SSC-209

RESULTS FROM FULL-SCALE MEASUREMENTS OF MIDSHIP BENDING STRESSES ON THREE DRY CARGO SHIPS

SHIP STRUCTURE COMMITTEE

1970

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ADDRESS CORRESPONDENCE TO:
SECRETARY
SHIP STRUCTURE COMMITTEE
U.S. COAST GUARD HEADQUARTERS
WASHINGTON, D.C. 20591

1970

Dear Sir:

A project initiated in early 1959 and reported through earlier SSC reports has been nearly completed. The objective was to obtain records for statistical analysis of the longitudinal bending moment strains experienced by various types of ships, operating on different trade routes.

Herewith is a report that covers the most recent three and one-half year's compilation of data.

Sincerely,

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

SSC-209

Technical Report

on

Project SR-153, "Ship Response Statistics"

to the

Ship Structure Committee

RESULTS FROM FULL-SCALE MEASUREMENTS OF MIDSHIP BENDING STRESSES ON THREE DRY CARGO SHIPS

by

I. J. Walters and F. C. Bailey

under

Department of the Navy
NAVSEC Contracts: NObs 94252
N00024-67-C-5312
N00024-68-C-5231

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

ABSTRACT

This report summarizes the activities undertaken by Teledyne Materials Research under Ship Structure Committee Project SR-153 during a three and one-half year period to investigate certain aspects of the structural response of three dry-cargo ships to wave loads. This work continues earlier studies sponsored by the Ship Structure Committee. Work is concluding on *MORMACSCAN* and *CALIFORNIA BEAR* and will continue on *WOLVERINE STATE* which is also instrumented to gather data for project SR-172, "Slamming Studies" to be reported under separate cover.

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I. INTRODUCTION

These investigations are providing statistical data from which maximum expected values of vertical longitudinal bending moment may be predicted. Ultimately, through correlation with model tests at the Davidson Laboratory of Stevens Institute of Technology, and analysis by Webb Institute of Naval Architecture, these data will contribute to the design of more efficient ships.

Data acquired by the investigators through April 1965 covering about 18,500 hours at sea were analyzed and presented in graphical form in Ship Structure Committee Reports SSC-164 and SSC-181 (References 1 and 2). The design and installation of the stress-measuring and recording system, and preliminary presentation of some data have been reported in Ship Structure Committee Reports SSC-150, 153, and 159 (References 3, 4, and 5). This present report includes data from thirteen voyages of the CALIFORNIA BEAR, twelve voyages of MORMACSCAN, and nineteen voyages of WOLVERINE STATE. These data represent a total of 16,000 hours at sea for the three ships during the period May 1965 to November 1968. Table I is a chronological record of ship visits necessary to acquire these data and maintain the equipment. Table II lists the specifications of the three ships. The results of the calibration of CALIFORNIA BEAR are reported in Appendix A-1 and the results of the calibration of MORMACSCAN are reported in Appendix A-2.

The data in this report were obtained under contracts NObs-94252, N00024-67-C-5312, and N00024-68-C-5231.

II. PRESENTATION OF DATA

The data shown as dot-plots were acquired by the following procedures, which are similar for stress and wave height data.

1. The shipboard magnetic tape system records the signals generated by the stress transducers for at least one-half hour out of every four hours at sea. At the beginning of each four-hour interval a calibration signal (obtaining by shunting one arm of the bridge with a known resistance) is superimposed. When the tape is played back in the investigators' laboratory, the Sierra Probability Analyzer is triggered by each calibration signal and provides a histogram and statistical data representing the first twenty minutes of each record interval (see Figure 15, SSC-169, Reference 1). At the playback speed of 60 inches per second, a half hour of ship data requires 9 seconds to be analyzed by the machine.

2. The officer on watch maintains a logbook. Every four hours an entry is made and given a sequential index number. At the time of the logbook entry the elapsed time meter reading is noted, from which the index number may be matched to the appropriate interval calibration signal. Report SSC-153 (Reference 4) contains reproductions of typical logbook pages.

3. The oscillographic output from the probability analyzer is transcribed manually in terms of a scale of counts from the digital registers. Only the bars representing the greatest peak-to-trough stress, the total number of stress variations analyzed, and the mean square value of the data sample are transcribed.

4. Two punched cards are prepared for each data interval. The first contains all the logbook data and the second contains the above quantities from the probability analyzer.

Table I
Ship Visits to Maintain Equipment

Date	Instrumented Voyage Number			Ship Voyage Number			Equipment Operation - Remarks
	WS	MMS	CB	WS	MMS	CB	
							Abbreviations: WS = SS WOLVERINE STATE MMS = SS MORMACSCAN CB = SS CALIFORNIA BEAR
5/12/65	37			243			Stbd Amplifier Failed, M-G problems, no data
6/4/65		7			27		Fuse Blew, 43 good intervals
6/16/65	38			245			Fuse Blew in record electronics, M-G problems, 32 good intervals
7/28/65	39			247			OK, 204 good intervals, calibration made 8/1/65
8/31/65		8			28		OK, 121 good intervals
9/1/65	40			249			M-G problems and recorder power supply problems, removed power supply, 102 good intervals
11/4/65		9			29		OK, 72 good intervals
12/16/65		10			30		OK, 88 good intervals
3/7/66		11			31		OK, 72 good intervals
3/9/66	41			259			OK, 48 good intervals, expanded system on board
3/22/66			1			25	OK, 79 good intervals
4/25/66	42			261			OK, 90 good intervals
4/27/66		12			32		OK, 120 good intervals
6/13/66		13			33		Rewind problem, one pass only, 65 good intervals
6/16/66	43			263			OK, 119 good intervals
6/16/66			2			26	OK, 98 good intervals
7/25/66	44			265			First roll NG, 2nd roll OK, 36 good intervals
7/30/66		14			34		OK, 131 good intervals
9/3/66	45			267			OK, 55 good intervals
9/19/66			3			27	Noise in data, several of 100 intervals unusble
10/7/66	46			269			Port amplifier failed, no data: 59 good interval from starboard gage
10/11/66		15			35		One pass only, recorder trouble; 28 good interva
11/2/66	47			271			OK, 88 good intervals
11/28/66		16			36		One pass only, recorder trouble; 66 good interval
12/12/66			4			28	Zero timer failure, 22 good intervals
12/20/66	48			273			OK, 93 good intervals
1/12/67		17			37		OK, 118 good intervals
2/16/67			5			29	OK, 115 good intervals
2/20/67	49			275			No data, new crew
3/2/67		18			38		OK, 135 good intervals

Table I

Ship Visits to Maintain Equipment (cont.)

Date	Instrumented Voyage Number			Ship Voyage Number			Equipment Operation - Remarks
	WS	MMS	CB	WS	MMS	CB	
4/3/67	50			277			Starboard amplifier failed after 47 good intervals; Port data 104 good intervals
5/1/67		19			39		Recorder bearing failed, 42 good intervals*
5/10/67			6			30	OK, 154 good intervals
6/20/67		*			40		No data, recorder inoperative
6/21/67	51			279			Both amplifiers failed midway in voyage, compensation channel drifting because of faulty VCO about 120 good intervals
7/26/67			7			31	OK, 98 good intervals
8/30/67		*			41		No data taken*
9/25/67	52			280			Port amplifier failed in voyage, compensation channel drifts, badly because of faulty VCO about 130 good intervals from port gage, 200 good intervals from stbd gage
10/6/67			8			32	Slight tape slippage at end of reels, 115 good intervals
11/9/67		*			42		No data taken*
12/18/67			9			33	OK, 105 good intervals
12/22/67	53			281			OK, 223 good intervals
2/1/68		*			43		Amplifier failed, 19 good intervals*
2/12/68	54			282			OK, 118 good intervals
3/8/68			10			34	OK, 128 good intervals
5/22/68			11			35	OK, 102 good intervals
6/20/68	56			284			OK, 149 good intervals
8/5/68			12			36	OK, 124 good intervals, calibration made
9/18/68	57			285			Port amplifier failed mid-voyage, 258 intervals starboard gage, 144 intervals port gage
9/30/68		*			46		Calibration made
10/25/68			13			37	Equipment removed
11/13/68	58			286			Starter control relay failed mid-voyage, 183 good intervals both transducers

*SS MORMACSCAN - minimum maintenance of equipment until calibrated and removal of equipment.

Table II
Ship Specifications

	WOLVERINE STATE	MORMACSCAN	CALIFORNIA BEAR
Type:	C-4-S-B5 Machinery-Aft Dry Cargo Vessel	1624 Machinery Amidships Dry Cargo Vessel	C4-S-1A Standard Mariner Dry Cargo Vessel
Builder:	Sun Shipbuilding and Drydock Company Chester, Pennsylvania	Same	Bethlehem Pacific Coast Steel Co. Shipbuilding Div. San Francisco, California
Date:	September 1945	October 1960	February 1954
Hull Number:	359	622	5463
Length Overall:	520' - 0"	483' - 3"	563' - 7-3/4"
Length Btwn Perp.:	496' - 0"	458' - 0"	528' - 6"
Beam, Molded:	71' - 6"	68' - 0"	76' - 0"
Depth, Molded:	54' - 0"	41' - 6"	44' - 6"
Load Draft, Molded, Design	30' - 0"	28' - 6"	27' - 0"
Load Draft, Keel	32' - 9-7/8"	31' - 5"	29' - 10-1/16"
Gross Tonnage:	10,747 L.T.	9,315 L.T.	9,216 L.T.
Net Tonnage:	6,657 L.T.	5,609 L.T.	5,366 L.T.
Midship Section Modulus	45,631 in^2 ft (to top of upper deck)	30,464 in^2 (to top of upper deck)	43,900 in^2 ft (to top of upper deck)
Light Ship Weight:	6,746 L.T.	5,882 L.T.	7,675 L.T.
Dead Weight at Load Draft:	15,348 L.T.	12,483 L.T.	13,418 L.T.
Propeller, Normal Operating RPM:	80	93	85
Shaft Horsepower, Normal	9,000	11,000	17,500
Shaft Horsepower, Maximum	9,900	12,100	19,250

5. Input cards and program cards are then processed by a digital computer. The computer calculates relative wave direction and transforms the probability analyzer output into maximum peak-to-trough stress in kpsi, mean square stress in $kpsi^2$, and root-mean-square stress in kpsi.

6. The computer output for each voyage consists of a tabulation by interval number and also, optionally, a set of output punched cards. The data from one pass of the magnetic tape aboard ship have been given a double-letter code for identification. This coding appears on the printout and on each output card. A compilation of the code letters for the data of this report and sample printouts are shown in Appendix B.

III. DISCUSSION OF DATA

A. General

When considering the absolute values of the stress data, it must be kept in mind that these data are presented as peak-to-trough stress variations, and not as single positive or negative amplitudes about an average level. Absolute average values are difficult to determine and are variable with loading and thermal conditions. Statistical procedures for analyzing peak-to-trough values of random variables, moreover, are well established.

The collection of statistical ship stress data can be of real significance to the ship designer and/or classification authority. When interpreted in terms of applied wave bending moment, such data can be used to determine a suitable design value of bending moment by two approaches, as dealt with in detail under Project SR-171.

1. A mathematical or probability model can be devised that will permit a long-term bending moment probability distribution to be extrapolated from two to five years of data, to the lifetime of a ship or of several similar ships. This leads to a means of predicting the highest expected bending moment in 20 years or 200 ship-years for one class of vessel.

2. Statistical data provides the basis for checking a prediction of long-term distribution made from model test results and ocean wave data. If good results are obtained in several cases, then the prediction technique can be applied with confidence to new and unusual design.

Each data point is based on a twenty-minute portion of a thirty-minute sample record (interval), and is assumed to be representative of four hours of operation of the ship in the seaway. In heavy weather situations where the tape recorder operates longer than one-half hour out of every four, only the twenty-minute portion following the calibration signal (every four hours) is analyzed, under current procedures. Coastwise and in-port data have been eliminated.

There is considerable scatter of the data points in the dot-plots. This scatter might be explained on the basis of the statistical nature of the data, since the ship operates at various headings relative to the sea, and at various speeds within a given sea state. Because the reported sea-state information is based on visual observations, some spread in these values as a result of individual interpretation is also likely.

Based on Appendices A and C, the MORMACSCAN data are probably accurate as reported; a small correction is optional on the CALIFORNIA BEAR data; and all WOLVERINE STATE data are subject to specified correction factors.

B. Discussion of Figures

1. CALIFORNIA BEAR

Figures 1 and 2 present uncorrected RMS stress and uncorrected maximum peak-to-trough stress plotted versus Beaufort Sea State for 13 voyages, all between the West Coast of the United States and the Orient. This represents a total of 1250 intervals taken from January 1966 when the system was first put into operation up to October 1968. The maximum peak-to trough stress recorded was 12,300 psi at a sea state of 8.

A satisfactory bending calibration was made on this ship in early August 1968 and is reported in Appendix A-1. Based on this calibration and other available information, the CALIFORNIA BEAR data should be corrected by a factor of 1.08. The recording instruments have been removed from this ship.

2. MORMACSCAN

The data collected from MORMACSCAN for the reporting period are presented in Figures 3 through 6, inclusive. They are divided into two groups, voyages to Europe (247 intervals) and voyages to South America (824 intervals). The average values of these plots are compared in Figures 33 and 34 along with previous data reported for this vessel in SSC 181. It appears that the stresses produced, sea state for sea state, vary between the European and the South American trade routes. Above sea state 3, the South American voyages produce RMS stresses 500 psi lower than the European voyages. Likewise, the maximum peak-to-trough stresses are about 1,000 psi lower. The curve labeled "mean" is the overall average for about 1,600 intervals, one quarter of them produced in North Atlantic crossings and three quarters of them on the trade route between the eastern seaboards of North and South America.

An adequate bending calibration was made on this ship in early October 1968 and is reported in Appendix A-2. No correction of the reported data is recommended.

No further data are being taken from this ship and the equipment will be removed at the next opportunity.

3. WOLVERINE STATE

Stress data from the WOLVERINE STATE are divided into three categories:

North Atlantic, Summer Season

North Atlantic, Winter Season

Pacific

The seasonal division was found necessary in the North Atlantic because of the greater likelihood of encountering large swells at relatively low Beaufort Sea States in the winter. This seasonal variation is not as severe in the Pacific and therefore these data are presented as a mixture of both summer and winter.

This ship is unique in that the stress gages mounted on the port and starboard sides are not combined into a single bridge, but are connected to form two separate bridges. This allows us to determine the effect of unfairness upon individual gages (see Appendix C). In order to get vertical bending stress the tapes are played back in the laboratory and the port and starboard channels are electrically combined. The individual channel sensitivities are adjusted such that unfairness corrections are applied and the resulting combined data represents true vertical bending stress. Data obtained from a single transducer is to be considered raw data in that the unfairness correction has not been applied. All these curves are labeled with the appropriate correction factor.

In addition, data obtained from only one side contains a component of horizontal bending stress which cancels out in the combined data. In order to determine the statistical effect of horizontal bending, dot-plots have been made showing the same data for combined, port uncombined (uncorrected), and starboard uncombined (uncorrected). The uncorrected averages are then corrected for unfairness and compared with the combined averages. The resulting correction for horizontal bending may then be applied to data which otherwise would be unusable because good data was collected from only one side.

a. North Atlantic Summer Data

These data were gathered from Voyages 245, 247, 249, 261, 263, 265, and 267. Figures 7 and 8 show data taken from the first six of these voyages as the electrical sum of the Port and Starboard Transducers. The discriminator gains on the tape playback unit were adjusted to compensate for the unfairness corrections for each gage (see Appendix C), and, of course, horizontal bending is eliminated by having gages on both sides of the ship. Therefore, the stresses in Figures 7 and 8 are the actual stresses in the ship and require no further corrections.

Figures 9 and 10 show the same data as seen by Port Transducer (uncorrected) and Figures 11 and 12 show the same data as seen by the Starboard Transducer (uncorrected). The data plotted in these figures should be identical to Figures 7 and 8 after applying a correction for unfairness and for horizontal bending. Since the effect of horizontal bending is unknown, the averages from Figures 7-12 were plotted in Figures 35 and 36, unfairness corrections made, and the effect of horizontal bending determined. A fairly good match was made by reducing the corrected uncombined stresses by 12% for each sea state. The horizontal bending was also found to be 12% for the Winter and Pacific Data.

Figures 13 and 14 represent uncorrected data taken on Voyage 267 where both channels were recording transducers from the starboard side. In order to make these data usable, the unfairness correction was applied and 12% was deducted from the result to correct for horizontal bending. This was then averaged with the averages from Figures 7 and 8 to produce the Atlantic Summer portion of Figures 41 and 42.

b. North Atlantic Winter Data

These data were gathered from Voyages 259, 271, 273, 277 and 282. On only one of these voyages (259) were data produced from both sides simultaneously. This is represented in Figures 15 and 16 as combined data to which no further corrections are required and in Figures 17-20 as individual uncorrected port or starboard data. The averages of these figures are compared in Figures 37 and 38. The effect of horizontal bending on these data is the same 12% as found in the summer data.

Figures 21 and 22 list the uncorrected data obtained from the Port Transducer during Voyages 271, 273, and 282. Figures 23 and 24 list the uncorrected data obtained from the New Starboard Transducer during Voyage 277. In order to make use of these data they have been corrected for unfairness, corrected for horizontal bending, averaged with the data of Figures 15 and 16 and plotted as the Atlantic Winter portion of Figures 41 and 42.

c. Pacific Data

These data were collected from Voyages 279, 280, 281, 283, 284, 285 and 286. Data were obtained from both sides during Voyages 279, 280, 281, 285 and 286 and are presented as port and starboard electrically combined data in Figures 25 and 26. As with the Atlantic data, these data require no further corrections. The data from the individual Port and Starboard Transducers (uncorrected) for these voyages are presented in Figures 27-30. A comparison is made of the electrically combined and the individual transducers in Figures 39 and 40. As before, the correction for horizontal bending is determined to be -12%.

During Voyages 283 and 284 data were taken only from the Port Transducer. The uncorrected results of these voyages are plotted in Figures 31 and 32. In order to utilize these data the averages of Figures 31 and 32 are corrected for unfairness and horizontal bending and averaged with the data of Figures 25 and 26. These data are presented as the Pacific portion of Figures 41 and 42.

4. WOLVERINE STATE WAVE DATA

A Tucker Wave Meter was installed aboard WOLVERINE STATE in April, 1966 and connected such that its electrical output was fed to one channel of the slow-speed magnetic tape recorder in lieu of the paper chart readout furnished with the machine. With the exception of two interruptions due to electrical faults in the Tucker, this device has been producing data since installation. Figures 45 through 62, taken from data from Voyages 279, 283 and 284 are used here to illustrate the nature of these data.

Figures 45, 51, and 57 are plots of RMS Stress vs. RMS Wave Height. Figures 46, 52 and 58 are plots of Maximum Peak-to-Trough Stress vs. Maximum Peak-to-Trough Wave Height. Each tape pass and hence, each section of the voyage has been plotted with different symbols. In some cases good correlation is indicated by a fairly well defined band of increasing stress with increasing wave height for a particular leg of a voyage. In other cases the data are scattered and much poorer correlation is exhibited. It should be emphasized here that there is no "observer" effect in this presentation. Both stress and wave height are primary transducer-generated quantities.

Figures 49, 55 and 61 are dot-plots of Estimated Wave Height (from the data logbooks) vs. Beaufort Sea State. Figures 48, 54 and 60 are dot-plots of Maximum Peak-to-Trough Wave Height vs. Beaufort Sea State. Figures 47, 53 and 59 are dot-plots of RMS Wave Height vs. Beaufort Sea State. Figures 50, 56 and 62 replot the averages from the dot-plots for each of the three voyages and include stress plots for comparison. The Tucker Wave Meter outputs do not follow either the Estimated Wave Heights or the stresses.

5. OVERALL AVERAGES

The overall averages, regardless of trade route or season, of all three ships are plotted in Figures 43 and 44.

IV. SUMMARY

CALIFORNIA BEAR data collection has ceased after 13 instrumented voyages. A calibration of the bending transducers indicates a correction factor of 1.08 should be applied to the data. The data listed in Figures 1 and 2 are raw data and should be multiplied by this factor to get actual bending stress. The CALIFORNIA BEAR averages in Figures 43 and 44 have already been corrected.

MORMACSCAN data collection has ceased after 19 instrumented voyages. A calibration of the bending transducers indicates that no correction factor is necessary. Figures 33 and 34 sum up the data taken for the period of this report and compare it with that reported in SSC181.

WOLVERINE STATE data collection continues. Further investigation of the corrections required because of side shell unfairness have increased confidence in their use. This investigation is reported in Appendix C.

The effect of horizontal bending on the WOLVERINE STATE data has been investigated. A reduction of 12% applied to the corrected average from a single transducer will statistically remove the effect of horizontal bending. Electrical summing of the port and starboard transducers will eliminate horizontal bending on a point-to-point basis if the individual channel gains are adjusted to compensate for the unfairness corrections. Figures 41 and 42 sum up all the WOLVERINE STATE data taken for the period of this report. No corrections to these data are necessary.

From the Tucker Wave Meter plots, which are representative of all the wave data collected, very little can be firmly concluded. Although the meter does not agree with the estimated wave heights, the accuracy of the estimates is probably very poor having been made by several different persons whose ability to judge wave heights correctly is unknown. The relationship between measured wave height and bending stress is also poor, but since the stress is directly proportional to both wave height and wave length, a large scatter would be expected in a sample containing a

V. ACKNOWLEDGEMENTS

This project is sponsored by the Ship Structure Committee with guidance from the Ship Hull Research Committee of the National Academy of Sciences, National Research Council.

The cooperation of States Marine Lines has continued to contribute to the progress of this investigation. Mr. John Ritter and the officers and men of SS WOLVERINE STATE should be recognized for their efforts in this project.

The wholehearted cooperation of Pacific Far East Lines and in particular Mr. V. J. Bahorich and the officers and men of SS CALIFORNIA BEAR deserve special vote of thanks.

Moore-McCormack Lines, Mr. F. A. Heess and the officers and men of SS MORMACSCAN also deserve acknowledgement for their continued contribution.

VI. REFERENCES

1. Fritch, D. J., Bailey, F. C., and Wise, N. S., Results from Full-Scale Measurements of Midship Bending Stresses on Two C4-S-B5 Dry-Cargo Ships Operating in North Atlantic Service, Ship Structure Committee Report SSC-164, September 1964.

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3. Fritch, D. J., and Bailey, F. C., An Unmanned System for Recording Stresses and Acceleration on Ships at Sea, Ship Structure Committee Report SSC-150, June 1963.

4. Fritch, D. J., Bailey, F. C., and Wise, N. S., Preliminary Analysis of Bending Moment Data from Ships at Sea, Ship Structure Committee Report SSC-153, December 1963.

5. Bailey, F. C., Fritch, D. J., and Wise, N. S., Acquisition and Analysis of Acceleration Data, Ship Structure Committee Report SSC-159, February 1964.

LIST OF FIGURES

Dot-Plots of Stress vs. Beaufort Sea State

AVERAGE PLOTS OF STRESS VS. BEAUFORT SEA STATE

WOLVERINE STATE WAVE PLOTS

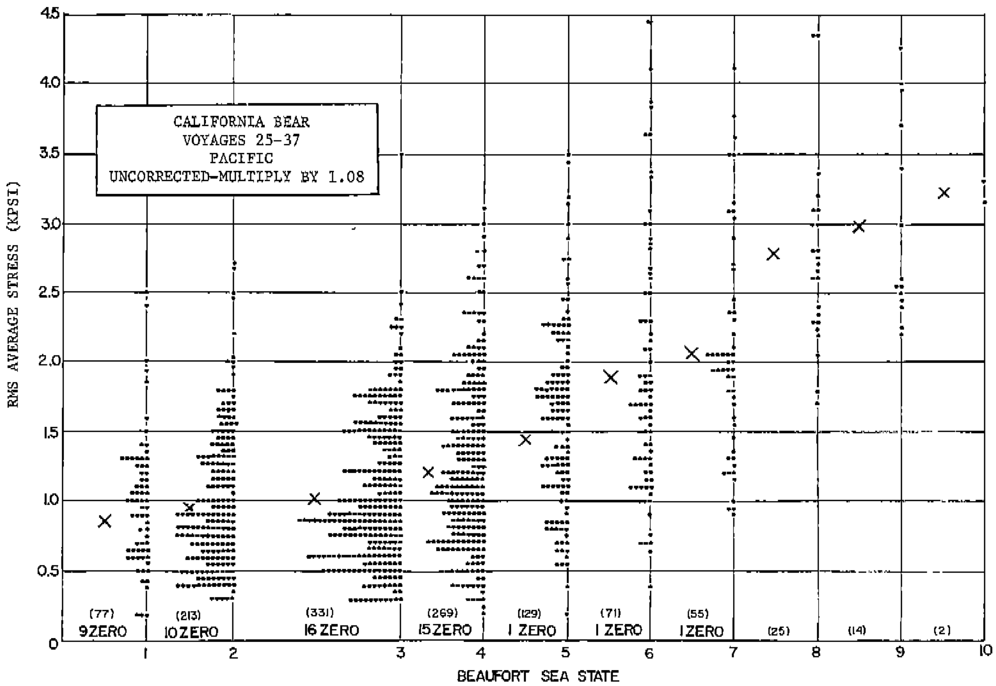

Fig. 1. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *California Bear*, Pacific, Voyages 25-37

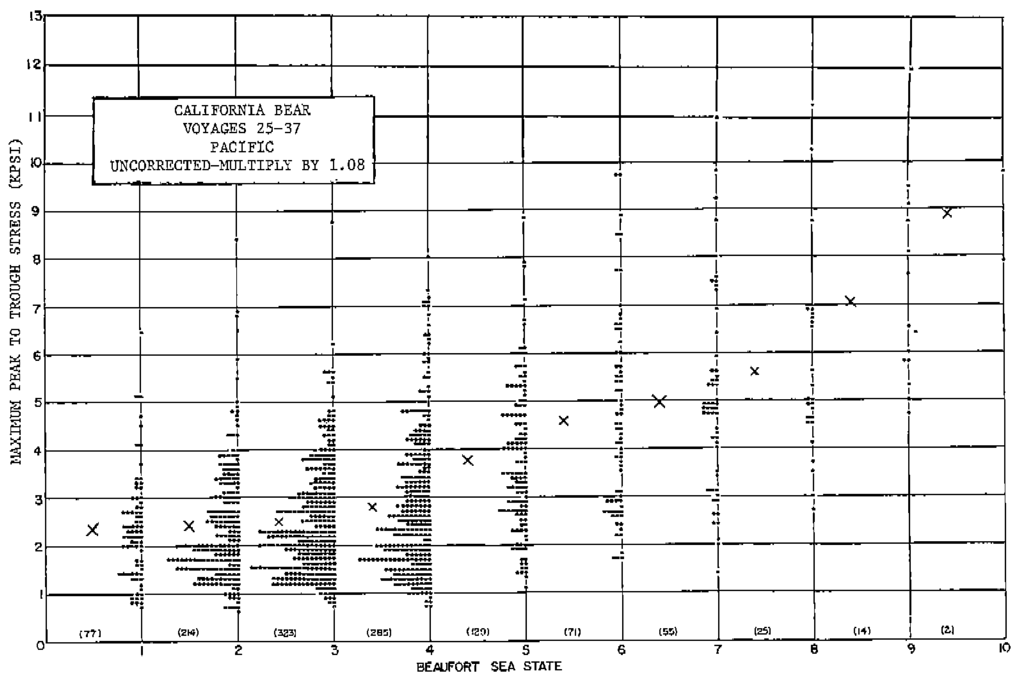

Fig. 2. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *California Bear*, Pacific, Voyages 25-37

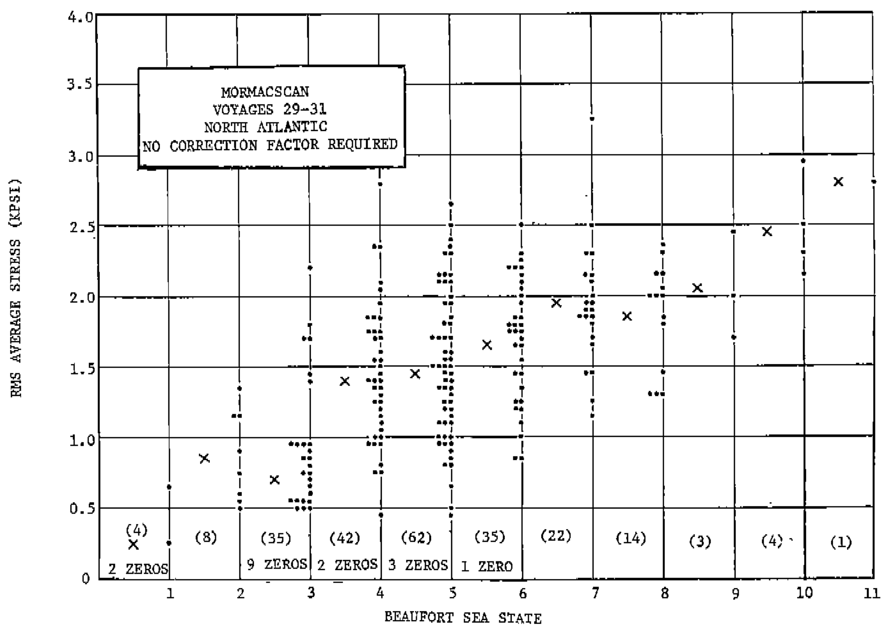

Fig. 3. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Mormacscan,* North Atlantic, Voyages 29-31

