SSC-212

SHIP RESPONSE RESULTS FROM THE FIRST OPERATIONAL SEASON ABOARD THE CONTAINER VESSEL S.S. BOSTON

SHIP STRUCTURE COMMITTEE

1970

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SECRETARY
SHIP STRUCTURE COMMITTEE
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1970

Dear Sir:

The advent of containership operation has encouraged the Ship Structure Committee to undertake a project involved in instrumenting one of the ships to develop data that will provide increased reliability and economy in future designs.

Herewith, is a technical report describing the instrumentation utilized and data from three voyages.

Sincerely,

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

SSC-212

TECHNICAL REPORT

on

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

to the

Ship Structure Committee

SHIP RESPONSE RESULTS FROM THE FIRST OPERATIONAL SEASON ABOARD THE CONTAINER VESSEL S.S. BOSTON

by

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Waltham, Massachusetts

under

Department of the Navy
Contract N00024-68-C-5486

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

1970

ABSTRACT

This report contains data, with associated discussions, collected from the SEA-LAND Vessel *SS Boston*, during the winter operating season, November 1968 to April 1969 in the North Atlantic. Ship's voyages 7, 9, and 10 were manned by Teledyne personnel with data collected during each Atlantic crossing. A total of 356, 15-minute data intervals was obtained, and three wave buoy launches were performed. Plots of various transducer outputs versus Beaufort sea state are provided along with comparisons with data from a similar class of vessel.

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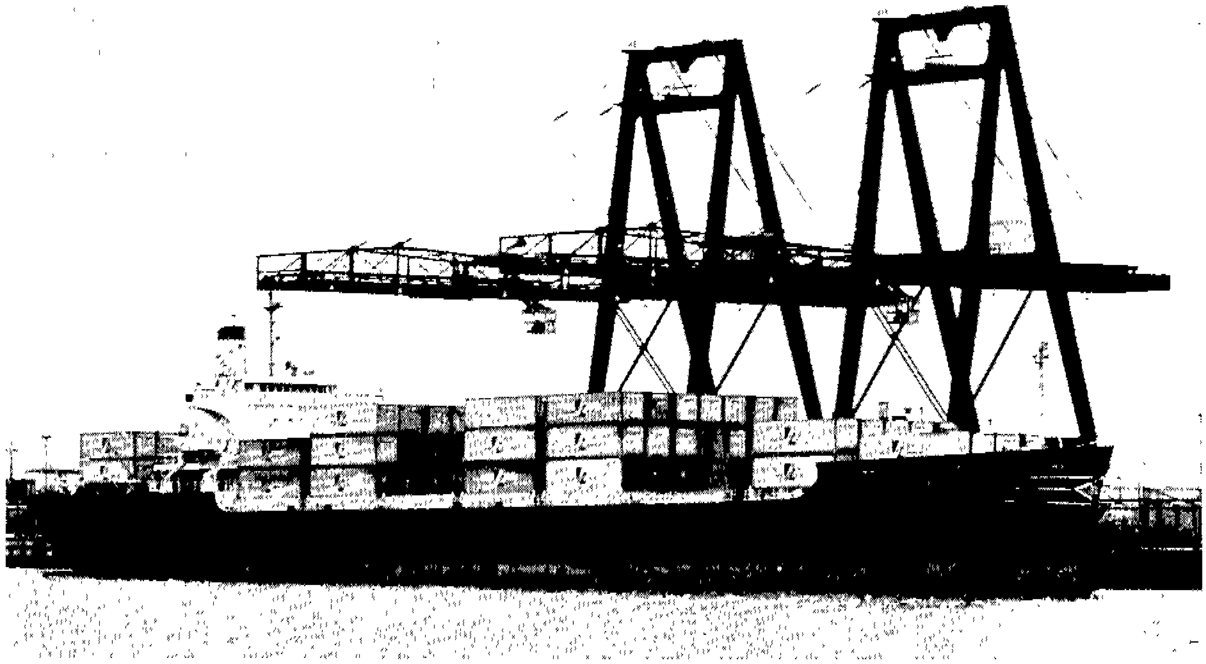


Fig. 1. Container Vessel *S. S. Boston*

1.0 INTRODUCTION

The container vessel S. S. BOSTON, Figure 1, is owned and operated by Sea-Land Service Incorporated. This vessel was formerly the S. S. GENERAL M. M. PATRICK, a C4-S-A1 personnel carrier, and was subsequently converted to a C4-X2 container ship by Todd Shipyards Corporation, Galveston Division, in early 1968.

Teledyne Materials Research, Waltham, Massachusetts, designed and installed a ship response instrumentation system starting in June of 1968 and began collecting data in December of 1968. A comprehensive discussion of the instrumentation system can be found in reference 1. The vessel operated on a route between Port Newark, New Jersey, U.S.A., and ports in Europe. During the period from late November 1968 to April 1969, a Teledyne engineer was aboard the vessel to operate the instrumentation system and to perform on-board data analysis. Data was obtained utilizing a fifteen-minute sampling every four hours during normal conditions with the option to switch to continuous recording during periods of high sea states. A total of 356 data intervals was collected during the past operating season.

In addition to ship response information, simultaneous sea state information was obtained by launching "wave buoy" units which provide sea state spectra upon data analysis. Three such launches were made during the past season. A summary of the voyages undertaken, along with the number of intervals of data obtained, is presented in Table I. Table II summarizes the characteristics of the S. S. BOSTON.

2.0 EQUIPMENT AND PROCEDURES

2.1 Data Acquisition Instrumentation Systems

Two functionally separate, but physically common, instrumentation systems were installed aboard the S. S. BOSTON. The ship response system was operated

Table I. 1968-1969 Voyage Summary

Ship's Voyage #7

From	On	To	On	Number of Channels	Number of Data Intervals
Newark	12/19/68	Rotterdam	12/30/69	7	48
Rotterdam	1/9/68	Rotterdam	1/14/69	11	24
Rotterdam	1/14/69	New York	1/24/69	14	49

Ship's Voyage #8

Involved movement of the vessel from Todd Shipyard, Brooklyn, New York upon conclusion of the longshoremen's strike.

Ship's Voyage #9

From	On	To	On	Number of Channels	Number of Data Intervals
Newark	2/21/69	Rotterdam	3/3/69	14	63
Felixstowe, England	3/10/69	Newark	3/18/69	14	58

Wave buoy launched at 1500 (GMT) on 2/25/69. Serial No. 49004

Ship's Voyage #10

From	On	To	On	Number of Channels	Number of Data Intervals
Baltimore	3/23/69	Rotterdam	4/1/69	14	58
Felixstowe	4/10/69	Newark	4/19/69	14	56

Wave buoy launch 1345 GMT 3/30/69 - Serial No. 49001

Wave buoy launch 1015 GMT 4/12/69 - Serial No. 49002

Table II. 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:	C4-5-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"

primarily in an automatic mode with a 15-minute sampling of data every four (4) hours. The system can be run continuously by switching to manual. The second system is an accelerometer wave buoy system with a free-floating wave buoy as the signal source. Data was recorded simultaneously on both systems during the buoy launch for a period of approximately 90 minutes depending upon the received signal strength.

2.1.1 Ship Response Instrumentation System

The ship response instrumentation presently installed aboard the S. S. BOSTON is designed to provide 14 channels of data for recording on an Ampex FR-1300 FM tape unit (Figure 2). Two categories of signals are monitored: channels 1 - 4 record signals developed from strain gage bridge circuits (Figure 3A to 3D) while channels 5 - 13 monitor the outputs of transducers located throughout the ship to sense accelerations and displacements. Channel 14 is a compensation channel used in the playback mode to correct recorder error contributions. Detail transducer specifications can be found in Appendix A, while Figure 4 presents a schematic view of the various transducer locations. A complete listing of channel assignment is provided in Table III. A discussion of the transducer calibration mode calculations is provided in Appendix B.

Fig. 2.
14-Channel
Shipboard Tape
Recorder
AMPEX FR1300

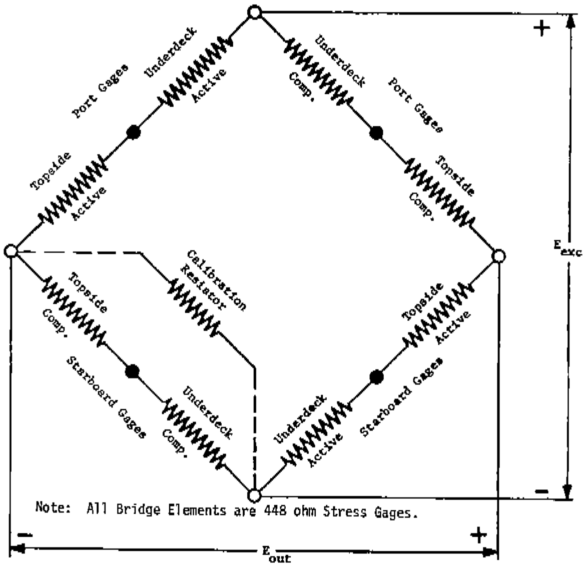


Fig. 3A. Bridge Circuit-Vertical Longitudinal Bending (Channel 1)

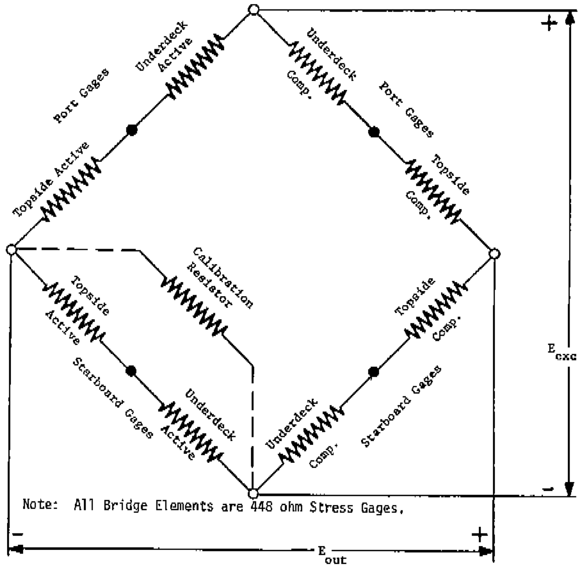


Fig. 3B. Bridge Circuit-Horizontal Longitudinal Bending (Channel 2)

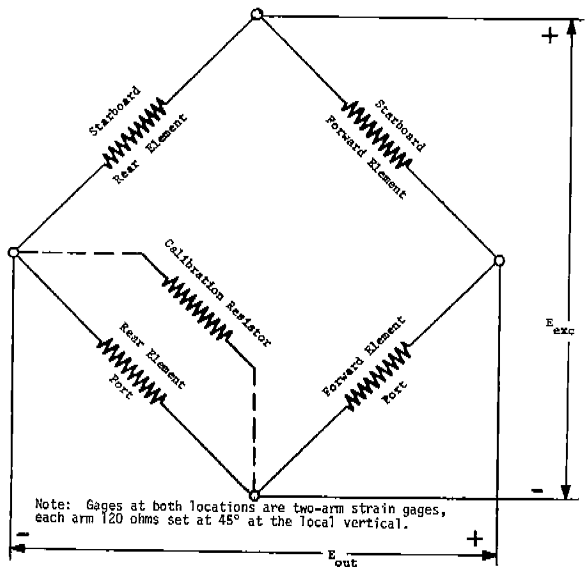


Fig. 3C. Bridge Circuit-Torsional Shear Stress (Channel 3)

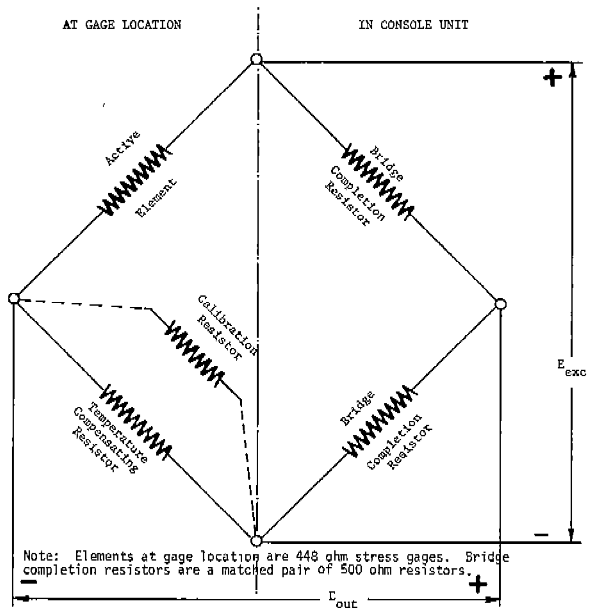


Fig. 3D. Single Element Strain Gage Bridge Circuit (Channel 4)(4A-SUDG-Starboard Underdeck Gage, 4B-SSPG-Starboard Side Plate Gage, 4C-SBBG- Box Beam Gage, 4D-PSWG-Port side Weld Gage.)

