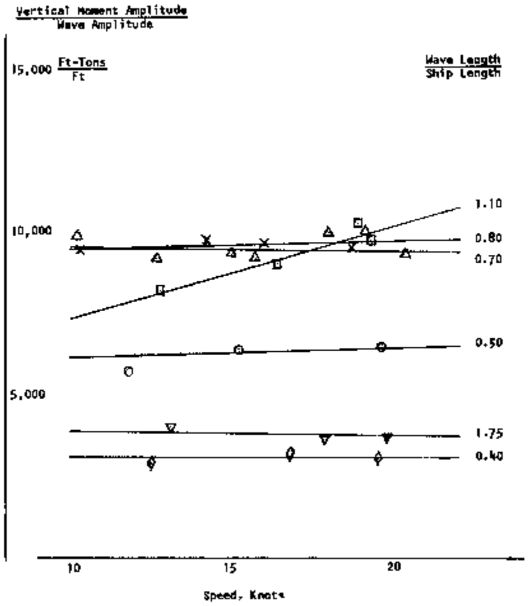

Fig. A-29. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 150° Heading

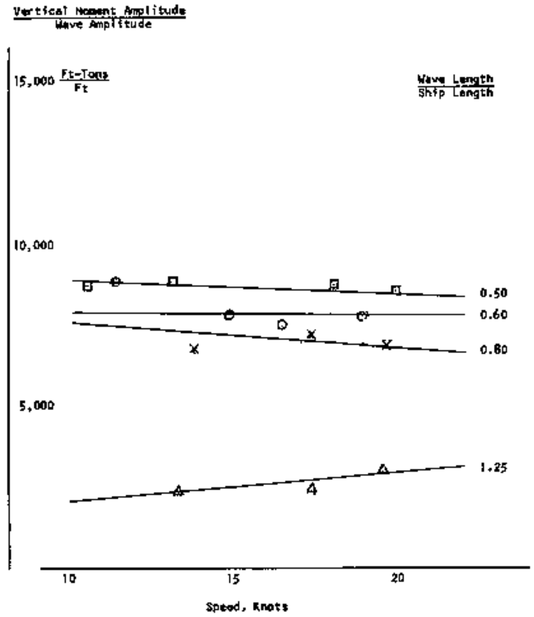

Fig. A-30. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 120° Heading

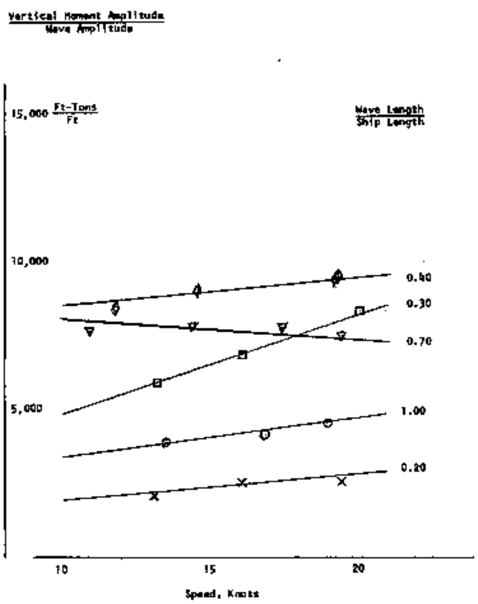

Fig. A-31. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 120° Heading

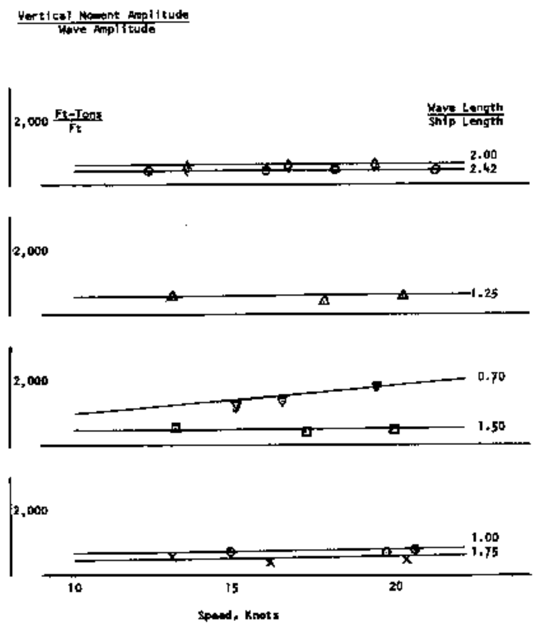

