SSC-214

SHIP RESPONSE INSTRUMENTATION ABOARD THE CONTAINER VESSEL S.S. BOSTON: RESULTS FROM TWO OPERATIONAL SEASONS IN NORTH ATLANTIC SERVICE

SHIP STRUCTURE COMMITTEE

1970

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Dear Sir:

To supplement existing service data, a joint cooperative industry-government effort has been completed.

The Ship Structure Committee and Sea-Land Service, Inc. have jointly sponsored full-scale ship board measurement of the longitudinal vertical and horizontal, seaway induced bending moments, torsional response and rigid-body motions of a converted "all-hatch" type container ship.

Herewith is a final report containing the data and analysis of two-seasons of instrumentation.

Sincerely,

W F Rea Jr

W. F. Rea, III
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

SSC-214

Final Report

on

Project SR-182, "Ship Instrumentation and Data Analysis"

to the

Ship Structure Committee

SHIP RESPONSE INSTRUMENTATION ABOARD THE CONTAINER VESSEL S.S. BOSTON: RESULTS FROM TWO OPERATIONAL SEASONS IN NORTH ATLANTIC SERVICE

by

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Teledyne Materials Rearch Company

under
Department of the Navy
Naval Ship Engineering Center
Contract No. N00024-70-C-5182

U.S. Coast Guard Headquarters
Washington, D.C.
1970

ABSTRACT

This summary report contains ship response data, with associated discussions, collected during two North Atlantic Winter operating seasons on the Sea-Land container vessel S.S. BOSTON. Seven voyages are covered with sea states ranging to force 12.

Maximum vertical bending peak-to-trough stress recorded in the program was 13,400 psi in a sea state of 10. Maximum hull torsional shear stress was 1,800 psi peak-to-trough, also occurring in force 10 seas. Bow vertical acceleration ranged as high as 1.5g and horizontal acceleration as high as .96g.

Results of an extensive static loading experiment are also presented and compare well with analytical calculations based on applied loads.

Vertical bending data collected on the S.S. BOSTON are compared with that collected on a similar unconverted C4, the S.S. WOLVERINE STATE.

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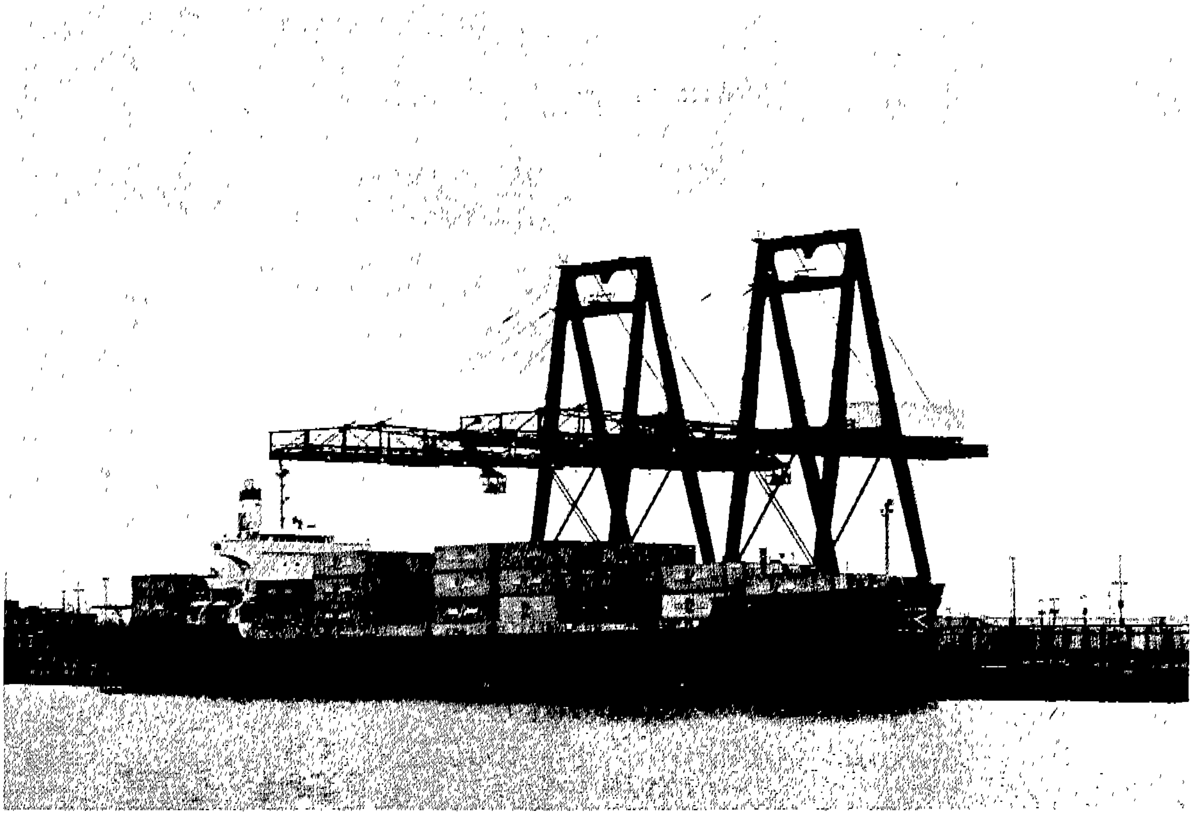


Fig. 1. Container Vessel *S.S. Boston*

This technical report summarizes the results of a two-year ship response data acquisition program on the container vessel S.S. BOSTON. (See Figure 1.) The vessel, owned and operated by Sea-Land Service, Inc., is a C4-X2 conversion of the GENERAL M.M. PATRICK, a C4-S-A1 personnel carrier. See Table I for the physical characteristics of the S.S. BOSTON. The BOSTON normally operates on a North Atlantic route between Port Newark, New Jersey, USA and European ports.

During the Summer of 1968, Teledyne Materials Research designed and assembled the ship response instrumentation system that was installed on the vessel during the final conversion days in the Fall of 1968. A Teledyne engineer was aboard the vessel during operation of the vessel from November 1968 to April 1969. Data collection started in December 1968 with the on-board engineer operating the system and performing initial data reduction en route.

During the first season (1968-1969), a total of 235 data intervals were collected during the manned voyages and analyzed. The ship response system was operated primarily in an automatic mode with a 15-minute data interval every four hours, although the system can be operated continuously in the manual mode. In addition to the ship response system data, three wave buoys were launched during this season to obtain simultaneous sea state information.

During the 1969-1970 season, the vessel was manned for five voyages from October through March. A total of 648 data intervals were acquired for a project total of 883 for the two seasons. Table II summarizes the manned voyages for both seasons and Figure 2 presents a profile of the data intervals collected at each sea state condition for the entire program. In addition to operating the original ship

Table I

Characteristics of *S.S. Boston*

Original Name:	GEN. M.M. PATRICK
Builder:	Kaiser Richmond (Hull #16)
Converter:	Todd Shipyards Corporation Galveston Division (Hull #87)
Type:	C4-S-A1 converted to C4-X2 Container Ship
Official Number:	511585
Length Overall:	522' - 10-1/2"
Length Between Perpendiculars:	496' - 0"
Breadth, Molded:	71' - 6"
Depth, Molded to Upper Deck Side:	45' - 6"
Depth, Molded to Second Deck:	35' - 0"
Double Bottom Depth:	5' - 0"
Tonnage (U.S.) Gross:	11,521.77
Net:	7,607.00
Load Draft, Scantling:	30' - 6"
Full Load Displacement:	20,250 Tons S. Water
Light Ship Draft:	17' - 8"
Dead Weight:	9,317
Center of Gravity (Full Load):	l.c.g. 1.35' aft of midships BP. v.c.g. 27.04' above base line
Light Ship:	l.c.g. 1.13' fwd of midships BP. v.c.g. 18.2' above base line
Block Coefficient:	0.654 (30' Molded Design Draft) 0.61 (18' Typical Present Operation)
Prismatic Coefficient:	0.664 (30' Molded Design Draft) 0.628 (18' Typical Present Operation)
Waterplane Coefficient:	0.752 (30' Molded Design Draft) 0.685 (18' Typical Present Operation)
Midship Section Modulus:	39,391 in^2 ft to Top of Upperdeck
Machinery:	Steam-Geared Turbine
Shaft Horsepower - Max. Cont.:	9,900 S.H.P.
Propeller (1):	5 Bladed 21' - 8" Dia.
Container Capacity (No.)	360
Container Geometry:	L - 35' - 0" W - 8' - 0" H - 8' - 6-1/2"

Table II
Program Voyage Summary

Voyage No.	From	To	No. Data Intervals
FIRST SEASON			
9-East	Newark 2-21-69	Rotterdam 3-3-69	63
9-West	Felixstowe 3-10-69	Newark 3-18-69	58
10-East	Baltimore 3-23-69	Rotterdam 4-1-69	58
10-West	Felixstowe 4-10-69	Newark 4-19-69	56
SECOND SEASON			
20-East	Newark 10-18-69	Rotterdam 10-26-69	45
20-West	Felixstowe 11-2-69	Newark 11-11-69	97
21-East	Newark 11-12-69	Rotterdam 11-27-69	123
21-West	Felixstowe 12-3-69	Newark 12-12-69	54
22-East	Newark 12-13-69	Rotterdam 12-25-69	76
22-West	Felixstowe 1-6-70	Newark 1-16-70	64
23-East	Newark 1-17-70	Rotterdam 1-29-70	49
23-West	Felixstowe 2-6-70	Newark 2-16-70	49
24-East	Newark 2-18-70	Rotterdam 3-3-70	47
24-West	Felixstowe 3-9-70	Newark 3-18-70	44

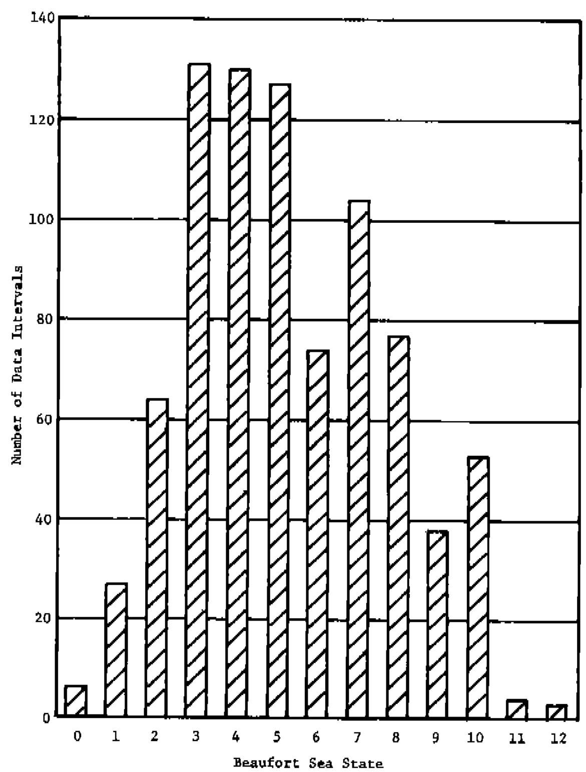


Fig. 2. Sea State Profile Summary, Both Seasons
(March 1969 - April 1969, and October 1969 to March 1970)

response instrumentation system, additional data were acquired on transverse deck beam stresses during the second season.

At the completion of Voyage 20 in November 1969, an extensive static loading experiment and system calibration was performed. This exercise consisted of initially unloading the vessel and then adding preweighed containers in a prescribed placement sequence to generate known twisting and vertical bending moments. A comparison was then made between the measured stresses and those calculated from the applied loads.

Two wave buoys were launched during the second data collection season on Voyages 22 and 24. However, only data from Voyage 22 have been analyzed because the buoy's transmitter from Voyage 24 malfunctioned.

II. EQUIPMENT AND PROCEDURE MODIFICATIONS

A. Ship Response Instrumentation System

The prime data collection system on the vessel is the ship response system. This is basically a 14-channel magnetic tape recording and signal conditioning equipment acquiring data from the various force and motion transducers located throughout the vessel. Reference 1 describes the system in detail with complete functional as well as schematic diagrams and specifications of all components. A photo of the equipment installation on the S.S. BOSTON appears as Figure 3.