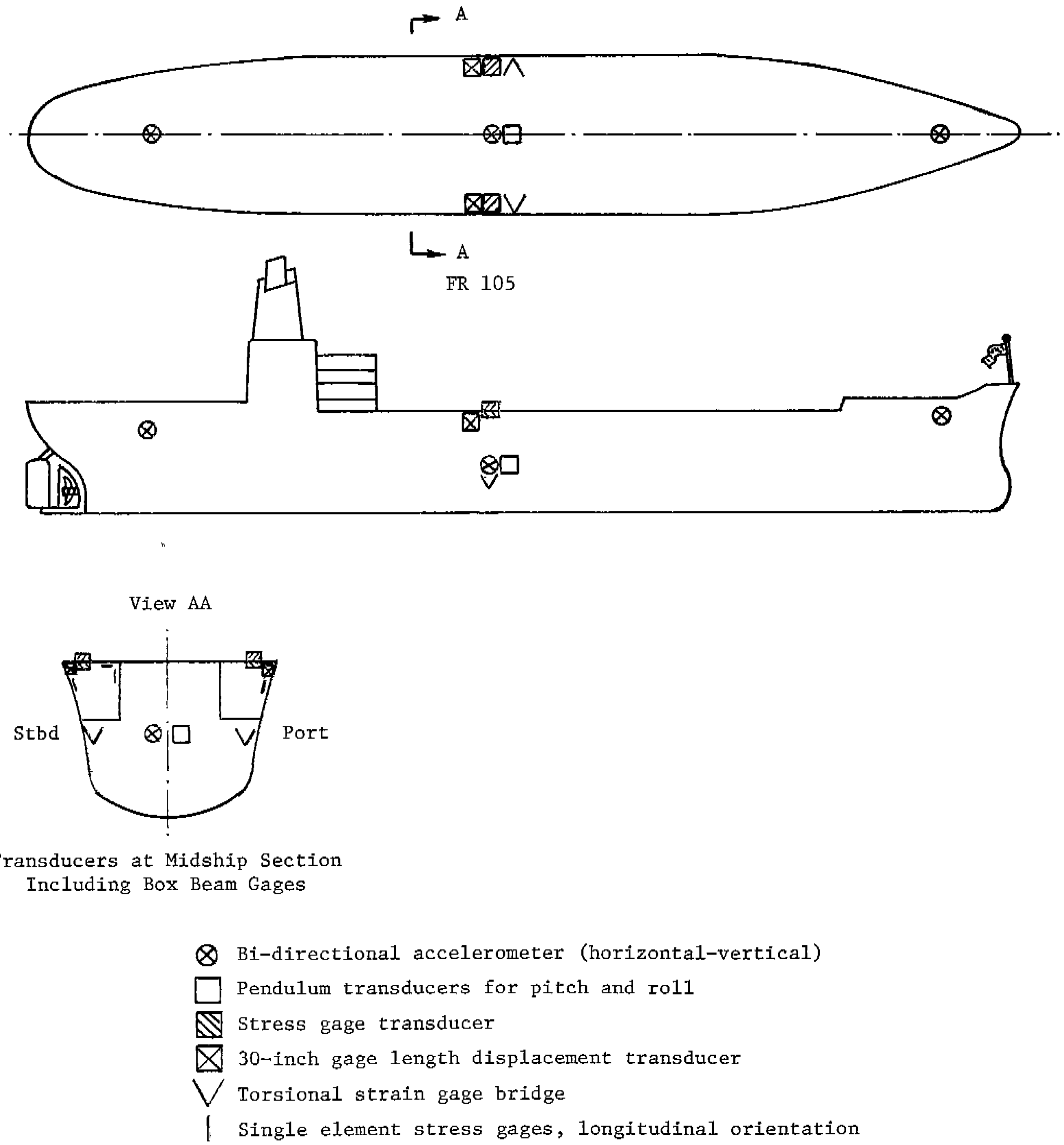


Fig. 4. Schematic View of Various Transducer Locations on *S. S. Boston*

Table III Tape Recorder Channel Assignment

Channel	Function	Source
1	Vertical Longitudinal Bending	Strain Gage Bridge
2	Horizontal Longitudinal Bending	Strain Gage Bridge
3	Torsional Stress	Strain Gage Bridge
4	Selected Stress	Strain Gage Bridge
5	Stern Vertical Acceleration	Accelerometer
6	Stern Horizontal Acceleration	Accelerometer
7	Midships Vertical Acceleration	Accelerometer
8	Midships Horizontal Acceleration	Accelerometer
9	Pitch	Pendulum
10	Roll	Pendulum
11	Bow Vertical Acceleration	Accelerometer
12	Bow Horizontal Acceleration	Accelerometer
13	Longitudinal Displacement	Supplementary Strain Gage
14	Compensation	Constant Frequency

The selected stress indicated for channel 4 of Table III relates to the stress gages applied to various areas of the box beam to obtain a measure of stress distribution in this structure. Figure 5 shows the location of these four gages. These elements were monitored on a time-sharing basis during a voyage.

Figure 6 is a view of the instrument console installed aboard the S. S. BOSTON. As previously stated, reference 1 should be consulted for details of the system.

An effort was made to acquire, where possible, data of the same type as that collected from the S. S. WOLVERINE STATE during a period of several years. Accelerometers were located at approximately the same position on the S. S. BOSTON i.e., forward, midship, and aft, so that data could be compared for similar crossings. The midships vertical bending moment is also of primary interest, and data from both ships is considered in this report.

2.1.1.1 Supplementary Strain Gages

In order to assess the possible presence of local effects due to the extremely short gage length of the stress gage transducers (approximately 1/4 inch) an alternate form of strain gage was also incorporated into the instrumentation system. This supplementary gage was previously referred to as a displacement gage in reference 1. This latter device consists of an electrical

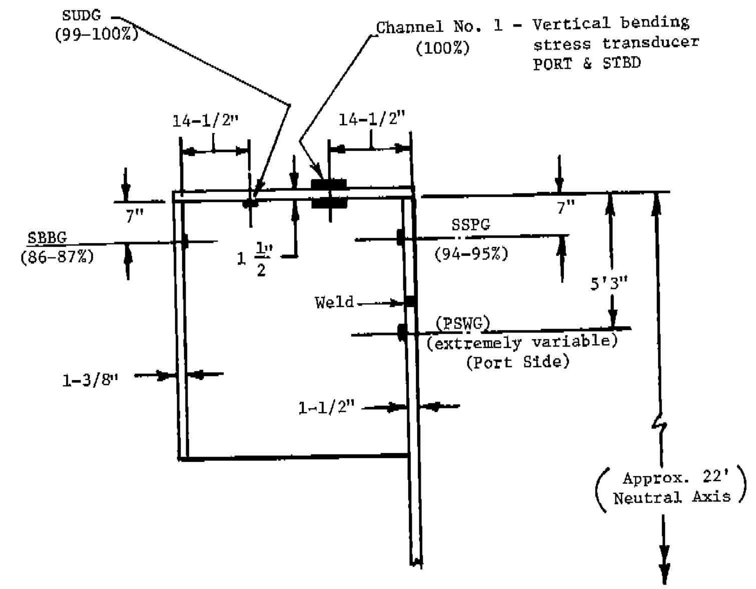


Fig. 5. Location & Stresses of Box Beam Gages

NOTE: Percentages indicate value of vertical longitudinal bending stress at location relative to Channel No. 1 value taken as 100 per cent.

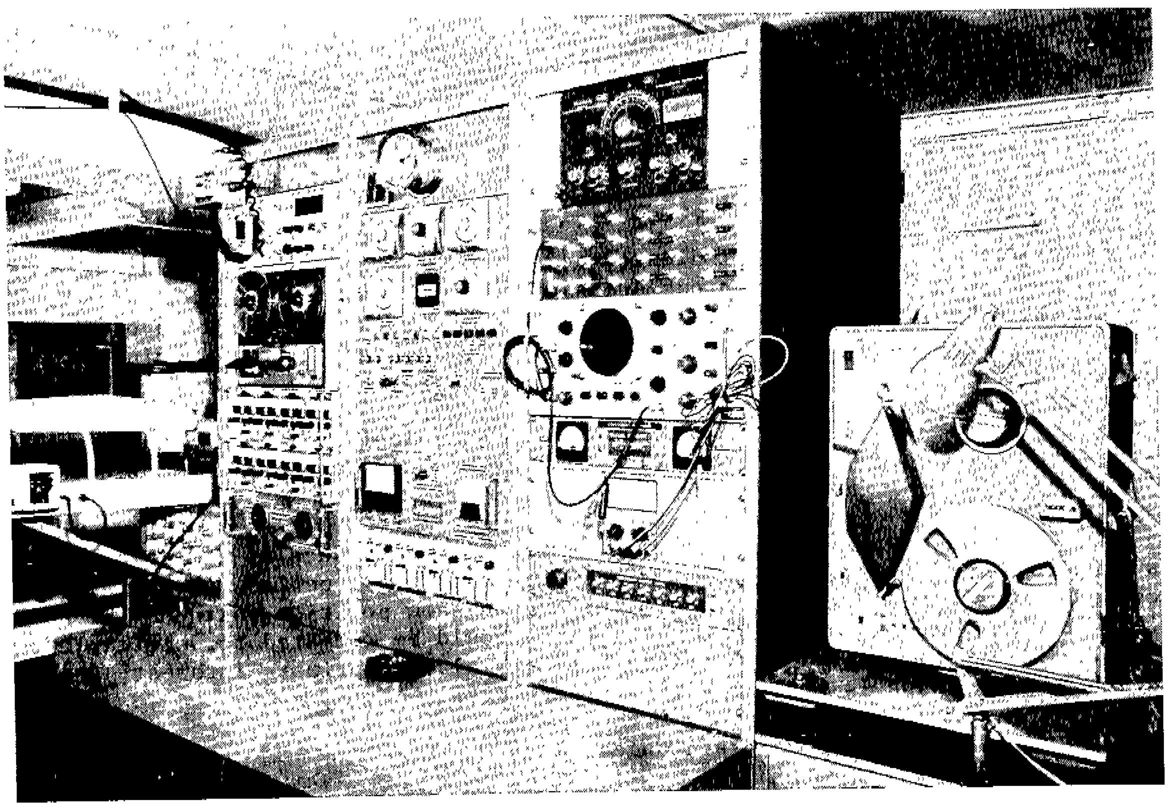


Fig. 6. Teledyne Instrumentation Console

element (direct current differential transrormer) which provides an output signal proportional to displacement. These transducers were arranged, by mechanical fixturing, to provide output data of the displacement over a 26-inch gage length, significantly longer than that of the stress gage. The elements will accommodate displacements of $\pm$ 0.050 inches which represents capability of measuring stresses of the order of $\pm$ 57,800 psi over the 26-inch gage length.

One each of these supplementary transducers was located, port and starboard, underdeck just forward of the midship stress gage installations and oriented to provide longitudinal bending stress data. Since each transducer was monitored independently, the stress data from each contained both vertical and horizontal bending stresses. Comparison of the total stress could be made against the algebraic sum of the data from the horizontal and vertical bending stress transducers. Outputs of the supplementary transducers were time shared on channel 13 of the tape recorder.

2.1.2 Accelerometer Wave Buoy System

The accelerometer wave buoy system consists of model 266 wave buoys together with the model 440 data acquisition unit for receiving and recording the output of the wave buoy. The principle of operation was that of measuring the rise and fall time of a moving body which is given an upwards impulse of fixed momentum relative to the case of the floating buoy. This motion through mechanical linkage changes the induced voltage in a coil within the accelerometer structure. The output is a train of pulses set to a zero acceleration rate of 30 pulses per second. These pulses are used to key the radio transmitter for relaying the buoy output to the shipboard receiver.

The operating frequency is in the range of 30 to 36 MHz and the output power of the transmitter is approximately 5 watts.

The model 440 wave data acquisition system receives and processes the transmitted wave buoy signal and records it on magnetic tape along with a reference signal and voice annotations. The reference signal provides a frequency base for subsequent compensation of flutter and wow in the tape recording. The reference signal is a stable 150 Hz oscillator feeding one of the recorder channels while the buoy signal is recorded on the second channel. The two recording channels are arranged in a standard four-track stereo configuration effectively doubling the recording time when the reels are reversed. The tape recorder is run at a speed of 3-3/4 inches per second providing 60 minutes of recording time on each pass of tape. The tape is computer processed with a power spectra of displacement and acceleration provided as an output signal. Details of this particular wave height measuring system can be found in reference 2.

2.1.3 System Reliability, Maintainability and Operation

Based on the relatively short 1968-1969 operating season, the Teledyne Instrument System (consisting of the ship response system and wave buoy system) has proved extremely reliable. Reliability is generally defined as the mathematical probability that a device (equipment-system) will function within specified characteristics in a defined environment for a specified period of time.

The system is usually evaluated on its susceptibility to failure, and the life of the system is expressed as the percent failure per thousand or million hours of operation. A calculation of this type is impractical with the small amount of data available. We will, therefore, consider the reliability of this system on the basis of three major design areas i.e., electrical, mechanical, and environmental.

Electrically, once the final installation and adjustments were complete, the system did not suffer downtime from electrical component failure. Initial design criteria was such that even a component failure would not cause a catastrophic reaction in the system. At worse, a reduction from a full 14-channel capability to some lesser number of channels would occur, and a priority assignment of information desired has been established to assist the operator in making the most of the equipment available for on-line operation. The system was 100% efficient with no data intervals lost because of equipment malfunctions.

Two failures were encountered during the 1968-1969 season. The first consisted of a shift to a fixed output level in one of the stern accelerometers on the homeward leg of voyage 10. The defective unit was replaced, and only a small amount of data for that channel was affected.