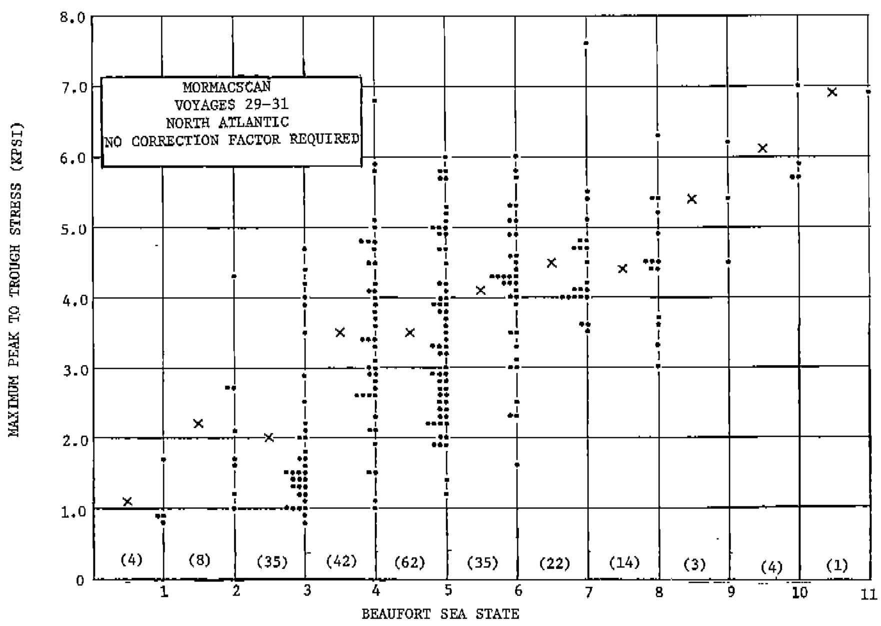

Fig. 4. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Mormacscan,* North Atlantic, Voyages 29-31

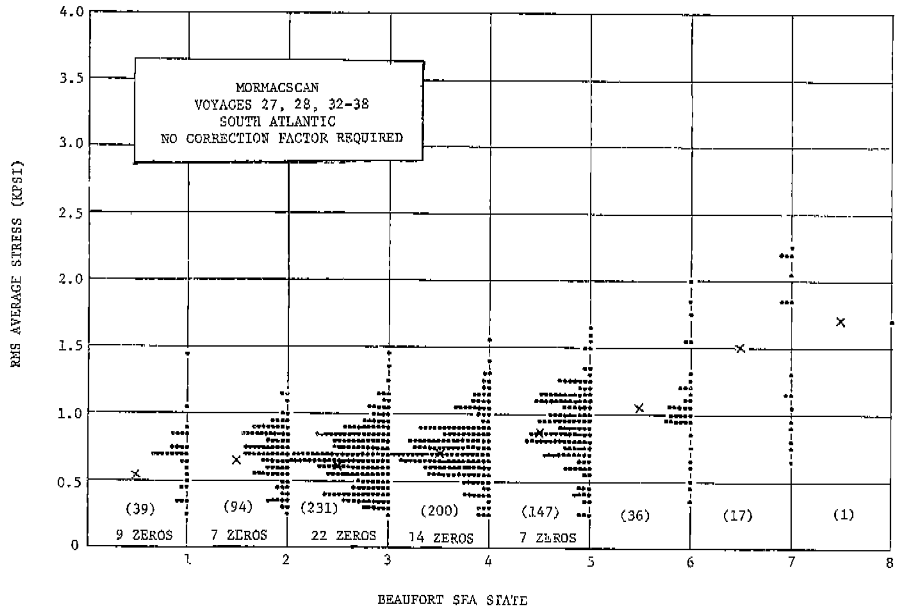

Fig. 5. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Mormacscan*, South Atlantic, Voyages 27, 28, 32-38

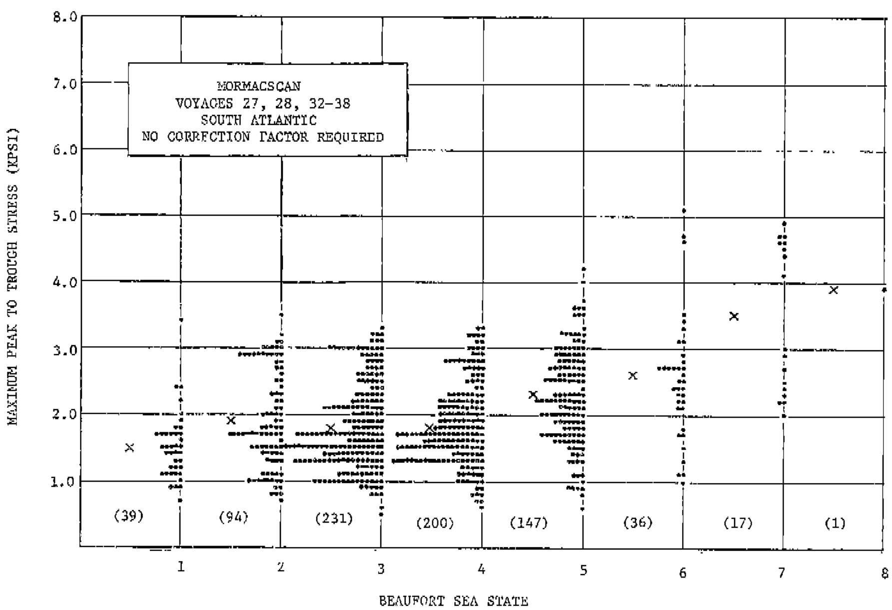

Fig. 6. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State *Mormacscan*, South Atlantic, Voyages, 27, 28, 32-38

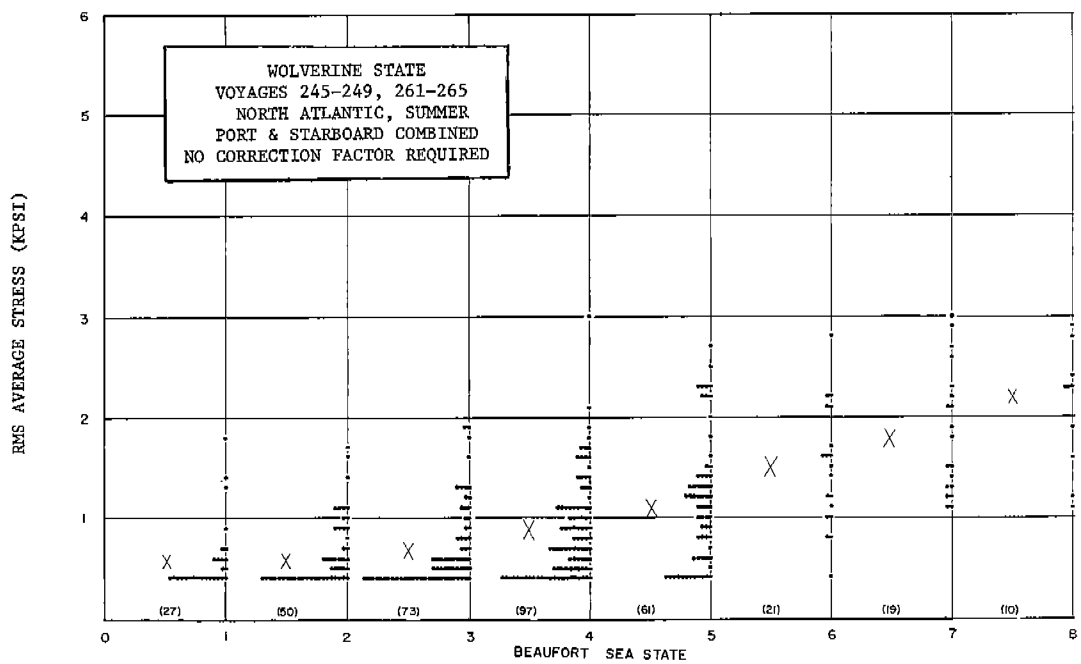

Fig. 7. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, Port & Starboard Combined, Voyages 245-249, 261-265

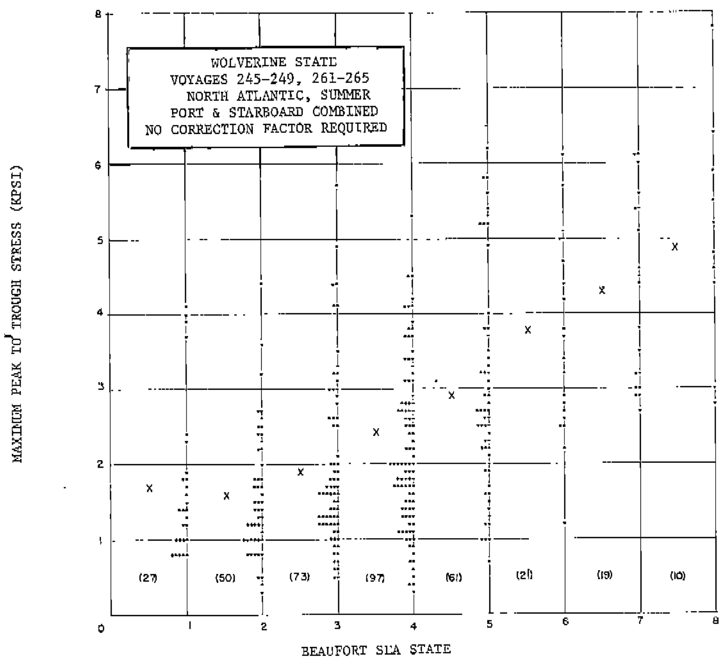

Fig. 8. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic Summer, Port & Starboard Combined, Voyages 245-249, 261-265.

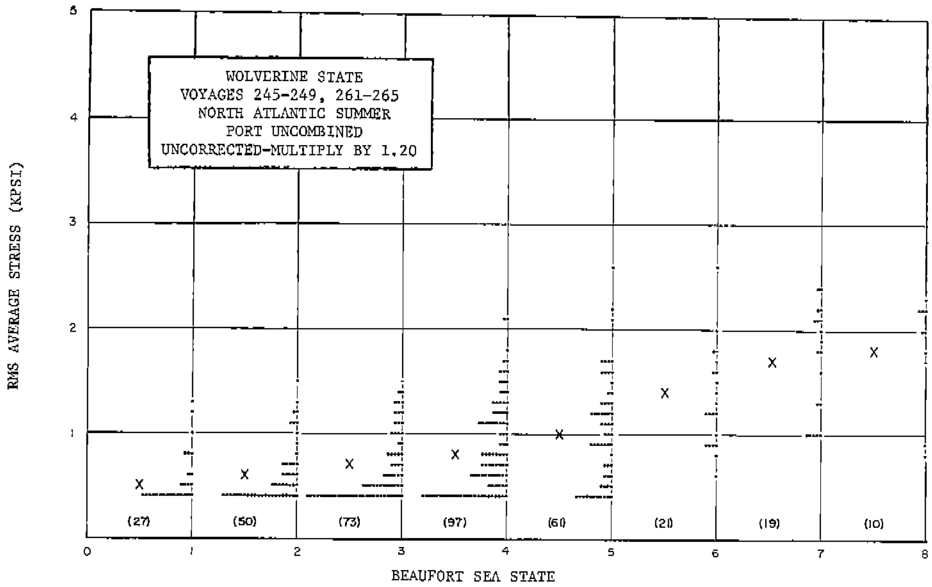

Fig. 9. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, Port Uncombined, Voyages, 245-249, 261-265

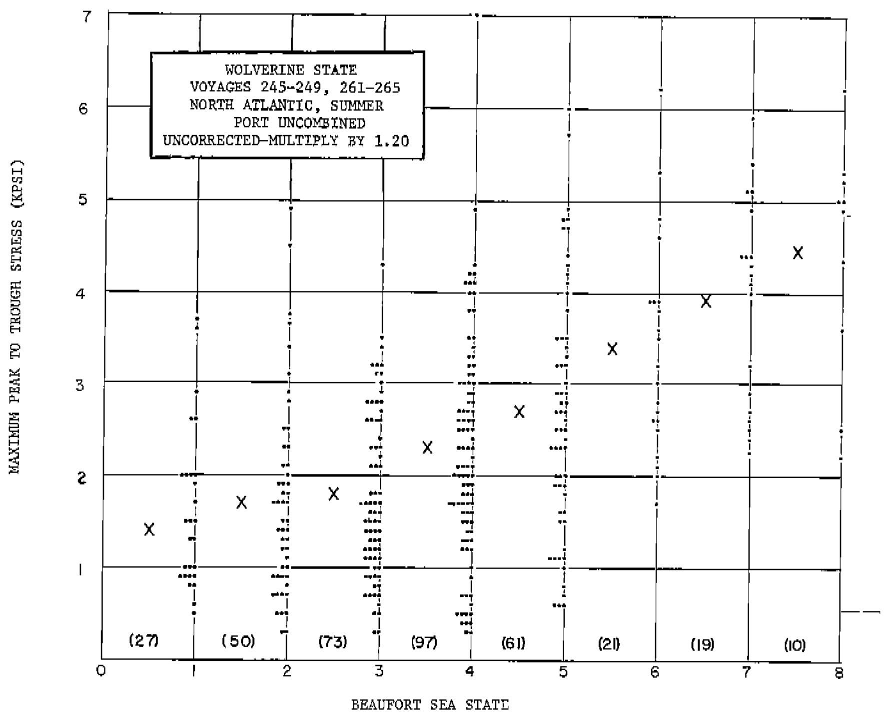

Fig. 10. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, Port Uncombined, Voyages 245-249, 261-265

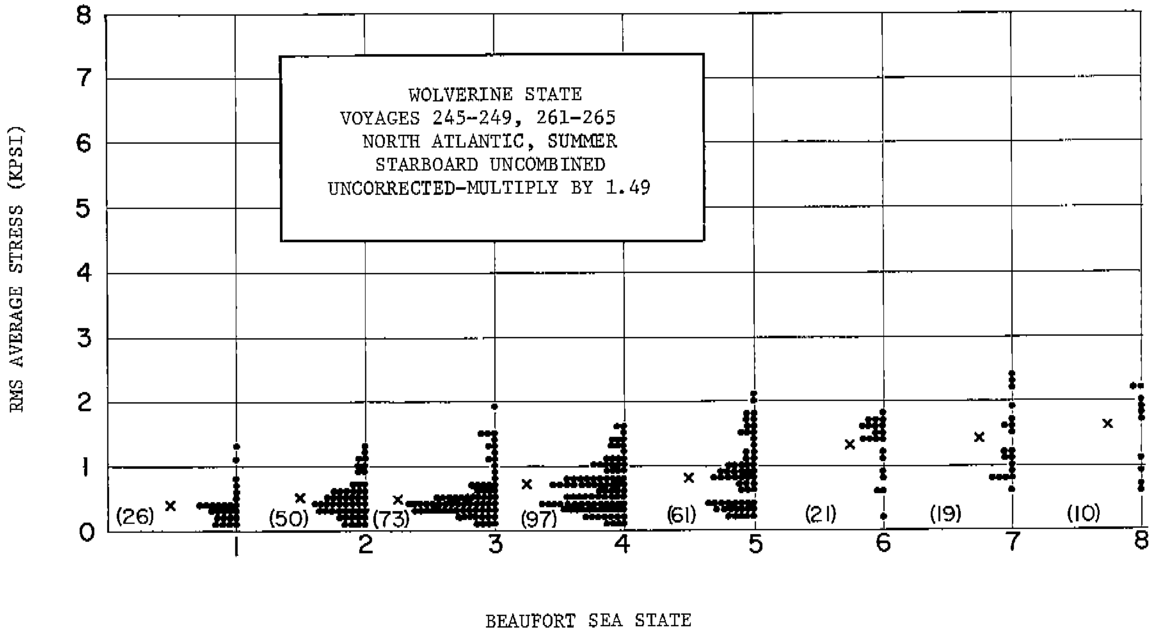

Fig. 11. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, Starboard Uncombined, Voyages 245-249, 261-265

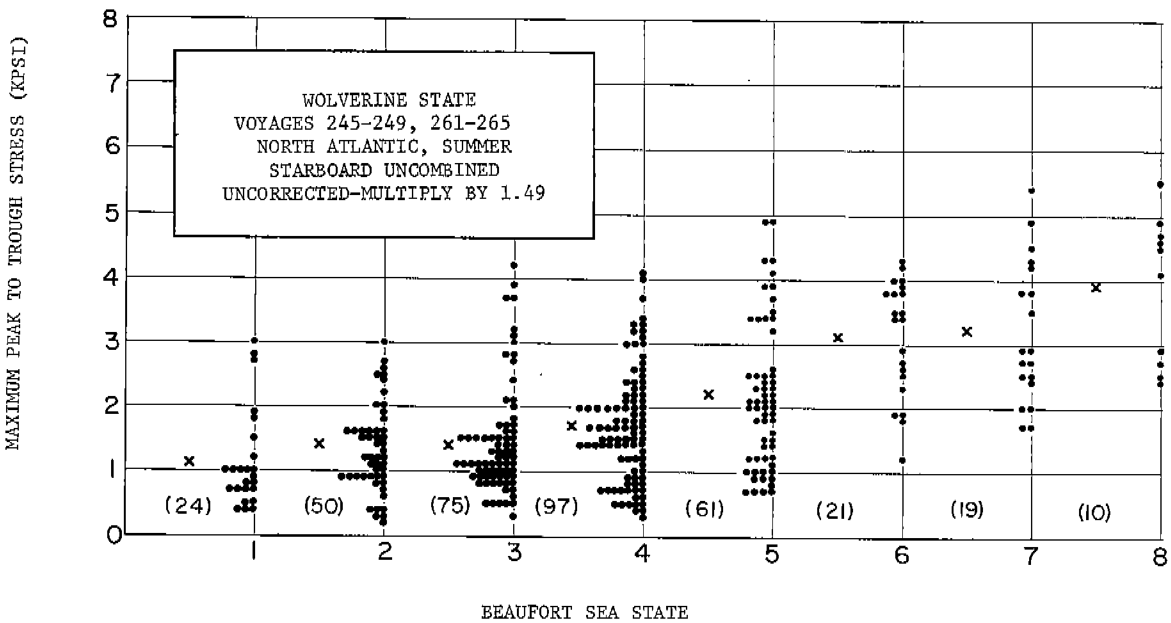

Fig. 12. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, Starboard Uncombined, Voyages 245-249, 261-265

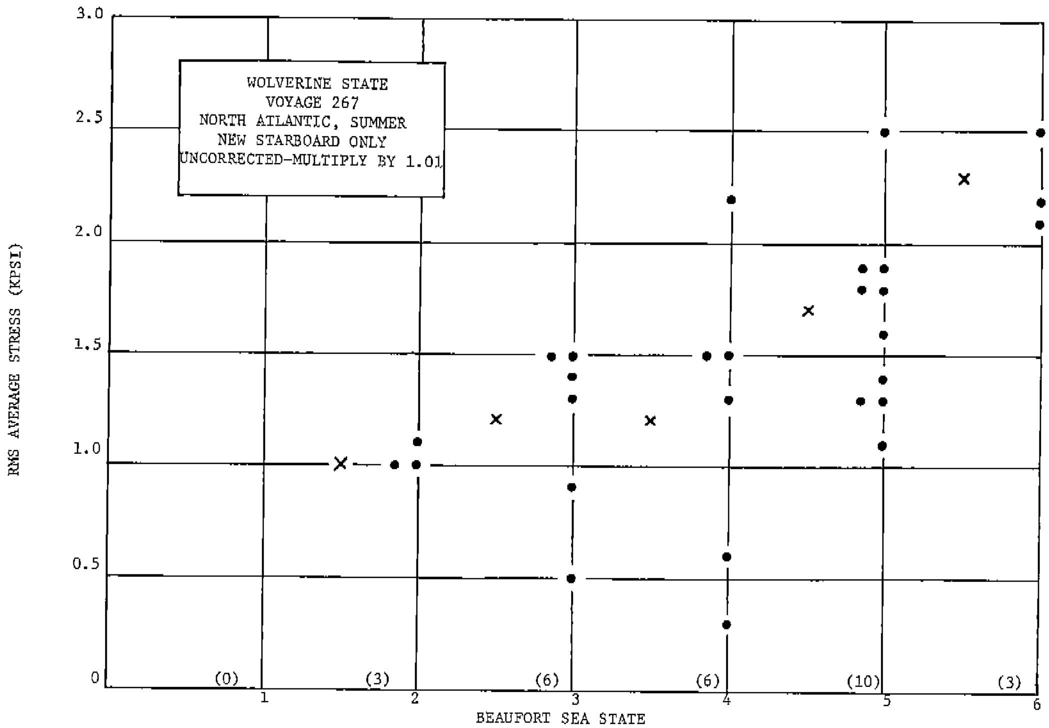

Fig. 13. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, New Starboard Only, Voyage 267

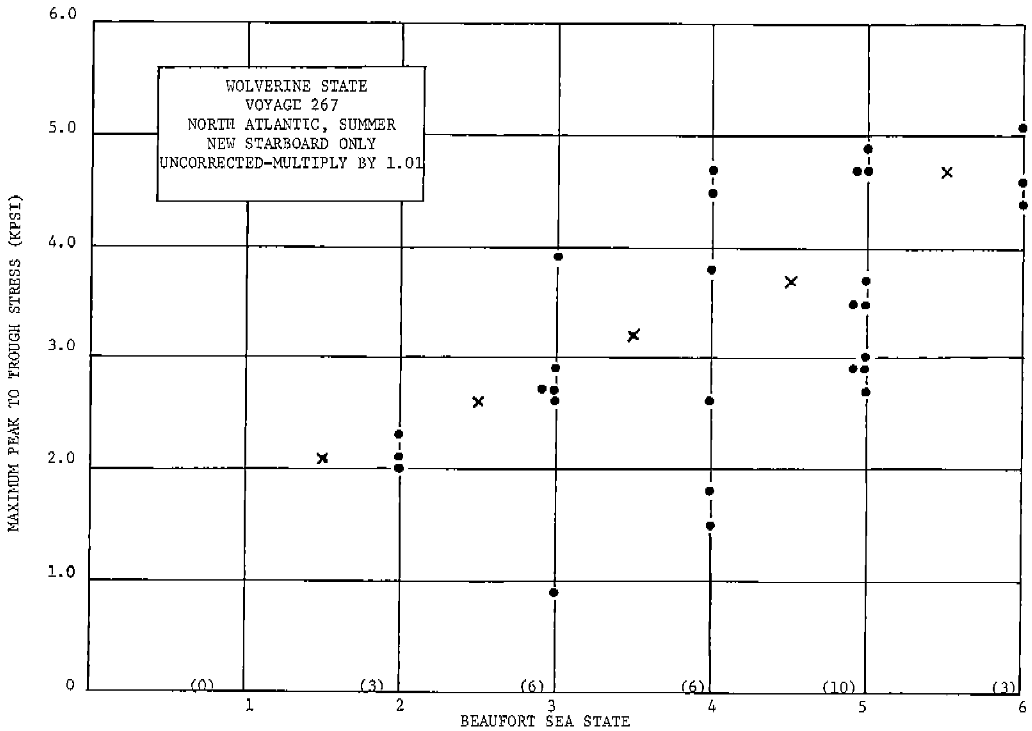

Fig. 14. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer, New Starboard Only, Voyage 267

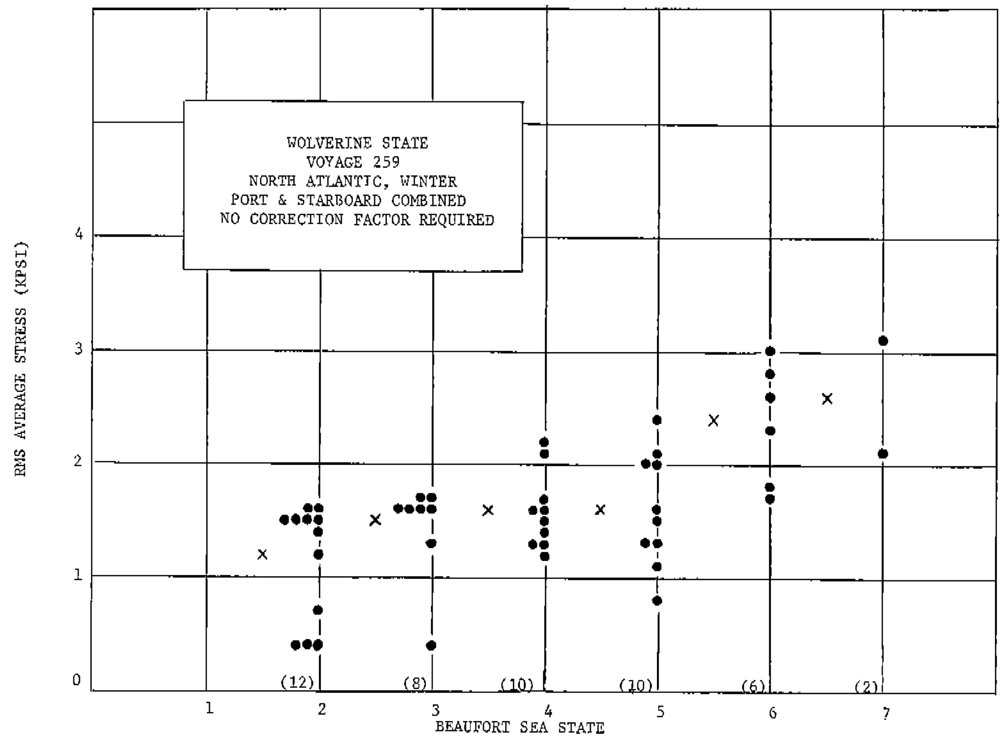

Fig. 15. Dot Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Atlantic, Winter, Port & Starboard Combined, Voyage 259

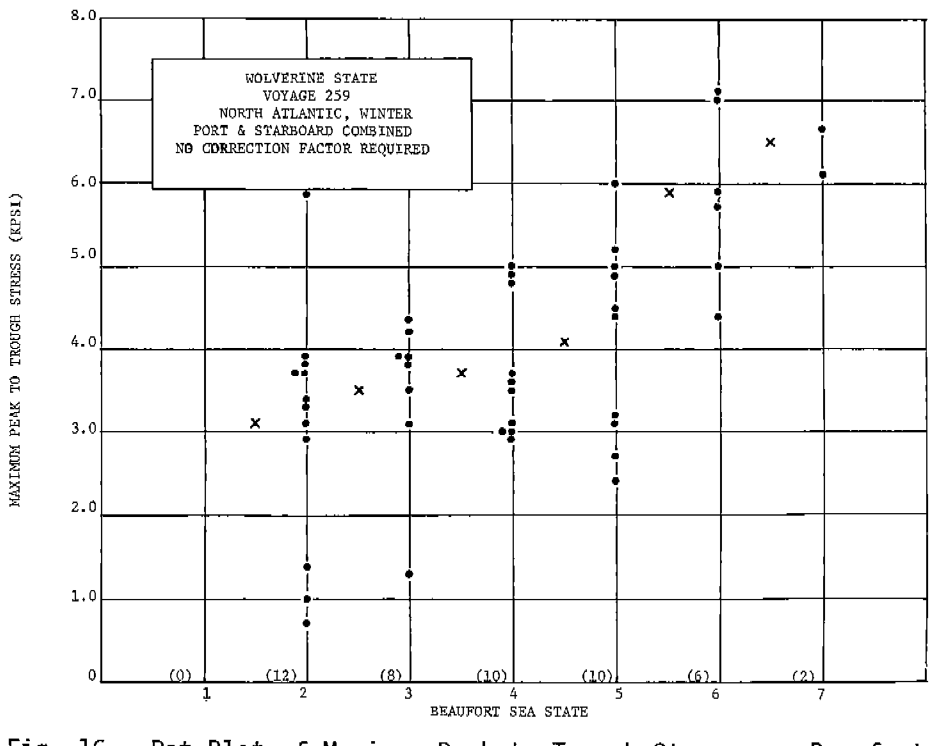

Fig. 16. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Winter, Port & Starboard Combined, Voyage 259