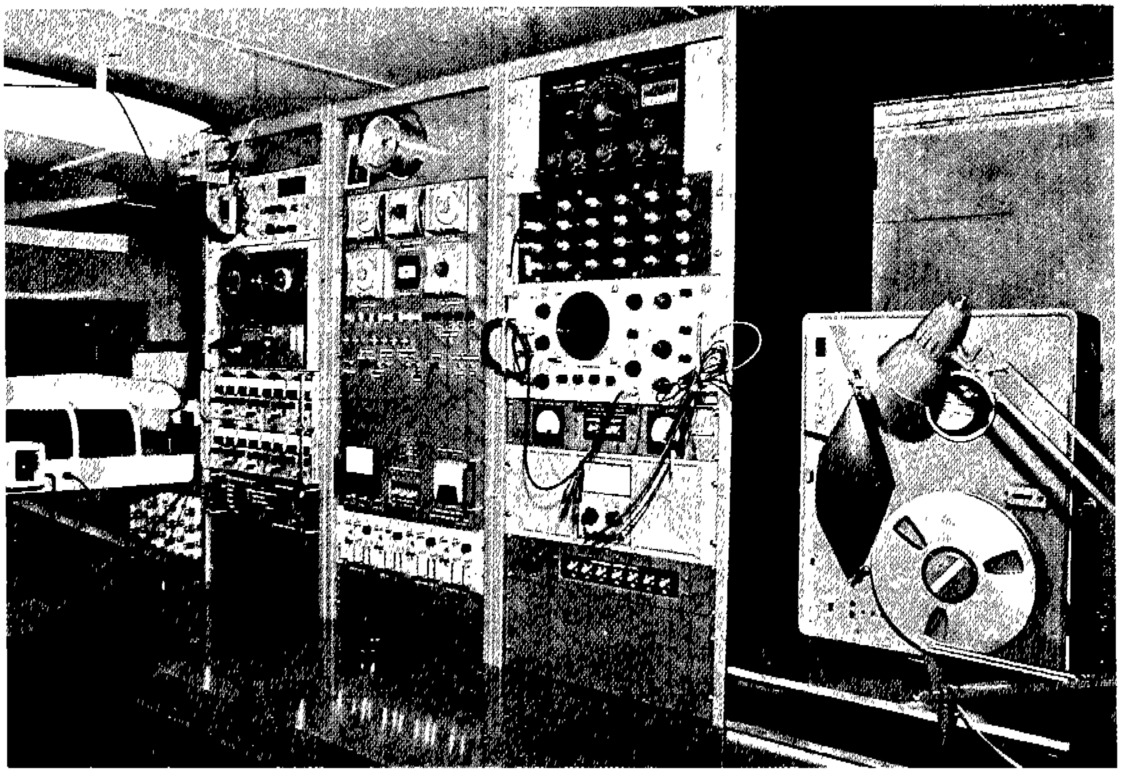


Fig. 3. Teledyne Instrumentation Console

In brief, channels 1-4 of the system record vertical and horizontal bending and hull torsional shear stress from strain gage bridges attached to the ship structure. Channels 5-13 monitor the outputs of transducers located within the ship to sense accelerations, motions and displacements. Channel 14 is used for error compensation in the recorder playback mode. Figure 4 depicts, in schematic form, the locations of the various transducers throughout the vessel.

1. Added Instrumentation

Prior to the start of the 1969-1970 operational season, three additional transducers, in the form of strain gage bridges, were bonded to the structure. These gages, connected as half bridges, were installed on the starboard end of the transverse beam between holds 5 and 6.

These transducers were designed to respond to double-cantilever bending strains on that cross-deck beam due to vessel cross-section warping. It was felt that quartering seas, generating hull twist and section warping would be better sensed on these cross-deck beams than at the original torsional shear gage locations. Figure 5 presents the details of this installation. Signals from these gages were directly recorded on an oscillographic-type chart recorder. The data collection procedure was manual (versus programmed) in that the on-board Teledyne engineer selected record intervals by watching the signal amplitude and recording only selected periods. The intent was to obtain high stress records at various seaway conditions; therefore, no rigorous data collection schedule was planned.

In order to improve the consistency of the sea state reports, a wind speed and direction system was installed in the bridge area for the second data collection season. The intent was to make the logbook entries more objective in nature, since many different personnel contribute to the logs.

2. Box Beam Gages

The recording technique for the four box beam gages, time-shared on one system channel, was modified in light of the results of the 1968-1969 season. See Reference 1 and Figure 6 of this report for location details of these gages. Originally each of these gages was recorded for one day out of four so that data from more intervals were available to permit comparisons with the longitudinal vertical bending data. Since the data from the 1968-1969 season indicated that the outputs from the side shear-plate gage (SSPG) and the side under-deck gage (SUDG) were nearly identical with the vertical bending output, and that the port side weld gage (PSWG) was somewhat variable, the starboard box beam gage (SBBG) was selected as the control gage for the current season.

For Voyages 20-24, SBBG was recorded, along with the primary transducer data at each data interval. In addition, during the first two voyages, the other three box beam gages were sampled at least once per day.

B. Accelerometer Wave Buoy System

As described in earlier reports (References 1 and 3), this system consists of free floating wave buoys and a radio receiver/tape recorder type data acquisition unit for receiving and recording the output signal of the wave buoy transmitter.

The intent of this system is to collect acceleration data from the buoy to be correlated with observed sea state data and stress records collected simultaneously.

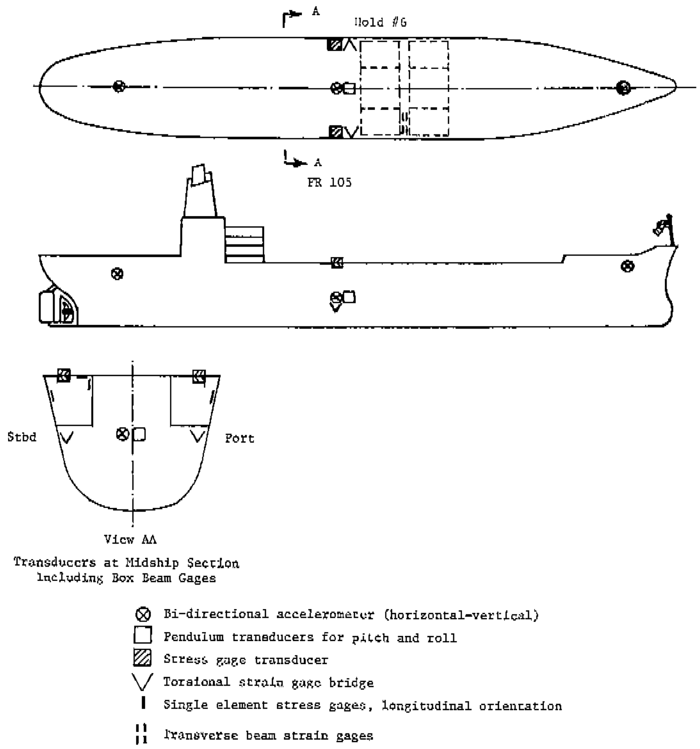


Fig. 4. Schematic View of Various Transducer Locations on *S.S. Boston*

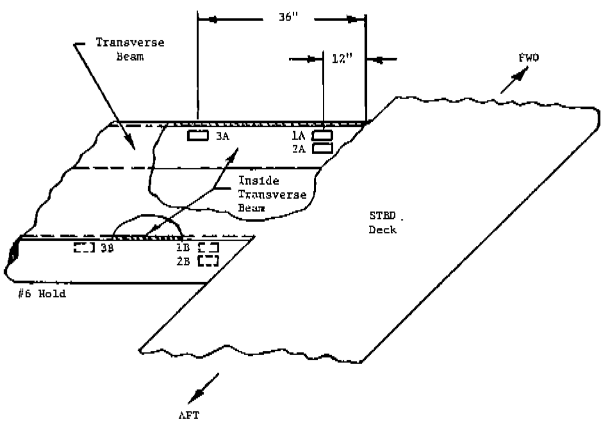
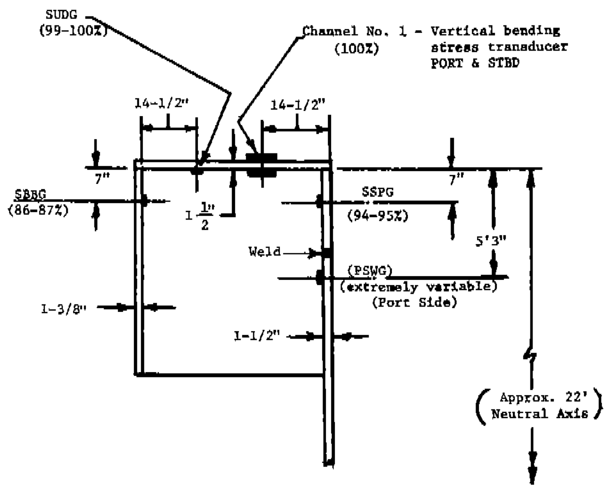


Fig. 5. Transverse Beam Strain Gages



NOTE: Percentages indicate value of vertical longitudinal bending stress at location relative to Channel No. 1 value taken as 100 per cent. (Values from 1968 - 1969 data.)

Fig. 6. Location of Box Beam Gages

C. System Operation

Throughout the two operating seasons, the entire system proved to be extremely reliable. Minor down time on a particular channel was usually remedied either en route or at the next turnaround. Consequently, no significant amount of data were lost.

At the system checkout, prior to the initiation of the 1969-1970 season, some system components were marginal from a reliability standpoint and were replaced as preventive maintenance. This was to be expected, since the equipment had been turned off all summer while the vessel continued the European runs.

III. VESSEL CALIBRATION

A static loading or calibration on an instrumented vessel is performed for two reasons: The first is for verification of the instrumentation and recording system to eliminate the possibility of installation errors; i.e., are the transducers responding as designed? The second reason is to compare measured and calculated stress values from a known applied moment.

During the final conversion days in 1968, an attempt was made to perform a calibration while the double bottom spaces were being filled with ballast mud. This attempt was unsuccessful due to the extreme temperature excursions during the 21-day loading sequence, as well as the gross structural modifications being performed on the vessel. Either of these situations was sufficient reason to negate the results of the experiment.

Subsequently, a second more successful calibration was accomplished in November 1969. The vessel was loaded with preweighed containers in a prescribed sequence over a 27-hour period in order to generate the desired bending and twisting moments.

Details of the entire calibration have been previously reported (Reference 2) and only a review of the procedure and results will be included in this report.

A. Added Calibration Instrumentation

Partial justification for adding the transverse beam gages mentioned earlier in this report was to obtain stress data during the static calibration of the vessel.

In addition to these strain gages complementing the normal ship response system, several devices were installed just for the calibration to obtain physical measurements not obtained during normal operation.

Plumb lines and their necessary supports for measuring the centerline twist of the vessel were attached to the open hatch coamings, as shown in Figure 7. Lines were approximately 43-ft long and measurements to 1/16 inch were possible with the technique used. Eight plumb-line locations were used, one each at the forward end of holds 2 through 8 with one more at the aft end of #8.

Distortion measurements of the #6 hold opening were taken at each loading condition to determine the rhomboidal effect produced in the opening by the applied twisting moment. Figure 8 depicts the four measurements obtained with a spring-scale tensioned engineer's tape, using center-punched bench marks on the hatch coaming.