The second failure was the lack of transmission from the third wave buoy launched again on the return run of voyage 10. This apparently was a problem inherent in the buoy itself as the system itself is still operating normally. A check of each buoy was made before each launch, and this unit functioned properly until shortly after being set free.

Mechanically, other than the replacement of a noisy bearing in the recorder unit at the completion of the season, there were no problems. The techniques used to mount all structures proved satisfactory even during extreme roll conditions. The equipment room environment, quite similar to normal laboratory conditions, proved friendly to the equipment, and no problems due to temperature, moisture, vibration or other environmental dynamics were encountered.

The system, based on operator reports, was functional in layout and provided accessibility to all major components. Maintenance, other than daily operational checks and routine operation, was not required to any extent during the past season. Only minor changes to the basic system or techniques are anticipated for the forthcoming 1969-1970 operating season.

2.1.4 Calibration of Vessel Instrumentation

An attempt was made in August of 1968 to obtain a "calibration" of the instrumentation aboard the S. S. BOSTON while the double-bottom spaces were being filled with ballast mud over a 21-day period at Galveston, Texas. A "calibration" by definition is a sequence of tests involving bending the ship with known loads and reading strain data with the instrumentation system. This calibration permits a comparison with computer calculations of the structure's behavior and provides a verification of the integrity of the instrumentation system.

Unfortunately, this test was not conclusive primarily due to the long period of the test, the extremes of temperature experienced and changes in the physical structure which were going on during the calibration sequence.

A comprehensive discussion of this test sequence and results achieved can be found in section 9.0 of reference 1.

A second calibration of the vessel was performed at Port Newark, N.J. on November 11 and 12, 1969, using preweighed containers to provide torsion and longitudinal bending moments. The complete report of this static test is in preparation and will soon be released. However, interpretation of the material to follow in this report may be aided by the observation that there was good agreement between calculated and measured torsion and bending stresses. A maximum torsional shear stress change of about 850 psi was achieved during the test, and a maximum longitudinal vertical bending stress change of 2500 psi was observed just before the vessel sailed.

2.2 DATA ACQUISITION PROCEDURES

2.2.1 Ship Response Instrumentation System

When the vessel leaves port for an Atlantic crossing, the operator normally has the system running in automatic mode. This mode turns the system on for a period of 15 minutes every four hours. Every 7-1/2 minutes, a zero-calibration sequence is repeated. (Note: This is a change from the original 5-minute sequence mentioned in section 6.0 of reference 1.) It was established, after the first season of operating, that three zero-calibration-sequences obtained with the 5-minute sequence were not required but that one every 7-1/2 minutes would be sufficient. Zero consists of opening the transducer signal lines and removal of excitation from bridge circuits for approximately 20 seconds. Observation of channel outputs during this interval establishes any shift in signal level due to amplifier or other component drift.

The calibration period consists of shunting one arm of the bridge circuits with a specified resistance (See Appendix B.) or, in the case of the other transducers, of substituting a calibration voltage. This sequence lasts approximately 1 minute with the remainder of the period used to monitor all 14 channels for data. The Teledyne operator keeps a running log book wherein he makes entries describing the sea and wind condition and descriptive ship parameters during the 15-minute recording interval. In addition, arrangements were made to have the mate on watch keep an identical, but independent, log book so that a comparison of entries could be made. In general, over the past season, agreement of the books was quite good.

In addition to this normal operating mode, the operator has set a "high stress level" so that in the event of stresses above the set limit, the system will turn on and record for a specified period. A high stress condition also sets off an alarm to alert the operator. The system can be switched to a manual continuous recording mode at this time, in order to acquire a larger sampling of high stress data information.

During periods of low sea states, as in port, the operator continually examined his data by displaying various channels on an oscillograph play-back unit. This procedure permits close examination of each channel to ensure that the system is functioning properly.

2.2.2 Wave Buoy Instrumentation System

A wave buoy launch is generally performed when the sea and wind conditions meet preset conditions. A Beaufort sea state of 6 with either head or following seas is considered to be a minimum requirement. The buoy to be launched is placed on deck, and after installation of its antenna, the power is turned on. In the equipment room the operator performs a checkout procedure and records on tape the conditions associated with the launch. The ship response instrumentation system is placed in a manual continuous record mode, and the wave data recorder is turned on. The buoy is then lowered over the side and allowed to drift away from the vessel. The operator continually monitors the receiver signal and adjusts his gain to keep signal at recordable levels for as long a period as possible.

At loss of signal, both systems are secured and appropriate entries made in the log book describing the launch sequence. The ship response system is returned to automatic operation and the wave tape removed, marked and prepared for later data analysis.

3.0 RESULTS OF 1968 - 1969 SEASON

3.1 Sea States Profiles

Tables IV, V and VI graphically represent the frequency of occurrence of the various Beaufort sea states during voyages 7, 9, and 10. These charts reflect the environmental conditions or background that prevailed throughout the periods of data acquisition and against which the ship response data was assessed.

Table IV. Sea State Profile Voyage #7 Dec. 21, 1968 - Jan. 23, 1969

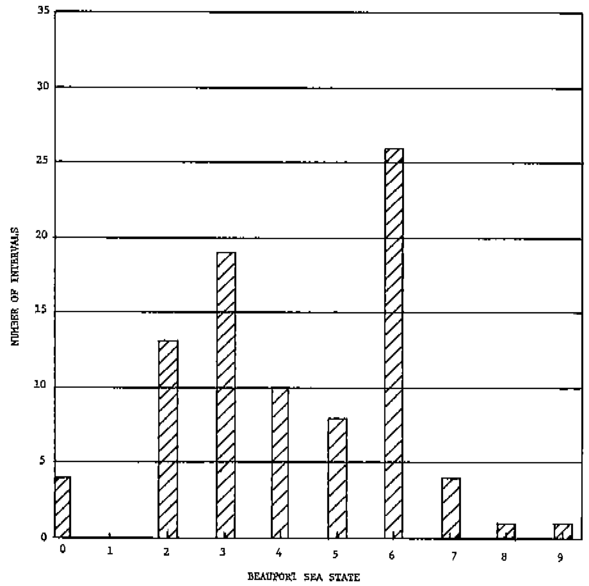


Table V. Sea State Profile
Voyage #9 Feb. 22, 1969-March 18, 1969

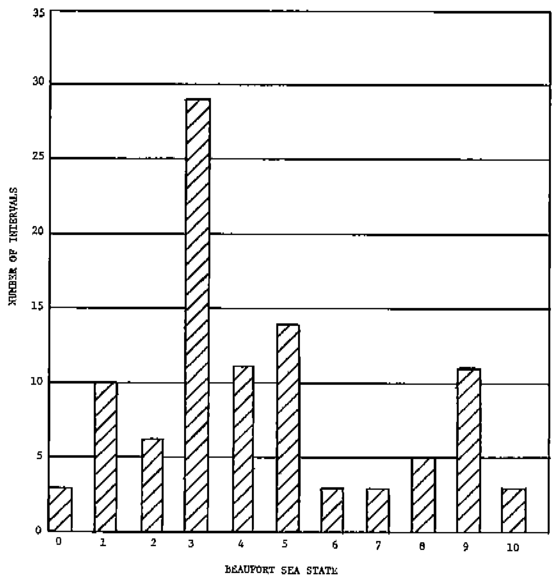
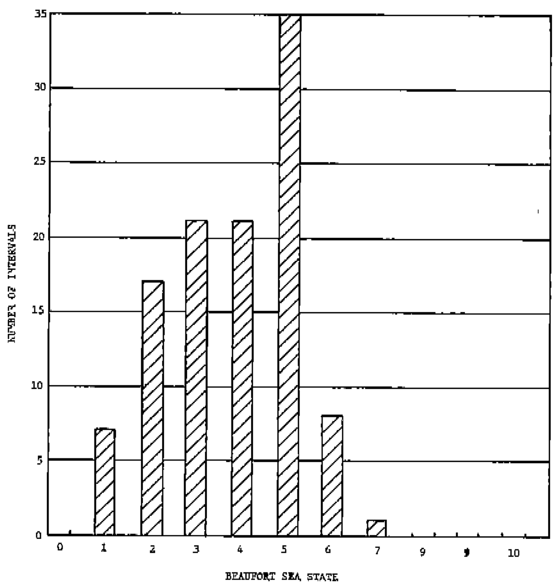


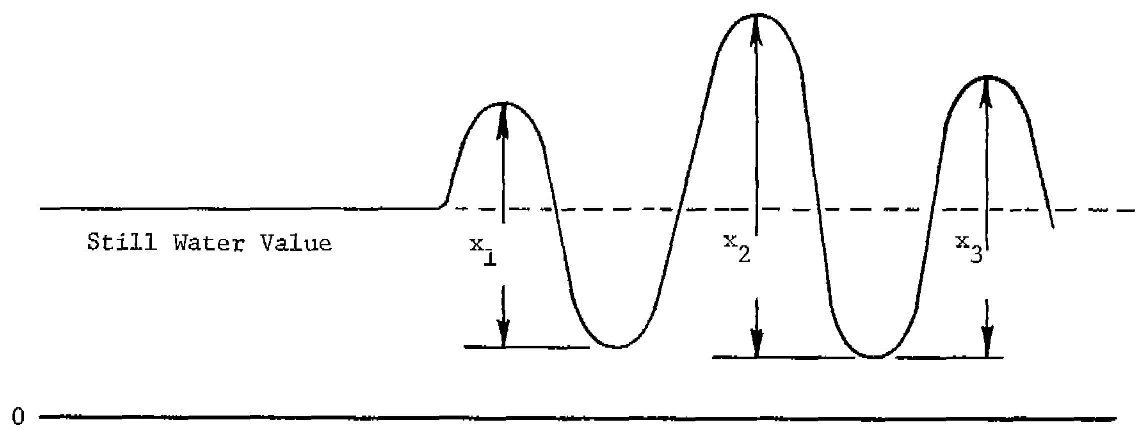
Table VI. Sea State Profile
Voyage #10 March 23, 1969-April 19, 1969



Establishment of the exact sea state without wind speed or direction measurements was extremely difficult, and it is planned to provide this information during the 1969-1970 season. The data displayed reflects an input from both the Teledyne operator's and mate's logs for each data interval. The lack of data from January 23 to February 22, 1969, caused by the vessel's being out of service due to the longshoremen's strike, is unfortunate; this time of the year being one of the most severe for North Atlantic crossings.

3.2 Stress Data

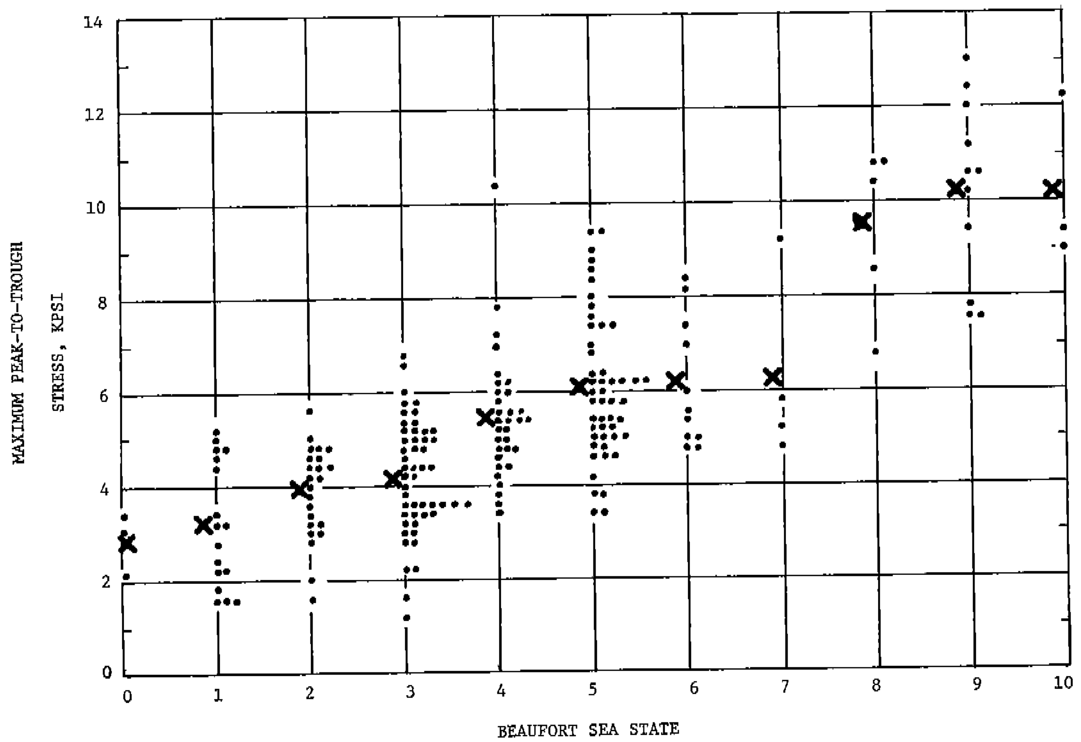
Figures 7 - 9 represent the combined data from voyages 9 and 10 of stress channels 1 - 3. The data from voyage 7 was deleted due to the varying number of channels recorded and the fluctuation in recording levels experienced while the system was being adjusted for optimum operation. Each data point was obtained by replaying the tape onto an oscillograph to create chart recordings of all recorded data. The maximum peak-to-peak value (i.e., peak-to-trough for those nautically oriented) for each data interval was tabulated and then plotted against the Beaufort sea state established from log book information. Each point represents the maximum signal received during a 15-minute sampling period. Note that the peak-to-trough value is approximately twice the usual value used in most engineering computations:



x_1, x_2, x_3 = Peak-to-trough (or peak-to-peak) values.