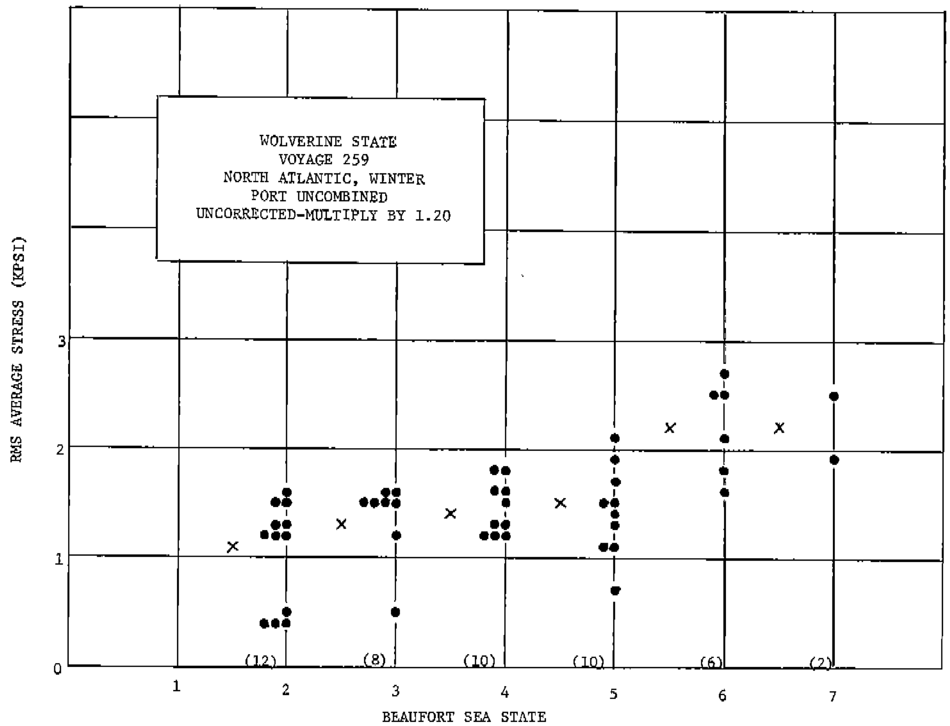

Fig. 17. Dot Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Atlantic, Winter, Port Uncombined, Voyages 259

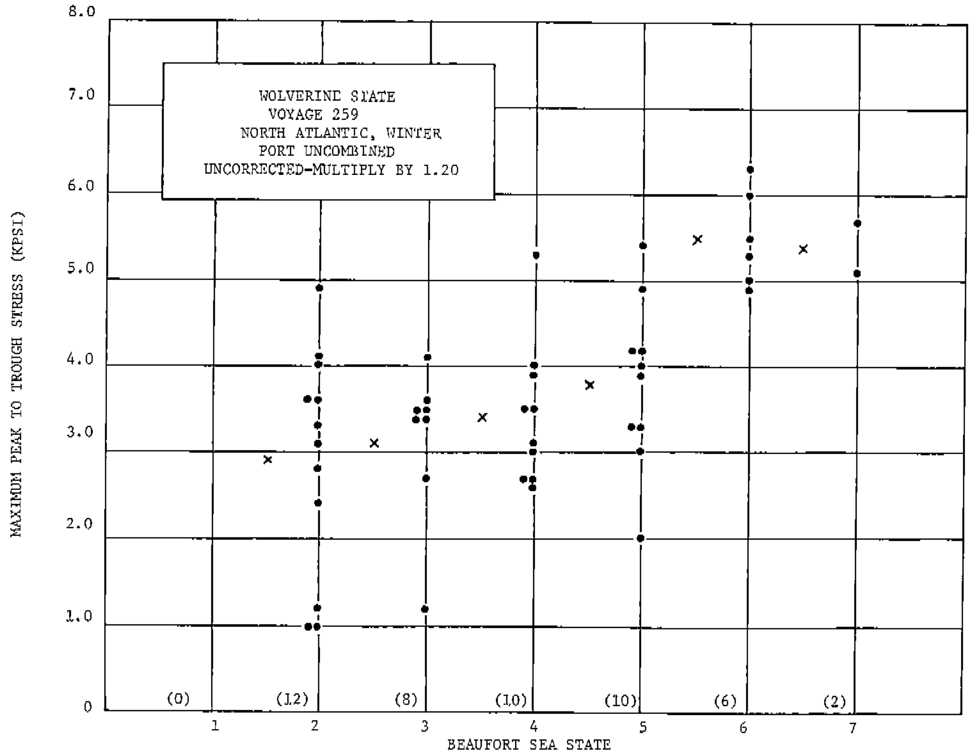

Fig. 18. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Winter, Port Uncombined, Voyage 259

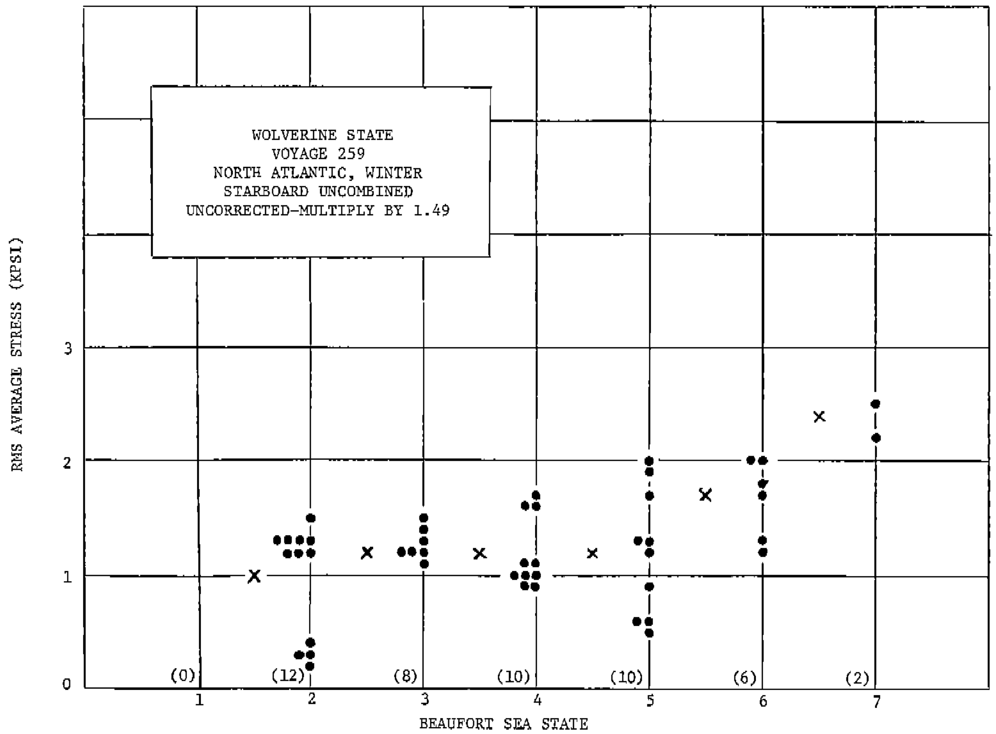

Fig. 19. Dot Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Atlantic, Winter, Starboard Uncombined, Voyage 259

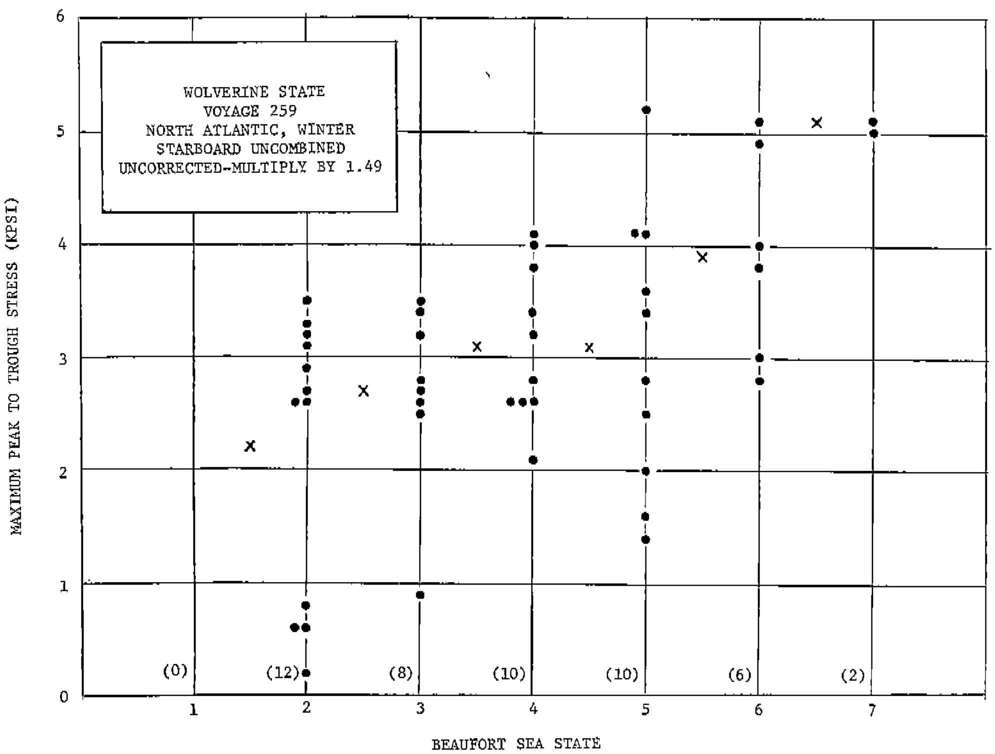

Fig. 20. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Winter, Starboard Uncombined, Voyage 259.

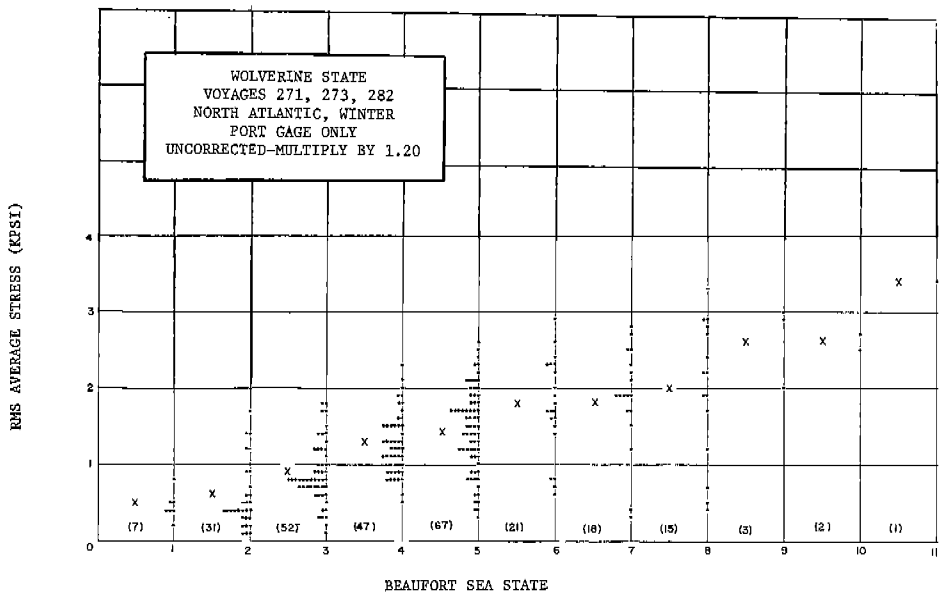

Fig. 21. Dot Plot of RMS Average Stress vs. Beaufort Sea State *Wolverine State*, Atlantic, Winter, Port Only, Voyages 271,273, 282.

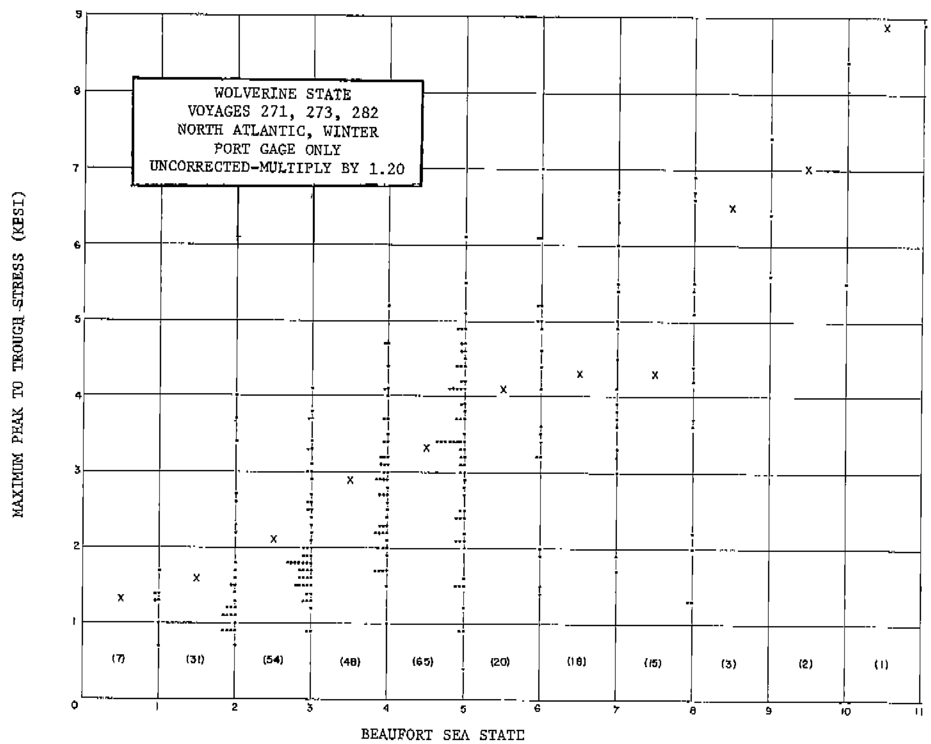

Fig. 22. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Winter, Port Only, Voyages 271, 273, 282

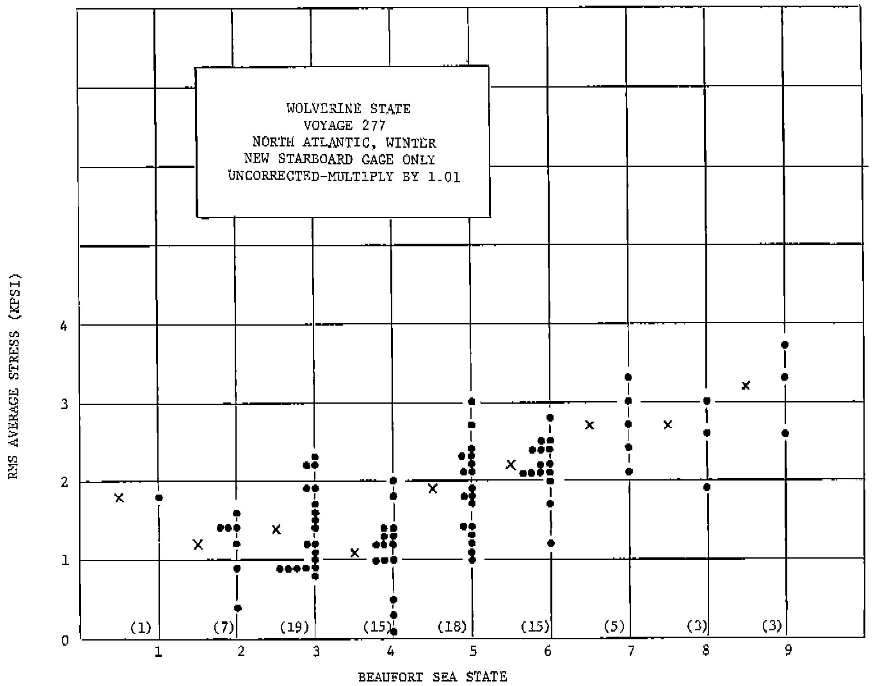

Fig. 23. Dot Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Atlantic, Winter, New Starboard Only, Voyage 277

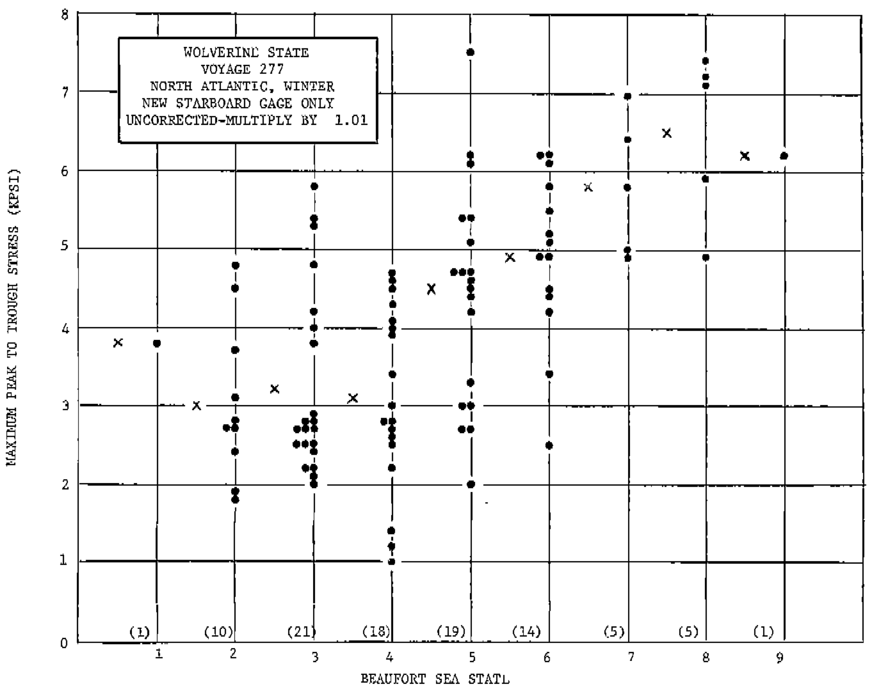

Fig. 24. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Winter, New Starboard Only, Voyage 277

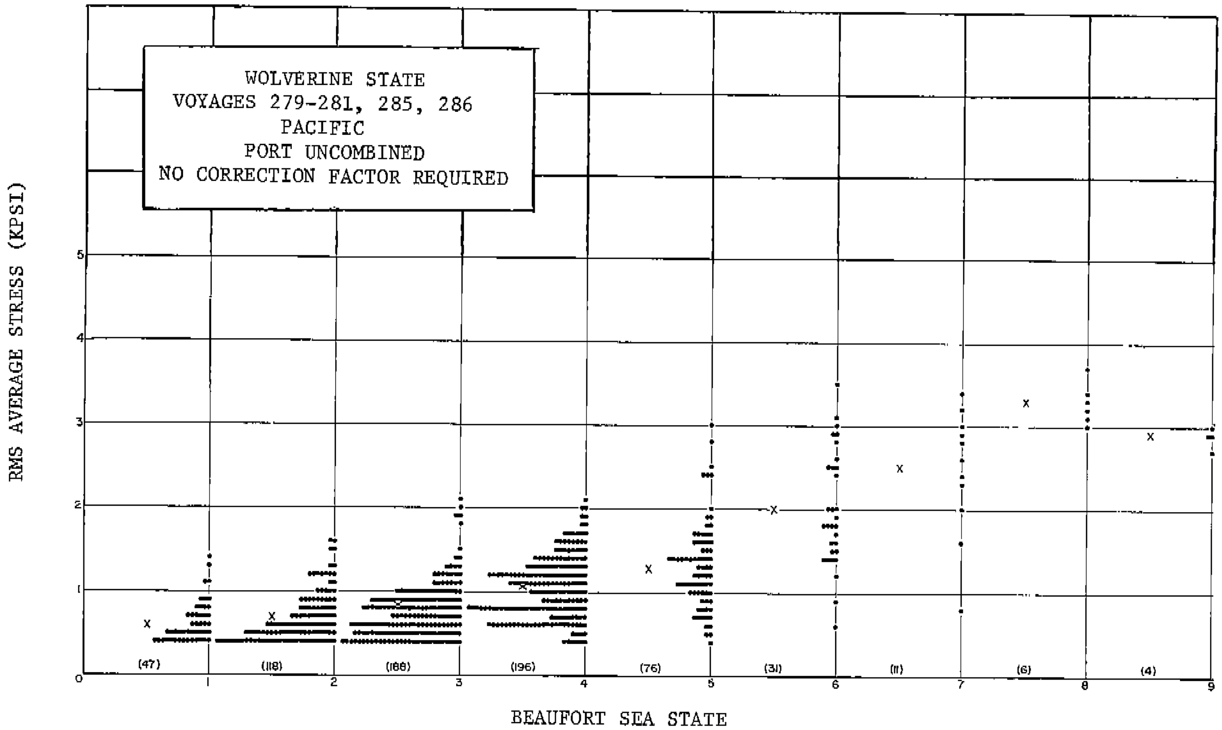

Fig. 25. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State* Pacific, Port & Starboard Combined, Voyages 279-281, 285, 286

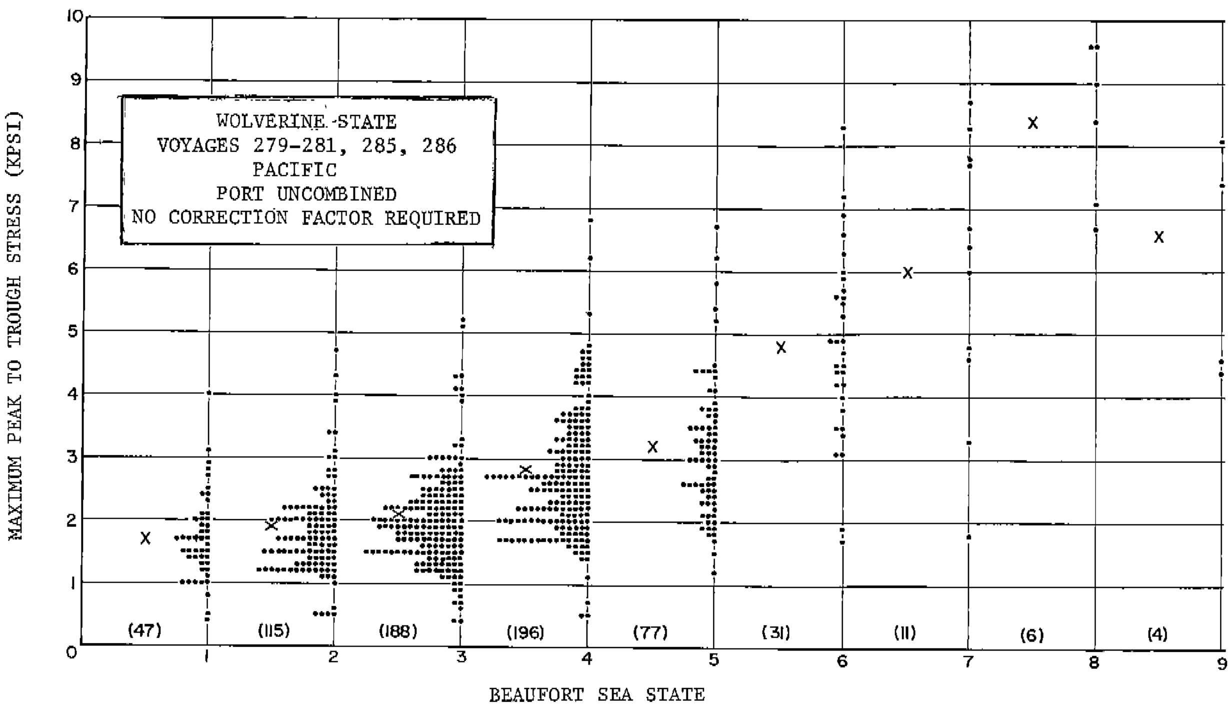

Fig. 26. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State *Wolverine State*, Pacific, Port & Starboard Combined, Voyages 279-281, 285, 286

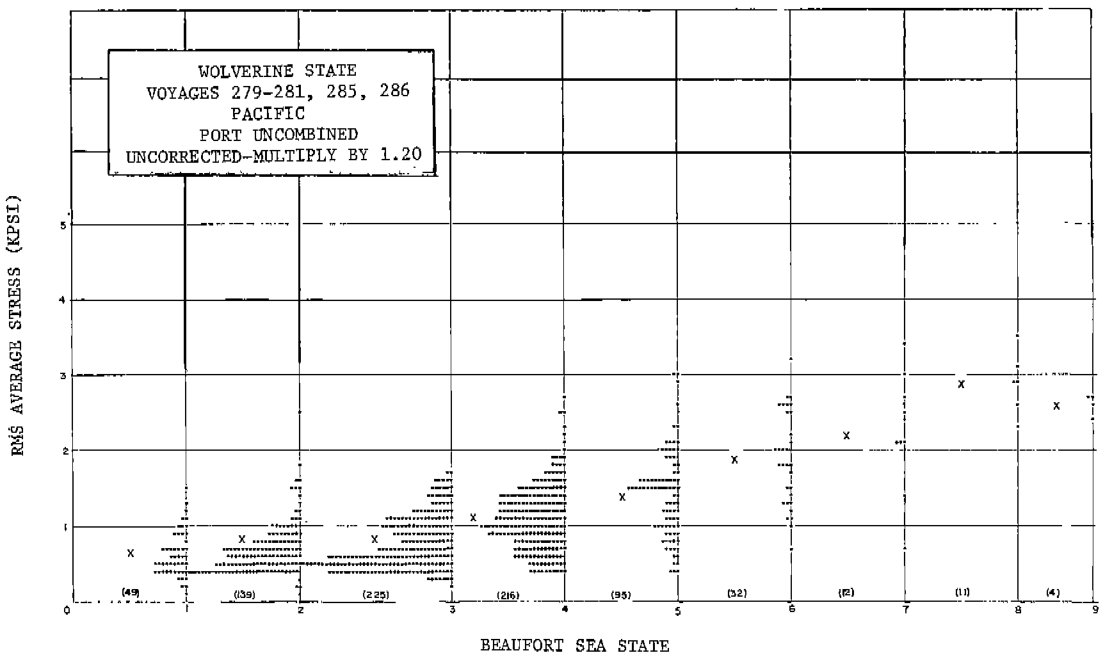

Fig. 27. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State*, Pacific, Port Uncombined, Voyages 279-281, 285, 286

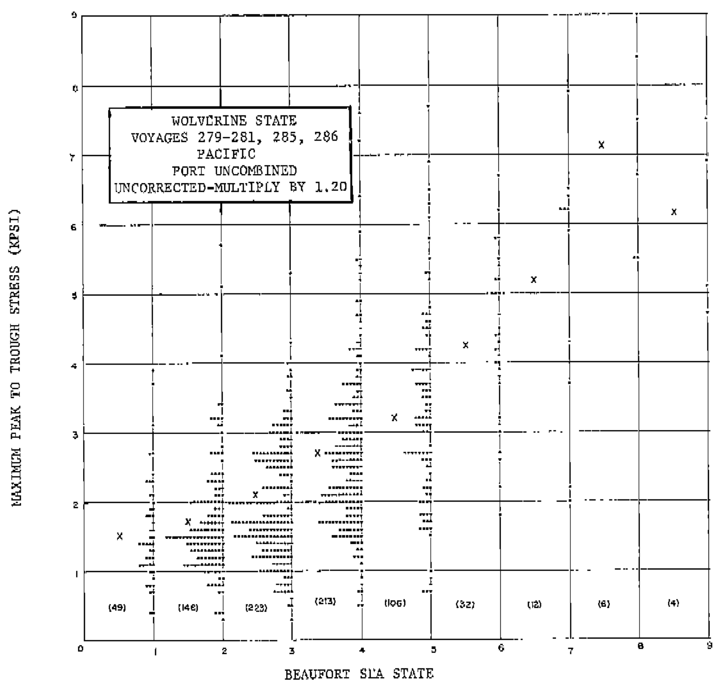

Fig. 28. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Pacific Uncombined, Voyages 279-281, 285, 286

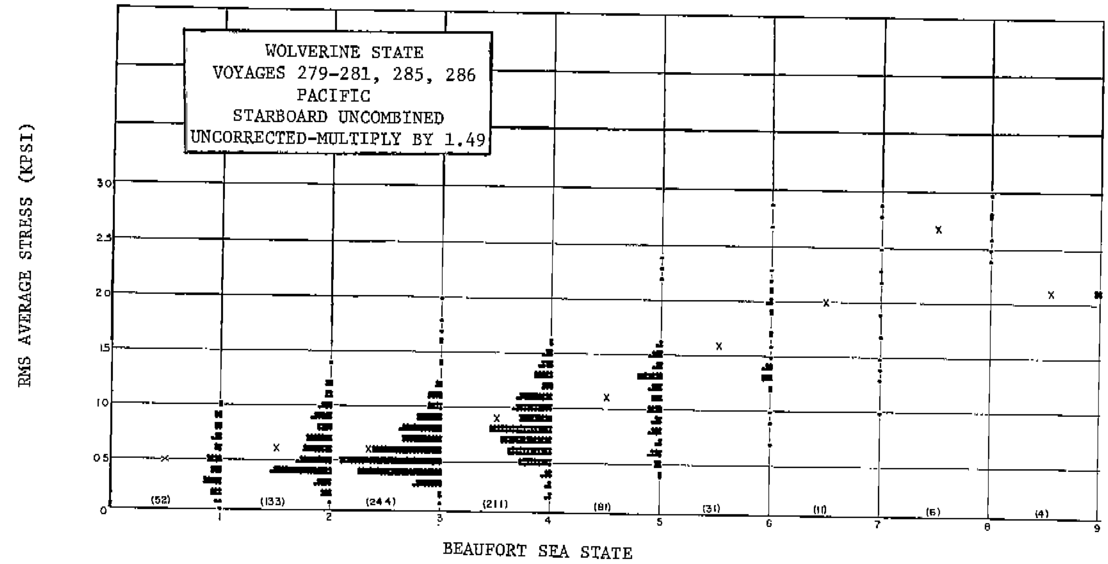

Fig. 29. Dot Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State* Pacific, Starboard Uncombined, Voyages 279-281, 285, 286