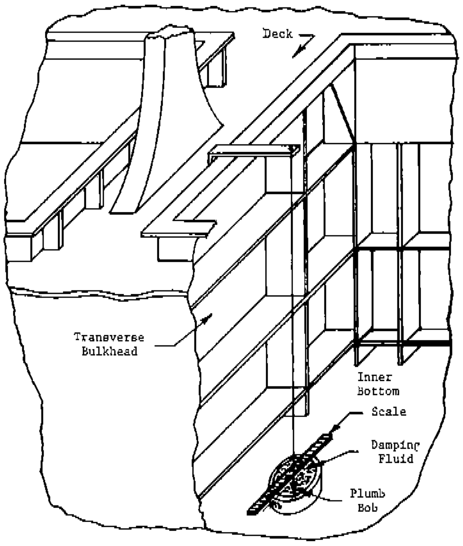
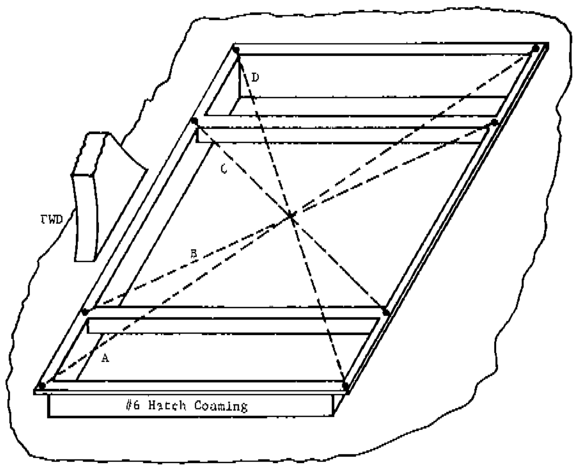


Fig. 7. Typical Plumb-Line Installation



Tape Measurements Taken on Four Diagonals A, B, C, D at Each Loading Condition

Fig. 8. Diagonal Hatch Distortion Measurement Technique

B. Calibration Procedure

Upon arrival from Europe on November 11, 1969, the vessel was emptied of all containers at the Sea-Land facility at Port Newark, N.J. The equipment mentioned above was installed and all "zero" data points were recorded. The vessel was assumed to be in maximum hog condition with no initial torsion. This empty ship condition is the base condition about which all other data were normalized.

The eight calibration conditions achieved during the experiment are shown in Figure 9. Numbers in each hold opening represent transverse moment at that location with respect to the vessel longitudinal centerline. The incremental loading technique depicted shows that torsional loading of the vessel was of prime interest, with vertical bending loading of somewhat less importance.

Good data collection weather conditions prevailed throughout the 27-hour period, with overcast skies and temperature in the 40° to 50° range.

Two shore-side cranes were used to load the vessel for each calibration condition in order to achieve a fairly symmetrical loading procedure both in port-to-starboard and fore-to-aft directions. For example, to establish condition 2, one crane worked #5 port hold while a second crane loaded #7 starboard. The cranes then moved fore and aft, respectively, in preparation of simultaneous loading of holds 4 and 8 to establish condition 3. As each condition was established, all magnetic tape, strain indicator and physical measurements were obtained while the vessel was essentially quiet and free of the dock with mooring lines slack. All containers used in the calibration were actual departure boxes so the procedure gradually filled the vessel to normal departure conditions.

C. Calibration Results

As previously mentioned, Reference 2 contains complete details of the entire calibration, including all strain gage data and physical measurements acquired. Only summary data are presented herein.

There are two very important points that must be remembered when studying the results of this experiment:

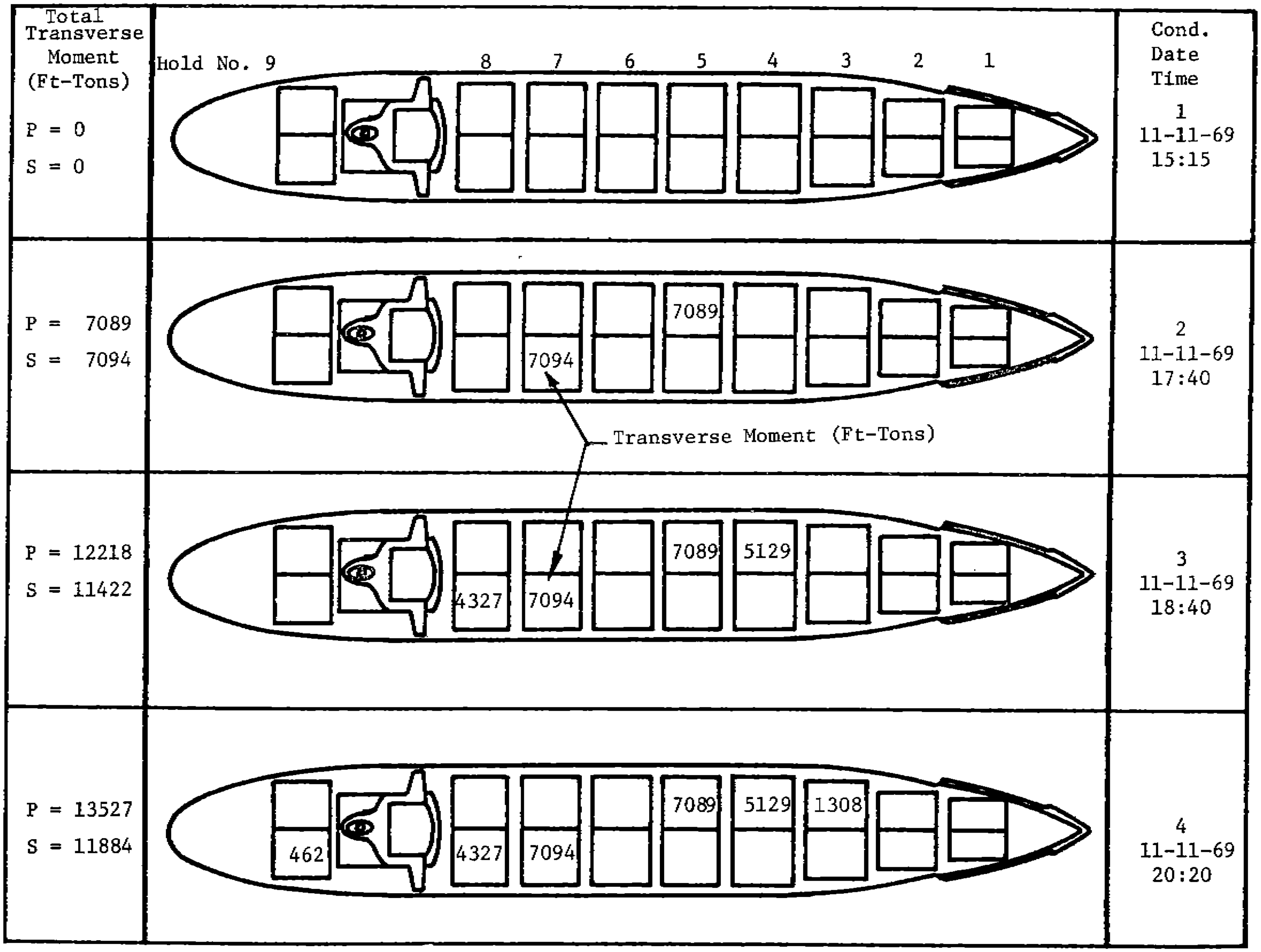


Fig. 9. Calibration Conditions and Transverse Moments

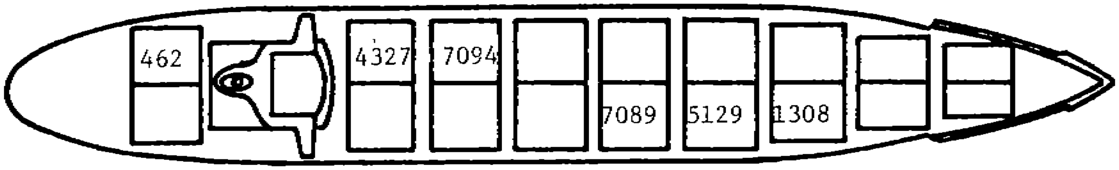
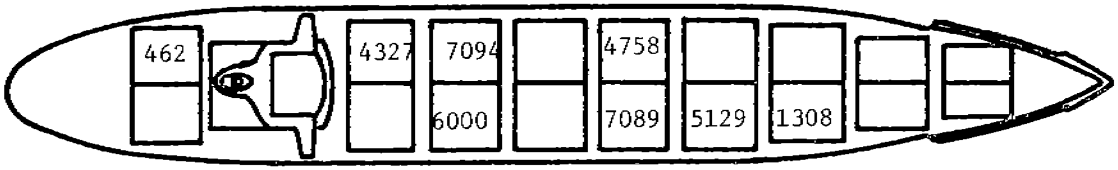
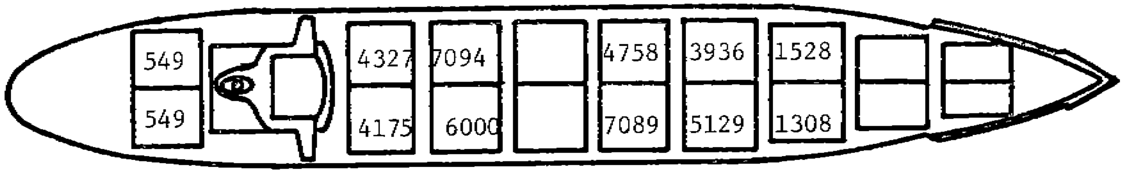
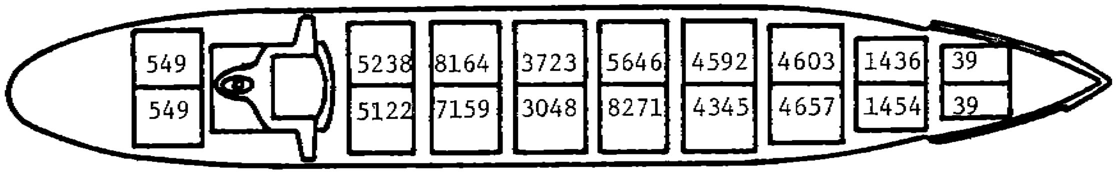
Total Transverse Moment (Ft-Tons)	Hold No. 9 8 7 6 5 4 3 2 1	Cond. Date Time
P = 11884 S = 13527		5 11-11-69 23:10
P = 16643 S = 19527		6 11-12-69 01:20
P = 22194 S = 24252		7 11-12-69 03:05
P = 33993 S = 34647		8 11-12-69 10:30

Fig. 9. Calibration Conditions and Transverse Moments (Continued)

1. The data, both analytical and experimental, have all been normalized about Condition 1. As mentioned earlier, the values obtained for this condition were set equal to zero and the differences from these "zeroes" are presented in the report.

2. Many of the stresses reported herein are less than 500 psi, and several are in the 100-200 psi range. When comparing a 200 psi measured stress with a 300 or 400 psi calculated value, one must remember that the measured value represents a strain of about 6 to 8 microinches per inch, which is at the limit of resolution of the equipment. Furthermore, a change in temperature of 1°F between one portion of the hull and another can result in stresses of about 100 psi. One should therefore consider two stress values that are within 200 to 400 psi of each other as being in acceptable agreement.

1. Torsion Results

Results of the torsional portion of the experiment are presented in Figure 10. Magnetic tape and strain indicator readings as well as calculated stresses are presented.

Conditions 4 and 5 are identically maximum in twisting moment but of opposite sense; i.e., all containers from condition 4 were shifted, cell for cell, to the opposite side of the vessel to establish condition 5. Results from the four different data sources, two experimental and two analytical, are generally in good agreement.

Maximum twisting moment applied to the vessel in these maximum conditions was approximately 12,700 ft-tons producing single amplitude calibration stresses of about 900 psi. The maximum seaway acquired torsion stress was in the range of 1,500 to 1,800 psi peak-to-trough or approximately the same single amplitude stress as produced in the calibration. Logically, one can then deduce that seaway twisting moment amplitudes are on the order of 12,000 to 15,000 ft-tons. This compares with a maximum design torsional moment of 17,500 ft-tons computed using de Wilde's method (see Reference 4), which is based on a vessel heading of 60° (bow seas), wave length of 250 ft and wave height of 35 ft.

Data acquired from the transverse beam gages are presented in Figure 11 with the calculated stress for condition 5 superposed. The agreement between the calculated and experimental results is quite acceptable. Transducer 1 appears throughout to have a slightly higher output than Gage 2 installed directly below it on the same structure (see Figure 5). Gage 3 was expected to have slightly lower output than Gage 1 for a given twisting moment and was consistent with the anticipated result.