Fig. A-32. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 90° Heading

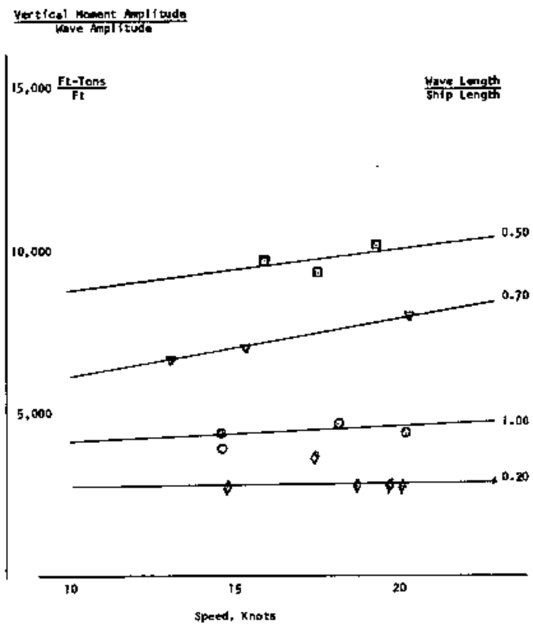

Fig. A-33. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 60° Heading

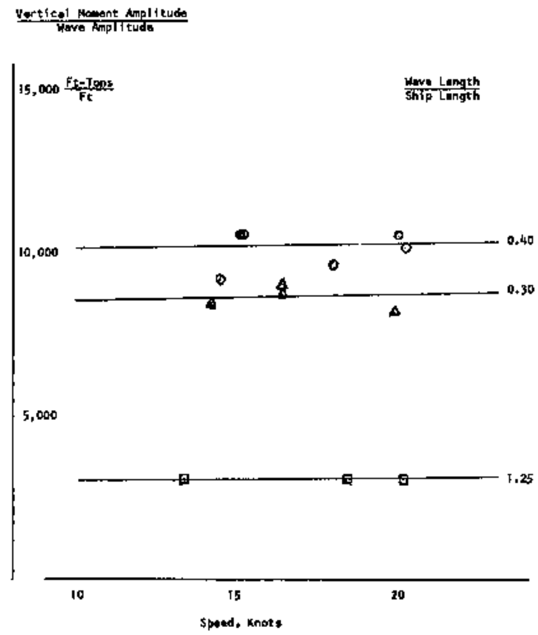

Fig. A-34. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 60° Heading

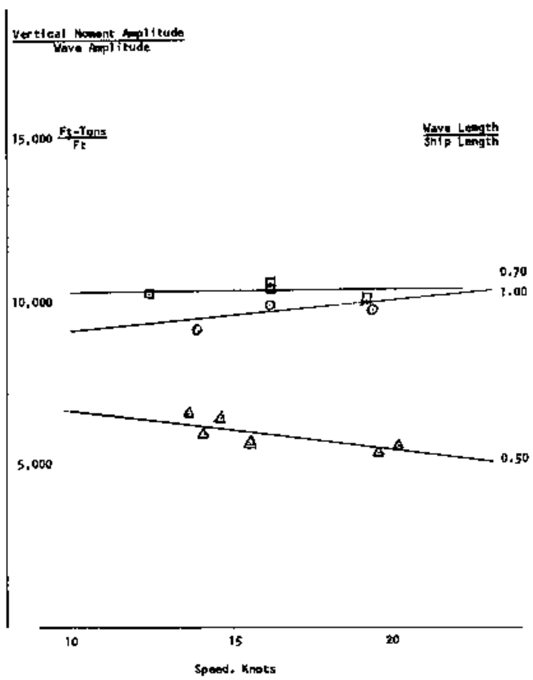

Fig. A-35. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 30° Heading