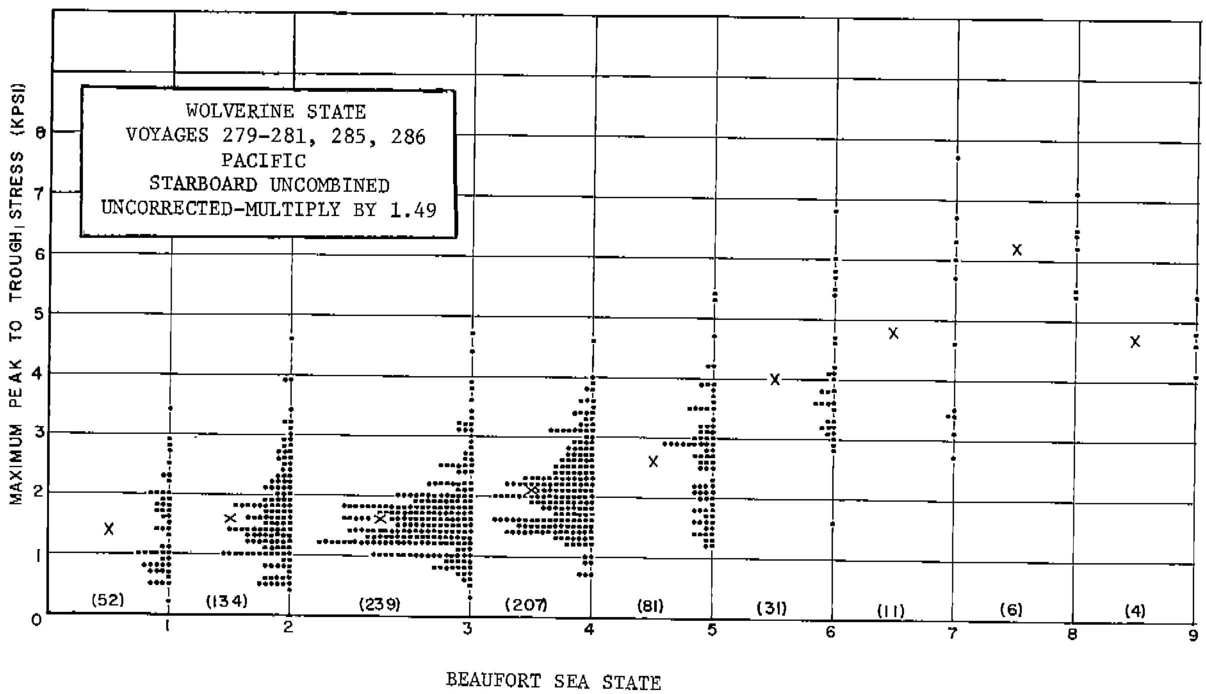

Fig. 30. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State *Wolverine State*, Pacific, Starboard Uncombined, Voyages, 279-281, 285 286

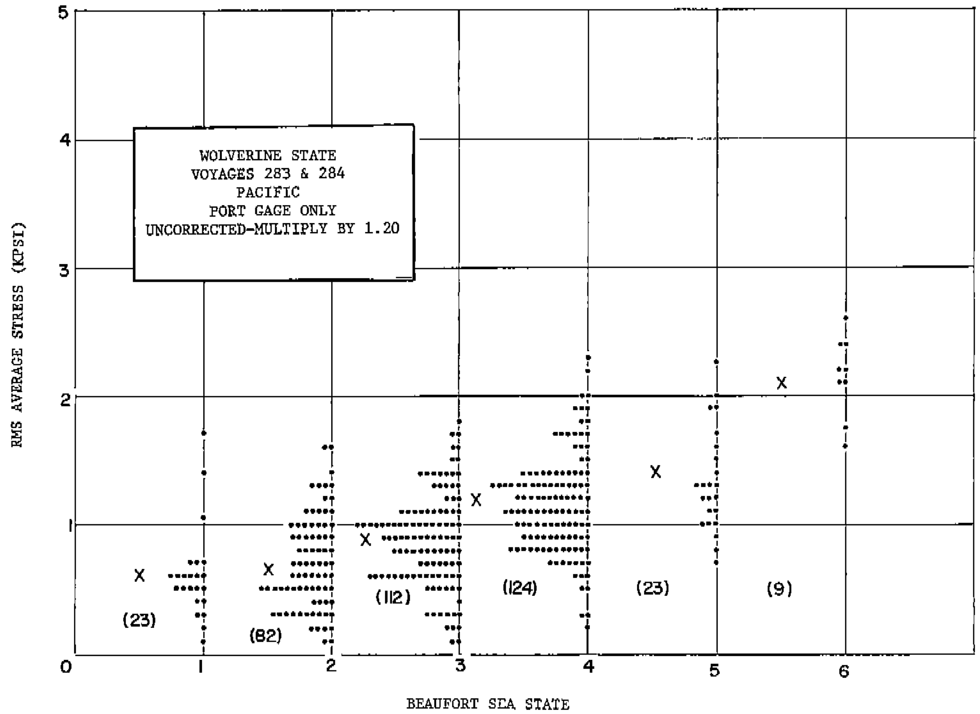

Fig. 31. Dot Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Pacific, Port Only, Voyages 283, 284

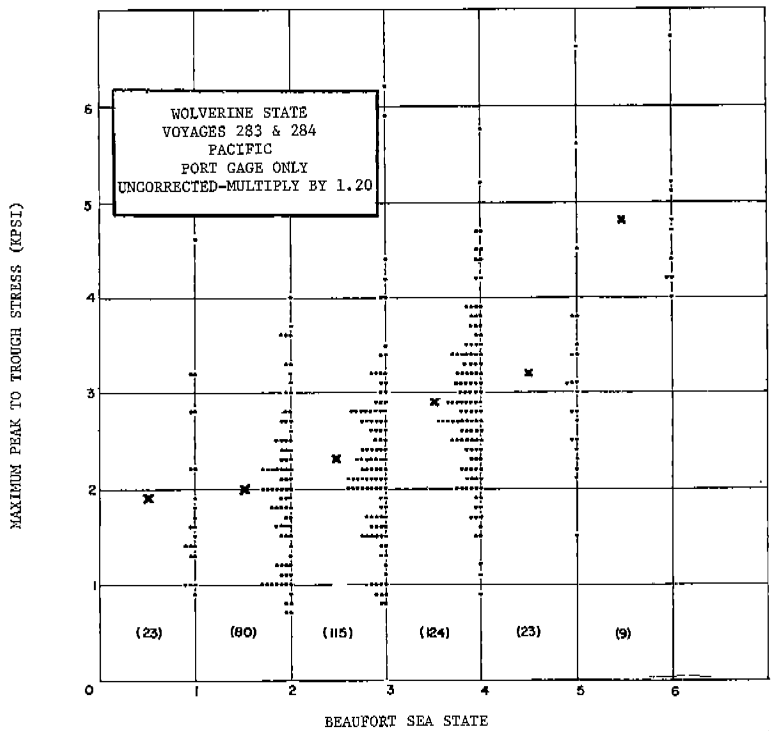

Fig. 32. Dot Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Pacific, Port Only, Voyages 283, 284

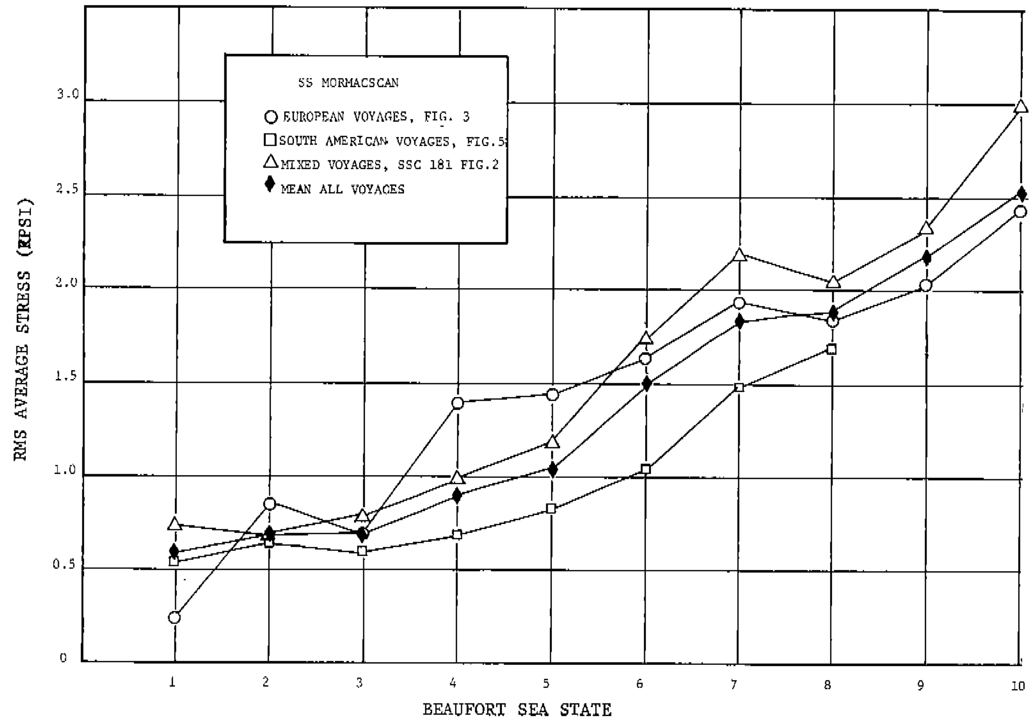

Fig. 33. Average Plot of RMS Average Stress vs, Beaufort Sea State *Mormacscan*

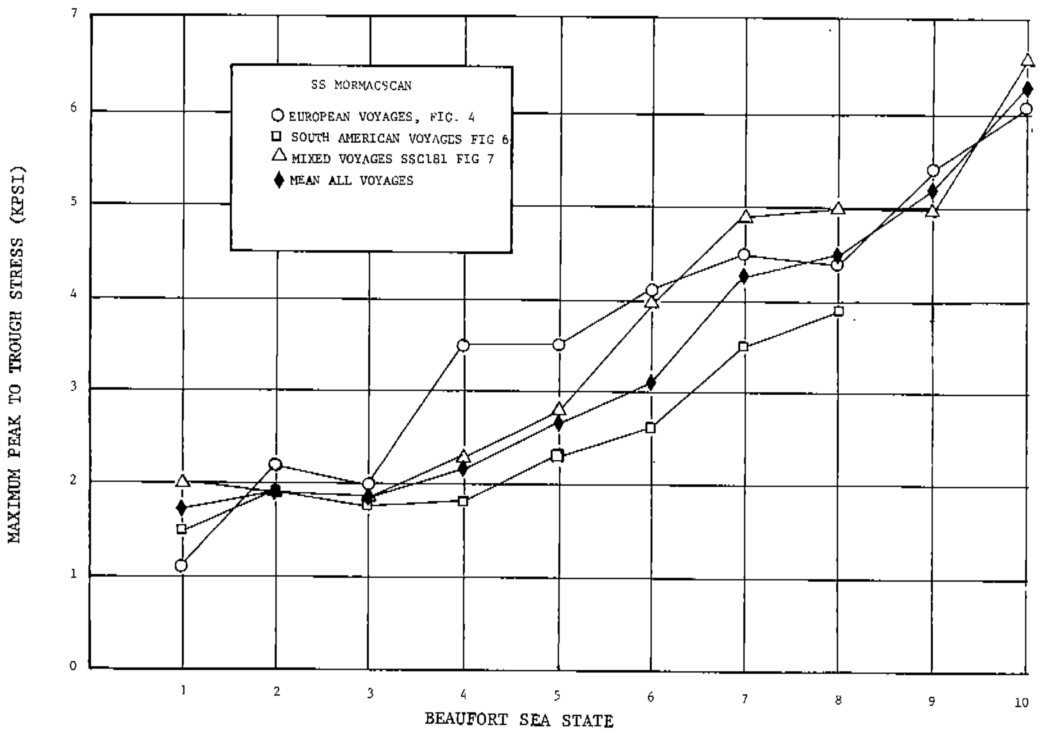

Fig. 34. Average Plot of Maximum Peak to Trough Stress vs,Beaufort Sea State, *Mormacscan*

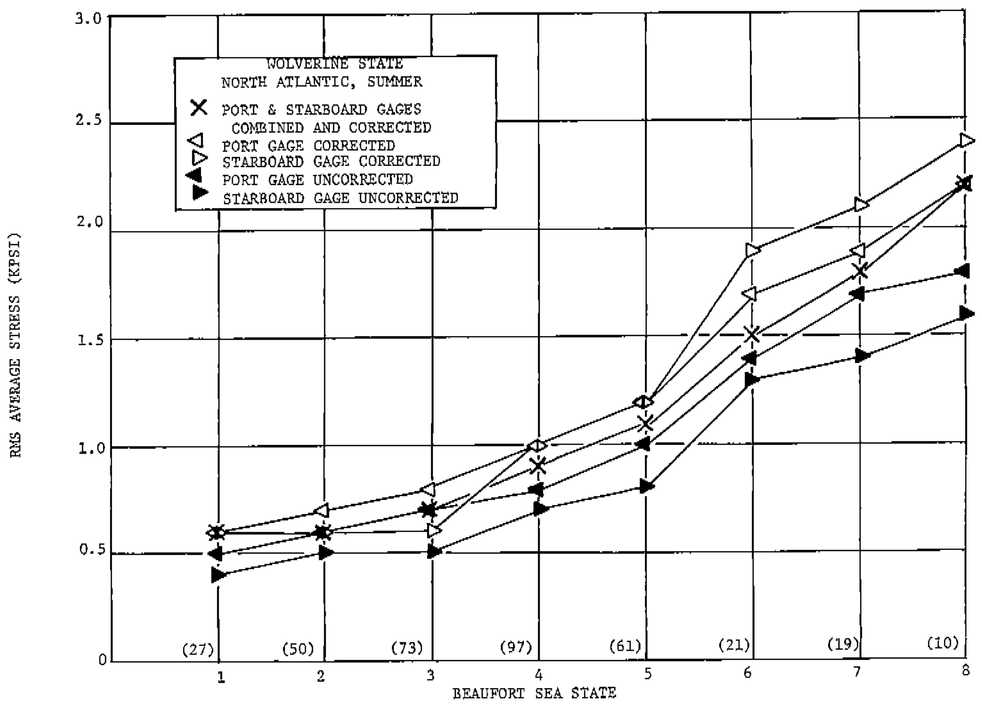

Fig. 35. Average Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Atlantic, Summer

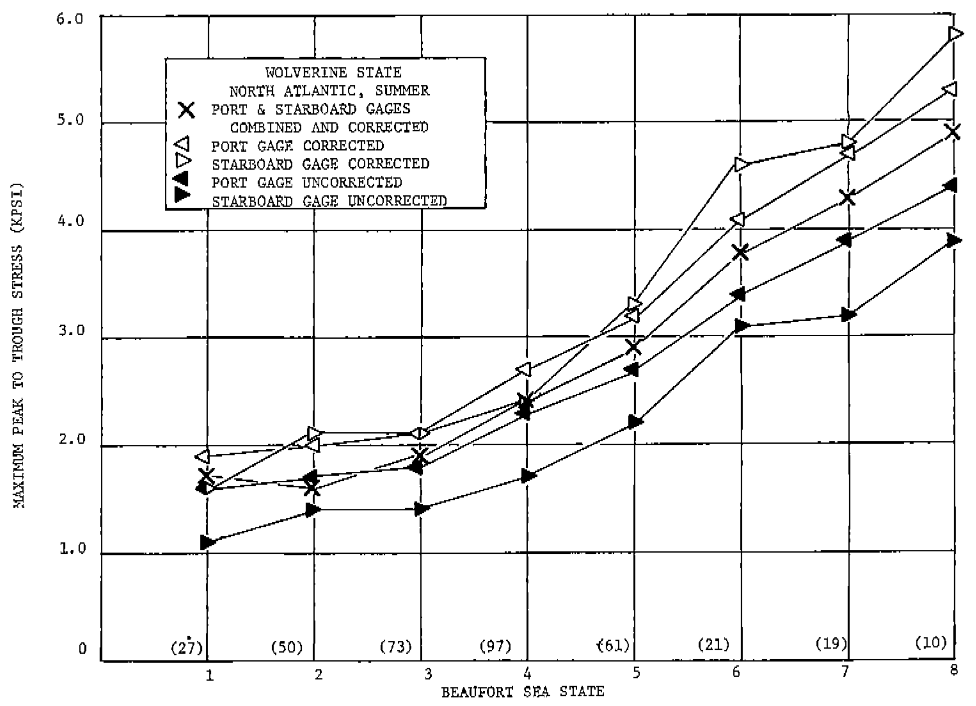

Fig. 36. Average Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Summer

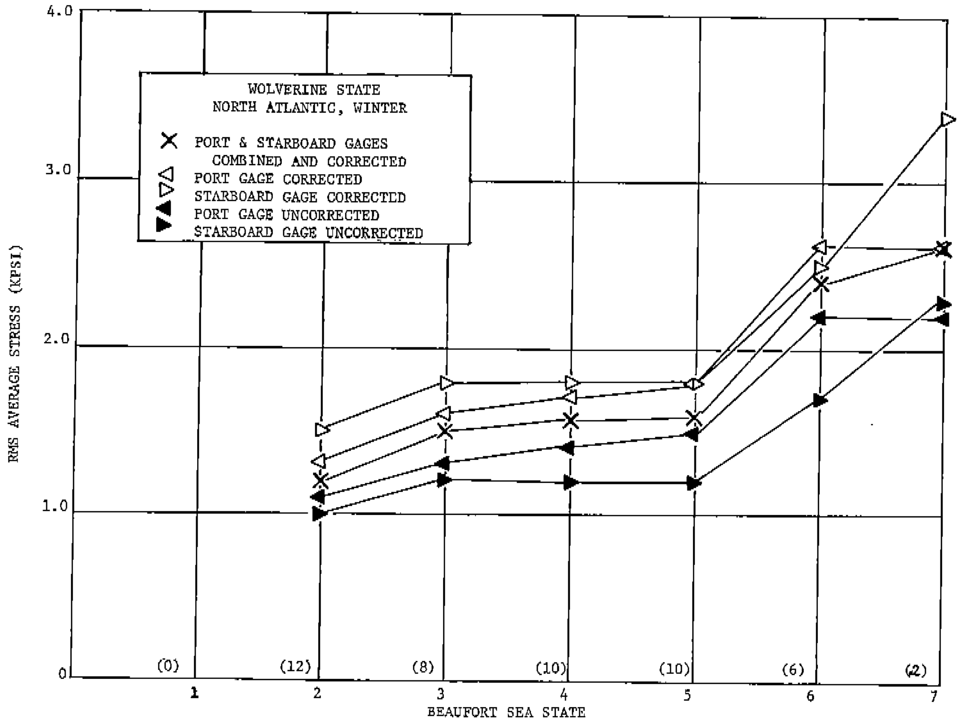

Fig. 37. Average Plot of RMS Stress vs, Beaufort Sea State *Wolverine State*, Atlantic, Winter

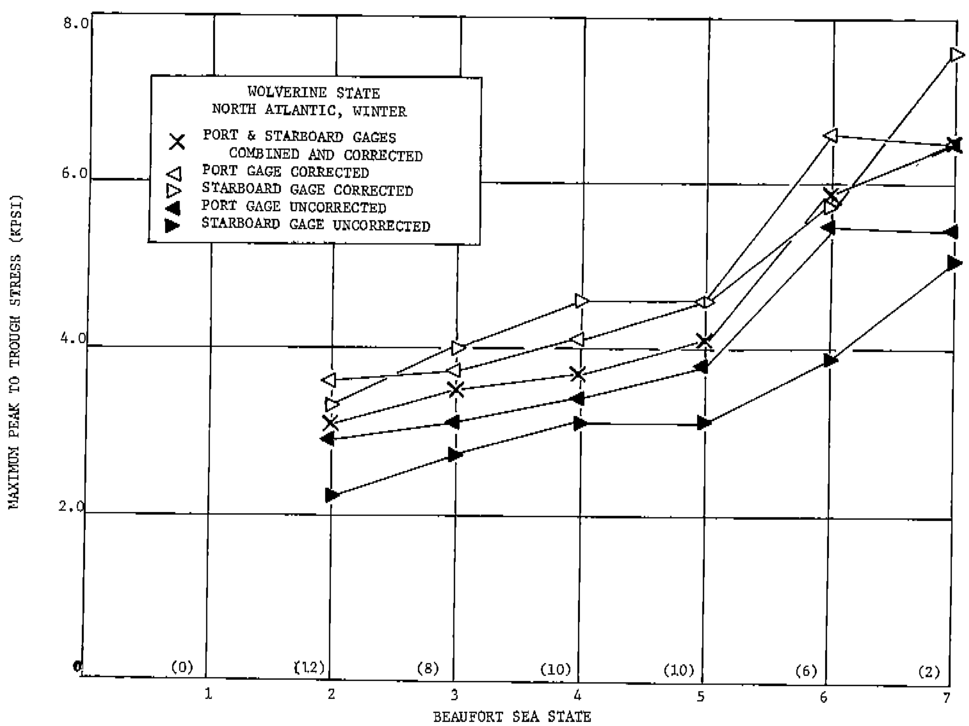

Fig. 38. Average Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Atlantic, Winter

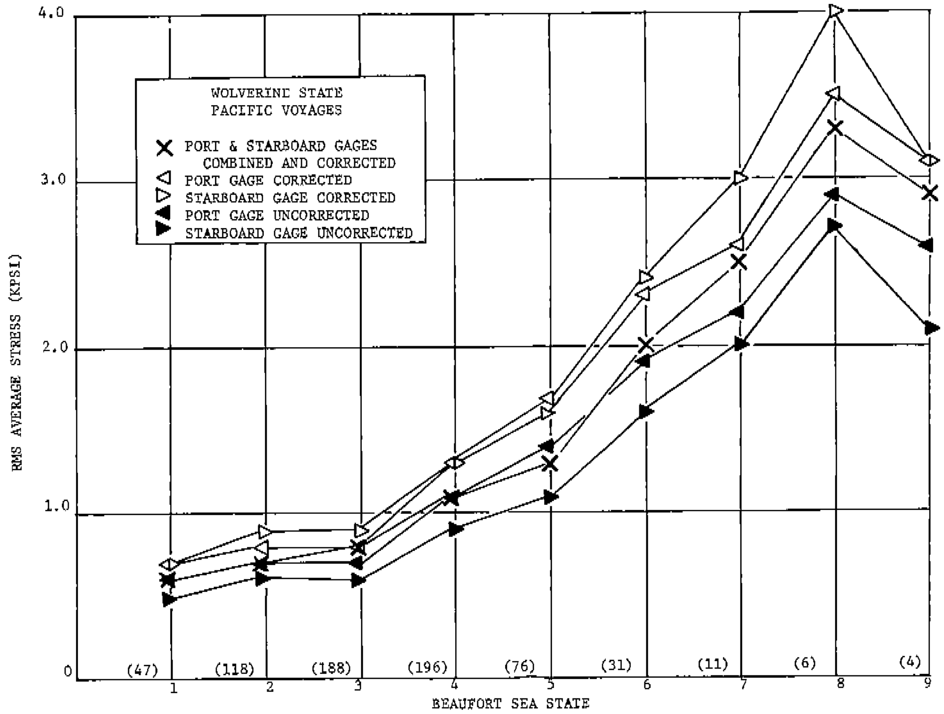

Fig. 39. Average Plot of RMS Average Stress vs, Beaufort Sea State *Wolverine State*, Pacific

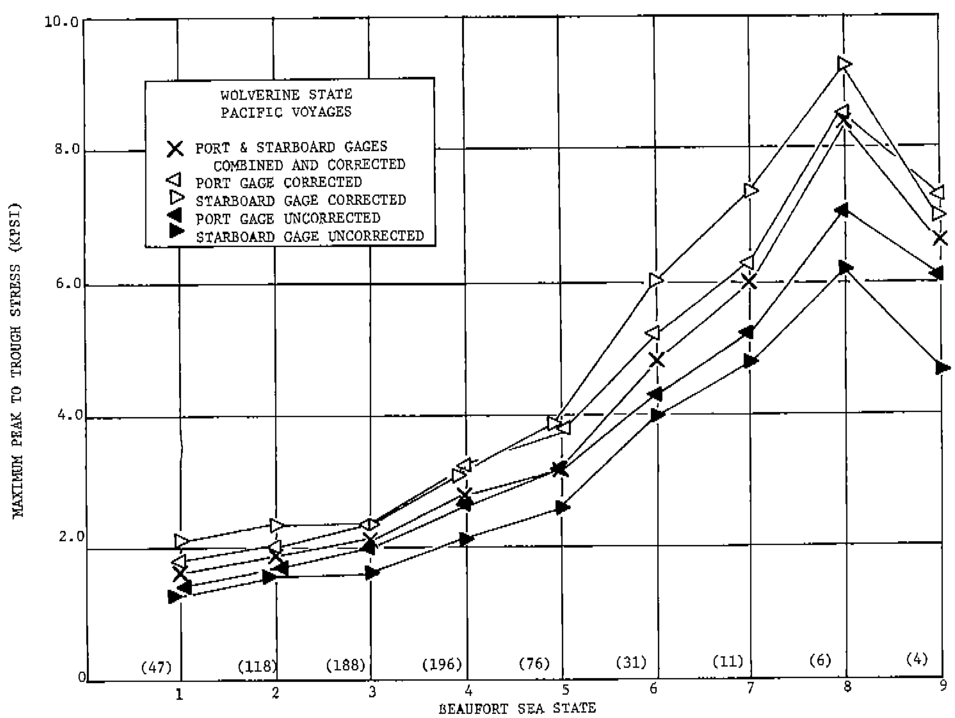

Fig. 40. Average Plot of Maximum Peak to Trough Stress vs, Beaufort Sea State, *Wolverine State*, Pacific

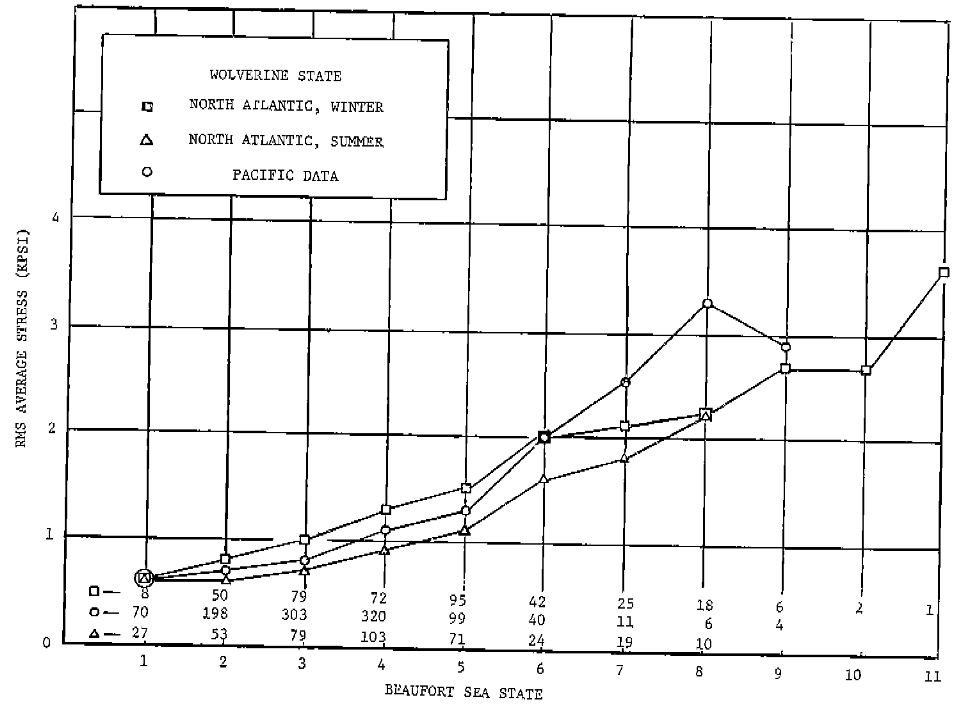

Fig. 41. Average Plot of RMS Average Stress vs, Beaufort Sea State, *Wolverine State*