The maximum peak-to-trough value of vertical longitudinal bending shown on Figure 7 is 13,000 psi at a sea state of 9. A predominance of data is found between 3,000 and 7,000 psi. In comparison the maximum peak-to-trough value of horizontal longitudinal bending as presented in Figure 8 is 3,000 psi. Very litle spread in signal level is experienced even at the higher sea states. The maximum peak-to-trough value of torsional shear stress observed during the 1968-1969 season, as shown on Figure 9, is approximately 1,260 psi at a sea state of 9. The average value of this signal across the range of sea states i.e., 0 to 10 is consistently under 1,000 psi. The maximum stress seen on the four box beam gages were as follows:

(SUDG)	13,800 psi at a sea state of 9
(SSPG)	5,500 psi at a sea state of 5
(SBBG)	8,000 psi at a sea state of 9
(PSWG)	8,000 psi at a sea state of 4



Note: X Indicates average value.

Fig. 7. *S.S. Boston* Vertical Longitudinal Bending-Ch. 1 Voyages #9 And #10

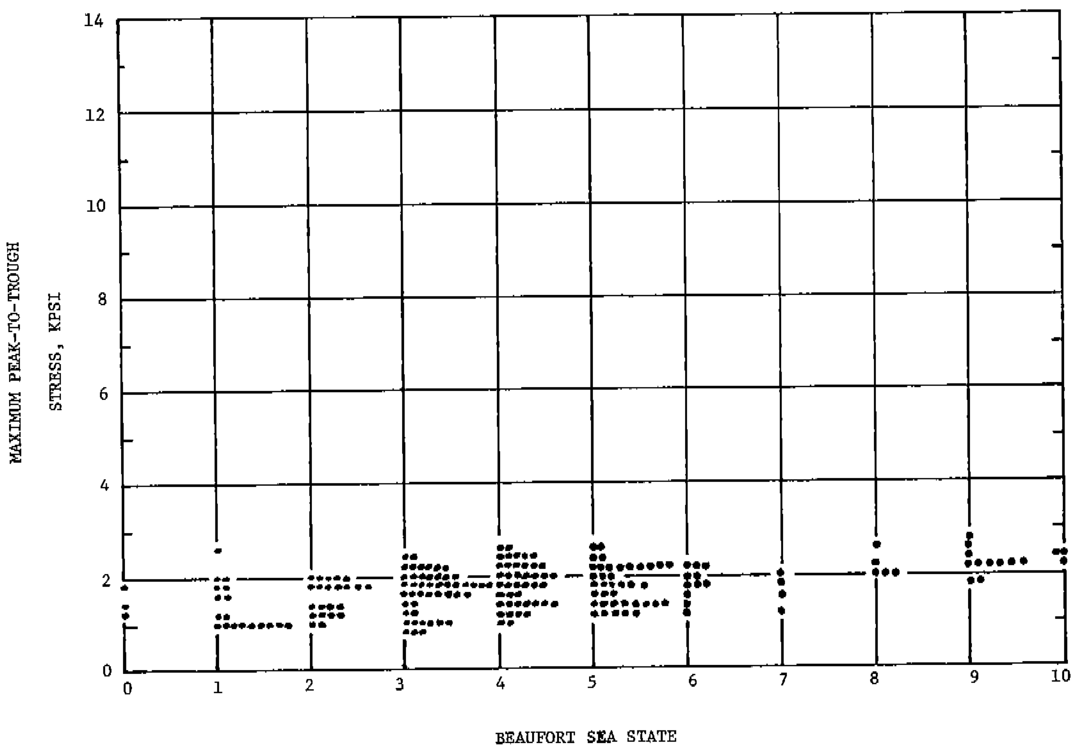


Fig. 8. *S.S. Boston* Horizontal-Longitudinal Bending-Ch. 2 Voyages #9 & #10

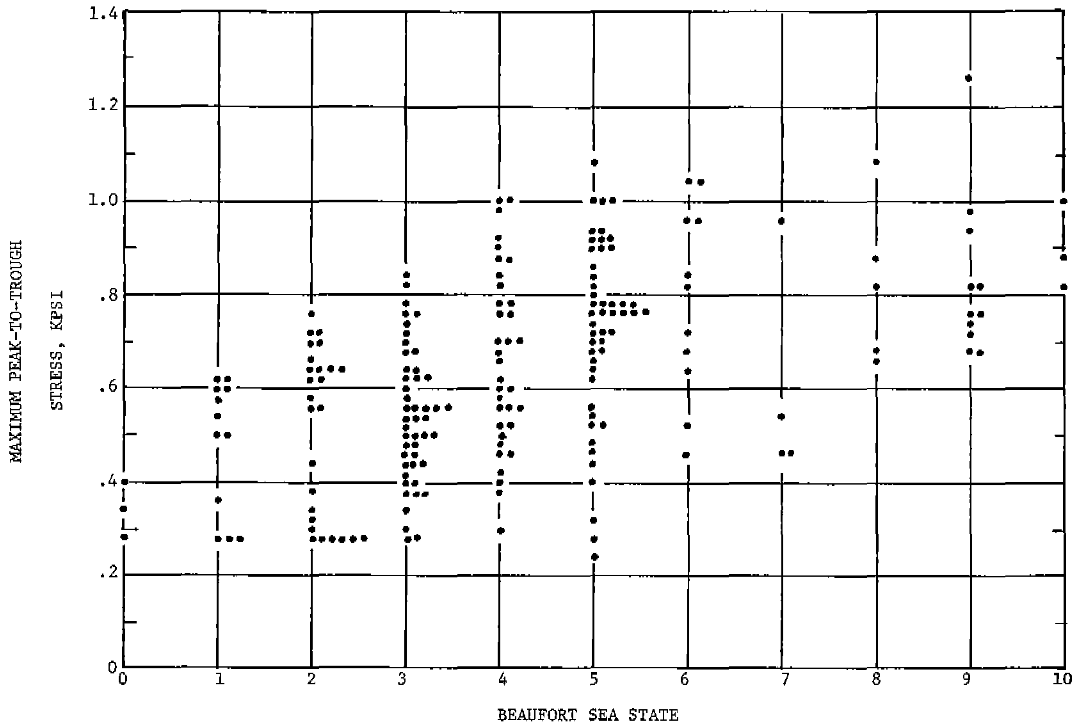


Fig. 9. *S. S. Boston* Torsional Shear Stress-Ch. 3 Voyages #9 And #10

It is not possible to compare these signals to each other at precisely the same instance of time, since only one of the four is recorded at any one time. However, the operator, by judiciously switching the instrumentation, can obtain data on all channels over a short period of time during which consistent and comparable sea conditions are sustained.

It is of interest to note that the total number of data intervals used in the presentation corresponds to the tabulation of sea states on Tables V and VI, but not in total to the number of intervals tabulated on Table I. The difference between the two totals reflects the fact that some intervals recorded on leaving or entering port displayed little or no information and were thus not included in the analysis.

3.3 Acceleration Data

Vertical and horizontal acceleration data was obtained at three locations aboard the S. S. BOSTON. These locations were chosen to be compatible with the installations aboard the S. S. WOLVERINE STATE in order to permit comparison of data.

The stern transducer units are located on the forward side of frame 195 under the upper deck amidships. Outputs from these two units are plotted in Figures 10 and 11.

The midship transducers are located on the aft side of frame 112 under the second deck amidships. An attempt was made to install these units as close as practical to the loaded center of gravity of the vessel. The output of these accelerations is plotted in Figures 12 and 13.