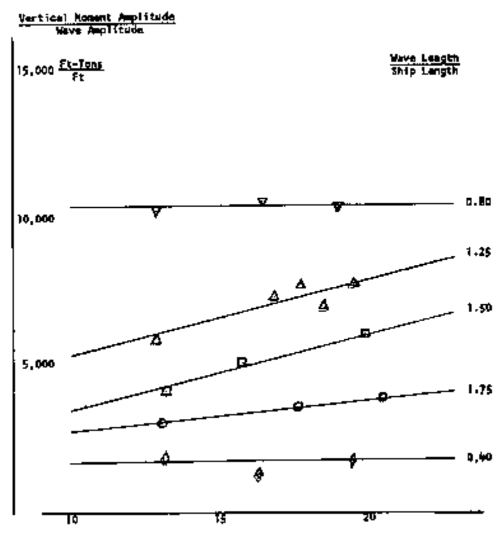

Fig. A-36. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 30° Heading

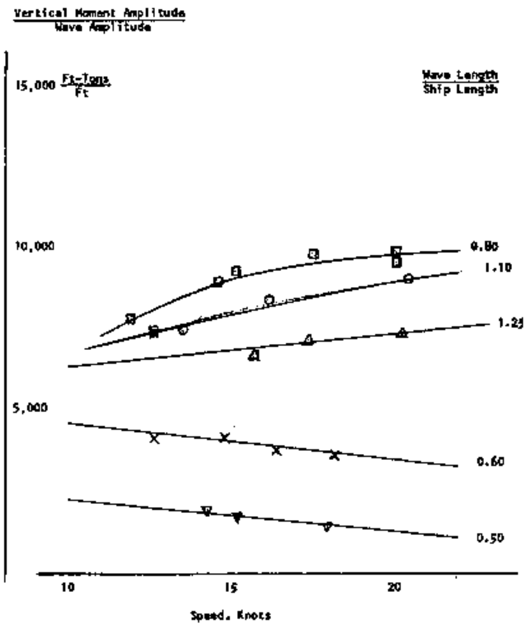

Fig. A-37. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 0° Heading

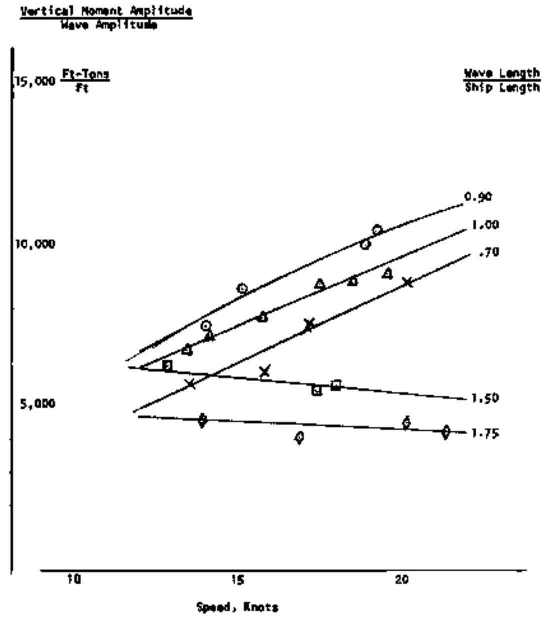

Fig. A-38. Vertical Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 0° Heading