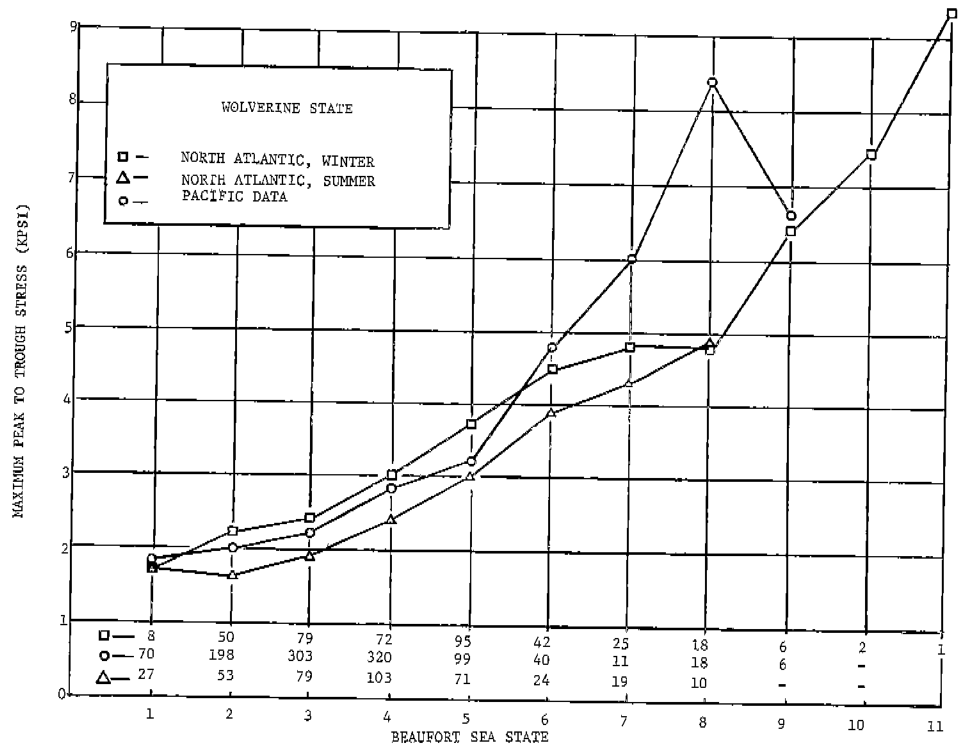

Fig. 42. Average Plot of Maximum Peak-to-Trough Stress vs, Beaufort Sea State, *Wolverine State*

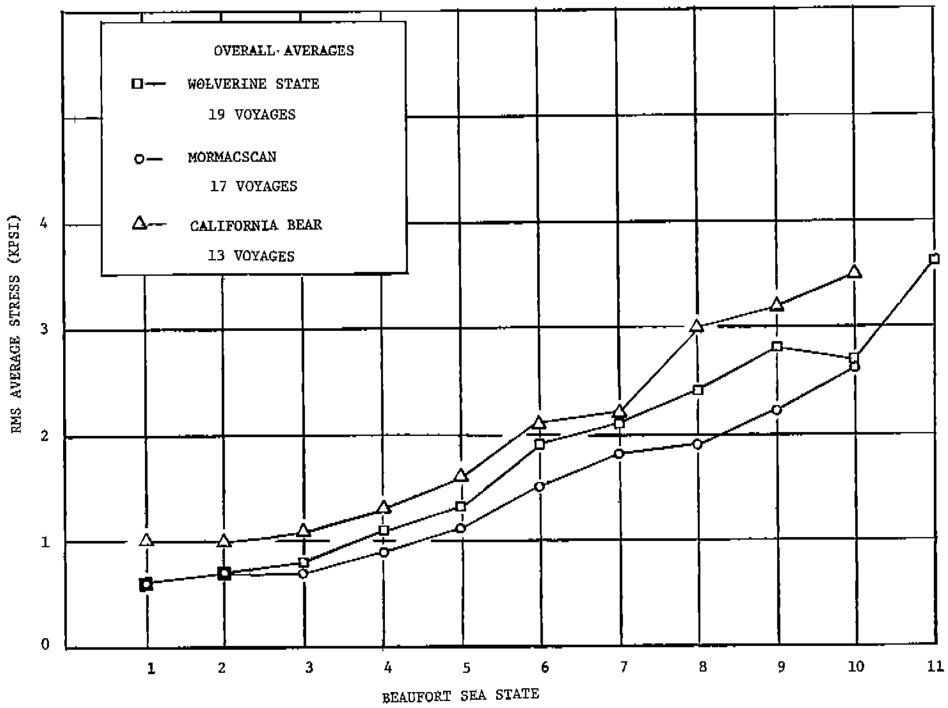

Fig. 43. Average Plot of RMS Average Stress vs, Beaufort Sea State *California Bear, Mormacscan, Wolverine State*

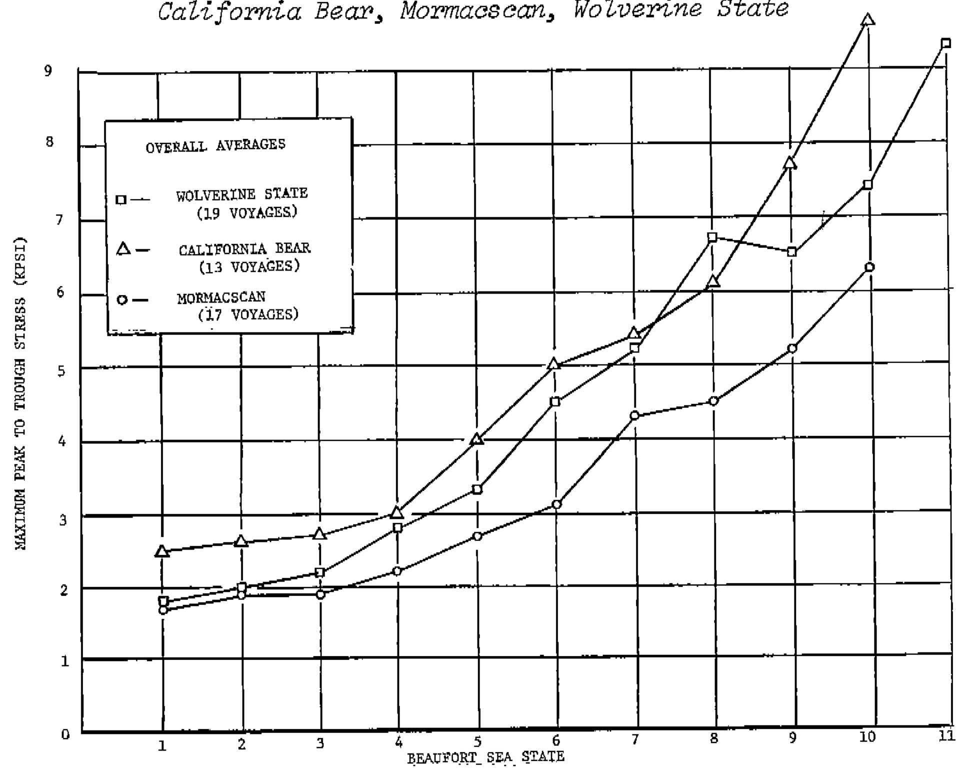

Fig. 44. Average Plot of Maximum Peak-to-Trough Stress vs, Beaufort Sea State, *California Bear, Mormacscan, Wolverine State*

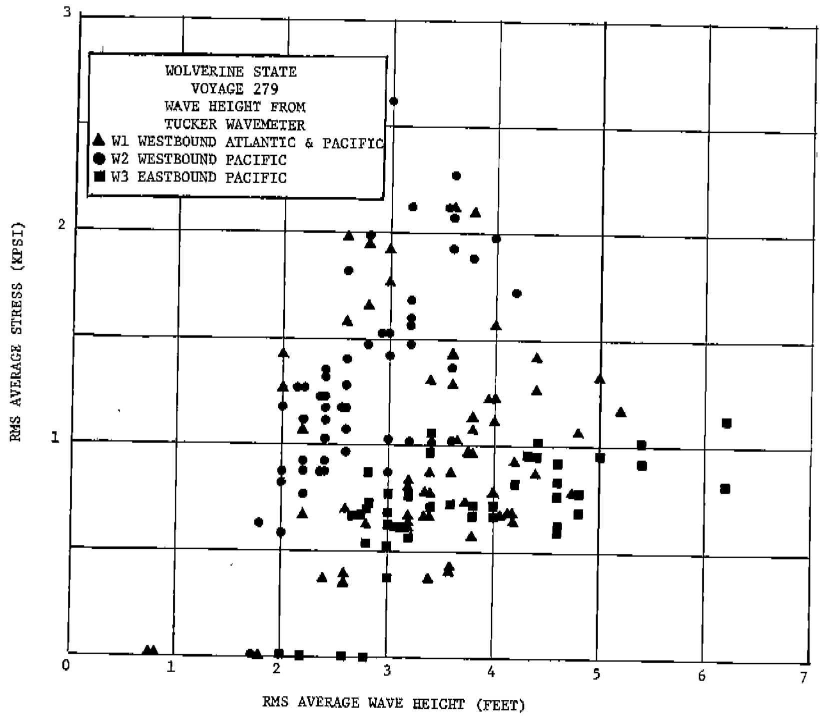

Fig. 45. Dot-Plot of RMS Average Stress vs. RMS Average Wave Height, *Wolverine State,* Voyage 279

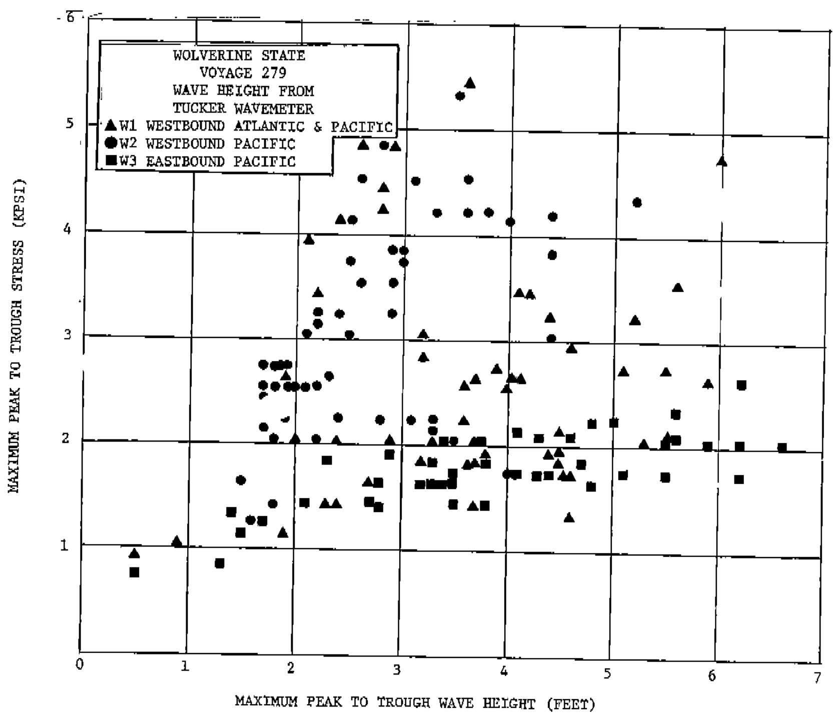

Fig. 46. Dot-Plot of Maximum Peak-to-Trough Stress vs. Maximum Peak-to-Trough Wave Height, *Wolverine State,* Voyage 279

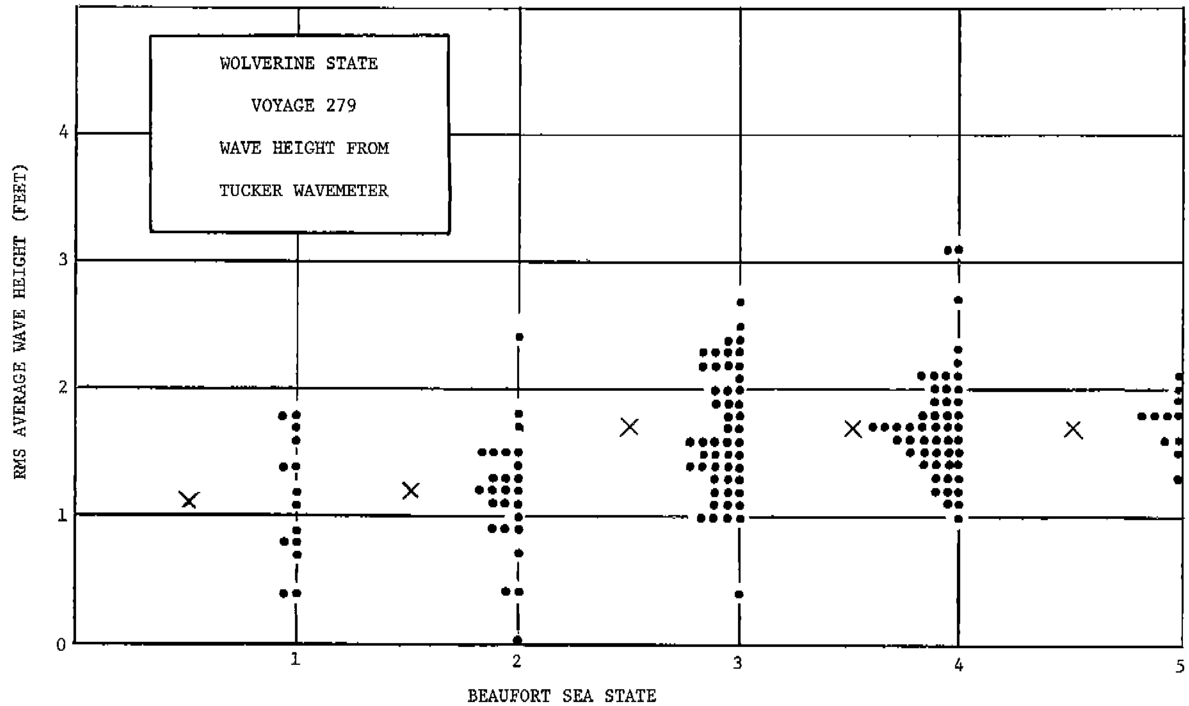

Fig. 47. Dot Plot of RMS Average Wave Height vs, Beaufort Sea State, *Wolverine State*, Voyage 279

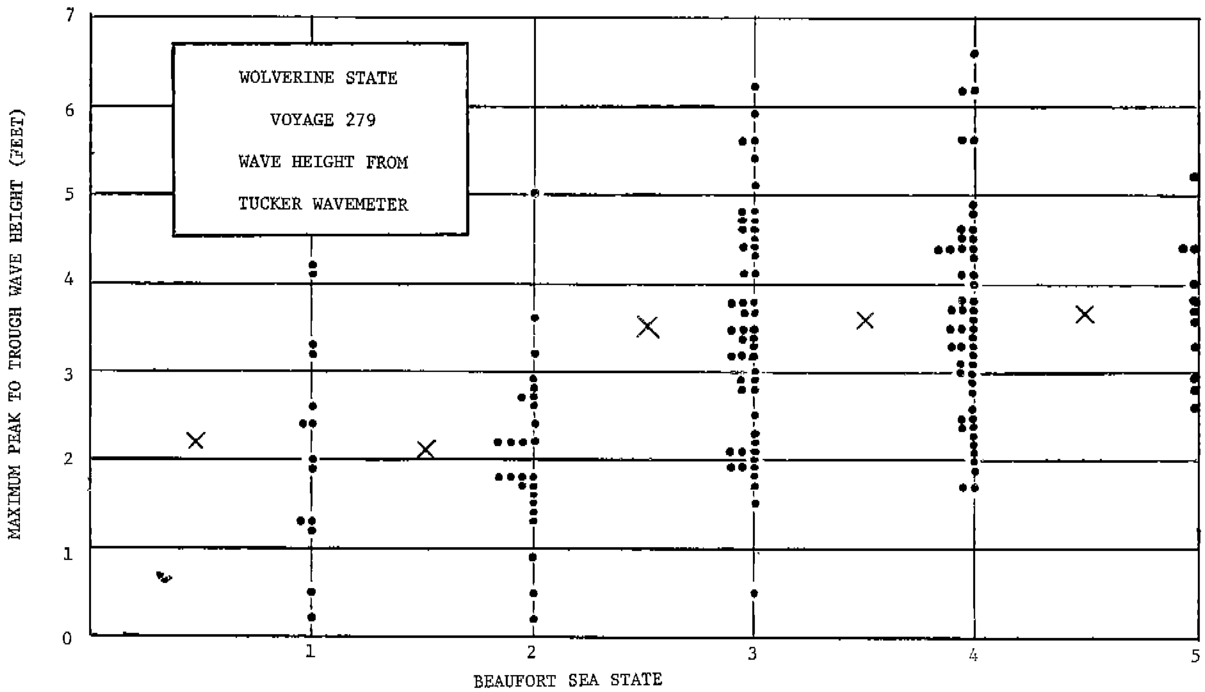

Fig. 48. Dot Plot of Maximum Peak to Trough Wave Heights vs, Beaufort Sea State *Wolverine State*, Voyage 279

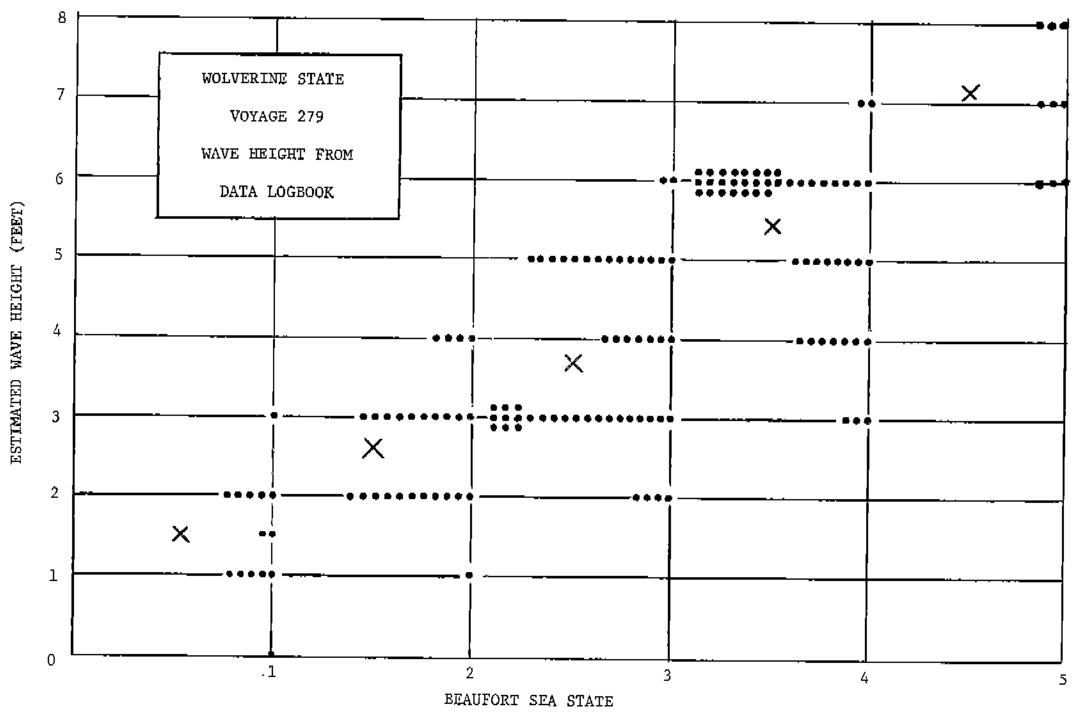

Fig. 49. Dot-Plot of Estimated Wave Heights vs. Beaufort Sea State *Wolverine State*, Voyage 279

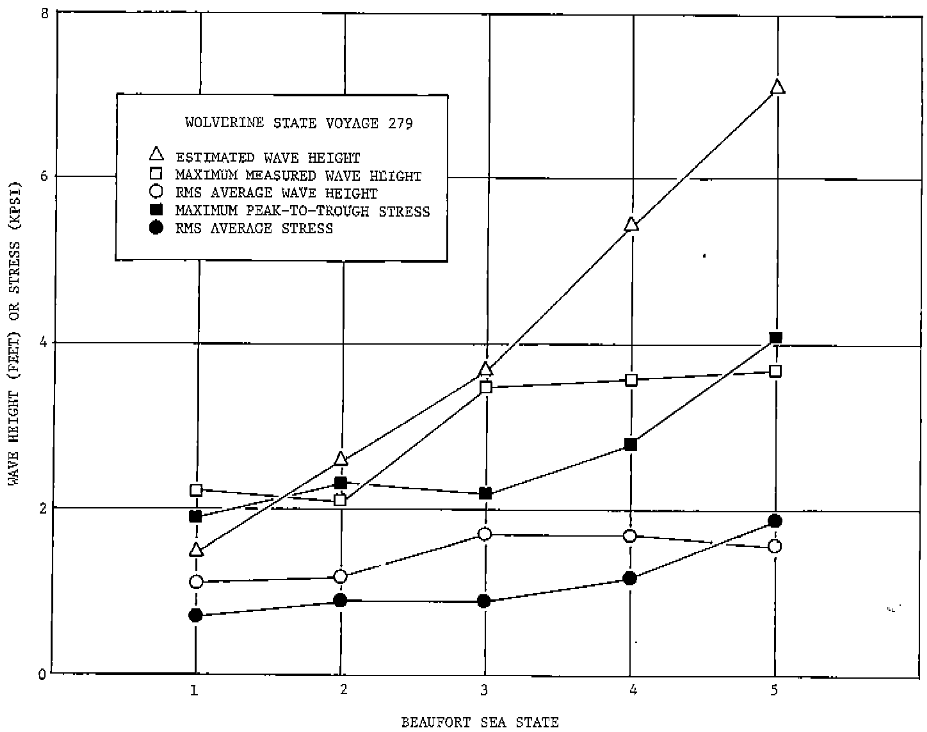

Fig. 50. Average Plot of Waves and Stress vs. Beaufort Sea State *Wolverine State*, Voyage 279

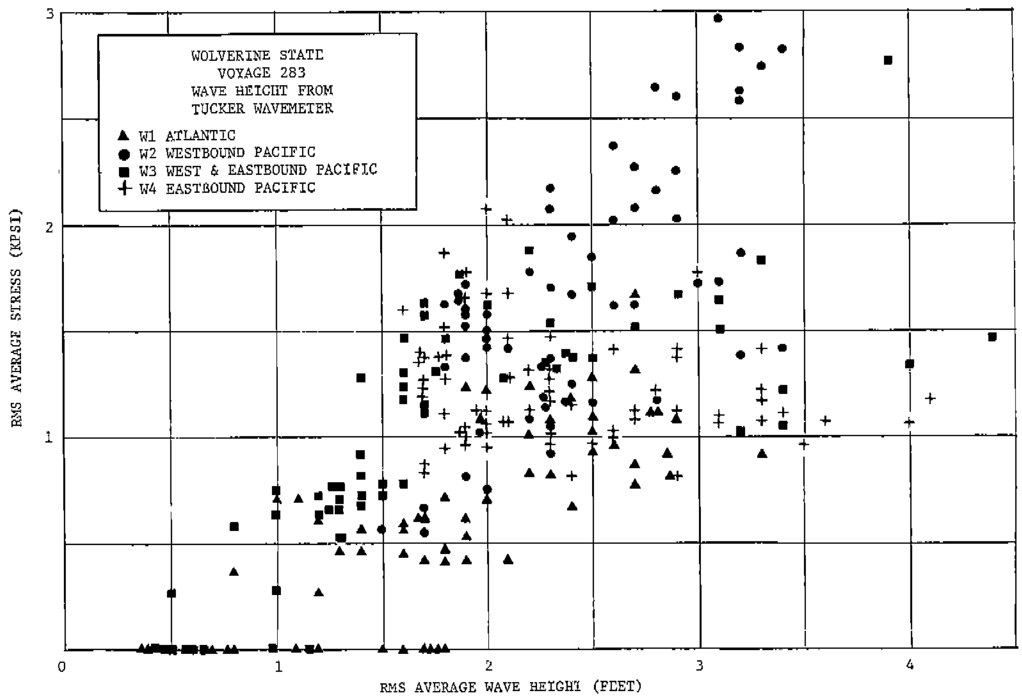

Fig. 51. Dot-Plot of RMS Average Stress vs. RMS Average Wave Height *Wolverine State*, Voyage 283

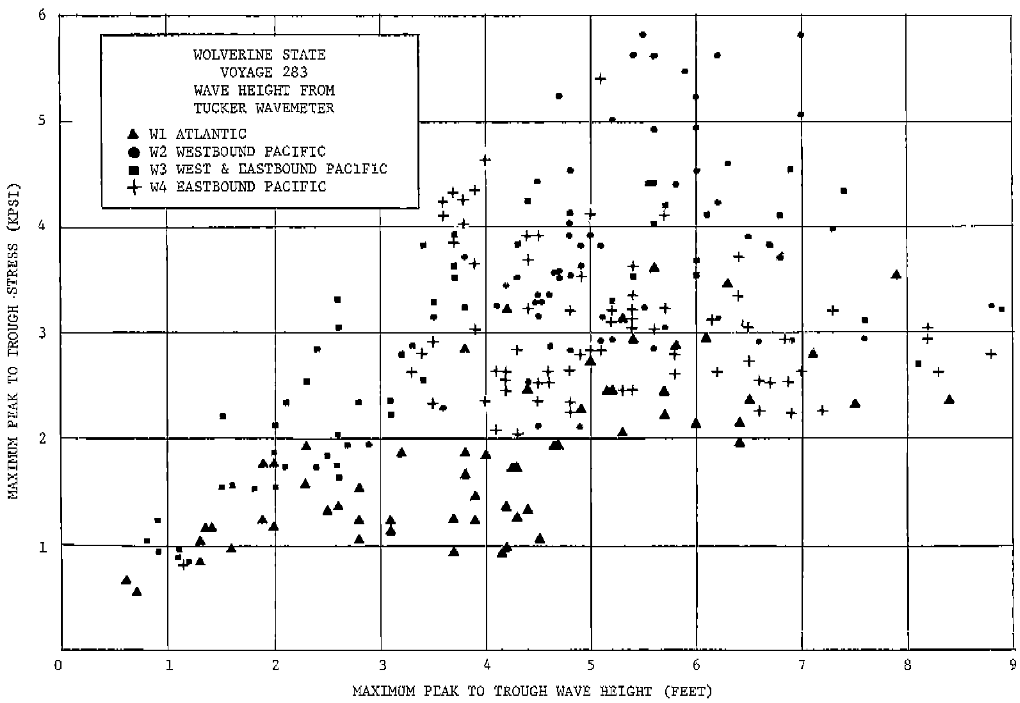

Fig. 52. Dot-Plot of Maximum Peak-to-Trough Stress vs. Maximum Peak-to-Trough Wave Height, *Wolverine State*, Voyage 283

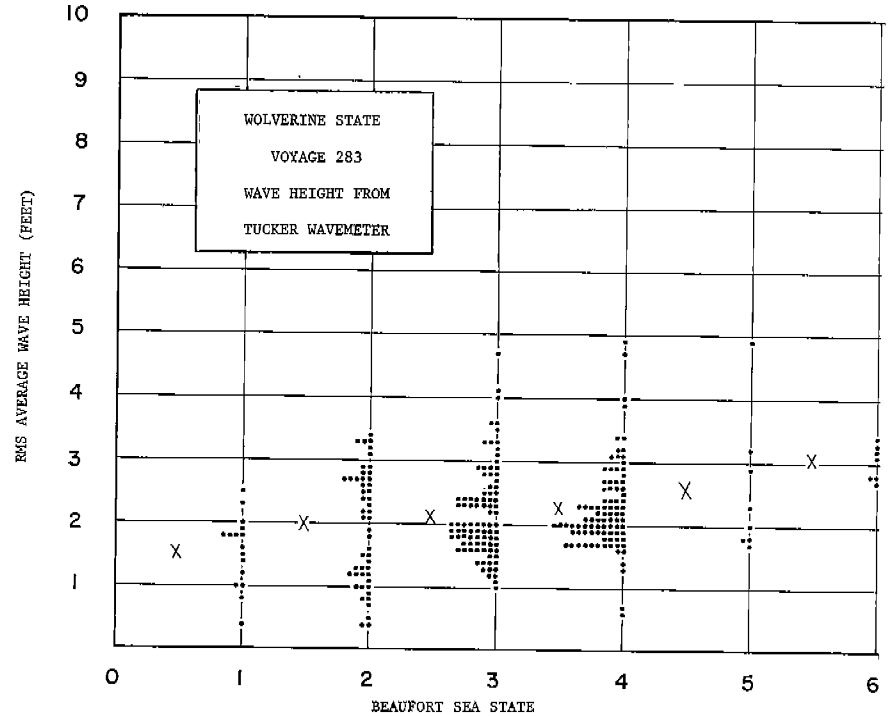

Fig. 53. Dot Plot of RMS Average Wave Height vs, Beaufort Sea State *Wolverine State*, Voyage 283