2. Vertical Bending Results

Although the vertical bending portion of the experiment was secondary in importance to the torsion, a similar analysis of the loading was performed. A ship status was assumed at condition 1 (empty ship) and changes in deck stress approximated at each other condition by knowing the change in vessel loading and hence the change in vertical bending moment.

The results of these calculations and the experimentally acquired data are presented in Figure 12 of this report. Agreement is certainly quite

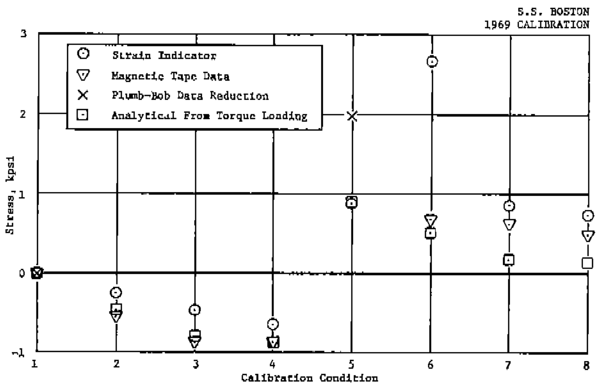


Fig. 10. Midship Torsional Stress-Calibration Data

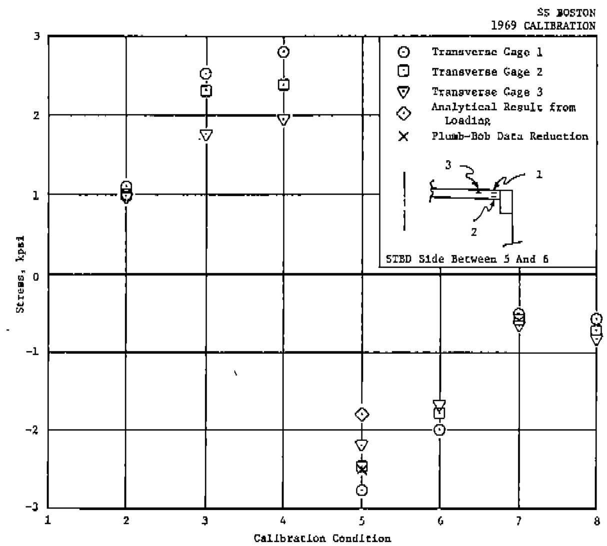


Fig. 11. Transverse Beam Stress-Calibration Data

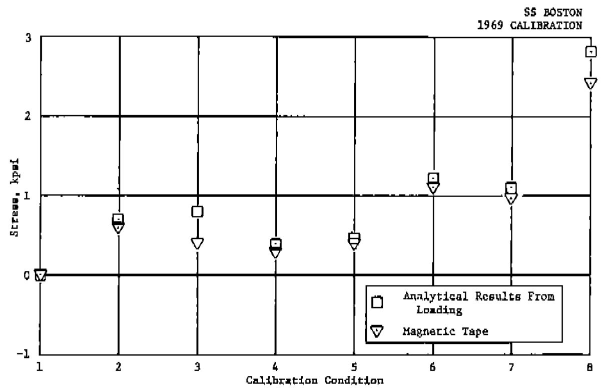


Fig. 12. Vertical Bending Stress-Calibration Data

satisfactory considering the relatively low stress values involved. The experimental data presented were collected on the magnetic tape system actually installed on the BOSTON. Agreement with the analytical results is sufficient confirmation of proper system operation.

It should be brought out that the vertical bending calibration stresses, on the order of 3,000 psi at departure, are static in nature and cannot be compared with seaway stresses recorded while underway. Instead, these departure condition stresses are the "zero" level about which the seaway stresses vary, both plus and minus.

IV. PROGRAM RESULTS

A. Stress Data

Summary plots of the data of principal interest are presented in Figures 13-15. These plots contain all recorded data from both operating seasons. The length of each stress level line is proportional to the number of maximum occurrences at that level of stress. A slight change in presentation format was required this year in that sea states to force 12 were encountered during the eastbound portion of Voyage 23.

Maximum peak-to-trough vertical bending stress recorded was 13,400 psi in sea state 10. A review of Figure 13 shows that the majority of data points fall in the 3,000 to 8,000 psi range.

Horizontal bending summary data are presented in Figure 14. The maximum recorded value obtained was 2,800 psi. This stress is relatively invariant with increase in sea state.

Peak-to-trough torsional shear stresses are presented in Figure 15. The highest stress recorded was just under 1,800 psi in a force 10 sea.

As mentioned earlier, the starboard box beam gage (SBBG) was selected from the four beam gages and recorded this season. The data from this gage are presented in Figure 16 of this report. An event by event comparative review of SBBG and vertical bending data has shown that in general SBBG ranges from 85% to 95% of the vertical bending stress at any particular instant in time. The maximum stress recorded from SBBG was 13,000 psi occurring in force 10 seas.

B. Acceleration Data

Vertical and horizontal accelerometers are installed on the S.S. BOSTON in bow, midship and stern locations. The devices were located at approximately the same positions as those on the S.S. WOLVERINE STATE to permit comparison with data acquired from that vessel. References 5, 6, and 7 should be reviewed for details of the S.S. WOLVERINE installation and its results.

Outputs from the stern units, located on frame 195 on the vessel centerline of the S.S. BOSTON, under the upper deck are presented in Figures 17 and 18.

The results of the midship units are presented in Figures 19 and 20. These transducers are located as near the vessel loaded center of gravity as possible, on frame 112 under the second deck, on the centerline.

Data from the bow accelerometers, located on frame 13 under the upper deck on the centerline, are presented in Figures 21 and 22.

The maximum peak-to-trough accelerations observed during the project span are as follows:

Unit	Acceleration(g)	Sea State
Stern Vertical	1.0	10
Stern Horizontal	.96	9
Midship Vertical	.37	8 and 9
Midship Horizontal	.28	10
Bow Vertical	1.5	8
Bow Horizontal	.92	4

C. Vessel Motion Data

Four transducers are installed to describe the motion of the S.S. BOSTON while underway. The two midship accelerometers provide heave (vertical) and sway (horizontal) signals (see Figures 19 and 20) while two separate pendulum-type potentiometric transducers, mounted at the same location, provide pitch and roll data. Figures 23 and 24 present the data from the pitch and roll devices.