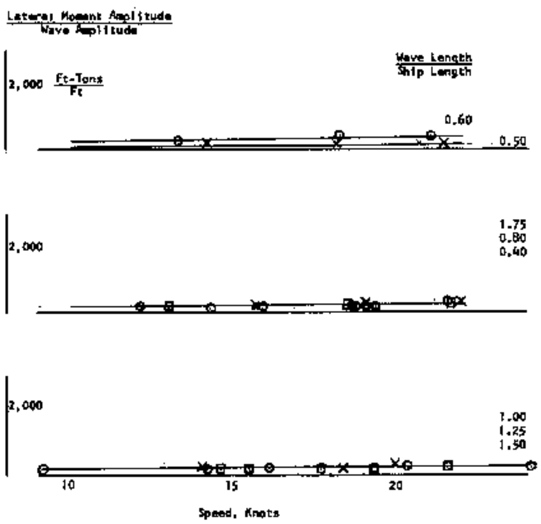

Fig. A-39. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 180° Heading

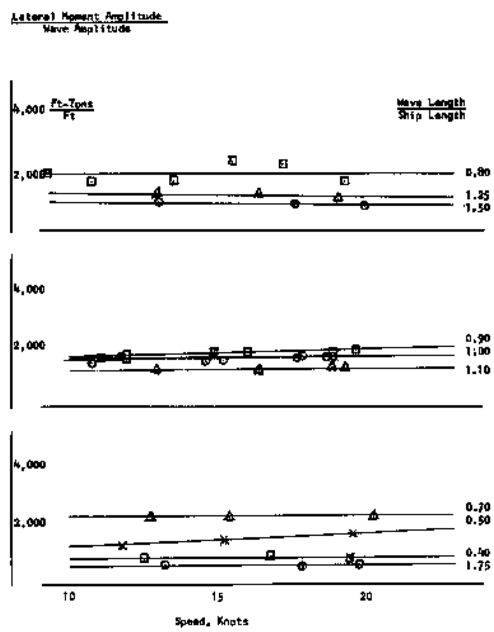

Fig. A-40. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 150° Heading

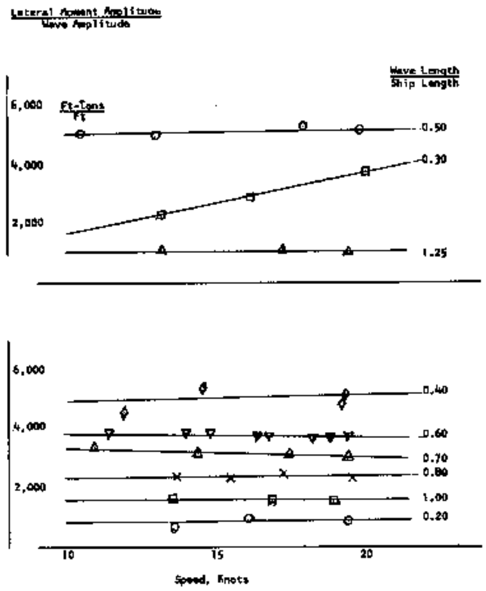

Fig. A-41. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 120° Heading

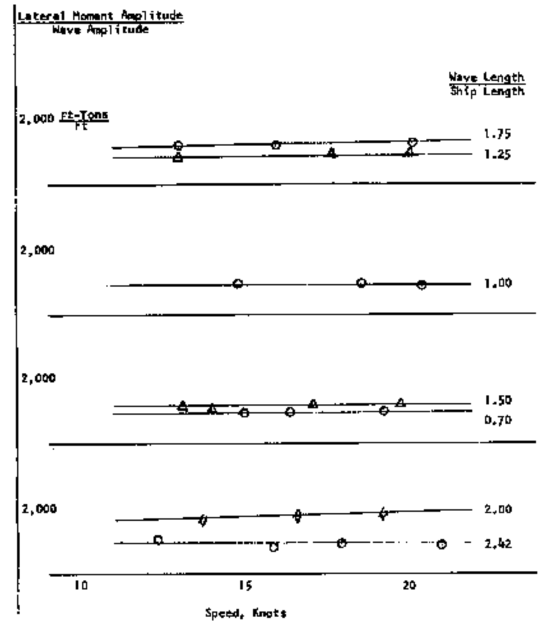

Fig. A-42. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 90° Heading

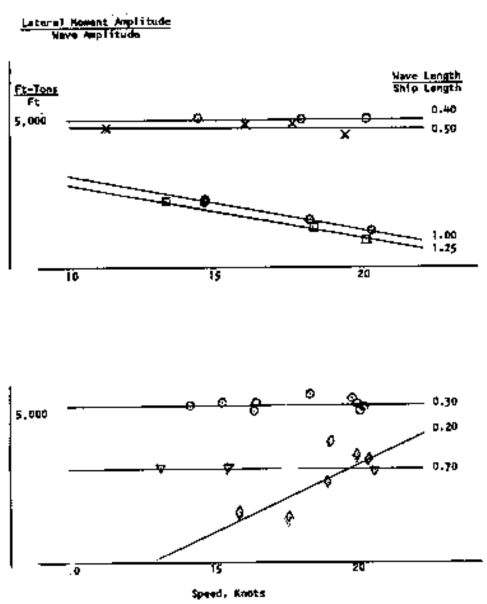

Fig. A-43. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 60° Heading

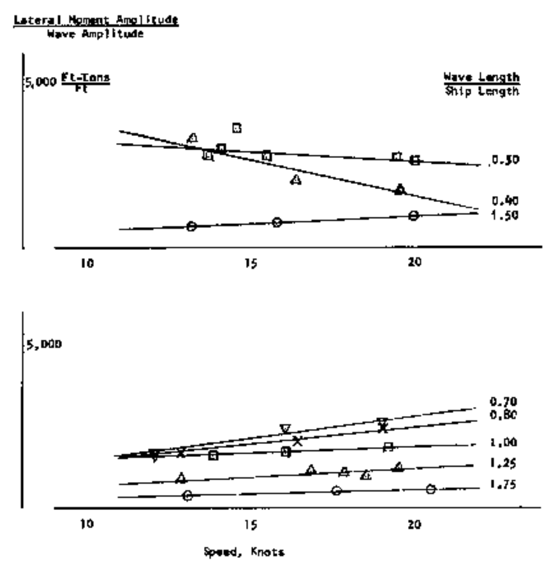

Fig. A-44. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 30° Heading

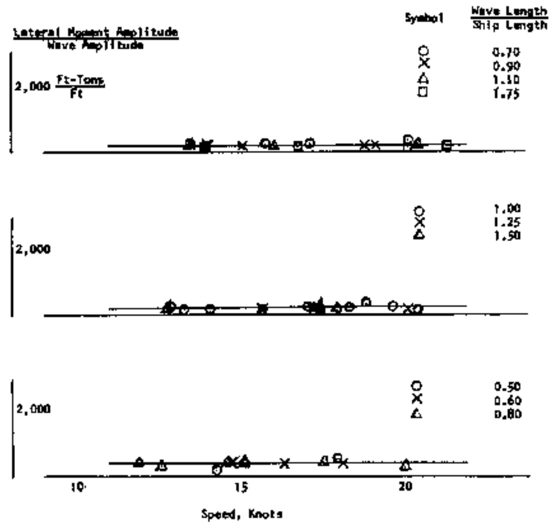

Fig. A-45. Lateral Wave Bending Moments Drafts: 23.70' Fwd, 25.55' Aft 0° Heading

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13. ABSTRACT

Vertical and lateral wave bending moments were measured at the midship section of a 1/96-scale model of the C4-S-1A MARINER-class cargo ship CALIFORNIA BEAR. The model was self-propelled through a ship speed-range of 10 to 22 knots at seven headings to regular waves of lengths between 0.2 and 2.0 times the length between perpendiculars; moderate wave heights not exceeding 1/50 of the model length were used. Results are presented in charts of bending-moment-amplitude/wave-amplitude versus ship speed, with wave length as the parameter. Two ship loading conditions, representative of actual westbound and eastbound trans-Pacific voyages, are covered.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Ship Hulls						
Ship Bending Moment						
Model Tests						
Water Waves						

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