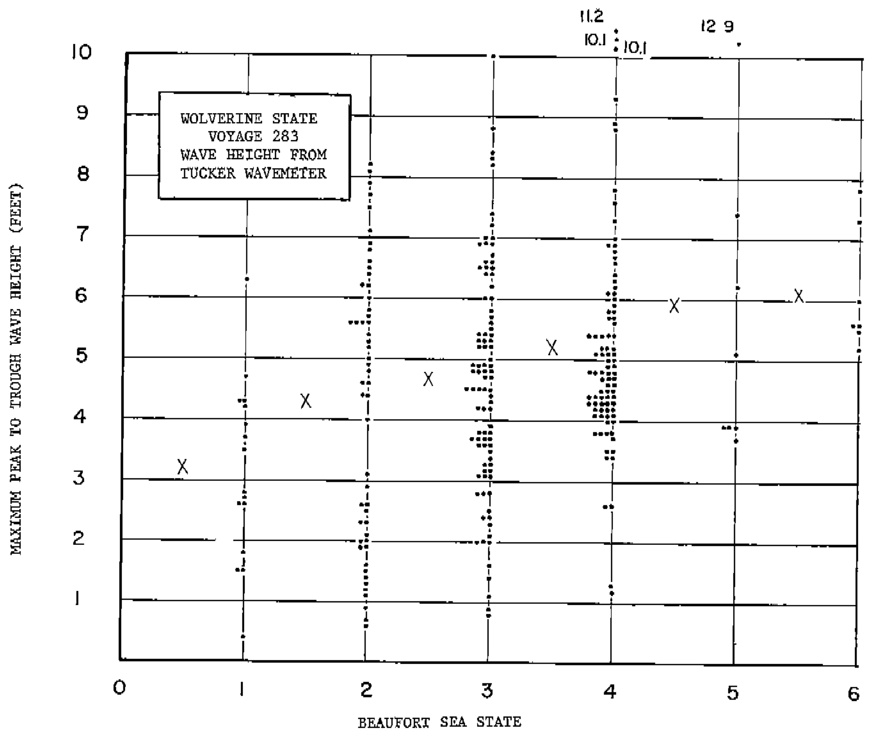

Fig. 54. Dot Plot of Maximum Peak to Trough Wave Height vs, Beaufort Sea State, *Wolverine State*, Voyage 283

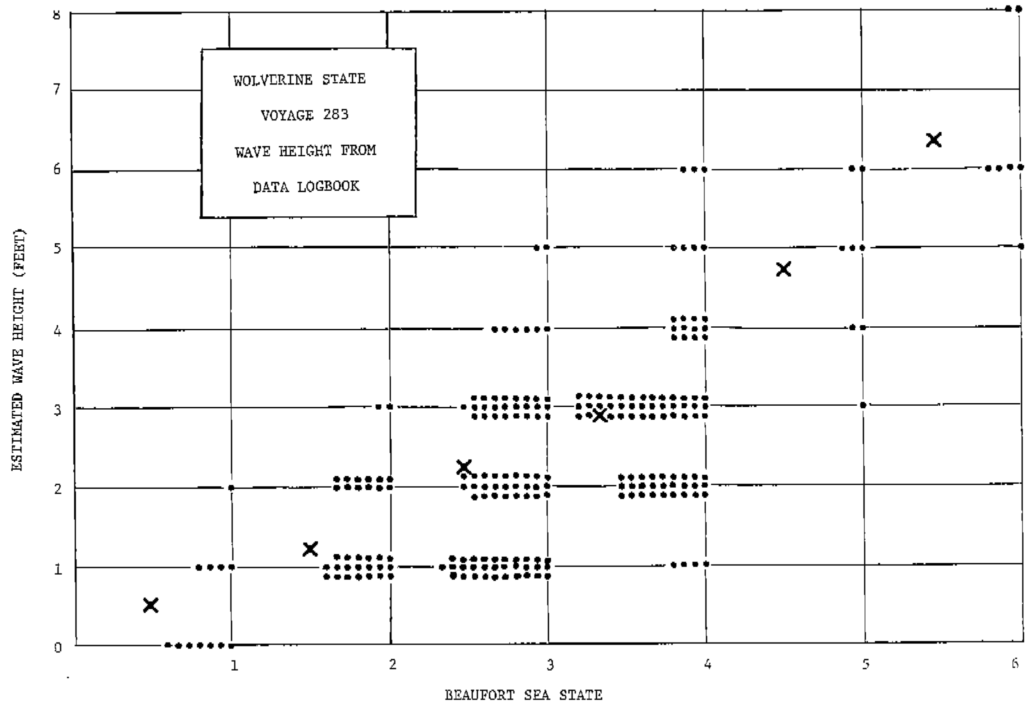

Fig. 55. Dot-Plot of Estimated Wave Heights vs. Beaufort Sea State, *Wolverine State*, Voyage 283

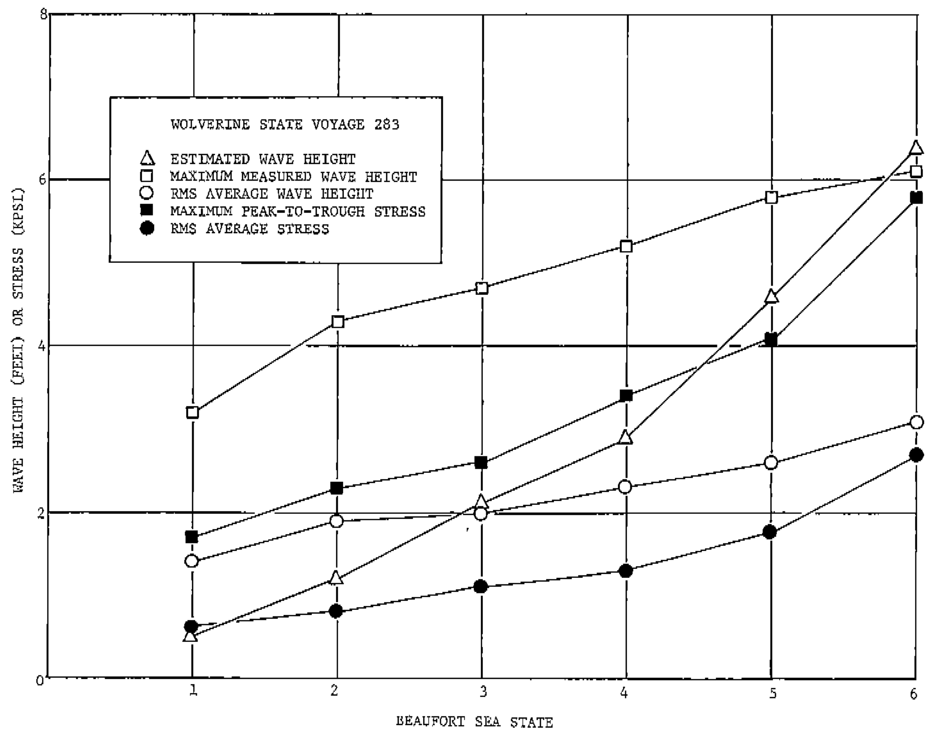

Fig. 56. Average Plot of Waves and Stress vs. Beaufort Sea State *Wolverine State*, Voyage 283

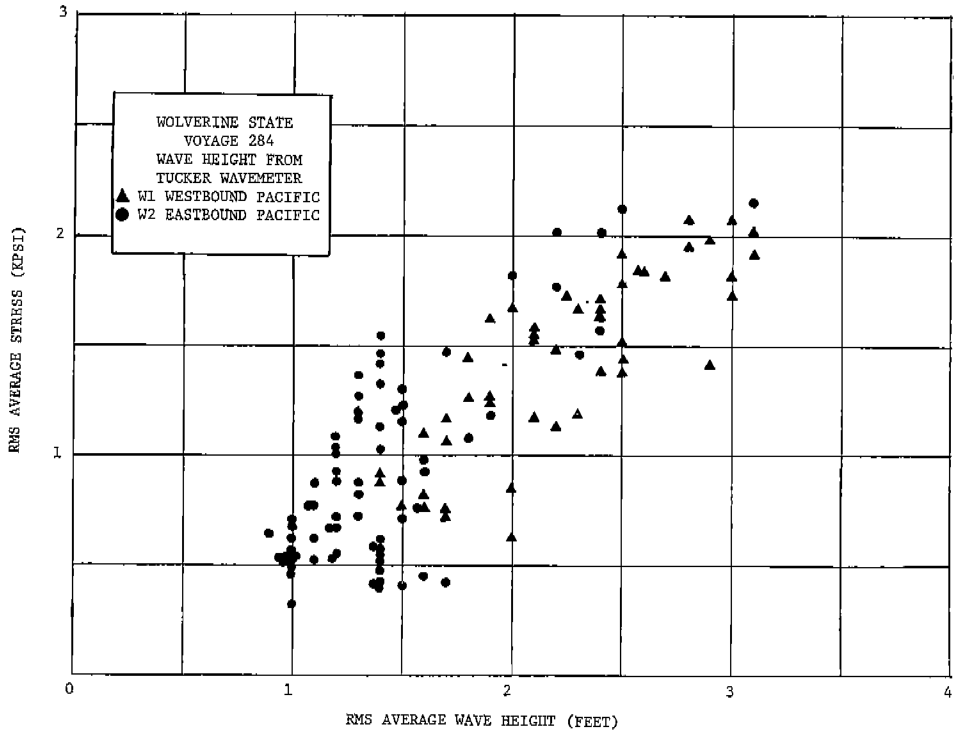

Fig. 57. Dot-Plot of RMS Average Stress vs. RMS Average Wave Height *Wolverine State*, Voyage 284

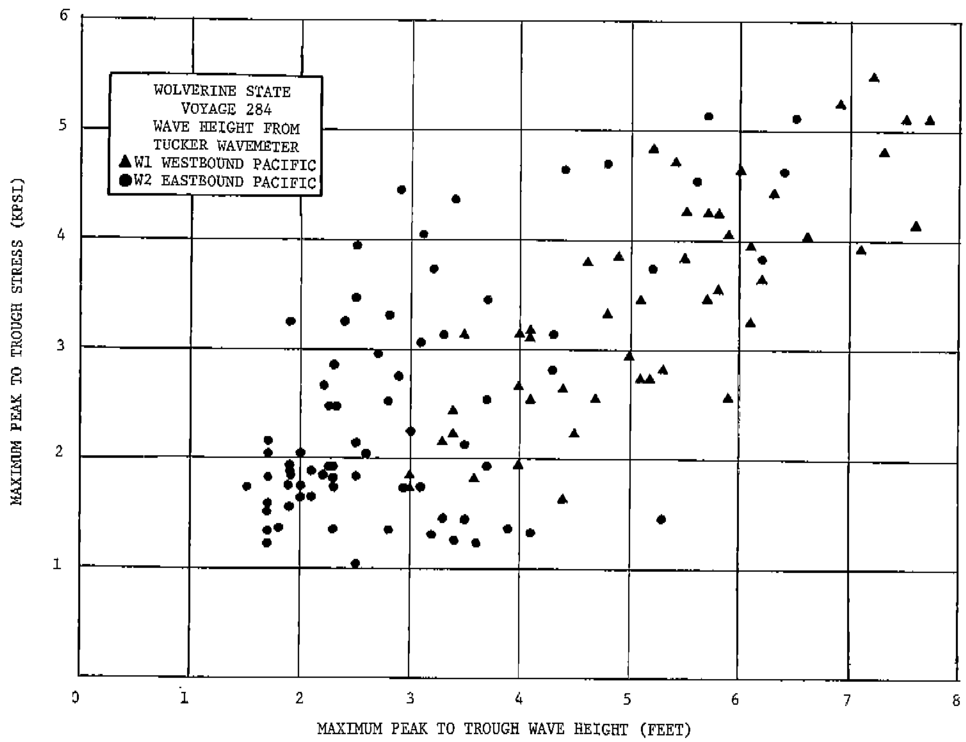

Fig. 58. Dot-Plot of Maximum Peak-to-Trough vs. Maximum Peak-to-Trough Wave Height, *Wolverine State*, Voyage 284

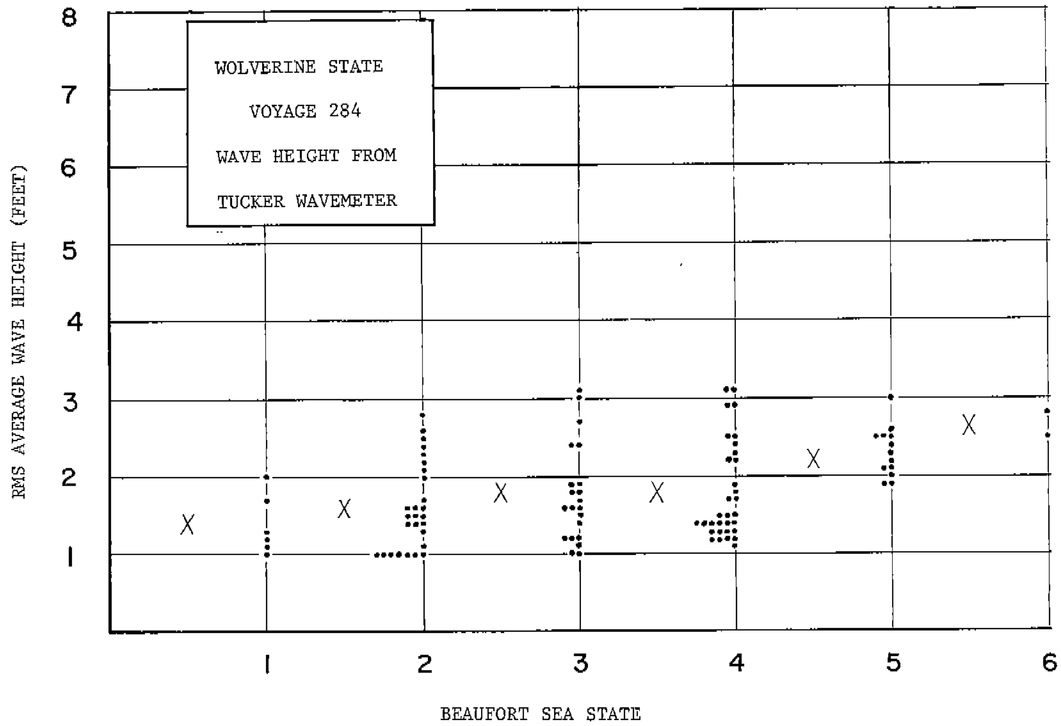

Fig.59. Dot Plot of RMS Average Wave Height vs, Beaufort Sea State, *Wolverine State*, Voyage 284

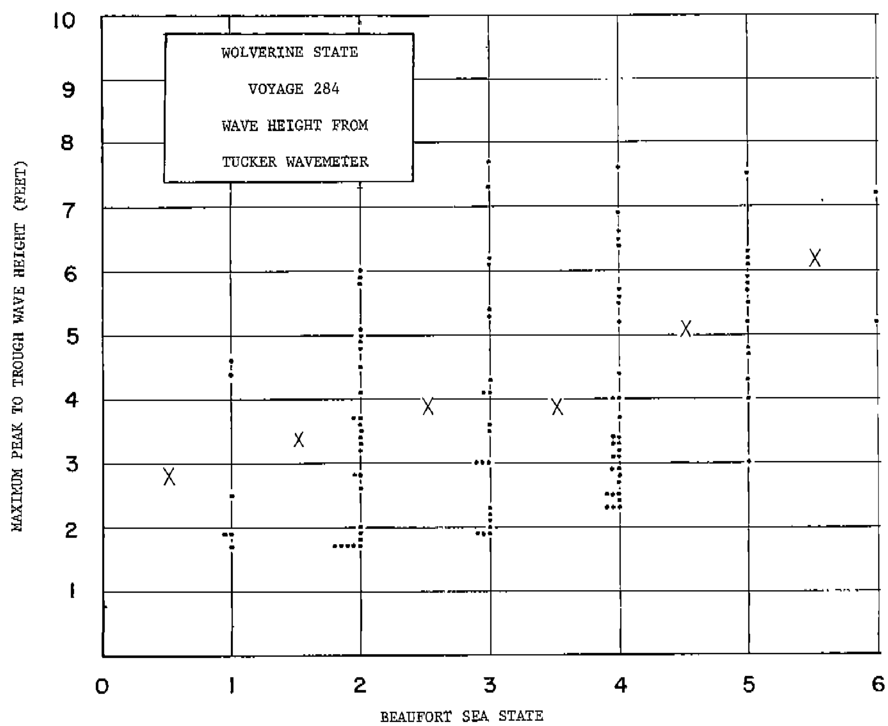

Fig. 60. Dot Plot of Maximum Peak to Trough Wave Height vs, Beaufort Sea State *Wolverine State*, Voyage 284

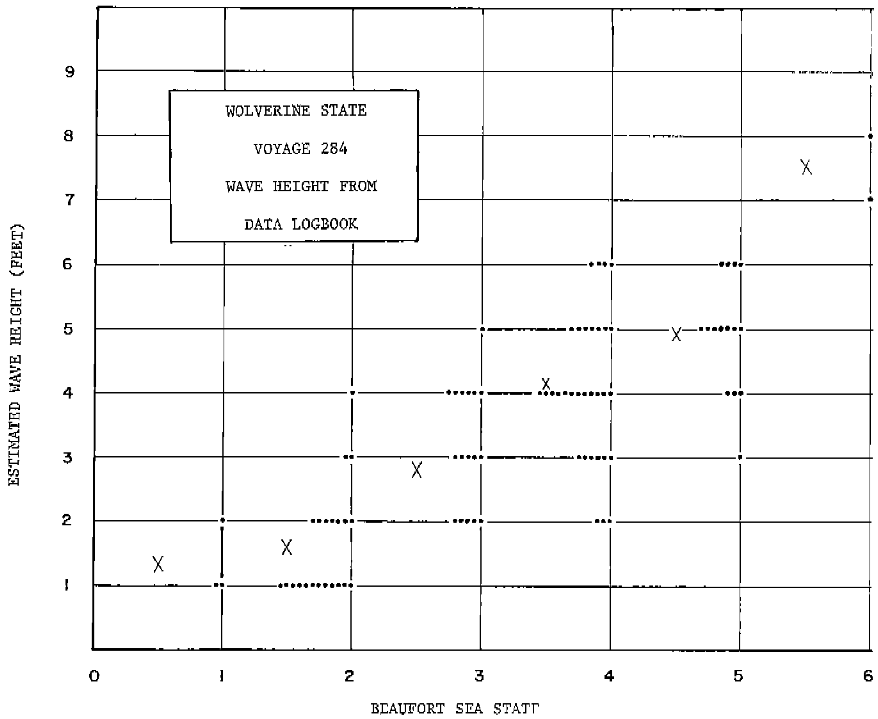

Fig. 61. Dot Plot of Estimated Wave Height vs, Beaufort Sea State, *Wolverine State*, Voyage 284

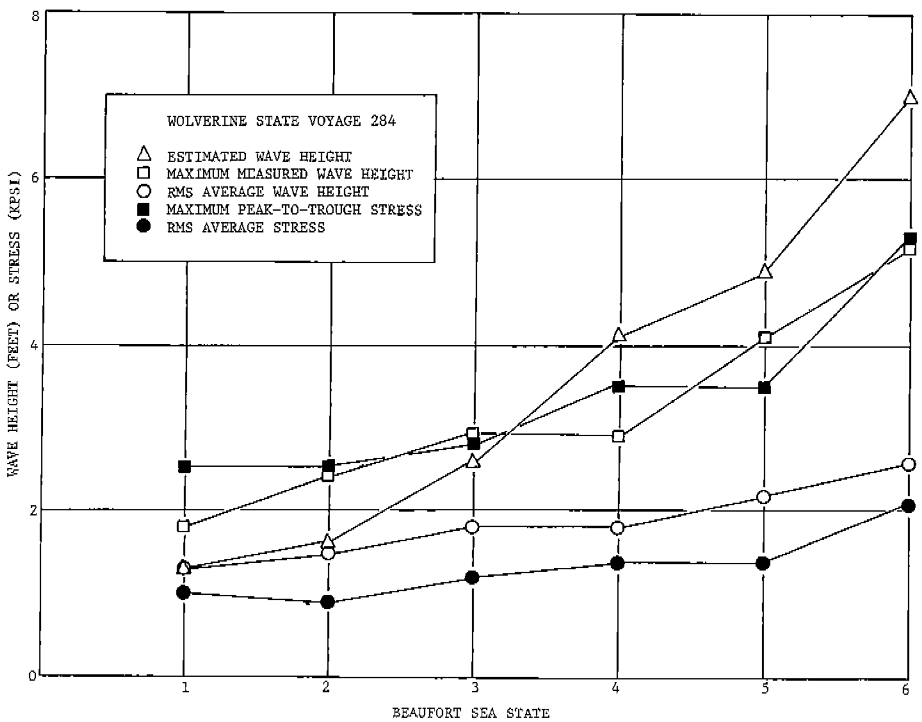

Fig. 62. Average Plot of Waves and Stress vs. Beaufort Sea State *Wolverine State*, Voyages 284

APPENDIX A-1

Calibration of the CALIFORNIA BEAR

I. GENERAL

Stress data from the CALIFORNIA BEAR is reduced based on a scale factor determined by the characteristics of the stress gage transducers. In order to confirm that these data do, in fact, correspond to the stress variations in the vessel, it is necessary to perform a basic calibration of the vessel by applying known loads, calculating the resulting bending moment stresses, and comparing these computed values with stress variations measured by the instrumentation system. Such a calibration was performed on the CALIFORNIA BEAR in August, 1968 at San Pedro, California.

Instrumentation aboard the CALIFORNIA BEAR consisted of the original slow-speed tape recorder and signal-conditioning system from the WOLVERINE STATE, plus new stress gages and transducer housings. Installation of this equipment was made in early January, 1966. Stress gage transducers were installed on the side shell plates, port and starboard, midway between frames 102 and 103 in Hold No. 4 at the Second Deck level. The center line of the housings was 10 inches below the overhead. The stress gages were connected together in one bridge circuit to measure average midship bending moment stress. For further details on this installation, see Lessells and Associates, Inc., Technical Report 894/i21, "Acquisition and Installation of Shipboard Recording Equipment," dated January 18, 1966, the final report on Contract NObs-92134.

II. PLANNING

On the recommendation of Pacific Far East Line, Inc., the naval architecture firm of Thomas T. Lunde, Inc., was asked to determine the most practical procedure for inducing the greatest possible bending moment in the CALIFORNIA BEAR during lightship condition by a loading sequence of bunkers, ballasting with water, and/or transfer of water and fuel oil. In addition, they were asked to compute the bending moments so achieved, and to assist in liaison between the investigators, the owner, and the shipyard.

The original plan (to perform the calibration immediately subsequent to a drydocking) was cancelled due to shipyard delays and ship schedule commitments. On the next visit, however, it appeared that the calibration could be performed while the vessel was in San Diego. Accordingly, personnel from Teledyne and Lunde met there on August 1, 1968.

Consultation aboard the vessel revealed that bunkering facilities were inadequate at the current location of the vessel, and it was decided to postpone the calibration until August 3 in San Pedro.

At a meeting aboard the ship in San Pedro a detailed pumping plan was established by Mr. R. McCardell of T. T. Lunde, Inc., and Mr. A. Cameron, Chief Engineer of the CALIFORNIA BEAR. As a result of the postponement, however, the vessel was no longer in the lightship condition, having loaded 2,642 long tons of cargo.

III. CALIBRATION PROCEDURE

A change in bending moment was achieved by a sequence of bunkering and ballasting which began at 2100, August 3, and ended at 0700, August 4, 1968 at the Consolidated Marine, Inc., pier in San Pedro. Detailed measurements of tankage conditions, draft, and freeboard were made, and the amount of cargo on board and being loaded during the calibration was noted. Weather conditions were good --

mild temperature and a slight overcast. The specific gravity of the water alongside the vessel was 1.025. The vessel was moored port side to dock, with negligible list. Computations of bending moment stress were based on the data shown in Tables I through III.

Measurements of the changes in bending moment stress were made by noting data from three sources located progressively along the instrumentation system. As illustrated in Figure 1, these sources are:

a) the transducers alone

b) the amplifier output, and

c) the reproduced analog signal from the magnetic tape recording

The scale factor for converting strain indicator readings to stress is derived in Figure 2. Scale factors for converting stress meter readings to stress are based on the simulation of 10,000 psi stress by adding a resistor in parallel across one arm of the transducer bridge on "CAL" command. The change in amplifier output so generated has been set to 80 divisions on the stress meter, thus giving a scale factor of 125 psi per division. To reduce the analog output on the magnetic tape to stress, changes in signal have been scaled against this same 10,000 psi "CAL" signal. Raw and reduced measurement data are shown in Table IV.

IV. STRESS COMPUTATIONS

Stress computations were made by Thomas T. Lunde, Inc. based on the "Integral Factors Method." This method is presented in a paper entitled "A Simplified Approximate Method to Calculate Shear Force and Bending Moment in Still Water at any Point of the Ship's Length," published by the American Bureau of Shipping in April, 1965. Displacements determined from draft readings (corrected for water density) were used to enter tables of factors for form and buoyancy. The bending moments derived by this procedure were divided by the midship section modulus (top) of 43,900 in^2 - ft. (provided by Bethlehem Steel Corporation).

V. RESULTS AND CONCLUSIONS

Results of the calibration are shown in Table V and plotted in Figure 3. Inspection of Figure 3 shows that the calculations agree very well with the measured data. If the tape-recorded result (Initial-to-Final) of 3,540 psi is taken as the correct value, the other two measured values are within 6 percent, and the computed value is 9 percent high.

Measurements of plating unfairness on the SS CALIFORNIA BEAR indicate that the measured average stress is probably 8% below the actual heart of plate stress. This brings the tape recorded and calculated stress values to within 1% of each other.

On the basis of the unfiarness measurements and the vessel calibration, the investigators recommend that the recorded stress data from the SS CALIFORNIA BEAR be multiplied by a factor of 1.08.

Table A-1. Initial Condition

Raw Data and Computed Stress, 2100 August 3, 1968

A. LOADING

ITEM	TONS	L.C.G. (FEET)	MOMENT (FOOT-TONS)
Lightship	7,682	- 17.6	-135,203
Stores & Provisions	24		- 644
Pass. Crew Effects	15		- 225
Dry Cargo	2,642		- 40,870
Fore Peak	107.8	+242.9	+ 26,185
Aft. Peak	90.4	-246.8	- 22,311
#4 Deep Tank P/S	110.0	- 36.0	- 3,960
#5 Deep Tank P/S	21.0	- 52.0	- 1,092
Dist. Tank	20.5	+ 4.3	+ 88
#1 D.B. Tank	48.3	+220.1	+ 10,631
#1-A	77.2	+195.1	+ 15,062
#5 CL & S	37.9	- 17.9	- 678
#7 P/S	163.3	-152.4	- 24,887
#I D. Tank	127.9	+219.7	+ 28,100
#IA	238.0	+194.9	+ 46,386
#2. #3 P/S Settlers	217.3	- 7.8	- 1,688
#7 P/S	274.5	-170.8	- 46,843
#8 P/S	70.4	-194.0	- 13,658
TOTAL	11,967	- 13.83	-165,607

B. DRAFTS

FWD	14' - 0 1/2"	AFT	22' - 5"
F/A AVG	18' - 2 3/4"	Ⓜ	18' - 3 1/4"

Displacement from curves corrected for trim and density: 11,985 L.T.

C. BENDING MOMENT at Frame 102-1/2 = 151,140 foot-tons

D. BENDING MOMENT STRESS = $\frac{151,140 \times 2240}{43,900}$ = 7,712 psi

Table A-II. Intermediate Condition

Raw Data and Computed Stress, 2400 August 3, 1968

A. LOADING

ITEM	TONS	L.C.G. (FEET)	MOMENT (FOOT-TONS)
Lightship	7,682	- 17.6	-135,203
Stores & Provisions	24		- 644
Pass. Crew Effects	15		- 225
Dry Cargo	2,660.0		- 42,569
#4 Deep Tank P/S	105.4	- 36.0	- 3,974
#5 Deep Tank P/S	19.4	- 52.0	- 1,009
Dist. Tank	19.0	+ 4.3	+ 82
#1 D.B. Tank	45.3	+220.1	+ 9,970
#1A	73.4	+195.1	+ 14,320
#3 P/S & CL	94.3	+ 97.5	+ 9,195
#4 P/S & CL	211.1	+ 37.6	+ 7,933
#5 S & CL	165.0	- 19.9	- 3,278
#6 P/S & CL	326.2	- 91.1	- 29,725
#7 P/S	165.9	-152.4	- 25,283
#1 Deep Tank	28.2	+219.7	+ 6,196
#1A	113.6	+194.9	+ 22,141
#2 & 3 P/S Settlers	211.9	- 7.8	- 1,649
#6 P/S	0.5	-141.2	- 71
#7 P/S	247.6	-170.7	- 42,265
#8 P/S	50.0	-194.0	- 9,700
TOTAL	12,258	- 18.41	- 225,758

B. DRAFTS

FWD 12' - 5"	AFT 24' - 3"
F/A AVG 18' - 4"	⊗ 18' - 4 3/8"

Displacement from curves corrected for trim and density: 12,070 L.T.

C. BENDING MOMENT at Frame 102-1/2 = 110,122 foot-tons

D. BENDING MOMENT STRESS = $\frac{110,122 \times 2240}{43,900}$ = 5,620 psi

Table A-III. Final Condition

Raw Data and Computed Stress, 0700 August 4, 1968

A. LOADING

ITEM	TONS	L.C.G. (FEET)	MOMENT (FOOT-TONS)
Lightship	7,682.0	- 17.6	-135,203
Stores & Provision	24.0		- 644
Pass. Crew Effects	15.0		- 225
Dry Cargo	2,689.0		- 45,306
#4 Deep Tank P/S	123.5	- 36.0	- 4,453
#5 Deep Tank P/S	108.4	- 52.0	- 5,637
Dist. Tank	16.5	+ 4.3	+ 71
#IAD.B Tank	4.7	+195.1	+ 917
#3 P/S & CL	250.4	+ 95.7	+ 23,951
#4 P/S & CL	403.5	+ 37.1	+ 14,961
#5 P/S & CL	486.0	- 24.0	- 11,642
#6 P/S & CL	372.0	- 91.6	- 34,069
#7 P/S	9.3	-152.4	- 1,417
#2 Settlers P/S	117.6	- 0.8	- 94
#3 Settlers P/S	91.4	- 17.0	- 1,554
#6 Deep Tank P/S	393.6	-141.2	- 55,576
TOTAL	12,787	- 20.01	-255,920

B. DRAFTS

FWD	11' - 11' 1/2"	AFT	26' - 2 1/2"
F/A AVG	19' - 1"	Ф	19' - 3 3/16"

Displacement from curves corrected for trim and density: 12,730 L.T.