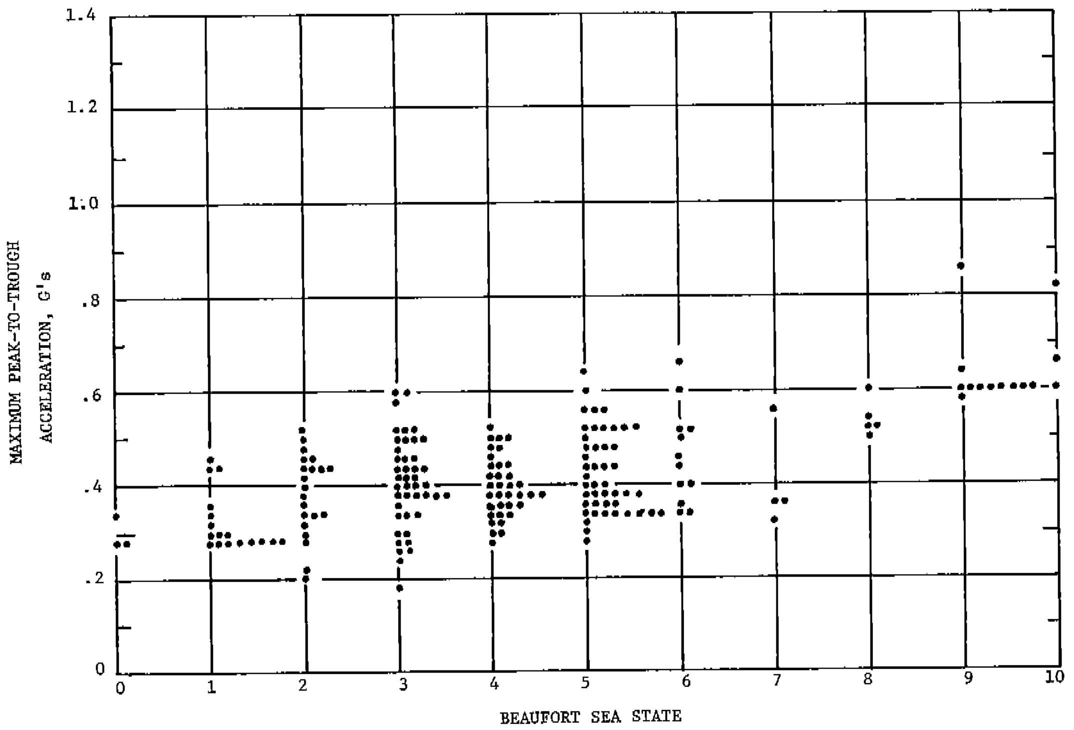


Fig. 10. *S. S. Boston* Stern Vertical Acceleration-Ch. 5 Voyages #9 & #10

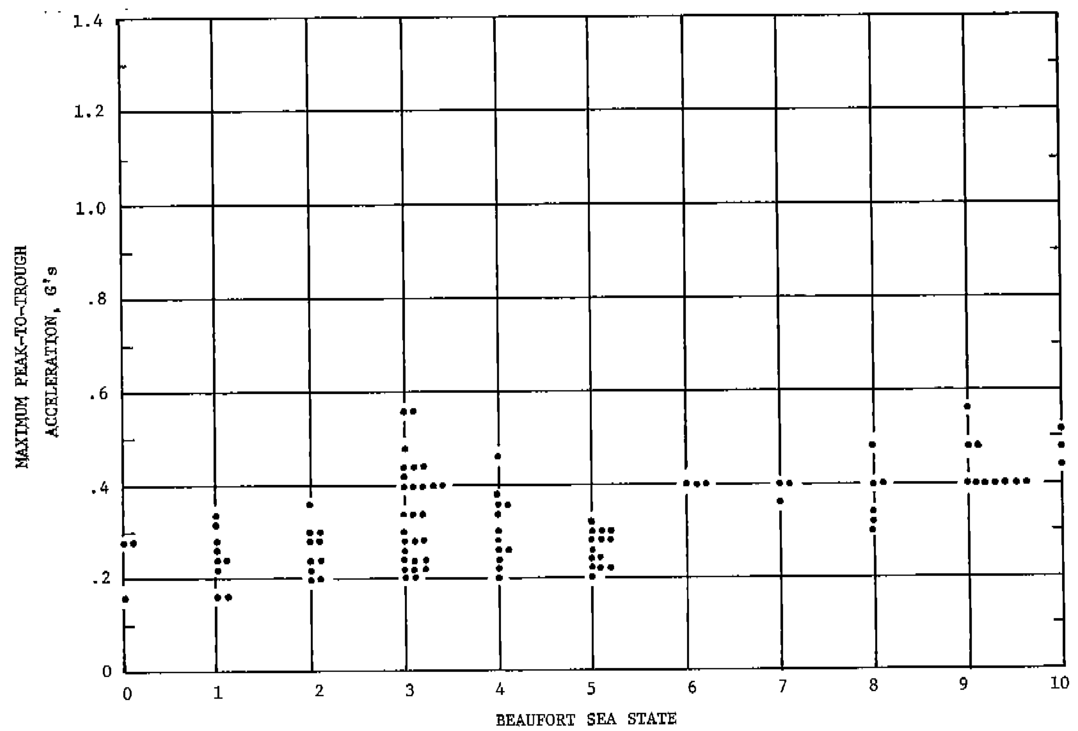


Fig. 11 *S.S. Boston* Stern Horizontal Acceleration-Ch. 6 Voyages #9 & #10

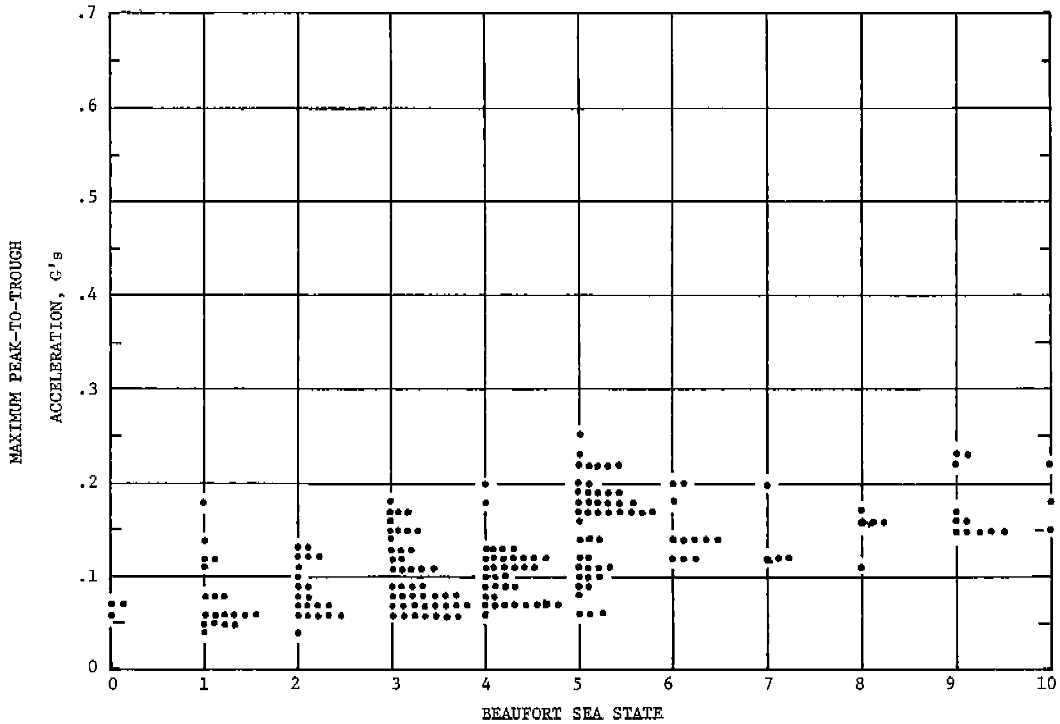


Fig. 12. *S.S. Boston* Midship Vertical Acceleration-(Heave)-Ch. 7 Voyages #9 & #10

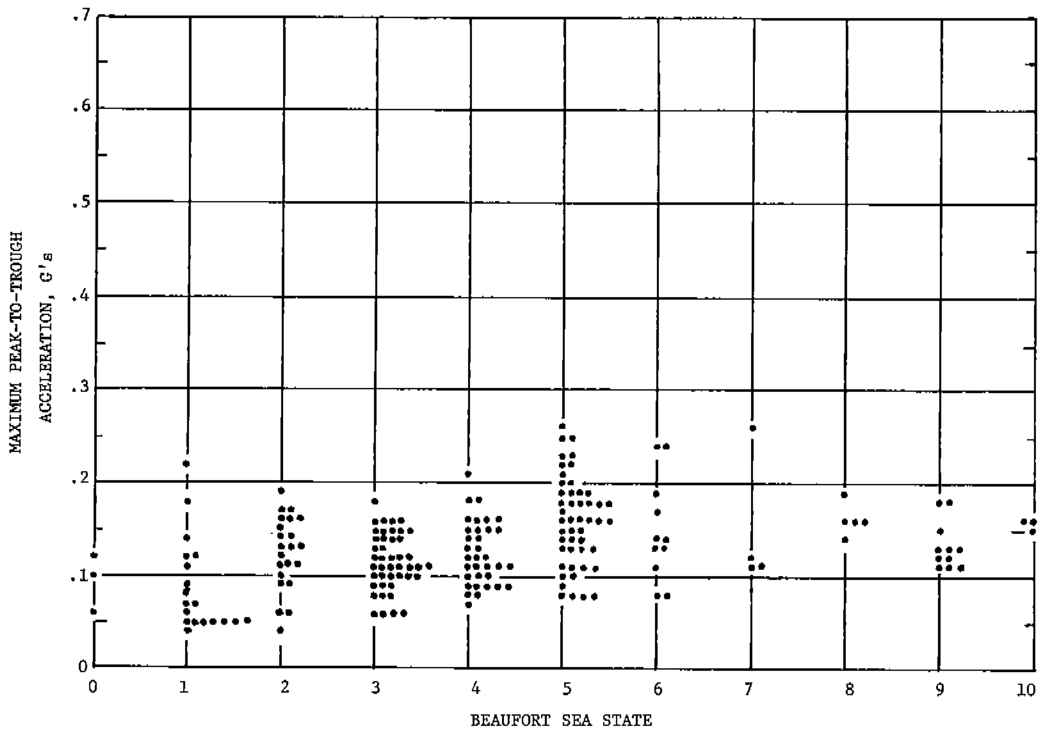


Fig. 13. *S.S. Boston* Horizontal Acceleration-(Sway)-Ch. 8 Voyages #9 & #10

The bow accelerometer units are located on the aft side of frame 13 under the upper deck amidships. These outputs are shown in Figures 14 and 15.

The maximum peak-to-trough accelerations observed during voyages 9 and 10 were as follows:

Stern Vertical	–	0.86g at a sea state of 9
Stern-Horizontal	-	0.56g at a sea state of 3 and 10
Midship Vertical	-	0.25g at a sea state of 5
Midship Horizontal	-	0.27g at a sea state of 5
Bow Vertical	-	1.02g's at a sea state of 9
Bow Horizontal	-	0.64g's at a sea state of 9

It is easily seen that the vertical accelerations of both the bow and stern present the highest signal output; the bow vertical is the larger of the two.

3.4 Ship's Motion Data

The motion of the ship is described by the outputs of four transducers. The midship accelerometer outputs of Figures 12 and 13 provide (heave)

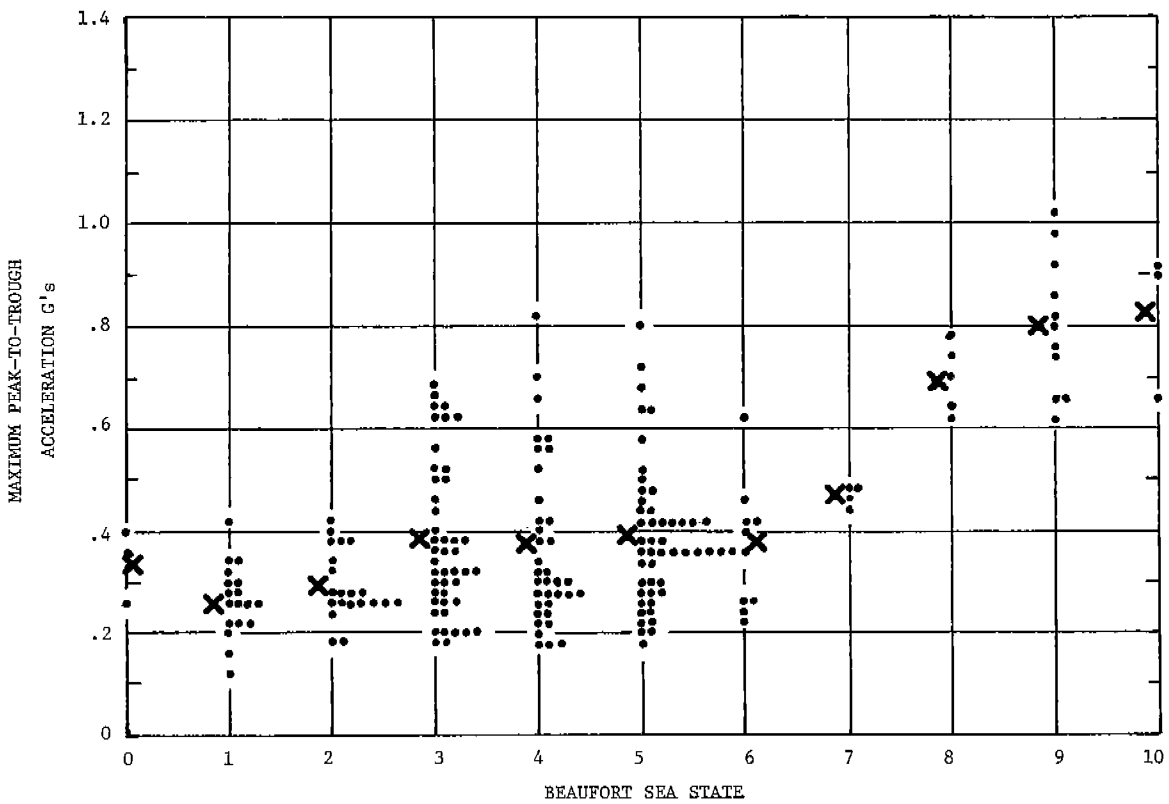


Fig 14. *S.S. Boston* Bow Vertical Acceleration-Ch. 11 Voyages #9 & #10

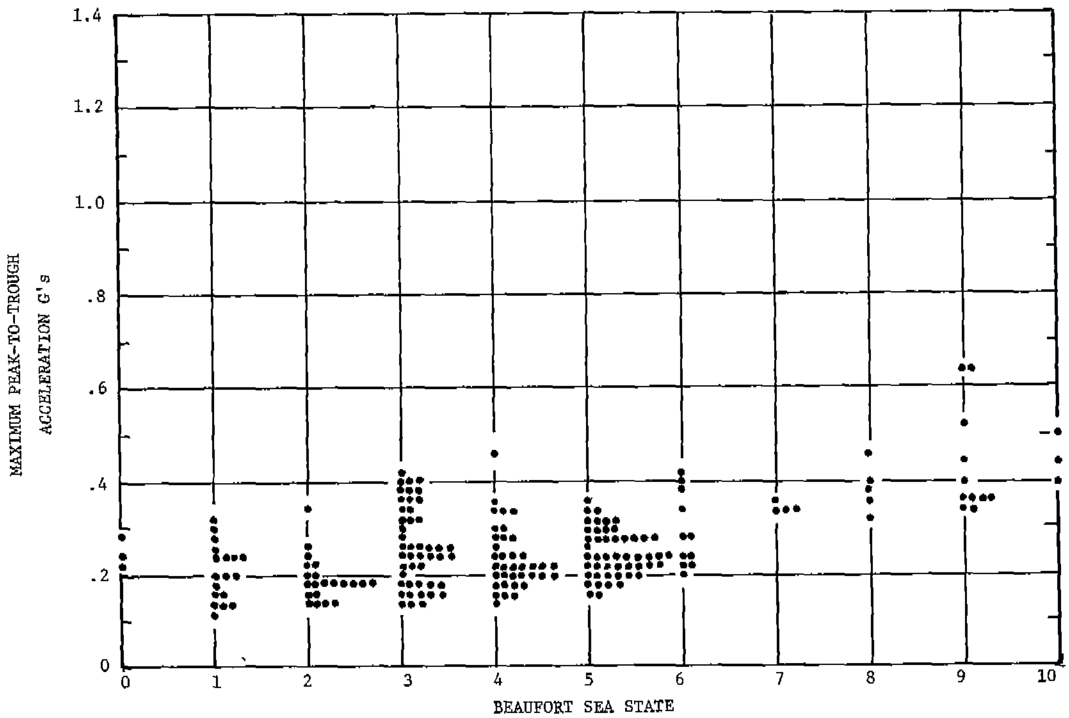


Fig 15. *S.S. Boston* Bow Horizontal Acceleration-Ch. 12 Voyages #9 & #10

vertical acceleration and (sway) horizontal acceleration. An additional package of two pendulum transducers at the same location provide a pitch and roll signal. This information is presented in Figures 16 and 17.

The maximum double amplitude value of pitch observed is 10.2° at a sea state of 9; while the maximum roll signal double amplitude is a 34° signal also at sea state of 9.

3.5 Supplementary Strain Gage Data

Data from the supplementary gages was obtained as a voltage level upon play back of the recorded tape. A signal of ± 1.5 VDC is equivalent to ± 0.050" displacement by design. This value in turn is equivalent to a stress of approximately 57,800 psi. Dynamic peak-to-trough variations in strain were readily observed, and it was a spot check of these values compared with data from channel 1 at the same interval of time which confirmed the validity of the measurements. To obtain a scale factor to evaluate the dynamic swings, it was necessary to feed a known voltage signal from an adjacent channel through the channel 13 play back route and then rerun the displacement signal and compare values. Values of stress consistent with the data of Figure 6 were obtained.

3.6 Wave Buoy Data

A total of three wave buoys was launched during the 1968-1969 operating season. The first launch was buoy 49004 at 1500 GMT on February 25, 1969. Table VII is a tabulation of the log book data for the period of the launch and Figures 18 and 19 present the power spectral density analysis associated with the wave buoy data received.