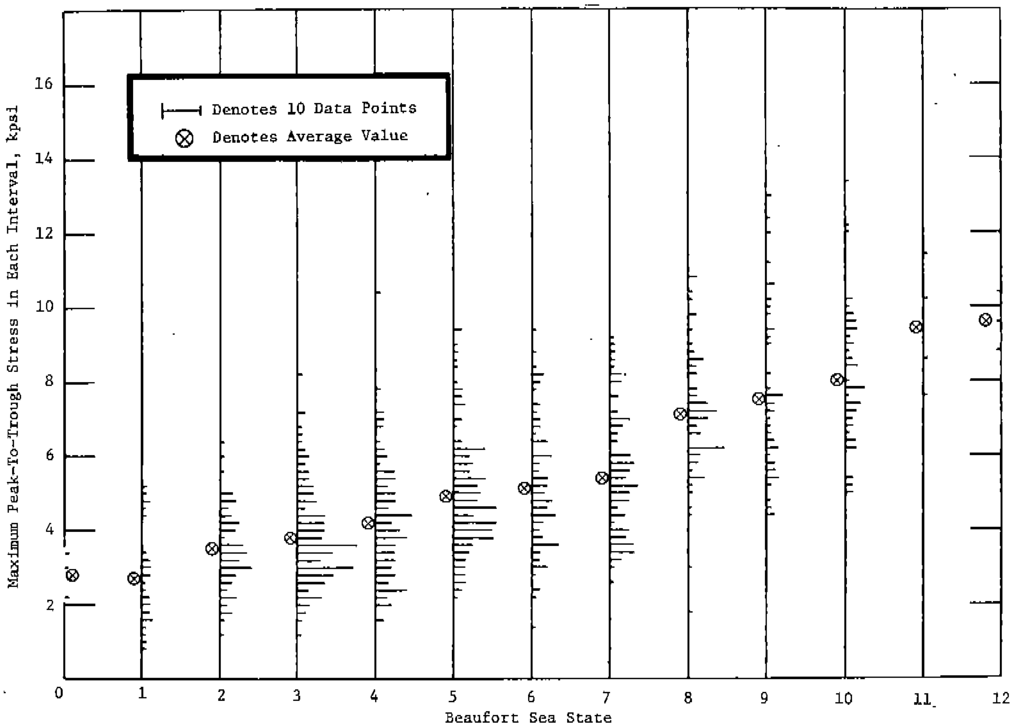


Fig. 13. CH-1. Vertical Bending Stress

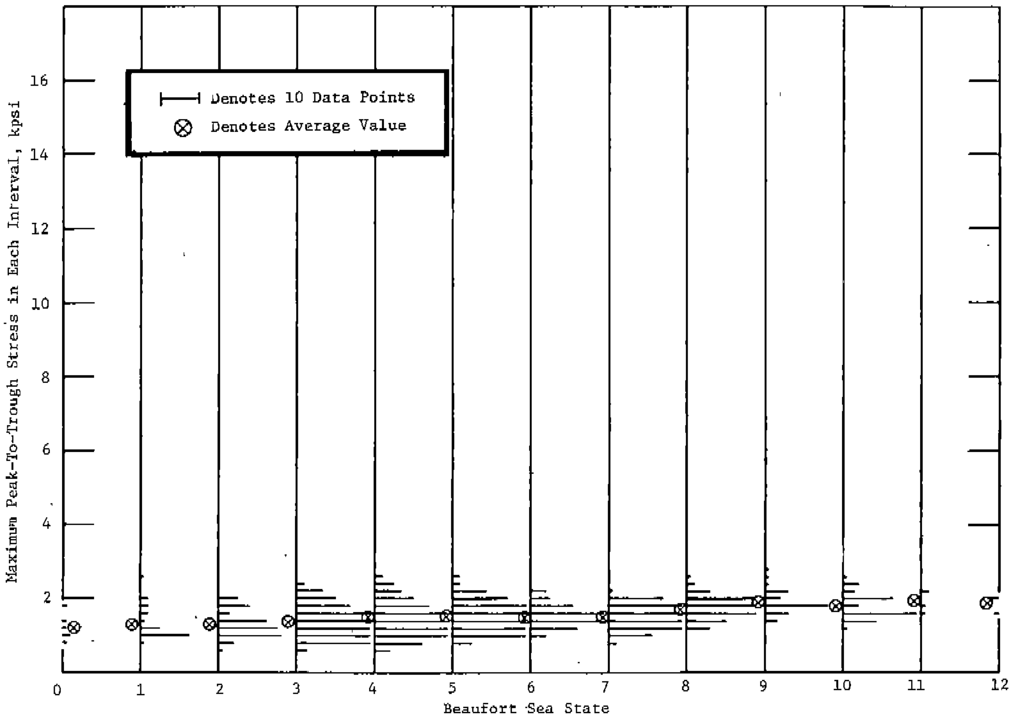


Fig. 14. CH-2. Horizontal Bending Stress

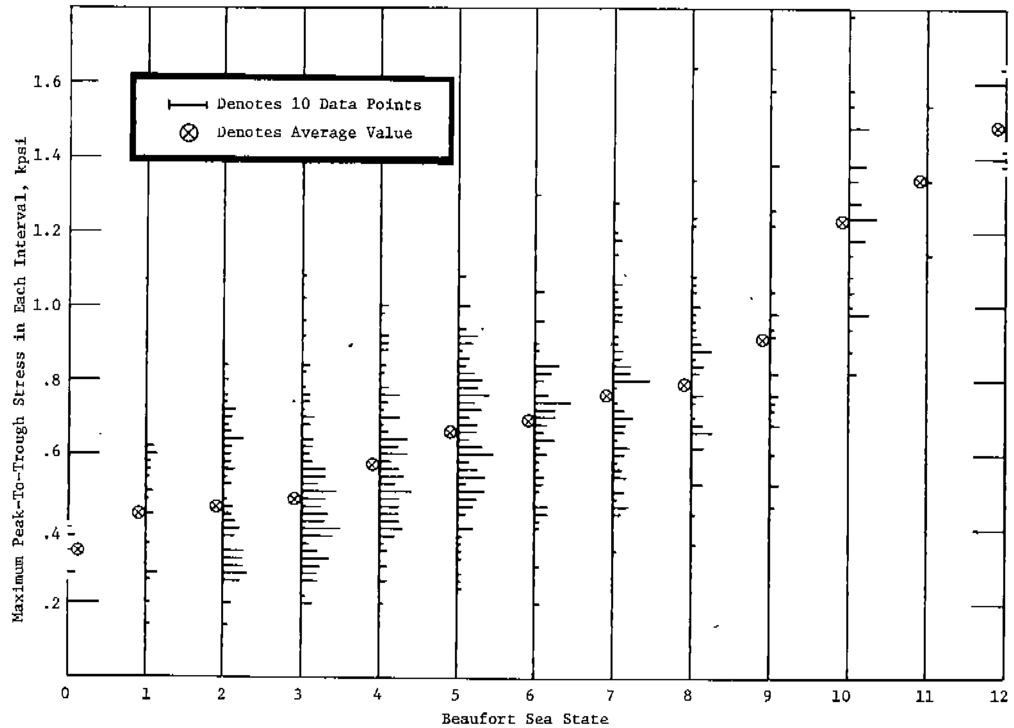


Fig. 15. CH-3. Hull Torsional Shear Stress

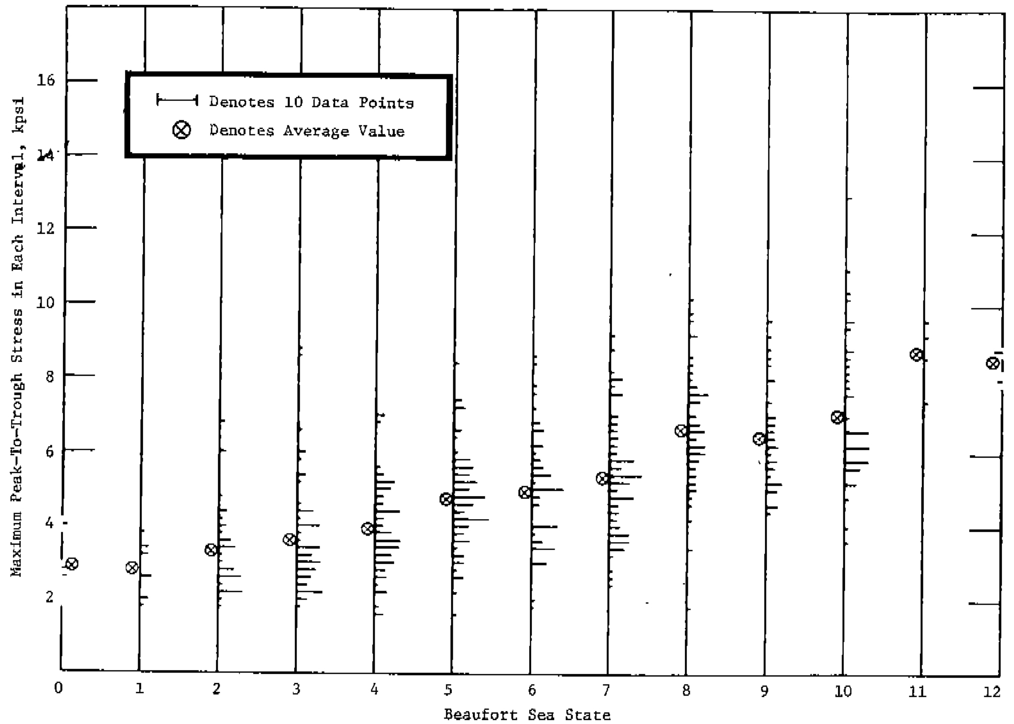


Fig. 16. CH-4. Starboard Box Beam Gage

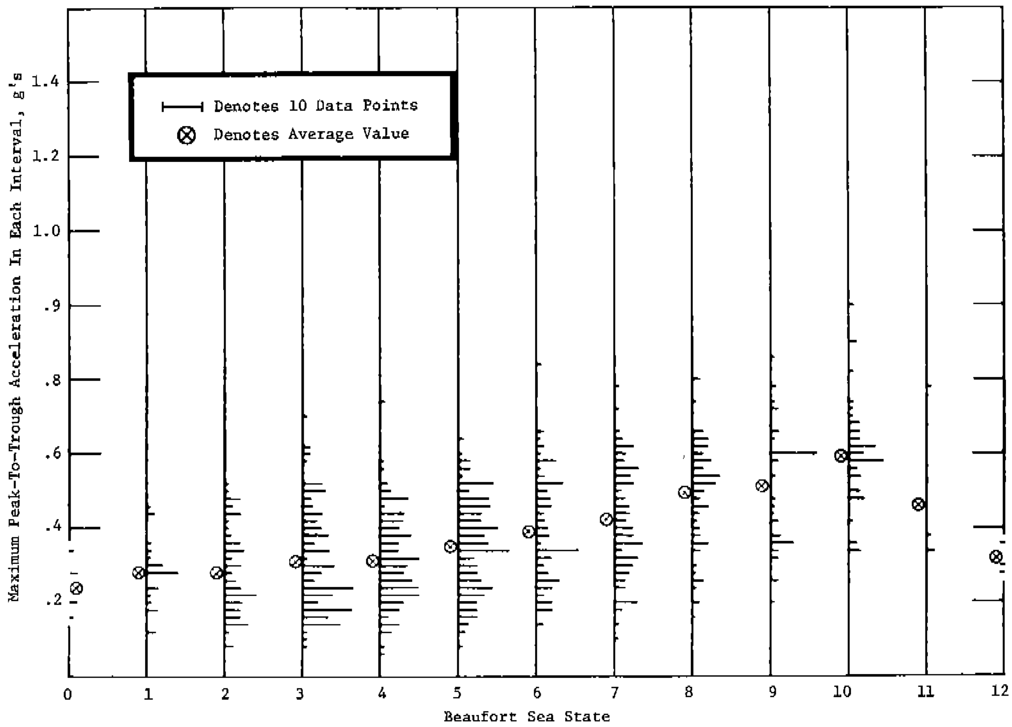


Fig. 17. CH-5. Stern Vertical Acceleration

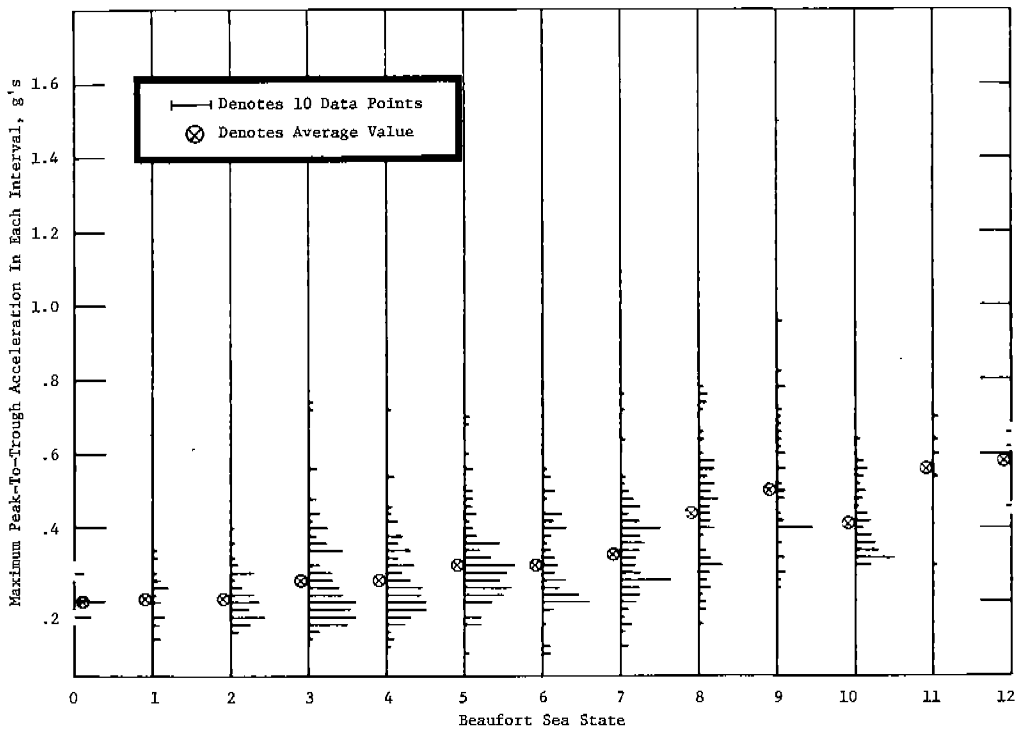


Fig. 18. CH-6. Stern Horizontal Acceleration

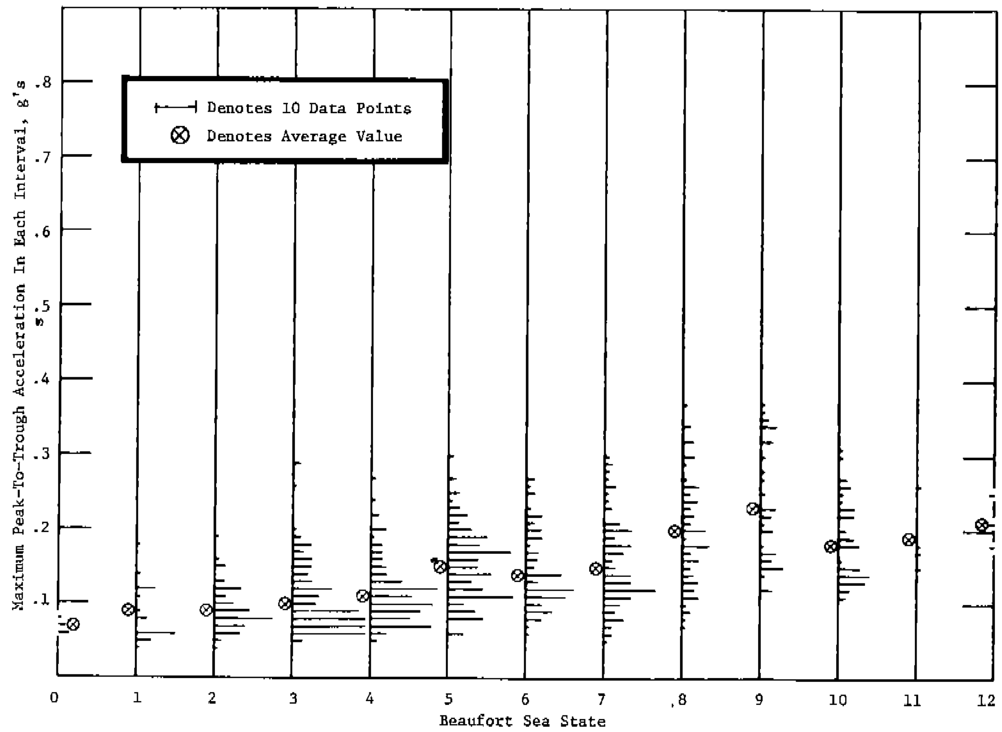


Fig. 19. CH-7. Midship Vertical Acceleration (Heave)