C. BENDING MOMENT at Frame 102-1/2 = 75,564 foot-tons

D. BENDING MOMENT STRESS = $\frac{75,564 \times 2240}{43,900}$ = 3,856 psi

Table A-IV

Raw Data and Measured Stress All Conditions

All Conditions

	Initial	Conditions Intermediate	Final	CAL Amplitude =10,000 psi
A. Raw Data				
Strain Indicator	0(-)1102	0(-)1189	0(-)1273	
Stress Meter Units	+6	-11	-24	80
Magnetic Tape Readout	+1.6	-4.3	-8.3	27.9
(Oscillograph paper divisions from nearest zero)				
B. Raw Data Referred to Initial Condition				
Strain Indicator	0	-87	-171	
Stress Meter Units	0	-17	-30	
Magnetic Tape Readout	0	-5.9	-9.9	
C. Stress Data Referred to Initial Condition (PSI)				
Strain Indicator (x20.3)	0	-1,766	-3,470	
Stress Meter Units (x125)	0	-2,125	-3,750	
Magnetic Tape Readout ($x\frac{10,000}{27.9}$)	0	-2,110	-3,540	

Table A-V

Comparison of Measured and Computed Stress Variations Between Conditions

	Initial to Intermediate	Intermediate to Final	Initial to Final
A. Measured			
Strain Indicator	-1,766	-1,704	-3,470
Stress Meter	-2,125	-1,625	-3,750
Tape Recorder	-2,110	-1,430	-3,540
B. Computed	(-)2,092	(-)1,764	(-)3,856

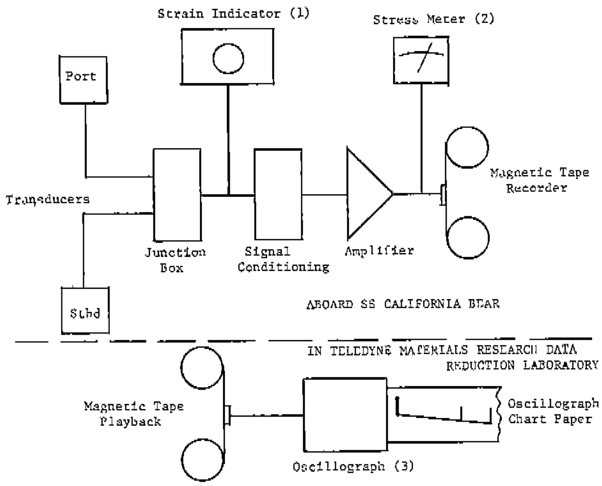

Fig. A-1. Instrumentation System Showing Three Sources of Calibration Data

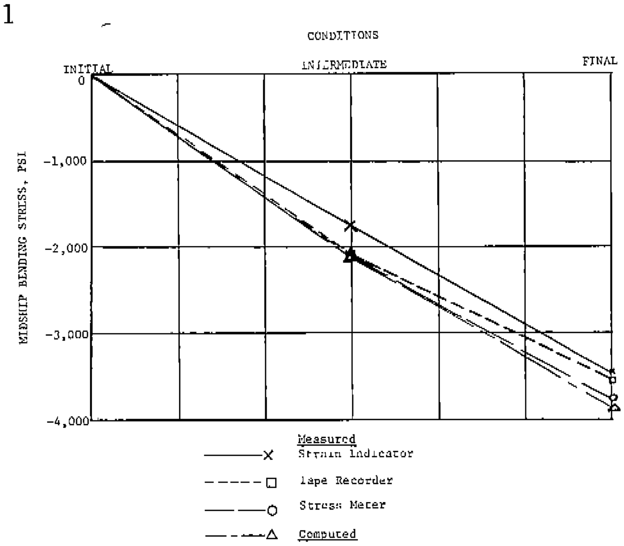

Fig. A-3. Graph of Measured and Computed Stress Variations

$$\sigma = \varepsilon_r E$$

$$\varepsilon_r = \varepsilon_i' \frac{GF_i}{GF_{rb}} \bullet \frac{1}{N}$$

$$\sigma = \left[\varepsilon_i' \frac{GF_i}{GF_{rb}} \bullet \frac{1}{N}\right] E$$

$$\sigma = \left[\varepsilon_i' \frac{2.00}{1.48} \bullet \frac{1}{2}\right]\left[30 \times 10^6\right]$$

$$\sigma = \varepsilon_i \bullet 20.3 \text{ psi}$$

where σ = bending stress, psi

ε_r = real strain, inches/inch

E = Young's modulus, 30×10^6 psi

ε_i' - strain indicated on strain indicator, inches/inch

ε_i = strain indicated on strain indicator, microinches/inch

GF_i = Gage Factor set on strain indicator

GF_{rb} = Effective Gage Factor for stress of two-element bending stress gages

N = number of active arms in bridge

Fig. A-2. Derivation of Stress/Strain Indicator Reading

APPENDIX A2

Calibration of the MORMACSCAN

I. GENERAL

Stress data from the MORMACSCAN is reduced based on a scale factor determined by the characteristics of the stress gage transducers. In order to confirm that these data do, in fact, correspond to the stress variations in the vessel, it is necessary to perform a basic calibration of the vessel by applying known loads, calculating the resulting bending moment stresses, and comparing these computed values with stress variations measured by the instrumentation system. Such a calibration was performed on the MORMACSCAN in October, 1968, at Montreal, Canada, and Duluth, Minnesota.

Instrumentation aboard the MORMACSCAN consisted of the original slow-speed tape recorder and signal-conditioning system, plus stress gages and transducer housings. Installation of this equipment was made in April, 1964. Stress gage transducers were installed on the side shell plates, port and starboard, midway between Frames 88 and 89 in Hold No. 4 at the "upper 'tween deck level." The center line of the housings was 16 inches below the overhead deck plate. The stress gages were connected together in one bridge circuit to measure average midship bending moment stress.

II. PLANNING

Webb Institute was asked to determine the most practical procedure for inducing the greatest possible bending moment in the MORMACSCAN by a loading sequence of bunkers, ballast water and/or both. They were asked to compute the bending moments achieved with the recommended sequence and to assist in liaison between the investigators and the owner.

The original plan, to perform the calibration before or after the annual drydocking, was cancelled because of problems which would be created by pumping dirty ballast into tanks used at times for vegetable oil cargo.

The vessel was boarded at Montreal, Canada, on October 4, 1968 for the calibration; but, after discussing the calibration procedure with the crew, the decision was made to try a calibration during the time the vessel was underway from Montreal to Duluth. The decision to try this approach was due to the long time involved in discharging ballast and reballasting for the Seaway (approximately 32 hours) and the reluctance of the Captain to delay the ship for that period of time.

There were obvious difficulties in attempting a calibration on this basis, not the least of which were the large thermal stress excursions anticipated. It was therefore decided to record stress and ship operating data every four hours (or less, if an event of interest was occurring) around the clock for the five days of the journey, in the hope that weather conditions could be matched fairly well for the extreme load conditions.

III. CALIBRATION PROCEDURE

A change in bending moment was achieved by discharging fresh water ballast used to trim ship for the Seaway and by bunkering change. Detailed measurements of tankage conditions, draft, and the amount of cargo and fuel were noted. As mentioned above, stress data were recorded at least every four hours during the voyage. At the termination of the voyage, measured stresses were reduced and calculations made for four conditions when extremes in bending moment were achieved and (with one exception) the environmental conditions were roughly similar.

Measurements of the changes in bending moment stress were made by noting data from three sources located progressively along the instrumentation system. As illustrated in Figure 1, these sources are:

a) the transducers alone

b) the amplifier output, and

c) the reproduced analog signal from the magnetic tape

The scale factor for converting strain indicator readings to stress is derived in Figure 2. Scale factors for converting stress meter readings to stress are based on the simulation of 10,000 psi stress by adding a resistor in parallel across one arm of the transducer bridge on "CAL" command. The change in amplifier output so generated has been set to 80 divisions on the stress meter, thus giving a scale factor of 125 psi per division. To reduce the analog output on the magnetic tape to stress, changes in signal have been scaled against this same 10,000 psi "CAL" signal. Raw and reduced measurement data are shown in Table X.

IV. STRESS COMPUTATIONS

Stress computations were made by Logikon Corporation on the basis of the data in Tables I through III and are shown in Tables IV through IX.

V. RESULTS AND CONCLUSIONS

Results of the calibration are shown in Table XI and plotted in Figure 3. Inspection of Figure 3 shows that the calculations agree surprisingly well with the measured data when weather conditions and time of day when measurements were made are similar. This is reassuring in view of the relatively small total stress change achieved, and the powerful effect thermal changes would have on the reading.

Probably the environmental conditions at I and III are most similar, and in this case the stress change from the tape record is only 0.8% different from the calculated change; whereas, at IV the difference between the two is nearer 15%. The stress meter and strain indicator data correlate well with the calculated value at both Conditions III and IV. The accuracy of the calculation was stated to be 3% and the tape data are no better than 80 psi, or 5% at 1600 psi. Thermal effects would be on the order of 50 to 100 psi per degree of gross temperature difference from one part of the vessel to another.

Measurements of unfairness in the sheer strake plating of the MORMACSCAN indicate probable values of unfairness at the gages of less than 0.010 inch in the .875-inch thick plate. This would suggest a correction of about 3.5% in the measured data to give heart of plate stress. Since this is well within the tolerance of the measured and calculated data, and since the deviations of measured data from calculated are not consistent in direction, there is no basis for using a factor on the measured data to correct it to true heart-of plate bending moment stress.

Table A2-I. Tankage Per Sounding (Tons)

TANK DESIGNATION	CONTENT	CONDITION			
		I	II	III	IV
FORE PEAK	F.W.	40.1	40.1	40.1	40.1
AFT PEAK	F.W.	63.8	63.8	63.8	63.8
NO. 1F CEN DEEP	F.W.	226.3	226.3	226.3	226.3
NO. 1A CEN DEEP	F.W.	500.6	500.6	-	-
NO. 4FP PORT DEEP	F.W.	325.0	325.0	-	-
NO. 4FS STAR DEEP	F.W.	292.0	292.0	-	-
NO. 4AP PORT DEEP	F.W.	206.0	206.0	-	-
NO. 4AS STAR DEEP	F.W.	181.5	181.5	-	-
FRESH WATER	F.W.	115.9	115.9	115.9	115.9
NO. 1 D.B. PORT	F.O.	1.5	1.5	-	-
NO. 1 D.B. STAR	F.O.	2.3	2.3	-	-
NO. 2 D.B. PORT	F.O.	32.5	32.5	-	-
NO. 2 D.B. CENT	F.O.	166.0	51.0	-	-
NO. 2 D.B. STAR	F.O.	1.5	1.5	1.5	34.7
NO. 3 D.B. PORT	F.O.	150.8	150.8	144.7	144.7
NO. 3 D.B. CENT	F.O.	185.2	185.2	185.2	185.2
NO. 3 D.B. STAR	F.O.	154.1	154.1	154.1	154.1
NO. 4 D.B. PORT	F.O.	108.3	108.3	105.6	105.6
NO. 4 D.B. CENT	F.O.	22.6	22.6	-	-
NO. 4 D.B. STAR	F.O.	51.2	51.2	39.2	39.2
NO. 5 D.B. PORT	F.O.	8.3	8.3	8.3	113.8
NO. 5 D.B. CENT	F.O.	73.9	73.9	73.9	73.9
NO. 5 D.B. STAR	F.O.	9.8	9.8	9.8	113.8
NO. 7 D.B. CENT	F.O.	106.2	106.2	106.2	106.2
NO. 5 DEEP PORT	F.O.	41.5	41.5	41.5	41.5
SETT. TANK PORT	F.O.	54.8	54.8	49.0	49.0
SETT. TANK STAR	F.O.	72.3	72.3	47.0	47.0

Table A2-II
Dunnage & Stores on Board During Calibration (tons)

LOCATION	WT
FORE	44.6
NO. 1 HATCH	4.5
NO. 2 HATCH	16.0
NO. 3 HATCH	8.0
NO. 4 HATCH	9.0
NO. 5 HATCH	5.3
AFT	17.8
AMIDSHIPS	118.0
TOTAL	223.2

Table A2-III
Draft Readings & Corresponding Displacements

CONDITION	FWD	AFT	MID MEAN
I	15'-04"	19'-02"	17'-03"
II	15'-00"	19'-00"	17'-00"
III	12'-09"	16'-03"	14'-06"
IV	13'-00"	16'-06"	14'-09"

Displacement From Above Drafts (tons)

CONDITION	EVEN KEEL	TRIM(FT)	TRIM CORR.	DISPLACEMENT
I	9040	3.83	12	9052
II	8900	4.00	12	8912
III	7450	3.50	5	7455
IV	7580	3.50	5	7585

Table A2-IV
Loading Information - Condition I (10/4/68 12 Midnight)

	Wt.	L.C.G. (FEET)	MOMENT (FOOT-TONS)
LIGHT SHIP	5882.0	- 8.0	- 47056
DUNNAGE & STORES	224.6	+ 29.1	+ 6536
PASS. CREW & EFFECTS	15.0	-	-
FORE PEAK	43.4	+ 209.6	+ 8468
AFT PEAK	63.7	- 204.7	- 13039
1F CE DEEP P&S	226.3	+ 184.5	+ 41752
1A CE DEEP P&S	500.6	+ 155.9	+ 78044
4F CE DEEP P&S	617.0	- 73.6	- 45411
4A CE DEEP P&S	385.1	- 111.7	- 43016
NO. 1 D.B. P&S	3.8	+ 164.3	+ 626
NO. 2 D.B. P,C&S	200.0	+ 103.7	+ 20740
NO. 3 D.B. P,C&S	490.1	+ 38.0	+ 18624
NO. 4 D.B. P,C&S	182.1	- 25.0	- 4553
NO. 5 D.B. P,C&S	92.0	- 72.9	- 6707
NO. 6 D.B. P,C&S	-	-	-
NO. 7 D.B. C	106.2	- 152.0	- 16142
NO. 5 D.T. P&S	41.5	- 145.7	- 6046
SETT. TANK P&S	127.5	- 43.7	- 5554
FRESH WATER	115.9	- 5.5	- 637
	9313.4	1.221	- 11371

Table A2-V
Loading Information - Condition II (10/7/68 13:00)

	Wt.	L.C.G. (FEET)	MOMENT (FOOT-TONS)
LIGHT SHIP	5882.0	- 8.0	-47056
DUNNAGE & STORES	224.6	+ 29.1	+ 6536
PASS. CREW & EFFECTS	15.0	-	-
FORE PEAK	43.4	+209.6	+ 8468
AFT PEAK	63.7	-204.7	-13039
1F CE DEEP P&S	226.3	+184.5	+41752
1A CE DEEP P&S	500.6	+155.9	+78044
4F CE DEEP P&S	617.0	- 73.6	-45411
4A CE DEEP P&S	385.1	-111.7	-43016
NO. 1 D.B. P&S	3.8	+164.3	+ 626
NO. 2 D.B. P, C&S	85.0	+103.7	+ 8814
NO. 3 D.B. P, C&S	490.1	+ 38.0	+18624
NO. 4 D.B. P, C&S	182.1	- 25.0	- 4553
NO. 5 D.B. P, C&S	92.0	- 72.9	- 6707
NO. 6 D.B. P, C&S	-	-	-
NO. 7 D.B. C	106.2	-152.0	-16142
NO. 5 D.T. P&S	41.5	-145.7	- 6046
SETT. TANK P&S	127.1	- 43.7	- 5554
FRESH WATER	115.9	- 5.5	- 637
	9198.4	2.75	-25297

Table A2-VI
Loading Information - Condition III (10/9/68 0017)

	Wt	L.C.G. (FEET)	MOMENT (FOOT-TONS)
LIGHT SHIP	5882.0	- 8.0	-47056
DUNNAGE & STORES	224.6	+ 29.1	+ 6536
PASS. CREW & EFFECTS	15.0	-	-
FORE PEAK	43.4	+209.6	+ 8468
AFT PEAK	63.7	-204.7	-13039
1F CE DEEP P&S	226.3	+184.5	+41752
1A CE DEEP P&S	-	+155.9	-
4F CE DEEP P&S	-	- 73.6	-
4A CE DEEP P&S	-	-111.7	-
NO. 1 D.B. P&S	-	+164.3	-
NO. 2 D.B. P,C&S	1.5	+103.7	+ 156
NO. 3 D.B. P,C&S	484.0	+ 38.0	+18392
NO. 4 D.B. P,C&S	144.8	- 25.0	- 3620
NO. 5 D.B. P,C&S	92.0	- 72.9	- 6707
NO. 6 D.B. P,C&S	-	-	-
NO. 7 D.B. C	106.2	-152.0	-16142
NO. 5 D.T. P&S	41.5	-145.7	- 6046
SETT. TANK P&S	96.0	- 43.7	- 4195
FRESH WATER	115.9	- 5.5	- 637
	7533.9	2.98	-22138

Table A2-VII
Loading Information - Condition IV (10/9/68 1430)

	WT	L.C.G. (FEET)	MOMENT (FOOT-TONS)
LIGHT SHIP	5882.0	- 8.0	-47056
DUNNAGE & STORES	224.6	+ 29.1	+ 6536
PASS, CREW & EFFECTS	15.0	-	-
FORE PEAK	43.4	+209.6	+ 8468
AFT PEAK	63.7	-204.7	-13039
1F CE DEEP P&S	226.3	+184.5	+41752
1A CE DEEP P&S	-	+155.9	-
4F CE DEEP P&S	-	- 73.6	-
4A CE DEEP P&S	-	-111.7	-
NO. 1 D.B. P&S	-	+164.3	-
NO. 2 D.B. P,C&S	34.7	+103.7	+ 3598
NO. 3 D.B. P,C&S	484.0	+ 38.0	+18392
NO. 4 D.B. P,C&S	144.8	- 25.0	- 3620
NO. 5 D.B. P,C&S	301.5	- 72.9	-21979
NO. 6 D.B. P,C&S	-	-	-
NO. 7 D.B. C	106.2	-152.0	-16142
NO. 5 D.T. P&S	41.5	-145.7	- 6046
SETT. TANK P&S	96.0	- 43.7	- 4195
FRESH WATER	115.9	- 5.5	- 637
	7776.6	4.34	-33786

Table A2-VIII
Stress Variations Calculations

W/2	X	K	(KL/2)	(X-KL/2)	Δ(B.M.)	$\Delta\sigma$(KPSI)
CONDITION I → II						
- 57.5	103.7	.299	68.5	35.2	- 2024	.149
CONDITION II → III						
-250.3	155.9	.326	74.6	81.3	-20349	1.454
-308.5	73.6	.381	87.2	-13.6	+ 4196	1.454
-192.55	111.7	.404	92.5	19.2	- 3697	1.454
- 1.9	164.3	.329	75.5	88.8	- 169	1.454
- 41.75	103.7	.299	68.5	35.2	- 1470	1.454
- 3.0	38.0	.267	61.2	-23.2	+ 70	1.454
- 18.6	25.0	.351	80.4	-55.4	+ 1030	1.454
- 15.5	43.7	.363	83.1	-39.4	+ 611	1.454
CONDITION III → IV						
+ 11.6	103.7	.249	68.5	35.2	+ 408	.100
+113.8	72.9	.282	64.6	8.3	+ 945	.100

(B.M.) = W/2 (X - KL/2)

X = distance of Wt to midships

$$\sigma_{KPSI} = \frac{(B.M.) \times 2.240}{I/Y}$$

L = ship length

K = form factor

Negative Δ(B.M.) indicate decrease in hogging moment

W = change in weight Ve^{+} ADDED Ve^{-} REMOVED

Table A2-IX
Stress Variations For Conditions I Through IV

CONDITION	STRESS CHANGE (KPSI)
I → II	.149
I → III	1.603
I → IV	1.503
II → III	1.454
II → IV	1.354
III → IV	.100

Table A2-X
Raw Data and Measured Stress All Conditions

DATE TIME WEATHER CONDITION	10/4/68 2400 Dense O'Cast I	10/7/68 1300 Broken II	10/9/68 0017 Rain III	10/9/68 1430 Rain IV
A. Raw Data				
Strain Indicator (microinches)	0(-) 525	0(-) 510	0(-) 450	0(-) 455
Stress Meter Units	-2	+3	+10	+11
Stress Meter Cal. = 10,000 PSI	80	80	80	80
Magnetic Tape Readout	-.25	+1.75	+5.0	+5.5
Magnetic Tape Cal. = 10,000 PSI	32.25	32.0	3215	32.5
(Oscillograph paper divisions from nearest zero & Ref.)				
B. Raw Data Referred to Initial Condition				
Strain Indicator (microinches)	0	+15	+75	+70
Stress Meter Units	0	+ 5	+12	+13
Magnetic Tape Readout (divisions)	0	+ 2	+5.25	+5.75
C. Stress Data Referred to Initial Condition (PSI)				
Strain Indicator (x 20.3)	0	+305	+1523	+1421
Strain Meter Units (x 125)	0	+625	+1500	+1625
Magnetic Tape Readout	0	+625	+1616	+1770

Table A2-XI
Comparison of Measured and Computed Stress Variations Between Conditions

CONDITIONS	I to II	I to III	I to IV
A. Measured			
Strain Indicator	+305	+1523	+1421
Stress Meter	+625	+1500	+1625
Tape Recorder	+625	+1616	+1770
B. Computed	149	1603	1503

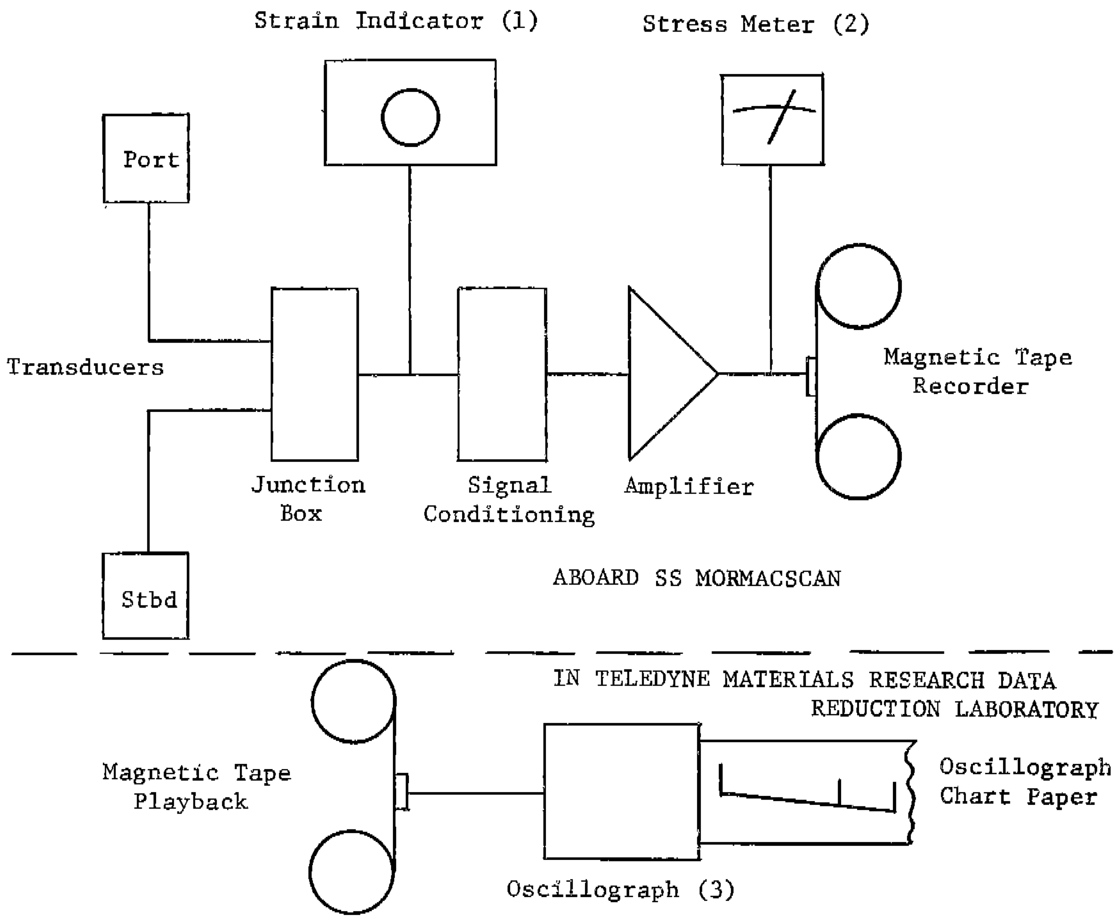

Fig. A2-1. Instrumentation System Showing Three Sources of Calibration Data

$$\sigma = \varepsilon_r E$$

$$\varepsilon_r = \varepsilon_i' \frac{GF_i}{GF_{rb}} \cdot \frac{1}{N}$$

$$\sigma = \left[\varepsilon_i' \frac{GF_i}{GF_{rb}} \cdot \frac{1}{N}\right] E$$

$$\sigma = \varepsilon_i' \frac{2.00}{1.48} \cdot \frac{1}{2} \cdot 30 \times 10^6$$

$$\sigma = \varepsilon_i \cdot 20.3 \text{ psi}$$

where σ = bending stress, psi

E = Young's modulus, 30×10^6 psi

ε_i' = strain indicated on strain indicator, inches/inch

ε_i = strain indicated on strain indicator, microinches/inch

GF_i = Gage Factor set on strain indicator

GF_{rb} = Effective Gage Factor for stress of two-element bending stress gages

N = number of active arms in bridge

Fig. A2-2. Derivation of Stress/Strain Indicator Reading

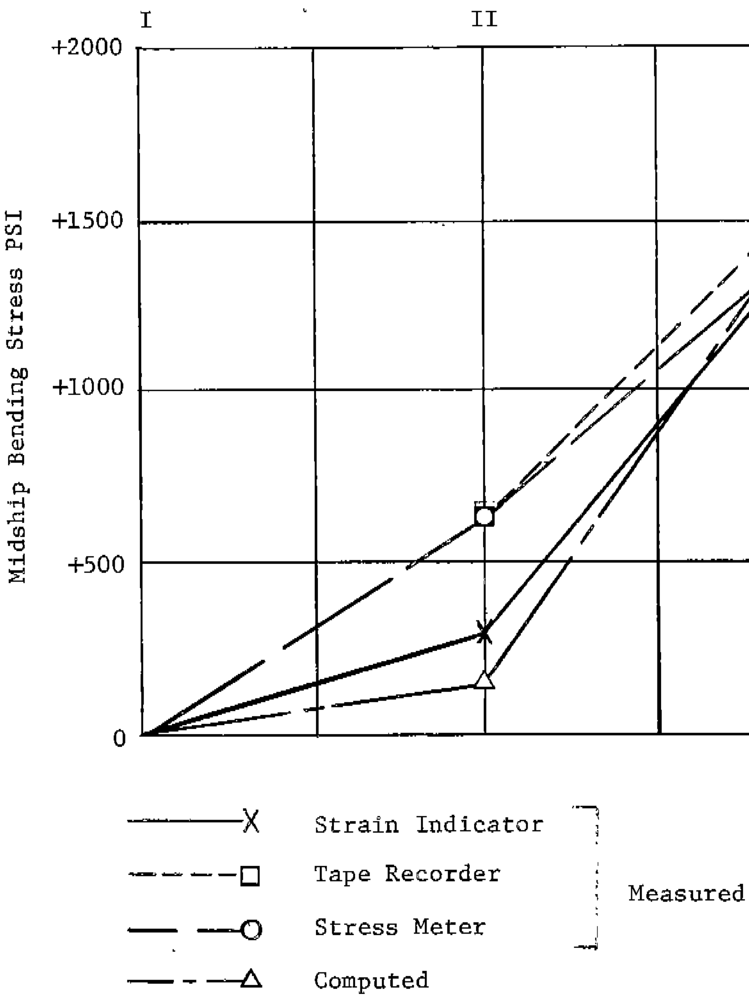

Fig. A2-3. Graph of Measured and Computed Stress Variations

I. 10/4/68 2400 - Temp 43 Dense Overcast - Underway Seaway -

II. 10/7/68 1300 - Temp 57 Broken - Underway Lake Huron - Full Speed

III. 10/9/68 0017 - Temp 52 Rain - Docked Duluth

IV. 10/9/68 1439 - Temp 53 Rain - Docked Duluth

APPENDIX B

A Guide to Tabulated Data

A two-letter alphabetic code is assigned each pass of valid data. These code letters are listed in Tables I, II, and III of this Appendix. Sample computer printouts from the 30th voyage of CALIFORNIA BEAR and the 30th voyage of MORMACSCAN are shown as Appendix B, Figures I and II. An explanation of the abbreviations used in the headings of these sheets are listed in Appendix B, Table IV.