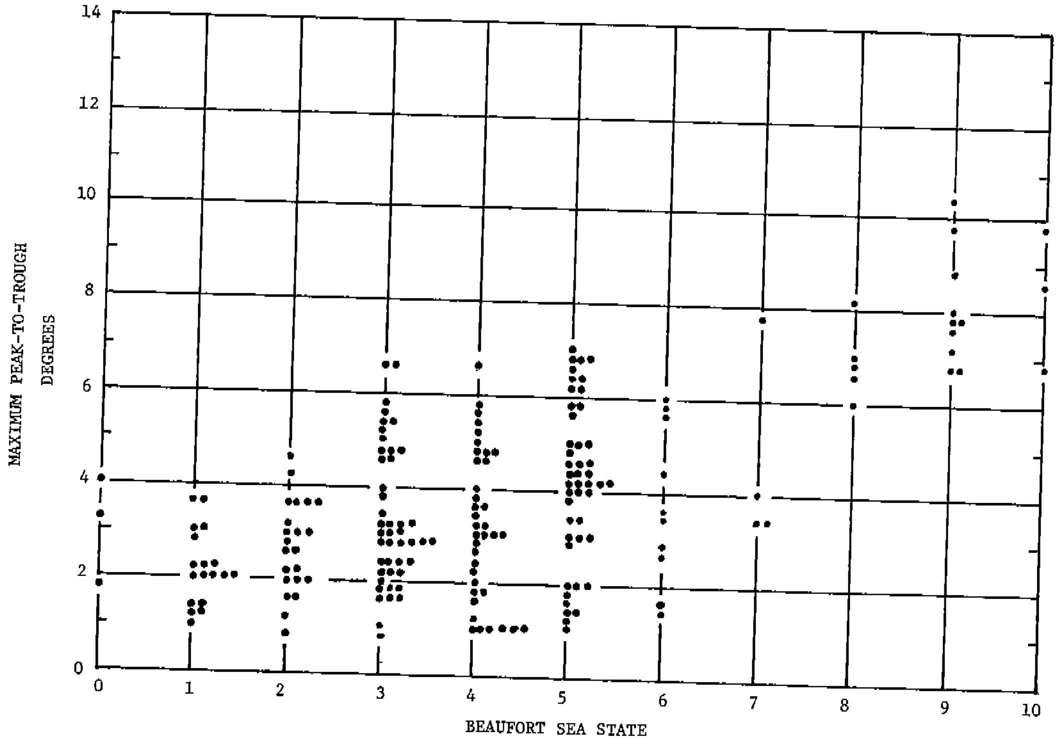


Fig. 16. *S.S. Boston* Pitch-Ch. 9 Voyages #9 & #10

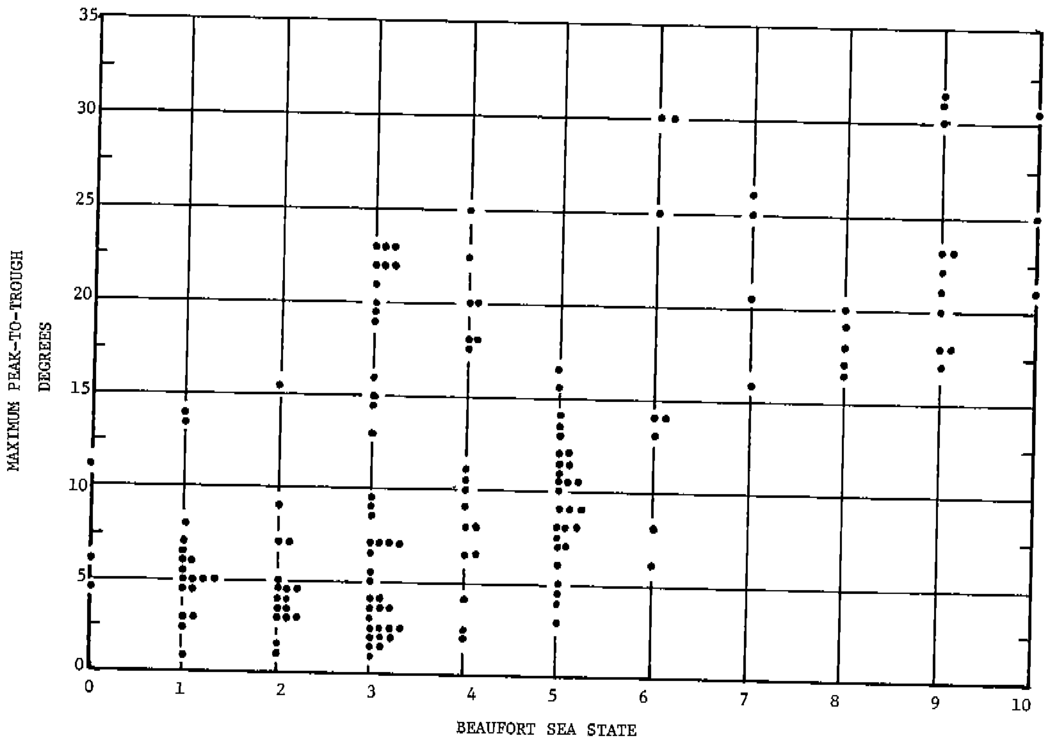


Fig. 17. *S.S. Boston* Roll-Ch. 10 Voyages #9 & #10

Table VII. Wave Buoy Launch No. 1 Log Book Data

Buoy Serial No. 49004	Voyage No. 9
Index Number	18
Date & Time	1500 GMT 2-25-69
Time Meter Reading	413.9
Latitude	49.2 N
Longitude	40.7 W
Course	078°
Speed	8.5 Knots
Engine	50 RPM
Wind Speed	45 Knots
Relative Wind Direction	NE
Beaufort Sea State No.	8-9
Relative Wave Direction	NE
Average Wave Height	20 Ft.
Average Wave Period	5 Sec.
Average Wave Length	125 Ft.
Average Swell Height	25 Ft.
Average Swell Length	350 Ft.
Relative Swell Direction	NE
Barometer Reading	29.58
Sea Temperature	58°F
Air Temperature	46°F
Weather	Overcast

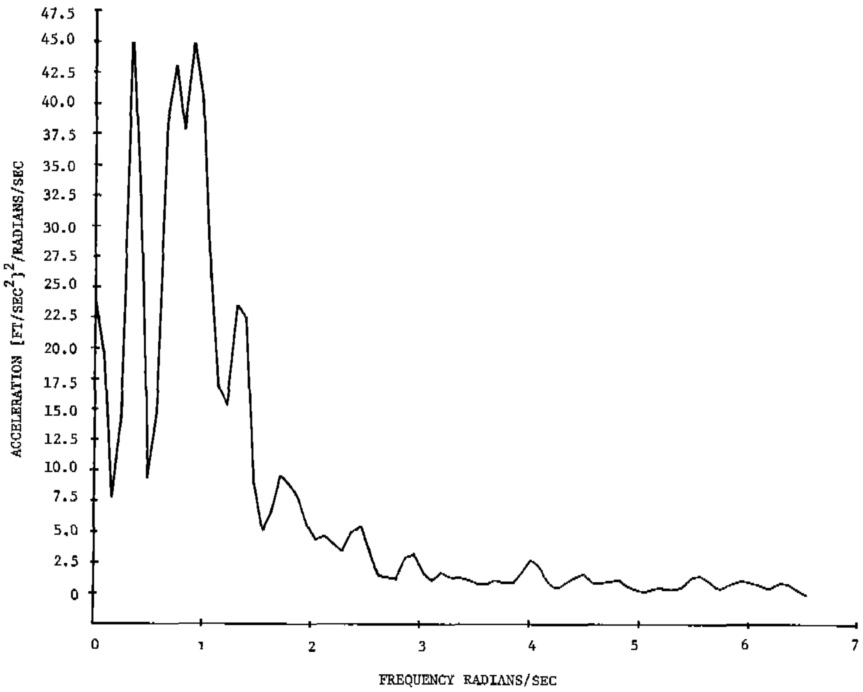


Fig. 18. *S.S. Boston* Buoy Serial 49004 Launched 2/25/69
Power Spectral Density Analysis Accelerometer Wave Buoy

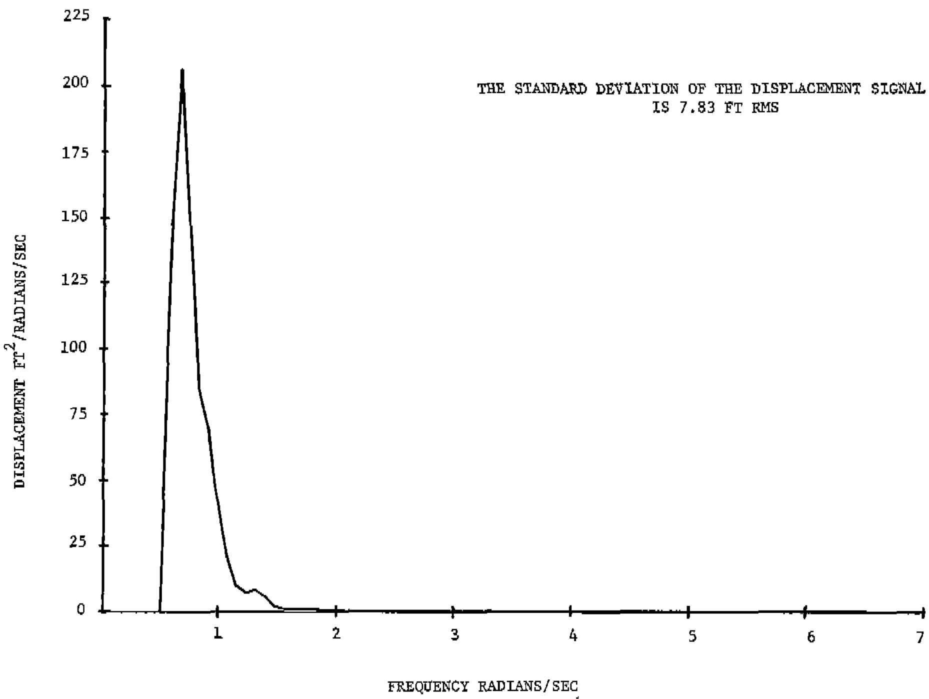


Fig. 19. *S.S. Boston* Buoy Serial 49004 Launched 2/25/69
Power Spectral Density Analysis Accelerometer Wave Buoy

The second launch was buoy 49001 at 1345 GMT March 30, 1969. Table VIII contains the log book data and Figures 20 and 21 display the power spectral density analysis.

The third launch of buoy 49002 occurred at 1015 GMT on April 12, 1969. Table IX contains the log book information, but unfortunately the buoy did not operate for a long enough period to permit computer analysis.

4.0 DISCUSSION OF RESULTS

4.1 Sea State Profiles

The three sea state profiles of Tables IV, V and VI display the various sea states encountered during the 1968-1969 season. Voyage 9 was by far the most productive in high sea state readings followed by voyage 7 and 10. It is easily observed that the sea conditions are somewhere between the states 2 and 6 for the majority of the time. Similar profiles will be generated for the 1969-1970 season, and it is anticipated similar results will be achieved after averaging all the voyages.

Table VII. Wave Buoy Launch No. 2 Log Book Data

Buoy Serial No. 49001	Voyage No. 10
Index Number	42
Data & Time	1345 GMT 3/30/69
Time Meter Reading	261.4
Latitude	49.8 N
Longitude	19.1 W
Course	079°
Speed	17 Knots
Engine	85 RPM
Wind Speed	15 Knots
Relative Wind Direction	W
Beaufort Sea State No.	5
Relative Wave Direction	W
Average Wave Height	5 Ft. *
Average Wave Period	6 Sec. *
Average Wave Length	8 Ft. *
Average Swell Height	5-6 Ft. *
Average Swell Length	20 Ft. *
Relative Swell Direction	W
Barometer Reading	30.18
Sea Temperature	60° F
Air Temperature	60° F
Weather	Cloudy

* The wave heights and lengths are reported directly from the mate's log. These data are subject to question, i.e., a 5 ft. wave height coincident with an 8 ft. wave length.