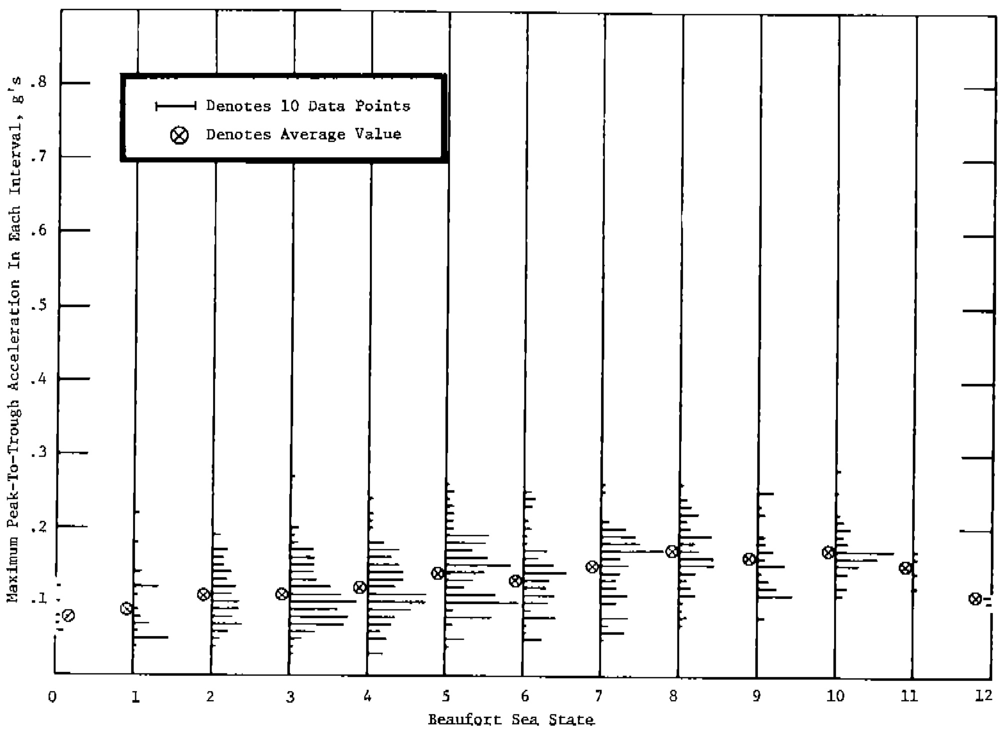


Fig. 20. CH-8. Midship Horizontal Acceleration (Sway)

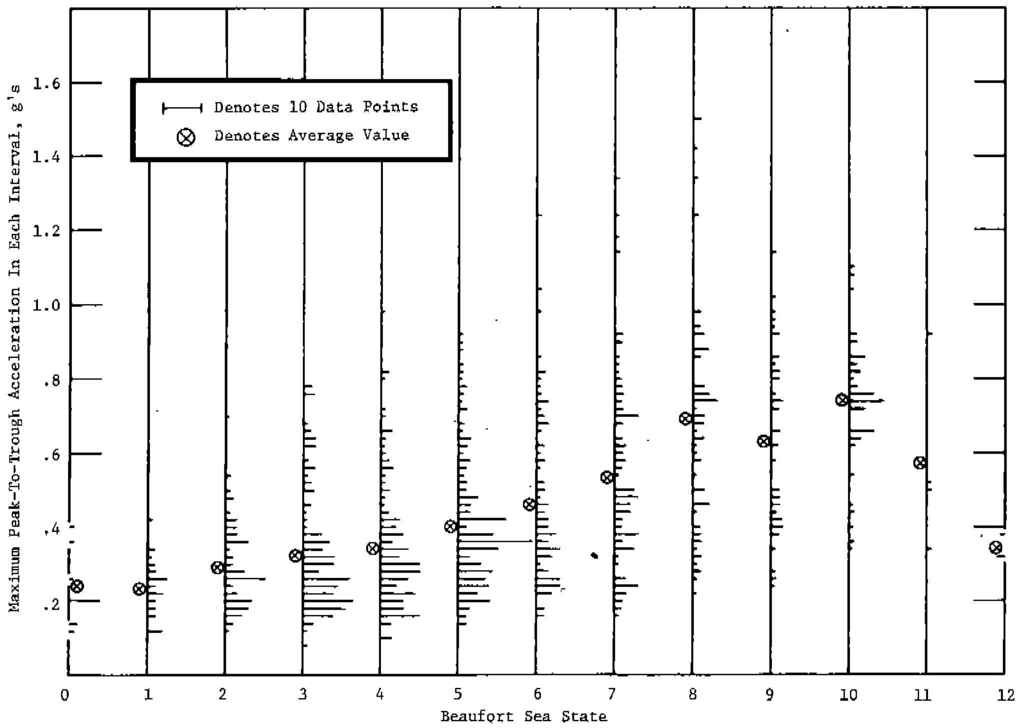


Fig. 21. CH-11. Bow Vertical Acceleration

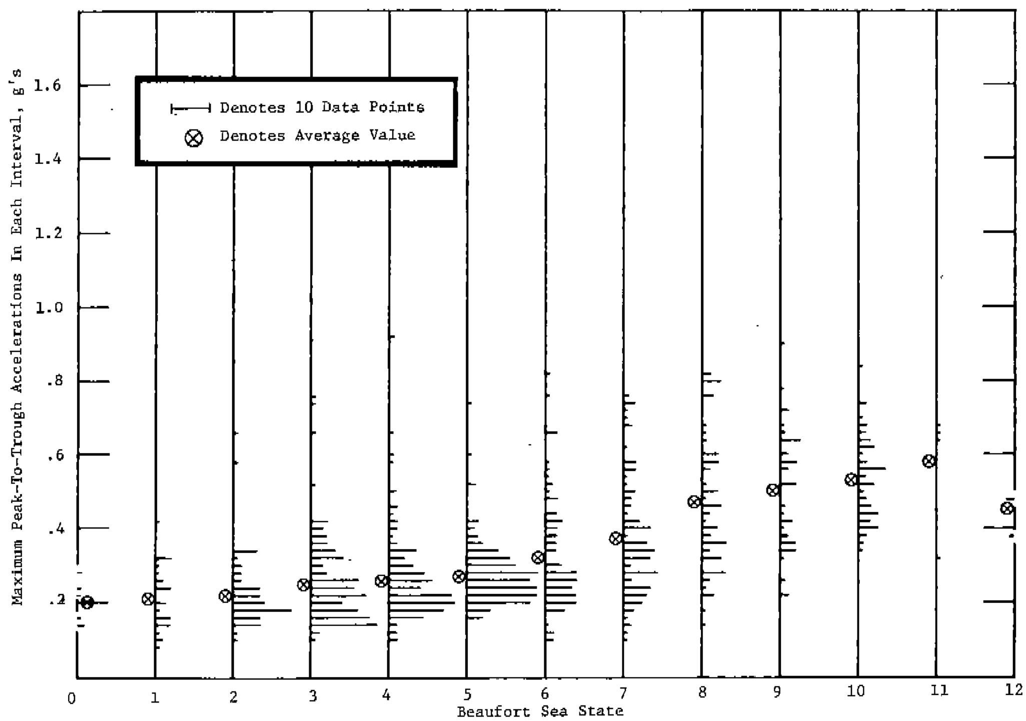


Fig. 22. CH-12. Bow Horizontal Acceleration

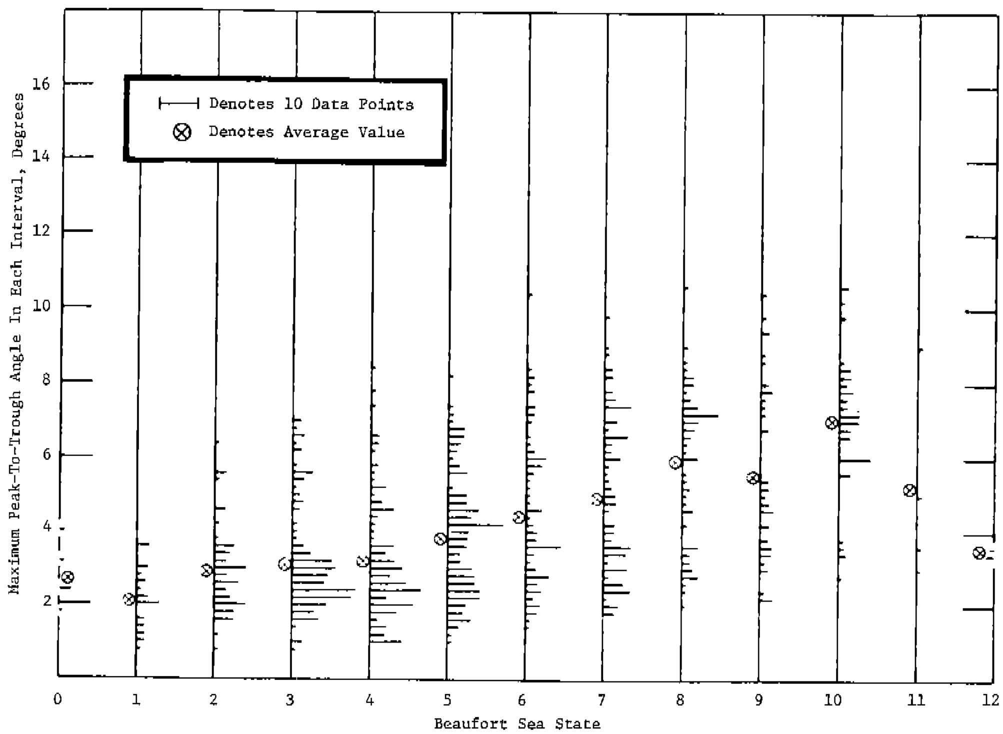


Fig. 23. CH-9. Pitch Angle

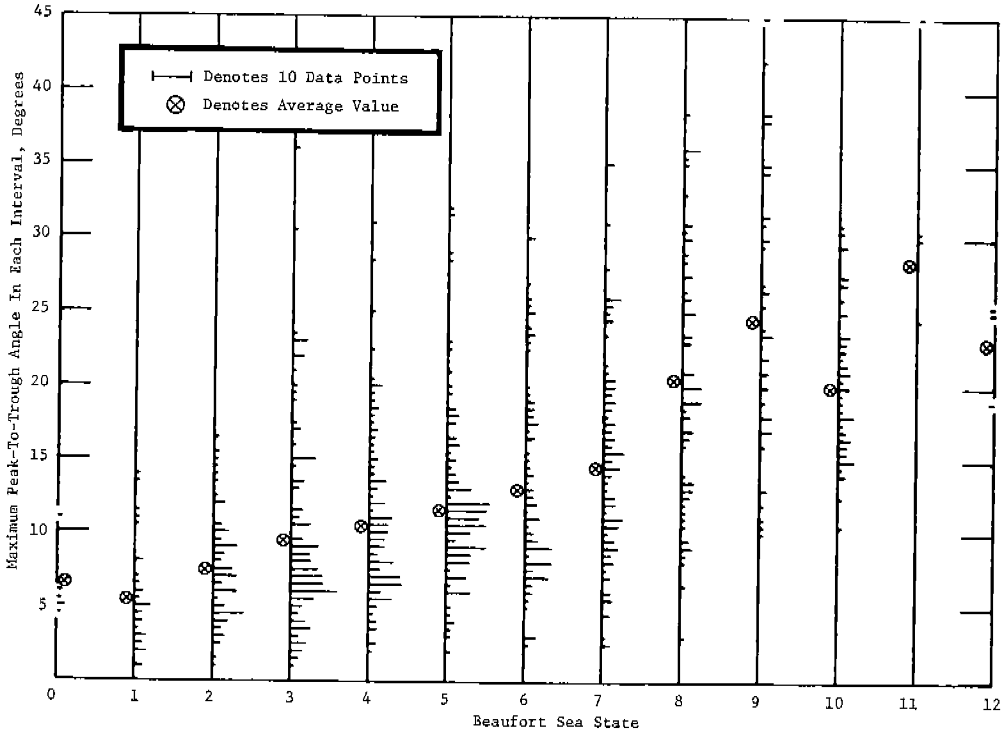


Fig. 24. CH-10. Roll Angle

Maximum peak-to-peak roll encountered during the program was 45° and maximum pitch angle was 10.6°. These are 22.5° and 5.3°, respectively, from the vertical reference.

D. Wave Buoy Data

A successful wave buoy launching was accomplished on westbound Voyage 22 as the sea was dropping from force 8 to 6. Details of the launch period excerpted from the engineer's logbook are presented in Table III and Figures 25 and 26 present the power spectral density analysis resulting from the computer analysis of the launch tape.

V. DISCUSSION OF RESULTS

A. Stress Data

As expected, the highest stresses recorded on the S.S. BOSTON were in the vertical longitudinal bending direction. Figure 13 presents the summary of the vertical bending data for the entire program. The "⊗" at each sea state is the average stress value at that sea state for all data collected from both operating seasons.