Copies of any of the other computer printouts may be obtained through the Secretary, Ship Structure Committee or by contacting the investigator.

Table B-1
S.S. California Bear Index to Tabulated Data

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TABLE I

S.S. CALIFORNIA BEAR
INDEX TO TABULATED DATA

Identification	Ship Code	Tape Channels	Number of Intervals
GA	25 CB1	3 AVG	25
GB		4 AVG	14
GC		7 AVG	29
GD		8 AVG	7
GF	26 CB1	3 AVG	48
GG		4 AVG	13
GH		7 AVG	9
GI		8 AVG	12
GJ		11 AVG	17
GK	27 CB1	3 AVG	70
GL		4 AVG	39
GM	28 CB1	3 AVG	22
GN	29 CB1	3 AVG	44
GO		4 AVG	12
GP		7 AVG	59
GQ	30 CB1	3 AVG	38
GR		4 AVG	59
GS		7 AVG	57
CT	31 CB1	3 AVG	57
GU		AVG	41
GV	32 CB1	14 AVG	42
GW		12 AVG	16
GX		11 AVG	9
GY		3 AVG	12
GZ		4 AVG	18
IA		7 AVG	18
IB	33 CB1	7 AVG	66
IC		8 AVG	39
ID	34 CB1	3 AVG	38
IE		4 AVG	14
IF		7 AVG	11
IG		8 AVG	6
IH		14 AVG	59
II	35CB1	3 AVG	10
IJ		4 AVG	16
IK		7 AVG	26
IL		8 AVG	8
IM		11 AVG	13
IN		12 AVG	9
IO		14 AVG	20
IP	36CB1	3 AVG	69
IQ		4 AVG	55
IR	37CB1	3 AVG	62
IS		7 AVG	54

Table B-II
S.S. Mormacscan Index to Tabulated Data

Identification	Ship Code	Tape Channels	Number of Intervals
FA	27 MMS1	1 AVG	43
FB	28 MMS1	1 AVG	67
FC		3 AVG	54
FD*	29 MMS1	1 AVG	37
FE*		3 AVG	15
FF*		5 AVG	20
FG*	30 MMS1	1 AVG	53
FH*		3 AVG	23
FI*		5 AVG	12
FJ*	31 MMS1	1 AVG	30
FK*		3 AVG	20
FL*		5 AVG	21
FM	32 MMS1	1 AVG	69
FN		3 AVG	51
FO	33 MMS1	3 AVG	65
FP	34 MMS1	3 AVG	71
FQ		4 AVG	60
FR	35 MMS1	3 AVG	28
FS	36 MMS1	3 AVG	66
FT	37 MMS1	3 AVG	74
FU		4 AVG	44
FV	38 MMS1	3 AVG	77
FW		4 AVG	59

*European Voyages; All others to South America

Table B-III
S.S. Wolverine State

APPENDIX B

TABLE III

SS WOLVERINE STATE

Identification	Ship Code	Tape Channels	Number of Intervals
EA	245W1	1 Starboard	25
EA	245W1	2 Port	27
EA	245W1	1+2 P+S	25
EB	247W1	1 Starboard	44
EB	247W1	2 Port	44
EB	247W1	1+2 P+S	44
EC	247W1	4 Starboard	43
EC	247W1	5 Port	43
EC	247W1	4+5 P+S	43
ED	249W1	1 Starboard	50
ED	249W1	2 Port	50
ED	249W1	1+2 P+S	50
EE	259W2	11 Port	40
EE	259W2	12 Starboard	40
EE	259W2	11+12 P+S	40
EF	259W3	11 Port	8
EF	259W3	12 Starboard	8
EF	259W3	11+12 P+S	8
EG	261W1	11 Port	35
EG	261W1	12 Starboard	35
EG	261W1	11+12 P+S	35
EH	261W2	11 Port	34
EH	261W2	12 Starboard	34
EH	261W2	11+12 P+S	34

Table B-III. (cont.)

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TABLE III (Continued)

Identification	Ship Code	Tape Channels	Number of Intervals
EI	263W1	11 Port	74
EI	263W1	12 Starboard	74
EI	263W1	11+12 P+S	74
EJ	263W2	11 Port	31
EJ	263W2	12 Starboard	31
EJ	263W2	11+12 P+S	31
EK	263W3	11 Port	13
EK	263W3	12 Starboard	13
EK	263W3	11+12 P+S	13
EL	265W2	11 Port	29
EL	265W2	12 Starboard	29
EL	265W2	11+12 P+S	29
EM	267W1	11 New Starboard	52
EN	267W1	12 Starboard	52
EQ	271W1	11 Port	58
ES	271W2	11 Port	30
EU	273W1	11 Port	65
EW	273W2	11 Port	38
EY	277W1	11 New Starboard	74
EZ	277W1	12 Starboard	47
HA	277W2	11 New Starboard	30
HB*	279W1	11 Port	55
HC*	279W1	12 Starboard	55
HB*	279W1	11+12 P+S	55
HD*	279W2	11 Port	53
HE*	279W2	12 Starboard	53
HD*	279W2	11+12 P+S	53
HF*	279W4	12 Starboard	42

Table B-III. (cont.)
S.S. Wolverine State

Identification	Ship Code	Tape Channels	Number of Intervals
HG*	280W1	11 Port	68
HH*	280W1	12 Starboard	68
HG*	280W1	11+12 P+S	68
HI*	280W2	11 Port	53
HJ*	280W2	12 Starboard	53
HI*	280W2	11+12 P+S	53
HK*	280W3	11 Port	15
HL*	280W3	12 Starboard	15
KK*	280W3	11+12 P+S	15
HM*	280W4	12 Starboard	24
HN*	281W1	11 Spare Port	64
HO*	281W1	12 New Starboard	64
HN*	281W1	11+12 P+S	64
HP*	281W3	11 Spare Port	48
HQ*	281W3	12 New Starboard	48
HP*	281W3	11+12 P+S	48
HR*	281W4	11 Spare Port	54
HS*	281W4	12 New Starboard	54
HR*	281W4	11+12 P+S	54
HT*	281W5	11 Spare Port	14
HU*	281W5	12 New Starboard	14
HT*	281W5	11+12 P+S	14
HV	282W1	11 Port	46
HW	282W1	12 Temp. Port	46
HX	282W2	11 Port	48
HY	282W2	12 Temp. Port	48
HZ*	283W1	11 Port	64
TA*	283W1	12 Temp. Port	64
TB*	283W2	11 Port	65

Table B-III. (cont.)
S.S. Wolverine State

Identification	Ship Code	Tape Channels	Number of Intervals
TC*	283W2	12 Temp. Port	65
TD*	283W3	11 Port	65
TE*	283W3	12 Temp. Port	65
TF*	283W4	11 Port	64
TG*	283W4	12 Temp. Port	64
TH*	284W1	11 Port	73
TI*	284W1	12 Temp. Port	73
TJ*	284W2	11 Port	76
TK*	284W2	12 Temp. Port	76
TL*	285W1	11 Starboard	74
TM*	285W1	12 Port	74
TL*	285W1	11+12 P+S	74
TN*	285W2	11 Starboard	70
TO*	285W2	12 Port	70
TN*	285W2	11+12 P+S	70
TP*	285W3	12 Port	64
TQ*	285W4	12 Port	50
TR*	286W1	11 Starboard	65
TS*	286W1	12 Port	65
TR*	286W1	11+12 P+S	65
TT*	286W2	11 Starboard	70
TU*	286W2	12 Port	70
TT*	286W2	11+12 P+S	70
TV*	286W3	11 Starboard	48
TW*	286W3	12 Port	48
TV*	286W3	11+12 P+S	48

*Pacific Voyages, all others North Atlantic.

Table B- IV

Definitions for Abbreviations for Tables in Appendix B

Computer Print-Out Symbol	Meaning
IR	Interval of data on one channel of the magnetic tape
IN	Index number, from logbook
LATIT	Latitude
LONGT	Longitude
COU	Course
SS	Ship Speed
WISP	Wind Speed
WID	Wind Direction
BSS	Beaufort Sea State
WVD	Wave Direction
WVH	Wave Height
WVP	Wave Period
WVL	Wave Length
HED	Heading (WVD-COU)
IH	Output of probability analyzer proportional to greatest peak-to-trough value in data sample
NS	Total number of peak-to-trough and trough-to-peak stress variations (half cycles)= Σn_i
K	Output of probability analyzer representative of mean square value of data sample = $\Sigma n_i \ell_i^2$
XM	Maximum peak-to-trough stress = X_{max}, kpsi
E	Mean square stress, $kpsi^2$
SRTE	RMS stress = $\sqrt{E}$, kpsi.

TELEDYNE MATERIALS RESEARCH

MORMACSCAN VOYAGE 30MMS1-3 FH

NO. OF RECORD INTERVALS = 23

NOTE ** A -0. AND A 999.9 INDICATE NO LOG DATA.
A 999 AND A 99.99 INDICATE NO STRESS DATA.

IR	IN	LATIT	LONGT	COU	SS	WISP	WID	BSS	WVD	WVH	WVP	WVL	HED	IH	NS	K	XM	E	SRTE
~~1~~	~~2~~	~~47.5N~~	~~31.8W~~	~~265.0~~	~~19.0~~	~~5.0~~	~~270.0~~	~~2.0~~	~~999.9~~	~~0.0~~	~~0.0~~	~~0.0~~	~~999.9~~	~~102~~	~~463~~	~~50~~	~~8.47~~	~~6.91~~	~~2.62~~
2	2	47.5N	31.8W	265.0	19.0	5.0	270.0	2.0	999.9	0.0	0.0	0.0	999.9	65	427	33	5.40	4.94	2.22
3	3	47.4N	32.7W	265.0	19.0	8.0	110.0	2.0	999.9	0.0	0.0	0.0	999.9	63	464	38	5.23	5.24	2.28
4	4	47.2N	34.8W	250.0	19.0	35.0	245.0	6.0	245.0	4.0	4.0	8.0	-5.0	117	434	82	9.72	12.09	3.47
~~5~~	~~5~~	~~46.8N~~	~~34.8W~~	~~220.0~~	~~19.0~~	~~35.0~~	~~245.0~~	~~6.0~~	~~245.0~~	~~4.0~~	~~4.0~~	~~8.0~~	~~25.0~~	~~110~~	~~325~~	~~91~~	~~9.14~~	~~17.92~~	~~4.23~~
6	6	46.2N	35.3W	212.0	5.0	30.0	215.0	8.0	210.0	6.0	5.0	10.0	-2.0	104	322	80	8.64	15.90	3.98
7	7	46.0N	35.5W	214.0	5.0	45.0	200.0	10.0	200.0	20.0	10.0	60.0	-14.0	137	319	122	11.38	24.47	4.94
8	8	45.9N	36.2W	260.0	10.0	20.0	220.0	5.0	220.0	5.0	10.0	10.0	-40.0	101	350	63	8.39	11.52	3.39
9	11	45.6N	38.2W	260.0	10.0	30.0	270.0	7.0	270.0	6.0	8.0	10.0	10.0	113	367	78	9.39	13.60	3.68
10	12	45.2N	39.3W	260.0	13.5	15.0	280.0	6.0	270.0	6.0	8.0	10.0	10.0	102	408	84	8.47	13.17	3.62
~~11~~	~~14~~	~~45.1N~~	~~40.5W~~	~~260.0~~	~~17.0~~	~~15.0~~	~~260.0~~	~~5.0~~	~~290.0~~	~~5.0~~	~~8.0~~	~~10.0~~	~~30.0~~	~~98~~	~~392~~	~~69~~	~~8.14~~	~~11.10~~	~~3.93~~
12	15	44.9N	41.4W	255.0	19.0	25.0	160.0	6.0	180.0	5.0	10.0	15.0	-75.0	58	425	30	4.82	4.51	2.12
13	16	44.5N	43.6W	255.0	18.0	35.0	280.0	8.0	270.0	12.0	10.0	15.0	15.0	78	420	43	6.48	6.55	2.55
14	18	44.2N	44.7W	255.0	14.0	40.0	280.0	8.0	292.5	12.0	10.0	15.0	37.5	129	439	142	10.72	20.70	4.54
15	19	44.0N	46.0W	255.0	15.0	35.0	280.0	7.0	270.0	8.0	10.0	12.0	15.0	100	424	95	8.31	14.49	3.80
16	20	43.8N	46.8W	250.0	14.0	35.0	250.0	7.0	270.0	8.0	10.0	12.0	20.0	96	430	74	7.98	11.01	3.31
~~17~~	~~21~~	~~43.5N~~	~~47.4W~~	~~235.0~~	~~16.0~~	~~35.0~~	~~300.0~~	~~7.0~~	~~292.5~~	~~8.0~~	~~10.0~~	~~12.0~~	~~57.5~~	~~100~~	~~425~~	~~70~~	~~8.31~~	~~10.54~~	~~3.24~~
18	22	43.3N	48.2W	260.0	13.0	45.0	290.0	9.0	292.5	8.0	10.0	12.0	32.5	106	447	80	8.81	11.45	3.38
19	23	42.9N	49.5W	265.0	12.0	35.0	290.0	8.0	292.5	6.0	10.0	12.0	27.5	108	381	94	8.97	15.79	3.97
20	26	42.8N	50.5W	265.0	12.0	35.0	290.0	8.0	292.5	6.0	10.0	12.0	27.5	104	374	74	8.64	12.66	3.55
21	28	42.7N	51.0W	265.0	12.0	30.0	290.0	8.0	292.5	5.0	10.0	12.0	27.5	124	349	88	10.30	16.13	4.01
22	30	42.8N	51.8W	300.0	8.0	45.0	290.0	9.0	292.5	10.0	10.0	15.0	-7.5	148	292	106	12.30	23.23	4.82
~~23~~	~~31~~	~~42.8N~~	~~51.1W~~	~~310.0~~	~~4.5~~	~~35.0~~	~~310.0~~	~~9.0~~	~~292.5~~	~~10.0~~	~~10.0~~	~~15.0~~	~~-17.5~~	~~129~~	~~309~~	~~77~~	~~10.72~~	~~15.94~~	~~3.99~~

Fig. B-1
Sample Computer Readout Sheet - *Mormacscan*

TELEDYNE MATERIALS RESEARCH

CALIFORNIA BEAR VOYAGE 30CB1-3 GQ

NO. OF RECORD INTERVALS = 38

NOTE ** A -0. AND A 999.9 INDICATE NO LOG DATA.
A 999 AND A 99.99 INDICATE NO STRESS DATA.

IR	IN	LATIT	LONGT	COU	SS	WISP	WID	BSS	WVD	WVH	WVP	WVL	HED	IH	NS	K	XM	E	SRTE
1	0			999.9	-0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	999.9	4	0	0	0.16	0.00	0.00
2	1	37.2N	124.7W	251.0	21.0	15.0	180.0	4.0	180.0	3.0	5.0	25.0	-71.0	30	301	0	1.24	0.00	0.00
3	2	36.8N	126.2W	251.0	20.1	15.0	315.0	4.0	315.0	4.0	5.0	25.0	64.0	26	325	1	1.08	0.04	0.22
4	3	36.3N	128.0W	251.0	20.0	18.0	350.0	5.0	350.0	4.5	6.0	30.0	99.0	121	401	94	5.02	3.75	1.93
5	4	35.9N	129.4W	251.0	19.0	18.0	10.0	4.0	10.0	3.0	3.0	15.0	-241.0	109	389	91	4.53	3.74	1.93
6	5	35.5N	130.9W	251.0	18.9	7.0	260.0	3.0	999.9	0.0	0.0	0.0	999.9	76	378	46	3.15	1.94	1.39
7	6	35.1N	132.6W	251.0	19.7	5.0	150.0	2.0	150.0	1.0	4.0	3.0	-101.0	70	385	36	2.90	1.49	1.22
8	7	34.6N	134.0W	251.0	20.0	8.0	180.0	3.0	180.0	1.0	2.0	2.0	-71.0	64	355	23	2.66	1.03	1.01
9	8	34.2N	135.6W	251.0	19.8	12.0	185.0	3.0	180.0	1.0	2.0	3.0	-71.0	54	341	15	2.24	0.70	0.63
10	9	33.7N	137.2W	251.0	19.8	16.0	220.0	5.0	220.0	3.0	4.0	12.0	-31.0	40	370	8	1.66	0.34	0.58
11	10	39.3N	139.0W	251.0	19.0	20.0	200.0	5.0	200.0	4.0	4.0	15.0	-51.0	45	442	17	1.87	0.61	0.78
12	11	32.9N	140.3W	251.0	19.0	18.0	190.0	5.0	190.0	4.0	4.0	17.0	-61.0	76	469	49	3.15	1.67	1.29
13	12	32.6N	141.7W	251.0	19.0	26.0	210.0	5.0	210.0	6.0	5.0	20.0	-41.0	103	462	79	4.28	2.73	1.65
14	13	32.2N	143.1W	251.0	19.5	15.0	270.0	4.0	999.9	3.0	2.0	0.0	999.9	111	457	101	4.61	3.53	1.88
15	14	31.6N	144.6W	251.0	19.5	12.0	310.0	4.0	310.0	2.0	2.0	15.0	59.0	89	407	52	3.69	2.04	1.42
16	15	31.4N	146.0W	251.0	19.1	8.0	320.0	2.0	999.9	0.0	0.0	0.0	999.9	87	362	59	3.61	2.60	1.61
17	16	31.0N	147.5W	251.0	19.0	15.0	310.0	3.0	310.0	2.0	3.0	6.0	59.0	86	347	49	3.57	2.25	1.50
18	17	30.4N	148.8W	251.0	19.6	9.0	355.0	3.0	355.0	2.0	3.0	6.0	104.0	84	363	51	3.49	2.24	1.49
19	18	30.0N	150.2W	270.0	19.7	18.0	30.0	5.0	30.0	4.0	5.0	15.0	-240.0	84	369	68	3.49	2.94	1.71
20	19	30.0N	151.8W	270.0	19.5	35.0	0.0	7.0	0.0	6.0	8.0	20.0	-270.0	117	366	91	4.86	3.97	1.99
21	20	30.0N	153.2W	270.0	19.4	18.0	10.0	5.0	10.0	5.0	5.0	13.0	-260.0	97	350	53	4.03	2.42	1.55
22	22	30.0N	156.6W	270.0	19.5	15.0	20.0	4.0	20.0	3.0	4.0	10.0	-250.0	99	340	57	4.11	2.68	1.63
23	23	30.0N	158.1W	270.0	20.0	17.0	75.0	4.0	75.0	3.0	4.0	8.0	-195.0	69	310	35	2.86	1.80	1.34
24	24	30.1N	159.8W	270.0	20.0	14.0	70.0	4.0	70.0	3.0	4.0	8.0	-200.0	69	304	25	2.86	1.31	1.14
25	25	30.2N	161.4W	270.0	20.0	28.0	80.0	6.0	80.0	5.0	5.0	15.0	-190.0	69	262	18	2.86	1.09	1.04
26	26	30.1N	162.9W	270.0	20.0	21.0	85.0	5.0	85.0	4.0	5.0	15.0	-185.0	57	199	10	2.36	0.80	0.89
27	27	30.1N	164.8W	270.0	20.0	20.0	110.0	5.0	110.0	4.0	5.0	15.0	-160.0	59	154	11	2.45	1.14	1.06
28	28	30.1N	166.3W	270.0	20.0	25.0	140.0	5.0	140.0	4.0	4.0	12.0	-130.0	70	160	15	2.90	1.50	1.22
29	29	30.1N	168.0W	270.0	20.4	20.0	135.0	4.0	135.0	4.0	4.0	12.0	-135.0	78	129	15	3.24	1.86	1.36
30	30	30.4N	169.0W	270.0	20.0	20.0	155.0	4.0	155.0	4.0	4.0	12.0	-115.0	85	119	14	3.53	1.88	1.37
31	-0			999.9	0.0	0.0	0.0	-0.0	-1.0	0.0	0.0	0.0	999.9	98	148	20	4.07	2.16	1.47
32	31	30.3N	170.7W	270.0	20.7	10.0	120.0	2.0	120.0	1.0	3.0	5.0	-150.0	86	125	16	3.57	2.04	1.43
33	32	30.3N	172.2W	270.0	20.8	8.0	120.0	2.0	120.0	1.0	3.0	2.0	-150.0	85	121	20	3.53	2.64	1.62
34	34	30.3N	175.8W	270.0	20.5	10.0	180.0	2.0	180.0	1.0	2.0	0.0	-90.0	80	112	14	3.32	2.00	1.41
35	35	30.3N	177.4W	270.0	20.0	15.0	5.0	4.0	0.0	3.0	4.0	15.0	-270.0	75	121	11	3.11	1.45	1.20
36	0			999.9	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	999.9	78	152	12	3.24	1.26	1.12
37	36	30.2N	178.8W	270.0	20.5	18.0	340.0	4.0	340.0	3.0	4.0	15.0	70.0	82	224	26	3.40	1.65	1.36
38	0			999.9	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	999.9	89	265	29	3.69	1.75	1.32

Fig. B-2
Sample Computer Readout Sheet - *California Bear*

APPENDIX C

WOLVERINE STATE Gages

Prior to this report it was noticed in the data that the port gage consistently read higher than the starboard gage. The appendix to SSC 181 (reference 2) theorizes that this anomaly is caused by an unfairness in the ships side shell plating at the gage location which induces localized stresses and which can be expressed mathematically:

$$\sigma \text{ indicated} = \sigma \text{ actual } \left(1 - \frac{3\varepsilon}{t}\right)$$ where ε is the unfairness and t is the plate thickness

In order to confirm this experimentally, unfairness measurements were taken and stress gages were installed one frame aft of the permanently installed gages. At a drydocking in February 1967 simultaneous readings were taken from both the permenent and the temporary gages while the ship experienced large changes of vertical bending stress. The results are summarized below.

I. UNFAIRNESS MEASUREMENTS

Gage	Unfairness	$\frac{3\varepsilon}{t}$	$1 - \frac{3\varepsilon}{t}$	Correction Factor $\frac{1}{\left(1 - \frac{3\varepsilon}{t}\right)}$
Old Port	0.050"	.165	.835	1.20
Old Starboard	0.100"	.330	.670	1.49
New Port	0.025"	.083	.917	1.09
New Temporary Port*	0.025"	.083	.917	1.09
New Starboard	0.003"	.010	.990	1.01.

*The new temporary Port gage was added later after the new Port gage was determined to be defective.

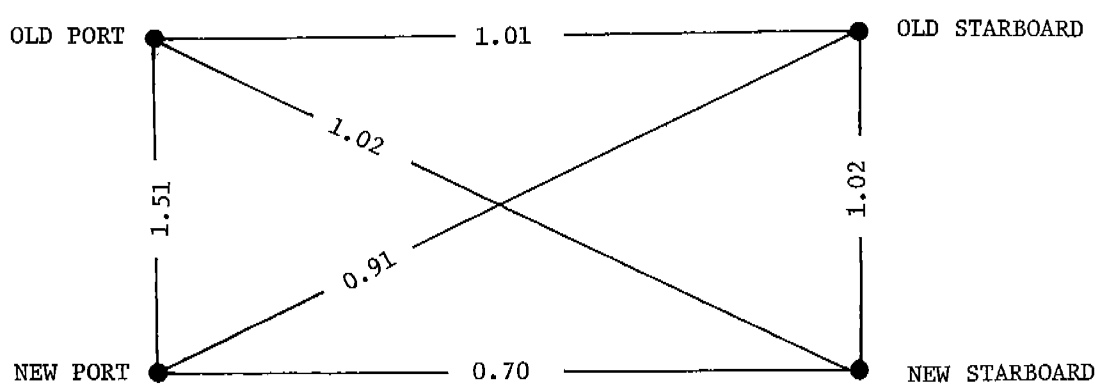
II. STRAIN MEASUREMENTS - DRYDOCK FEBRUARY 1967

Gage	Change #1	Change #2	Change #3
Old Por	129 μ in./in.	154	194
Old Starboard	102 "	126	153
New Port	97 "	118	147
New Starboard	150 "	184	222

III. CALCULATIONS

The changes measured in Section II (above) by the four strain gages are then organized into six different ratios and an average value taken. If the average is multiplied by the corresponding correction factors in Section I (above) the result should be unity.

Ratio	Change 1	Change 2	Change 3	Average Ratio ×	Correction Factor =	Product
$\frac{OP}{NP}$	$\frac{129}{97} = 1.33$	$\frac{154}{118} = 1.31$	$\frac{194}{147} = 1.32$	1.32	$\frac{1.20}{1.09}$	1.51
$\frac{OP}{NS}$	$\frac{129}{150} = 0.86$	$\frac{154}{184} = 0.84$	$\frac{194}{222} = 0.87$	0.86	$\frac{1.20}{1.01}$	1.02
$\frac{OP}{OS}$	$\frac{129}{102} = 1.26$	$\frac{154}{126} = 1.22$	$\frac{194}{153} = 1.27$	1.25	$\frac{1.20}{1.49}$	1.01
$\frac{NP}{OS}$	$\frac{97}{102} = 0.95$	$\frac{118}{126} = 0.94$	$\frac{147}{153} = 0.96$	0.95	$\frac{1.09}{1.49}$	0.91
$\frac{NP}{NS}$	$\frac{97}{150} = 0.65$	$\frac{118}{184} = 0.64$	$\frac{147}{222} = 0.66$	0.65	$\frac{1.09}{1.01}$	0.70
$\frac{OS}{NS}$	$\frac{102}{150} = 0.68$	$\frac{126}{184} = 0.69$	$\frac{153}{222} = 0.69$	0.69	$\frac{1.49}{1.01}$	1.02



By using Latin square analysis above the NP gage is determined to be faulty while the other three gages agree with one another.

IV. CURVE CORRECTION FACTORS

In order to spare the reader any uncertainty as to which corrections have been made to which curves the following lists all WOLVERINE STATE data published together with the corrections which have been made and those which should be made.

A. SSC 164

Figure 2 - uncorrected, multiply by 1.35 to get actual RMS Stress

Figure 3 - uncorrected, multiply WOLVERINE STATE points by 1.35 to get actual RMS Stress. Combined points will also have to be recomputed.

Figure 5 - uncorrected, multiply by 1.35 to get actual maximum Peak-to-Peak (Peak-to-Trough) Stress

Figure 6 - uncorrected, multiply WOLVERINE STATE points by 1.35 to get actual maximum Peak-to-Peak (Peak to Trough) Stress. Combined points will also have to be re computed.

Figure 7 - uncorrected, multiply by 1.35 to get actual RMS Stress

Figure 8 - uncorrected, multiply by 1.35 to get actual maximum Peak-to-Peak (Peak-to-Trough) Stress

Figure 13 - uncorrected, multiply WOLVERINE STATE points by 1.35 to get actual RMS Stress. Combined points will also have to be recomputed.

B. SSC 181

Figure 1 - uncorrected, multiply by 1.35 to get actual RMS Stress

Figure 3 - uncorrected, multiply by 1.49 to get actual RMS Stress

Figure 4 - uncorrected, multiply by 1.20 to get actual RMS Stress

Figure 5 - uncorrected, multiply by 1.35 to get actual RMS Stress

Figure 6 - uncorrected, multiply by 1.35 to get actual maximum Peak-to-Peak (Peak-to-Trough) Stress

Figure 8 - uncorrected, multiply WOLVERINE STATE points by 1.35 to get actual RMS Stress

Figure 9 - uncorrected, multiply port data by 1.20, starboard data by 1.49, electrical average by 1.35 to get actual RMS Stress.

Figure 10 - uncorrected, multiply WOLVERINE STATE data by 1.35 to get actual maximum Peak-to-Peak (Peak-to-Trough Stress

Figure 12 - uncorrected, multiply by 1.35 to get actual RMS Stress

C. THIS REPORT

Figures 1 & 2 - multiply by 1.08 to get actual stresses

Figures 3 - 8 - no corrections needed

Figures 9 & 10 - uncorrected, multiply by 1.20 to get actual Port Transducer Stress

Figures 11 - 12 - uncorrected, multiply by 1.49 to get actual Starboard Transducer Stress
Figures 13 - 14 - uncorrected, multiply by 1.01 to get actual new Starboard Transducer Stress
Figures 15 & 16 - no corrections needed
Figures 17 & 18 - uncorrected, multiply by 1.20 to get actual Port Transducer Stress
Figures 19 & 20 - uncorrected, multiply by 1.49 to get actual Starboard Transducer Stress
Figures 21 & 22 - uncorrected, multiply by 1.20 to get actual Port Transducer Stress
Figures 23 & 24 - uncorrected, multiply by 1.01 to get actual New Starboard Transducer Stress
Figures 25 & 26 - no corrections needed
Figures 27 & 28 - uncorrected, multiply by 1.20 to get actual Port Transducer Stress
Figures 29 - 32 - uncorrected, multiply by 1.49 to get actual Starboard Transducer Stress
Figures 33 - 62 - no corrections needed

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DOT PLOTS						
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CALIFORNIA BEAR						
MORMACSCAN						
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