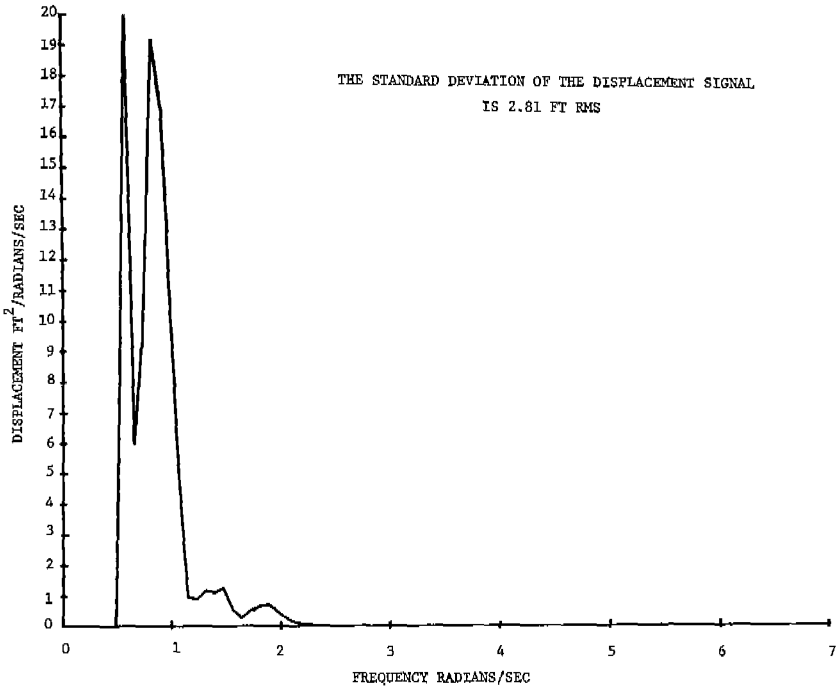


Fig. 20. *S.S. Boston* Buoy Serial No. 49001 Launched 3/30/69
Power Spectral Density Analysis Accelerometer Wave Buoy

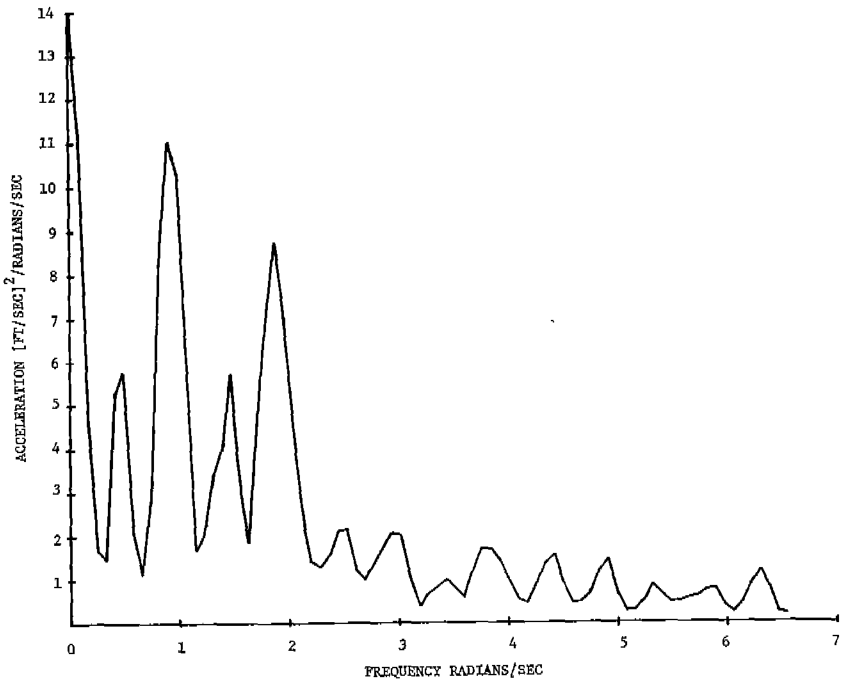


Fig. 21. *S.S. Boston* Buoy Serial No. 49001 Launched 3/30/69
Power Spectral Density Analysis Accelerometer Wave Buoy

Table IX. Wave Buoy Launched No. 3 Log Book Data

Buoy Serial No. 49002	Voyage No. 10
Index Number	14
Date & Time	1015 GMT 4/12/69
Time Meter Reading	181.6
Latitude	49° 46' N
Longitude	07° 15' W
Course	250°
Speed	12 Knots
Engine	75-80 RPM
Wind Speed	25 Knots
Relative Wind Direction	SW
Beaufort Sea State No.	5-6
Relative Wave Direction	SW
Average Wave Height	6 Ft. *
Average Wave Period	10 Sec. *
Average Wave Length	30 Ft. *
Average Swell Height	20 Ft. *
Average Swell Length	150 Ft. *
Relative Swell Direction	SW
Barometer Reading	30.41
Sea Temperature	57° F
Air Temperature	58° F
Weather	Cloudy

* See footnote on Table VIII

4.2 Stress Data

Figure 7 reflects the information from channel 1, vertical longitudinal bending, and is of primary importance. This function was monitored as "Bending Moment" on several previously instrumented vessels. The "X" at each sea state level is the average value for that sea state, combining the voyage 9 and 10 data. The highest peak-to-trough stress recorded aboard the S. S. BOSTON was approximately 13,000 psi at a sea state of 9. The highest average value is a little over 10,000 psi occurring at sea states 9 and 10.

Figure 22 provides a comparison of the vertical bending stress data from the S. S. BOSTON and S. S. WOLVERINE STATE. The S. S. WOLVERINE STATE is a similar C4, normally carrying break-bulk cargo on the North Atlantic run during the winter months. The WOLVERINE STATE experienced an average maximum peak-to-trough stress value in an interval of approximately 7400 psi at a sea state of 10 while the BOSTON recorded an average maximum stress of slightly higher than 10,000 psi. From this figure it is apparent that the vertical bending stresses in the BOSTON are consistently and significantly higher than those experienced on the WOLVERINE STATE. All WOLVERINE STATE data used was appropriately corrected for plate unfairness and reflects the average value of combined port and starboard transducers. Reference 3 elaborates on the development of this correction factor. Table X provides the WOLVERINE STATE characteristics.

There is some noticeable scatter to parts of the data reflective of the various headings and speeds assumed by the vessels and somewhat by the uncertainty of attempting to establish exact Beaufort sea state by visual observations. In general the average vertical bending stress on the BOSTON is about 66% higher than that on the WOLVERINE STATE. Approximately 16% of this can be attributed to the lower section modulus of the BOSTON (39,391 in^2 ft) compared to the WOLVERINE STATE (45,631 in^2 ft). Further examination into other possible causes for this discrepancy is continuing. Since the comparison is based on only 2 voyages for the BOSTON, it is anticipated that inclusion of data from the 1969-1970 season will provide a firmer basis for comment.

Figure 8 displays the horizontal longitudinal bending signal of channel 2 which is of considerably lower magnitude than the vertical component of channel 1. This difference in signal level clearly demonstrates, as predicted, that the vertical component is of significantly higher magnitude and of primary importance.

The torsional shear stress values presented in Figure 9 are quite low in magnitude, the maximum shear stress observed being approximately 1250 psi peak-to-trough. The location selected for these gages (discussed also in Appendix A of reference 1) at the neutral axis of the vessel resulted as a compromise of several differing opinions. Subsequent consideration among personnel at Teledyne and discussions with Sea-Land technical personnel suggest that other locations may provide slightly higher shear stress values, such as just below the box beam structure. Nevertheless, the present location does provide a reasonable measure of the severity of the torsional shear stress induced on the vessel, and inasmuch as the magnitudes are very low, far from structural concern, there does not appear to be any immediate need to alter the instrumentation. As a complementary approach to improve insight into the torsion behavior additional strain gages were installed on the transverse deck girder between hatches 5 and 6 on the starboard side. These strain gages will measure stresses induced by the double-S bending of the transverse member, thereby providing information on the severity of the torsional distortion. These measurements will be made in the forthcoming voyages of the 1969-1970 winter season. The calibration test will also include distortional measurements of a hatch opening adjacent to the midship section.

The stress data from the four box beam gages was compared to the vertical longitudinal bending stress as a reference. The detailed location of these gages and the box beam plate thickness at these locations are indicated in Figure 5. Under ideal conditions of beam bending it is clear from the locations of Figure 5 that the upper three gages should show stress values very nearly equal to those of the vertical bending deck gages which represent the maximum bending stress. The port side weld gage will exhibit stress values lower in proportion to its smaller distance from the neutral axis.

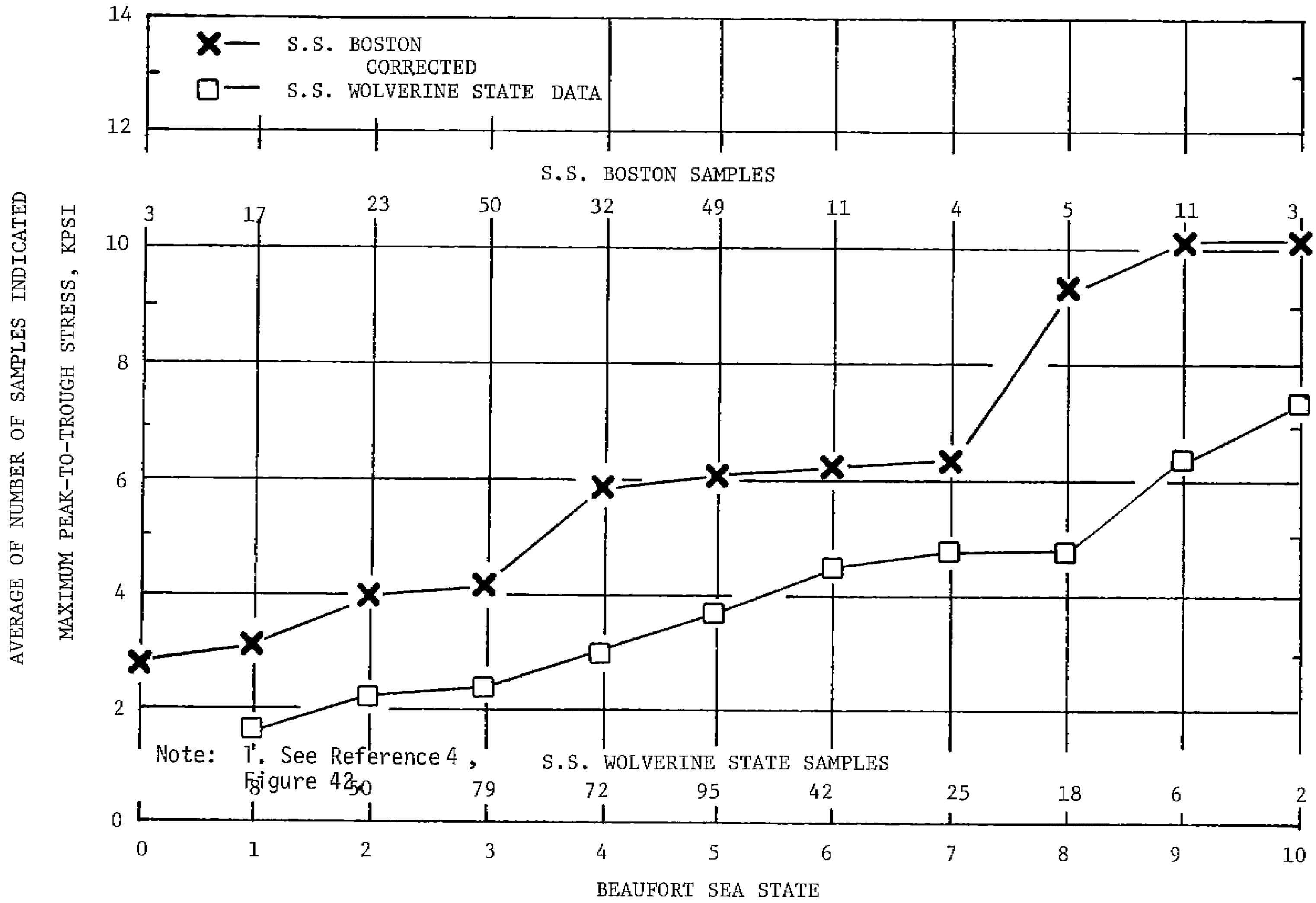


Fig. 22. Vertical Longitudinal Bending *S.S. Wolverine State* North Atlantic Winter
S.S. Boston-Voyages #9 & #10

Table X. 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	9900
First Reduction Gear, H.P. Turbine	9,096	
First Reduction Gear, L.P. Turbine	7.508	
Second Reduction Gear	6,930	

It should be noted that each of these stress gages is monitored as a single active arm bridge. (See Figure 3D.) Consequently, longitudinal stresses induced by all stress modes are algebraically present in each gage in contrast to the four-active arm bridges which can be and are so arranged to cancel stresses induced by stress modes other than that desired. Each single element gage therefore provides the total longitudinal stress level present at each location.

The data from each gage was examined on an instantaneous basis against both the vertical and horizontal bending stresses to determine the contribution of each to the total stress in the single element. Generally, there is very little stress contribution from horizontal bending, but on occasion values as high as 15 per cent of the vertical stress were observed. The percentages shown in Figure 5 represent the amount of vertical bending stress at the location, relative to the deck location taken as 100 per cent. On the basis of pure bending, it would be anticipated that the two gages SBBG and SSPG would show the same percentage values since the vertical positions are identical. The inside gage SBBG exhibits about a 13 per cent drop in bending stress as compared to the 6 per cent for SSPG which is moderately higher than that to be expected for the 7-inch shorter distance from the neutral axis. This data indicates that some lag is present in the structural participation of the inside portion of the box beam; however, the magnitudes are not of major proportions. Inasmuch as the data acquired on these gages is time shared, and hence fewer data points are obtained, the accuracy of the values will be significantly improved with the added data of the forthcoming winter season.

Total stress values of these transducers, which includes horizontal and vertical bending plus stress induced by other modes, did not exceed 115 per cent of the vertical bending stress on any of the four gages. The major increment to the total stress over and above the vertical bending stress is attributed to the horizontal bending stress indicating that very little stress is contributed by all other modes.

4.3 Acceleration Data

Figures 10 through 15 display the six acceleration signals i.e., three vertical and three horizontal. The bow vertical signal of Figure 14 is the most significant. A comparison of the average value of this signal for voyages 9 and 10 of the S. S. BOSTON with the average value from 14 round trip voyages of the S. S. WOLVERINE STATE is provided in Figure 23. A very close agreement was achieved as anticipated since such response is primarily a function of hull form which is not altered in the conversion of the vessel and hence remains similar to the S. S. WOLVERINE STATE.

The levels of acceleration sensed on the other five channels were significantly below that of Figure 14 as theory predicts and thus are of secondary interest.