Figure 27 is a comparison of the S.S. BOSTON average vertical bending stress with that of the S.S. WOLVERINE STATE. The S.S. WOLVERINE STATE is an unconverted C4, normally carrying break-bulk cargo on the North Atlantic run. Table IV lists the principal physical characteristics of this vessel. The comparison is valid in that only winter season data from the S.S. WOLVERINE STATE are included.

Some of the disparity in the comparison is undoubtedly due to the 16% greater section modulus on the S.S. WOLVERINE STATE, effectively lowering the deck stress for the same bending moment that the S.S. BOSTON experiences.

Horizontal bending stress is quite low. A data summary of results is presented in Figure 14.

Seaway-induced torsional shear stress data are summarized in Figure 15. These peak-to-trough stresses are approximately equal to the calibration torsion stresses, since the latter are single amplitude measurements from a normalized "zero" condition.

Results of the transverse beam gages are not presented as plots, since the twofold intent of their temporary installation did not include statistical acquisition of data throughout the sea state spectrum. Instead, these gages were primarily installed for measurements during the calibration (Figure 11) and were also monitored for three European voyages during high sea state conditions.

The addition of these transverse beam gages required a separate data recording system. There was no "real-time" correlation connection between this direct record system and the normal ship response magnetic tape system. Consequently, an event by event comparison of these gages with the hull torsion gages, for example, is not possible except statically in the calibration data.

Table V summarizes data from these gages for the two roughest Voyages, 20 and 21. A review of the included list of approximate course and wind directions confirms the expected high transverse beam stresses associated with the encountering of quartering seas.

Table III
Logbook Data, Voyages 22 Wave Buoy Launch

Buoy Serial No. 49008	Voyage No. 22
Index Number	23
Date and Time	1230 GMT 1-11-70
Time Meter Reading	60.4
Latitude	48.7 N
Longitude	39.3 W
Course	270°
Speed	7 Knots
Engine	17 RPM
Wind Speed	25 Knots
Relative Wind Direction	N to NE
Beaufort Sea State No.	8 - 6
Relative Wave Direction	NE
Average Wave Height	6 FT
Average Wave Period	5 SEC
Average Wave Length	70 FT
Average Swell Height	20 FT
Average Swell Length	250 FT
Relative Swell Direction	NW
Barometer Reading	29.32
Sea Temperature	52°F
Air Temperature	50°F
Weather	Cloudy and Overcast

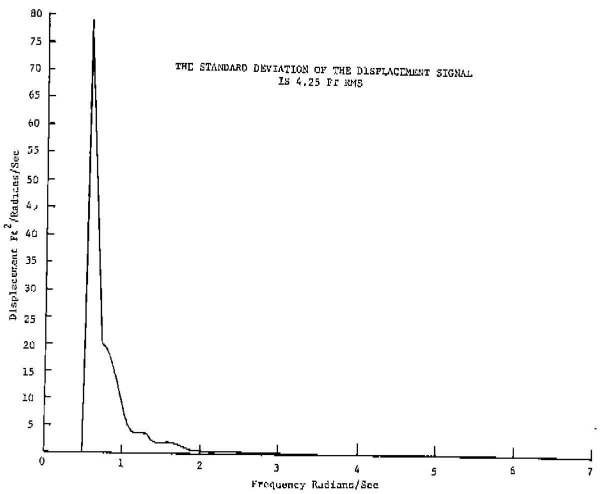


Fig. 25. Wave Buoy Power Spectral Density Analysis *S.S. Boston* Buoy No. 49008 Launched 1/11/70

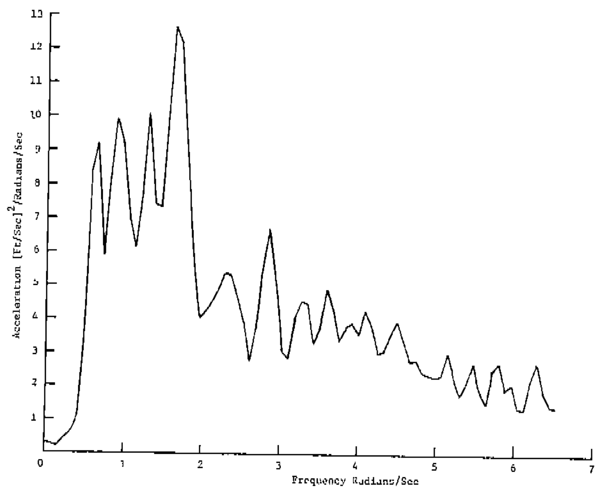


Fig. 26. Wave Buoy Power Spectral Density Analysis *S.S. Boston* Buoy No. 49008 Launched 1/11/70

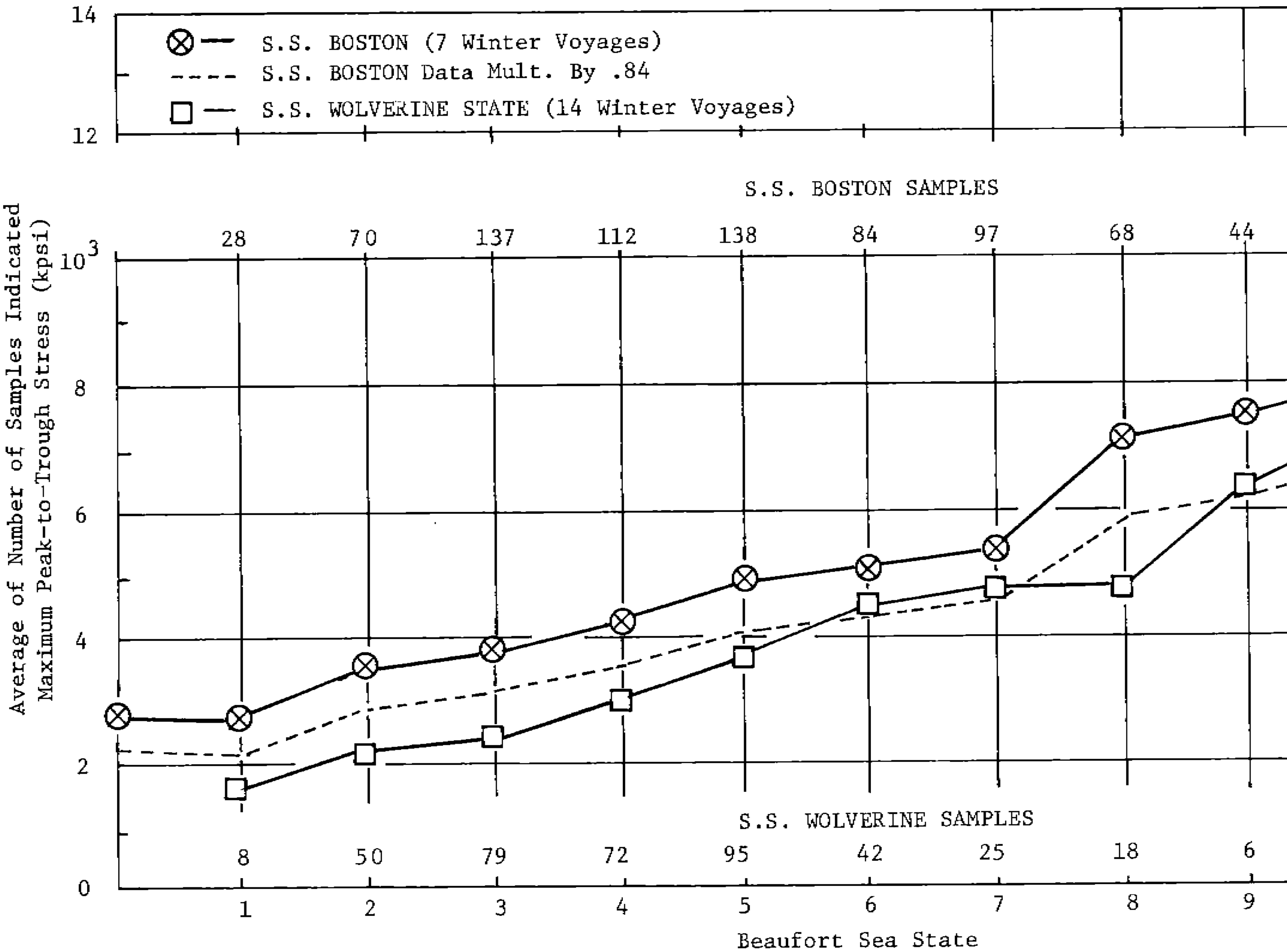


Fig. 27. Vertical Longitudinal Bending Stress Comparison *S.S. Boston* and *S.S. Wolverine State*

Talbe IV
Characteristics of the *S. S. Wolverine State*

Original Name	MARINE RUNNER
Builder	Sun Shipbuilding and Drydock Company
Type	C4-S-B5 Machinery-Aft Dry Cargo Vessel
Official Number	248740
Length Overall	520' - 0"
Length Between Perpendiculars	496' - 0"
Breadth, Molded	71' - 6"
Depth, Molded	54' - 0"
Depth, Molded to Poop Deck	43' - 6"
Depth, Molded to Second Deck	35' - 0"
Depth, Molded to Third Deck	26' - 0"
Tonnage (U.S.) Gross	10,747
Net	6,657
Load Draft, Molded (Design)	30' - 0"
Load Draft, Keel (Full Scantling)	32' - 9-7/8"
Light Ship Drafts	3' - 7" Fwd
	19' - 9-1/2" Aft
	11' - 8-1/4" Mean
Dead Weight (at 32' - 9-7/8")	15,348 L.T.
Light Ship Weight	6,746 L.T.
Center of Gravity	30.4 Ft Above Keel
	24.2 Ft Aft of Midships. B.P.
Block Coefficient	0.654 (30' Molded Design Draft)
	0.61 (18' Typical Present Operation)
Prismatic Coefficient	0.664 (30' Molded Design Draft)
	0.628 (18" Typical Present Operation)
Waterplane Coefficient	0.752 (30' Molded Design Draft)
	0.685 (18' Typical Present Operation)
Midship Section Modulus	45,631 In^2 Ft (To Top of Upper Deck And With Deck Straps)

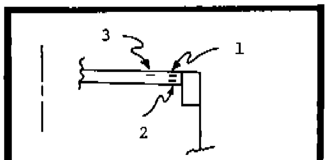
Machinery

Steam Turbine With Double Reduction Gear

	Normal	Maximum
H.P. Turbine, Design R.P.M.	5,358	
L.P. Turbine, Design R.P.M.	4,422	
Propeller, Design R.P.M.	85	88
Propeller, Normal Design R.P.M.	80	
Shaft Horsepower, H.P. Turbine	4,500	
Shaft Horsepower, L.P. Turbine	4,500	
Shaft Horsepower, Total	9,000	9,900
First Reduction Gear, H.P. Turbine	9,096	
First Reduction Gear, L.P. Turbine	7,508	
Second Reduction Gear	6,930	

Table V
Transverse Beam Stresses

Date	GMT	Sea State	Peak-To-Trough Gage Stress (psi) 1	2	3	Vessel Course	Wind Direction
VOYAGE 20							
10-18-69	2300	4	2044	1679	1606	088	West
10-19-69	1540	5	1825	1679	1460	084	290
10-20-69	1200	4	2409	2044	1898	071	WNW
10-21-69	1200	7	3139	2628	2555	071	095
10-21-69	1600	8	6351	5329	5256	064	180
10-23-69	1200	3	2409	2007	1898	075	310
VOYAGE 21							
11-15-69	1530	7	2930	2266	1824	077	260
11-16-69	1300	4	2488	2045	2156	077	270
11-17-69	1200	10	2930	2211	2488	070	030
11-18-69	1200	10	2266	1769	1935	070	045
11-19-69	1120	10	2874	2211	2211	056	045
11-20-69	1200	8	4478	3483	3372	056	090
11-21-69	1200	7	2764	2156	2266	056	135
11-22-69	1200	5	1382	1106	1106	061	080
11-23-69	1030	6	2764	2100	2488	080	030
11-24-69	1000	6	2543	2045	2100	080	040
11-25-69	0900	3	1271	884	940	090	000



STBD Side Between 5 And 6

The maximum stress condition on these gages occurred on October 21, 1969, and is associated with the following conditions excerpted from the mates and Teledyne engineer's logbooks:

Course ....064°

Wind Speed.................40 kts

Wind Direction...............180°

Wave Height.................8-12 ft

Sea State.....................8

Swell Length...............700 ft

This data was accompanied by the comment "Rolling heavily in a quartering sea and long heavy swell..........spray breaking over sides of ship."

These are the exact conditions that one might expect would produce high stress on a cross-deck beam due to imposed hull twist. Maximum measured stress values were Gage 1-6351 psi, Gage 2-5329 and Gage 3-5256 psi.

A review of both Figure 11 and Table V indicates that there is little decay in bending stress from the outboard to inboard gage positions.

Appended to this report is a calculation of the twisting moment required to generate 6350 psi of bending stress in the transverse beam structure.

B. Acceleration Data

Figures 17 through 22 present the summary data from the six acceleration channels. Figure 28 compares the S.S. BOSTON'S bow vertical acceleration data with that collected on the S.S. WOLVERINE STATE. Agreement between the two sets of data is acceptable.

The drop-off in g level at the higher sea states in the S.S. BOSTON curve is most likely due to the Sea-Land policy of immediate "slow-down" if strong head seas are encountered. This is to minimize water over the bow with consequent on-deck container and cargo damage. Figure 27 shows that the vertical bending stress level remains high in these sea states, although the g level has dropped considerably.

C. Ship's Motion Data

Figures 23 and 24 present the two-season summary of pitch and roll measurements. Roll continues to be the largest amplitude motion. Rather than ship water over the bow and damage cargo, the master normally adjusts the vessel's course to lessen pitch with a consequent increase in roll rather than slow down excessively and maintain course.

D. Wave Buoy Data

The Teledyne Materials Research Power Spectral Density Program was used to produce the wave buoy displacement and acceleration curves presented as Figures 25 and 26. A computer analysis of the vertical bending stress data acquired during the wave buoy launch period has been performed producing an RMS and maximum peak-to-trough signal for each data interval.

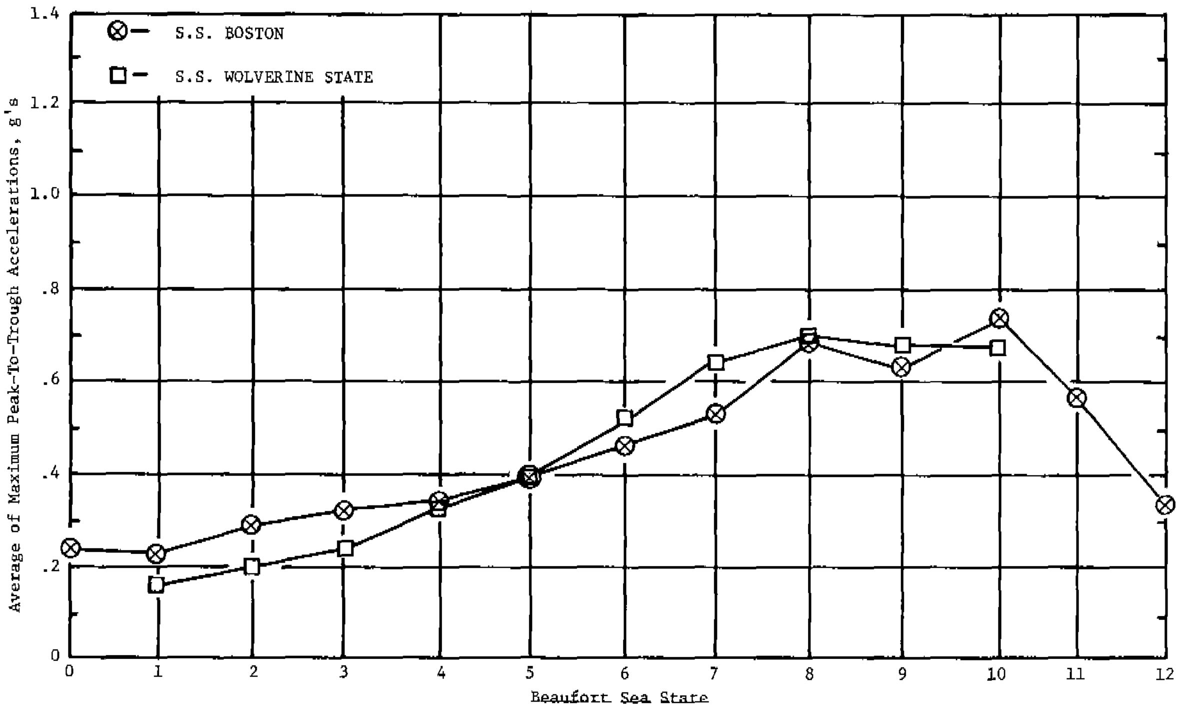


Fig. 28. Bow Vertical Acceleration Comparison
S.S. Boston and *S.S. Wolverine State*

RMS stress values computed from the 11 data interval of vertical bending data range from 1,600 to 2,900 psi, while the maximum peak-to-trough stress value was 4,800 psi. Although these stress values are rather low, they appear to be consistent with the logbook data in that the sea was rapidly subsiding from force 8 to force 6 level.

The Power Spectral Density Program computed a standard deviation of displacement of the wave buoy launched during Voyage 22 of 4.25 ft RMS. Average wave height from Table III is listed as 6 ft with swell height to 20 ft. If a "significant" wave height is arbitrarily defined as four times the computed RMS value or 17 ft, the agreement with the subjective logbook information is acceptable.

VI. FINDINGS AND CONCLUSIONS

Data were successfully collected from the stress and motion transducers on the S.S. BOSTON on seven North Atlantic voyages during two winter seasons. Two voyages were manned during late winter of the first season, as the weather was already subsiding from the midwinter maximums. Sea states to force 12 were encountered during the second (1969-1970) full winter season providing a complete sea/weather spectrum for the program period.

Maximum vertical bending peak-to-trough stress recorded in the program was 13,400 psi in a sea state 10, while hull torsional shear stress at the gaged location was only 1,800 psi.

The bow vertical accelerometer recorded g levels as high as 1.5, a level sufficiently high to cause damage to cargo not properly secured. Horizontal accelerations ranged as high as .96 g.

A comparison of vertical bending data with that collected on the S.S. WOLVERINE STATE, an unconverted C4, shows that in general, taking in consideration the smaller section modulus of the S.S. BOSTON brought about in her conversion, the vertical bending moment response of the S.S. BOSTON was reasonably similar to that of the S.S. WOLVERINE STATE.

Experimental results of the vessel static calibration compare well with analytical calculations based on the applied loads.

VII. ACKNOWLEDGMENTS

This work was sponsored jointly by the Ship Structure Committee and Sea-Land Service, Inc. The investigators wish to acknowledge wholehearted cooperation by both organizations throughout the two-and-one-half year program period.

Special thanks go to Mr. John Boylston, Sea-Land Naval Architect, Captain Burger, Master of the S.S. BOSTON and Captains Ralph Haugneland, John Nixon, and Robert Murray of the Sea-Land Operations' Department. Without the excellent cooperation and assistance of these gentlemen, the work could not have been accomplished.

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APPENDIX

TRANSVERSE BEAM ANALYSIS

By using the calculation technique of Appendix B of Reference 2, we can approximate the deflection of the transverse beam and the twisting moment necessary to produce the peak-to-trough stress in the beam.

Results of Appendix B, Reference 2, show a discrepancy between theoretical and measured values for the transverse beam stress generated by a vessel twisting moment.

For example:

Twisting Moment, T = 12,700 Ft-Tons

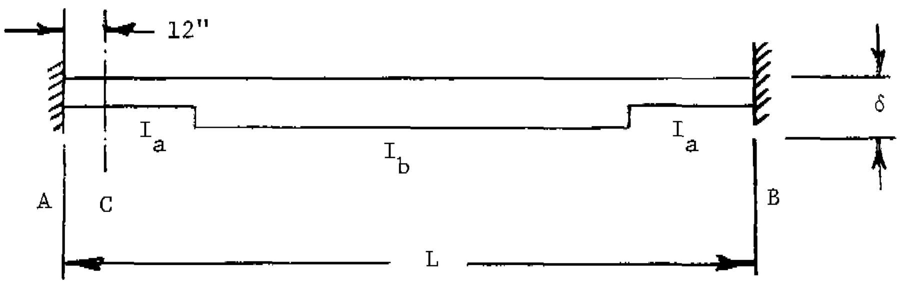
Transverse Beam Stress, $\sigma_{meas} = 2{,}500$ psi

Transverse Beam Stress, $\sigma_{theor} = 1{,}800$ psi

or $\sigma_{meas} = 1.4\ \sigma_{theor}$

The maximum measured seaway-induced stress on the transverse beam was 6,350 psi peak-to-trough. If we correct this for single amplitude equivalence and by the ratio we get:

$$\sigma_{corr} = \frac{6{,}350}{2(1.4)} = 2{,}267 \text{ psi}$$



$$M_c = \frac{\sigma_c\ I_a}{C_c} = \frac{2{,}267(23{,}664)}{25} =$$

$$M_c = 2.15(10^6) \text{ in\#}$$

L = 740 in

$I_a = 23{,}664$ in^4

$I_b = 44{,}563$ in^4

K = 995.2 (Ref.2, App.B, P.14)

$$M_A = \frac{6EI_b\delta}{LK}$$

$$M_c = \left[\frac{\frac{L}{2} - 12}{\frac{L}{2}}\right] M_A$$

$$\delta = \left[\frac{\frac{L}{2}}{\frac{L}{2} - 12}\right] \frac{M_c LK}{6EI_b}$$

$$= \left[\frac{\frac{740}{2}}{\frac{740}{2} - 12}\right] \frac{2.15(10^6) \quad 740(995.2)}{6(30)\ (10^6)\ (44{,}563)}$$

$$= .204 \text{ in deflection}$$

$$\frac{\phi' GK_t}{T} = .11 \qquad \text{(P. 14, App. B, Ref. 2)}$$

$$\text{and } \delta = \phi' \left[\int_0^B \rho_o ds - \int_0^A \rho_o ds\right]$$

$$\text{and } \int_0^B \rho_o ds = 280{,}096 \text{ in}^2$$

$$\int_0^A \rho_o ds = 15{,}600 \text{ in}^4$$

$$\text{so } \phi' = \frac{\delta}{280{,}096 - 15{,}600}$$

$$\phi' = \frac{.204}{264{,}496} = .77 \times 10^{-6} \quad \text{rad/in}$$

$$T = \frac{\phi' GK_t}{.11}$$

$$= \frac{.77(10^{-6}) \quad 11.5(10^6) \quad (5.118) \quad (10^6)}{.11}$$

$$= 411(10^6) \text{ in\#}$$

$$T = 17{,}125 \text{ ft tons moment}$$

This compares with the maximum design moment of 17,500 ft tons using de Wilde's method.

A local stress concentration may be causing the 40% discrepancy between calculated and measured transverse beam stresses. The theoretical analysis is somewhat general in nature and does not include such second order refinements as concentration effects.

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13. ABSTRACT

This summary report contains ship response data, with associated discussions, collected during two North Atlantic Winter operating seasons on the Sea-Land container vessel S.S. Boston. Seven voyages are covered with sea states ranging to force 12.

Maximum vertical bending peak-to-trough, stress recorded in the program was 13,400 psi in a sea state of 10. Maximum hull torsional shear stress was 1,800 psi peak-to-trough, also occurring in force 10 seas. Bow vertical acceleration ranged as high as 1.5g and horizontal acceleration as high as .96g.

Results of an extensive static loading experiment are also presented and compare well with analytical calculations based on applied loads.

Vertical bending data collected on the S.S. Boston are compared with that collected on a similar unconverted C4, the S.S. Wolverine State.

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SHIPBOARD INSTRUMENTATION SYSTEM						
NORTH ATLANTIC CROSSINGS						
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ACCELERATIONS						
TORSIONAL STRESS						
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