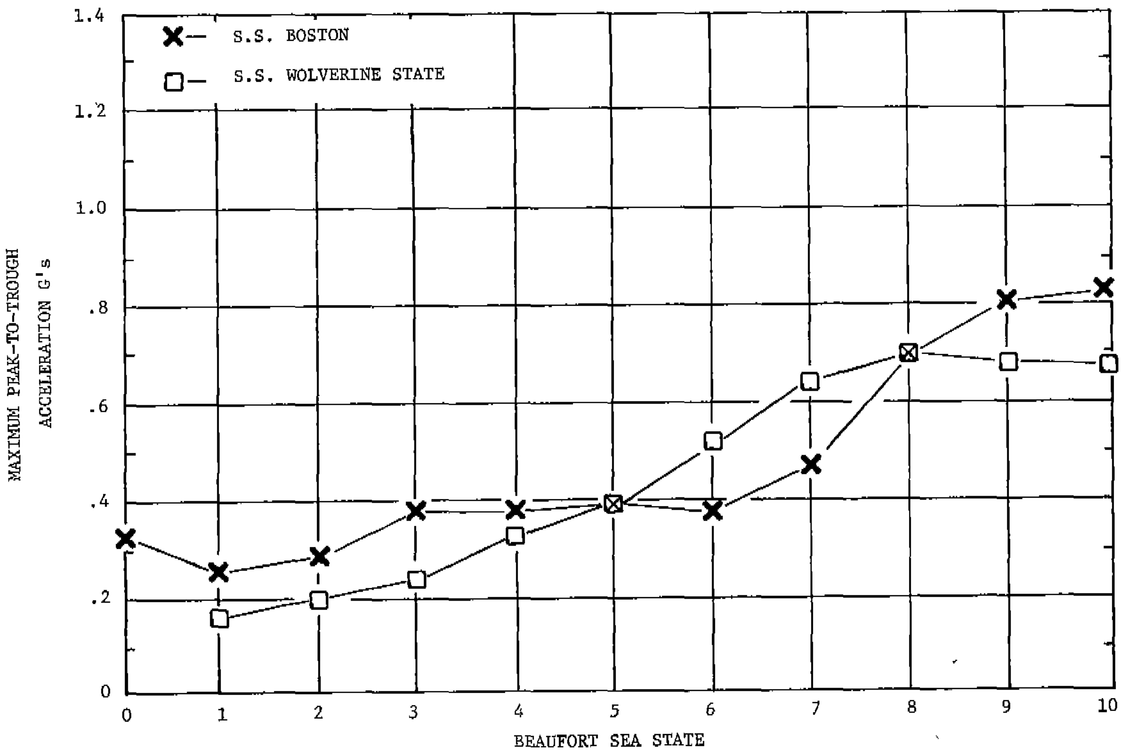


Fig. 23. Wave-Induced Bow Vertical Acceleration *S.S. Boston* Voyages #9 & #10 *S.S. Wolverine State* 14 Roundtrip Voyages

4.4 Ship's Motion Data

Figures 16 and 17 (pitch and roll) describe the attitude of the vessel in the various sea conditions. Close observation of this information displays quite clearly the unique mode of operation peculiar to container vessels. In order to prevent possible damage to on-deck containers, the ship's master is inclined to avoid head seas and reduce the pitch at the cost of increasing the roll. Naturally, a trade off is made between ship's speed and the maximum pitch and roll permitted. The tendency is to be in a roll mode even during light seas verified by our operating personnel during the past season. In addition to contributing to the discomfort factor, this phenomenon limits the extent of data analysis which may be accomplished while at sea.

It can be observed from Figure 16 that pitch is predominantly under 6 degrees double amplitude or only 3 degrees on the average from the horizontal. This low degree of pitch certainly would keep the amount of water taken over the bow to a minimum and prevent damage to the on-deck container.

The roll information of Figure 17 displays a much greater angle. Even at sea states of 3 and 4, rolls of 10 degrees or more to the vertical are quite common. The pitch and roll signals when correlated with the log book data, provide the in-house personnel with a good picture of what took place on the vessel on a winter's crossing.

4.5 Supplementary Strain Gage Data

No plots of the supplementary data were provided for the past season since these devices were installed primarily to validate the accuracy of the stress gage transducers insuring against the influence of local effects. The two units, one port and the other starboard, were recorded on alternate days. A comparison of the data channel showed a consistency of data between the two units. A periodic conversion of the stress data was made and compared to the vertical stress data with good results. A typical comparison gave a reading of 9090 psi on channel 1, a value of 9,000 psi on channel 4A (SUDG) and a supplementary gage value of 9,240 psi.

The 1969-1970 season will find each interval of supplementary strain gage data accomplished by a calibration signal which should allow for a much better presentation of the available data. It is still planned to record these devices on alternate days on the same channel.

4.6 Wave Buoy Data

Wave buoy data for two out of the three launches was reduced on the Teledyne Materials Research Power Spectral Density Program to provide the outputs shown on Figures 18-20. In addition, a computer analysis of channel 1 vertical longitudinal bending stress was performed on data taken during the wave buoy recording period. An RMS value, as well as the maximum peak-to-trough signal for each interval, is obtained from this computation. Spectral data should be considered conditional until final analyses are completed.

The analysis of the first unit, buoy 49004 generated a standard deviation of the displacement signal of 7.83 ft. RMS. Arbitrarily calling a "significant" wave height four times the RMS, one finds the significant wave height would be about 30 feet. A comparison of log book data for this period of time indicated an average wave height of 20 feet and an average swell height of 25 feet. These visual observations were difficult to interpret, but the wave buoy results seem to be of the same order of magnitude. The computer printout generated an RMS stress value ranging from about 3000 psi to 5000 psi for these intervals with a maximum peak-to-trough value of 11000 psi.

The second launch of buoy 49001 provided an RMS displacement of 2.813 ft. Four times this amount gives a corresponding significant sea of 11.25 feet. Log book data listed an average wave height of 5 feet with a 5 to 6 foot swell running. The range of RMS vertical stress was from 2600 psi to 4600 psi with a maximum peak-to-trough value of 10,000 psi.

A comparison of sea states of the two launches (the first at 8-9 and the second at 5-6) appeared consistent with the values obtained; certainly, they shift in the proper direction.

5.0 CONCLUSIONS

On the basis of two voyages during the 1968-1969 season the data indicate that the longitudinal bending stresses are significantly higher for the converted structure of the S. S. BOSTON as compared to a similar class C-4 before conversion, e.g., S. S. WOLVERINE STATE. The level of the stress values is nevertheless not of sufficient magnitude to be of structural concern for the sea states encountered.

Although the shear stress transducers may not be located at the precise region of maximum torsional shear, it is apparent that values two to three times those observed, which is considered quite unlikely, would not be of structural concern. Therefore, if one considers the very low values, little advantage would be gained by the addition of more torsional shear transducers at other locations. Torsional distortions are, however, of importance, and additional instrumentation has been introduced into the program to obtain torsional deformation data during both the calibration test and seaway voyages.

Stress intensification data obtained on the BOSTON box beam indicates some lag in participation of the inside portion of the box beam; however, additional data is required before definitive values can be obtained.

A recently completed static test on the BOSTON (see subsequent report) indicated good agreement between measured torsion and bending stress changes and those calculated from the applied twist and bending moments. The data reported herein can therefore be treated with some confidence.

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2. Wheaton, J. W. "Wave Height Measurement Test." Teledyne Materials Research Technical Report No. E-1184, 25 August 1969.

3. Fritch, D. J., Bailey, F. C., Wheaton, J. W. "Results From Full-Scale Measurements of Midship Bending Stresses on Two Dry-Cargo Ships - Report No. 2. Ship Structure Committee Report SSC-181, March 1967

4. Bailey, F. C., Walters, I. J., "Results From Full-Scale Measurements of Midship Bending Stresses on Three Dry Cargo Ships" - Ship Structure Committee Report SSC-209, 1970.

APPENDIX A

TRANSDUCER SPECIFICATIONS

1. Stress Gages

BLH Electronics, Inc., Type FAB-28-S6

Longitudinal Gage

Resistance: 350.0 ± 2.5 Ohms
Gage Factor: 2.06 ± 1%

Lateral Gage

Resistance: 98.0 ± 1.0 Ohms
Gage Factor: 2.05 ± 1%
Poisson Ratio: .28 ± 1%
Stress Gage Factor: 1.48 ± 1%

2. Torsion Gages

BLH Electronics, Inc., FABD-25-12S6

Gage Factor: 2.02 ± 1%
Resistance: 120.0 ± .2 Ohms

3. Bow and Stern Accelerometers

Setra Inc., Model 100

Range: ± 5g
Maximum Static Acceleration: ± 100g
Approximate Natural Frequency: 490 Hz
Transverse Acceleration Response: <0.01g/g
Excitation: 6 VDC at 20 ma
Full Range Output: ± 1.5 VDC
Output Impedance: 400 Ohms

4. Midships Accelerometers

Statham Instruments, Inc., Model A3-2.5 - 350

Range: ± 2.5g
Nominal Bridge Resistance: 350 Ohms
Approximate Natural Frequency: 55 Hz
Transverse Acceleration Response 0.02g/g
Excitation: 11 Volts DC or AC (RMS)
Full-Scale Output: ± 20 mv
Used with Statham Instruments
Model CA9-56 Strain Gage Signal Amplifier
with an output of ± 2.5 VDC

5. Midships Pitch-and-Roll Signals

Humphrey Inc., Pendulum Transducers, Model CP17-0601-1

Range: $\pm 45^{\circ} \pm 0.5^{\circ}$
Resistance: 2000 Ohms $\pm$ 5%
Power Dissipation: 0.5 watt at 130°F
Accuracy: $\pm$ 1% with straight line approximation
Natural Frequency: 2 Hz

6. Displacement Transducers

Hewlett Packard, Model 7DCDT-050

Full-Scale Output: 1.5 VDC
Range: $\pm$ 0.050 inches
Scale Factor: 30 V/in
Maximum Nonlinearity: $\pm$ 0.5% FS
Excitation Voltage: 6 VDC Nominal
Output Impedance: 2.2 K Ohms
Frequency Response: 3 db down at 350 Hz

7. Wave Data Acquisition System

Eastech Limited, Windsor, Nova Scotia, Model 440

Used with Model 266 Wave Buoys.
Data recorded as positive pulses approximately 3 milliseconds in duration, approximately 1.5 volts peak at 30 pulses per second at zero acceleration

APPENDIX B

CALIBRATION MODE CALCULATIONS

The four stress/strain gage bridge circuits which provide the data for channels 1-4, shown on Figures 3A to 3D, are placed in a calibration mode by paralleling a known fixed precision resistance across one arm of the bridge. This action creates an output signal equivalent to a precalculated output. The following discussion develops the procedure used to establish the value of calibration resistor and stress level achieved.

For stress gages the following equation was derived based on a 4-arm bridge circuit made up of gage elements and a fixed resistor (R_c) used to provide shunt calibration.

$$R_c = \frac{ER_gM}{(GF)_c\tau_cN}$$

where R_c is the value of the calibration resistor in ohms

E = Modulus of elasticity taken to be 30 x 10^6 psi for steel

R_g = Combined gage resistance i.e., longitudinal plus lateral components; 448 ohms for the gages used in this system

M = Number of stress gages per arm

$(GF)_c$ = The combined gage factor; 1.48 for the stress gages used

τ_c = The calibration stress in psi

N = Number of active arms in the bridge circuit

For channels 1 and 2 (Figures 3A and 3B) a 445 kilohm calibration resistor was used. This value produces a calibration stress equivalent to:

$$\tau_c = \frac{E R_g M}{(GF_c) R_c N} \quad \text{with M and N = 2}$$

of

$$\tau_c = 20{,}400 \text{ psi}$$

The other channel using stress gages is channel 4 (Fig. 3D). In this arrangement M and N = 1. R_c was selected as 889 kilohms, thus:

$$\tau_c = 10{,}200 \text{ psi}$$

Channel 3 signal is provided by a strain gage bridge rather than a stress gage circuit. The equation is modified slightly to include the effects of (μ) Poisson's ratio. For a bridge circuit made up of 4 active strain gage elements of 120 ohms each, a gage factor of 2, $\mu = 0.28$ and a calibration resistor of 183 kilohms. The resulting equation becomes:

$$\tau_c = \frac{ER_g}{4(G.F.)(1+\mu)R_c} \quad \text{and}$$

$$\tau_c = 1921 \text{ psi}$$

The transducers for channels 5-12 are devices which provide a fixed gradient of output i.e., $\pm$ 0.3v/g or 0.1v/degree. To provide a calibration signal, a precision voltage source is established at the transducer to generate a specified voltage when the system is in a calibration mode.

These calibration signals are as follows:

Channel	Function	Calibration voltage-unit
5	Stern Verical Acceleration	0.3v = 1g
6	Stern Horizontal Acceleration	0.3v = 1g
7	Midships Vertical Acceleration	1v = 2g
8	Midships Horizontal Acceleration	1v = 20^{o}
9	Pitch	1v = 20^{o}
10	Roll	1v = 20^{o}
11	Bow Vertical Acceleration	0.3v = 1g
12	Bow Horizontal Acceleration	0.3v = 1g

Channel 13 information is developed from displacement gages. No calibration mode signals are generated for this signal. A physical calibration of these units was performed at the time of installation and will be repeated during the upcoming calibration tests. Channel 14 is the compensation channel, and again no calibration signal is generated or required. A short across the input provides for a 0 volt input i.e., the center frequency of the oscillator is not changed. Any change of the frequency and subsequent output signal would be the result of the recorder itself causing a shift of frequency due to its environment. This signal is used to control the recorder in the play-back mode, and the data is thus corrected for any deviation.

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