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Departmental Report

Motion Responses for Selected Cargo Location Points on a T-ACS 4 Auxiliary Crane Ship in an Open Seaway

by
Kelly Cooper

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NSWCCD/MSSPO(102)-96/01 Motion Responses for Selected Cargo Locations Points on a T-ACS 4 Auxiliary Crane Ship in an Open Seaway

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This report presents predictions of ship motion responses due to the presence of waves for the T-ACS 4 Auxiliary Crane Ship, which is representative of a typical military container ship. It discusses an analytical procedure for considering a combination of sea and swell conditions. This report specifically addresses the motion responses of particular points on the ship which correspond to cargo locations. From these motion response predictions, this report develops a three-dimensional motion envelope for multiple wave headings.

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ABSTRACT

This report presents predictions of ship motion responses due to the presence of waves for the T-ACS 4 Auxiliary Crane Ship, which is representative of a typical military container ship. It discusses an analytical procedure for considering a combination of sea and swell conditions.This report specifically addresses the motion responses of particular points on the ship which correspond to cargo locations. From these motion response predictions, this report develops a three-dimensional motion envelope for multiple wave heading.

ADMINISTRATIVE INFORMATION

The work documented in this report was conducted at the Naval Surface Warfare Center, Carderock Division, (NSWCCD) for the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research. This report covers the analytical procedures for prediction of ship motion responses for the T-ACS 4 Auxiliary Crane Ship in irregular seas. This task is in support of contract work initiated under the Maritime Platforms Technology Program. Funding for this project was provided by the Advanced Research Projects Agency (ARPA) Order C251 and was performed under the NSWCCD Work Unit Numbers 1-1020-622 and 1-1020-623.

INTRODUCTION

A critical issue in cargo transfer at sea is ship motion in the presence of waves. Analysis of ship motions in wave and swell environments enables those involved in the design of cargo transfer equipment to develop design criteria. Use of computer simulated wave spectra provides predictions for ship responses to wave action. Absolute displacement of multiple points corresponding to container locations is then calculated and used to determine a range of motion for each point. From this information, a motion envelope for possible cargo locations on the ship is developed.

APPROACH

In order to provide a realistic simulation of sea environment most likely encountered during cargo transfer operations, many parameters were considered. They included, significant wave height for wind driven sea, modal period, heading and swell. Specific cargo locations were selected for examination to include the points likely to provide extreme displacement responses to wave action. Finally, the format of output was selected to provide information on absolute displacement in the longitudinal, lateral and vertical directions as well as velocities and accelerations along these three axes.

INPUT PARAMETERS

The first parameter considered was significant wave height. Significant wave height is defined as the average height of the one-third highest waves in an irregular wave train. Significant wave height is a statistical definition used to standardize references to wave height and sea state. At a specific wave height, a broad range of modal periods is possible, although a most probable peak modal period can be identified. For this analysis a significant wave height of 6.17 ft was selected. This wave height represents a NATO Standard mid sea state 4[1] for open ocean northern hemisphere. As can be seen in Table 1, at this wave height, the range of modal periods is 6.1 to 16.2 seconds, with a most probable peak modal period of 8.8 seconds.

Table 1. NATO Standard table. Annual sea state occurrences in the open ocean northern hemisphere.

Sea State	Significant Wave Height Range (ft)	Mean Significant Wave Height (ft)	Modal Period Range (sec)	Most Probable Modal Period (sec)	Sustained wind speed (kts)
0-1	0 - 0.3	0.16	-	-	0 - 6
2	0.3 - 1.6	1	4.2 - 13.8	6.9	7 - 10
3	1.6 - 4.10	2.9	5.1 - 15.4	7.5	11 - 16
4	4.10 - 8.2	6.17	6.1 - 16.2	8.8	17 - 21
5	8.2 - 13	10.7	7.2 - 16.6	9.7	22 - 27
6	13 - 20	17	9.9 - 17.4	12.4	28 - 47
7	20 - 30	25	11.7 - 19.2	15.0	48 - 55
8	30 - 46	38	14.4 - 20.0	16.4	56 - 63
>8	>45.93	>45.93	17.2 - 23.1	20.0	>63

Ocean wave spectra depend on wind velocity, duration and fetch. Wave spectra are said to be fully developed when they reach an equilibrium state independent of duration and fetch. Locally wind-generated waves are generally shortcrested waves, meaning the wave components advance in various directions, while longcrested wave components are assumed to advance in only one direction. The energy from longcrested waves impacts the vessel directly; the energy from shortcrested waves is spread out and may impact the vessel from many directions around its primary heading. Although analytical techniques to investigate the effects of shortcrested wave spectra on ship motion are being developed, information on directional spectra is limited. Therefore, with the presumption that a conservative estimate of wave effects on ship motion will result, it is customary to proceed with the assumption that the waves are longcrested[2].

Swell is spectrally defined as uni-directional, narrow banded and superimposed on a wind-generated sea. For examining ship motion responses, a swell modal period closely matching the natural roll period of the vessel is of interest, particularly where that natural roll period has a reasonable probability of occurrence[3].

T-ACS 4 CARGO LOCATION POINTS

The T-ACS 4 Auxiliary Crane Ship (Figure 1) was selected as representative of a typical military container ship. To encompass a wide range of possible absolute point motion, eight cargo locations were considered. These cargo locations (listed below in Table 2) were selected to include the extreme longitudinal, lateral and vertical cargo placement locations from the center of gravity (CG) of the vessel. Each point location represents the geometric center of a cargo container and was translated directly from a MARAD drawing of the T-ACS 4 ship.[4] Figures 2 and 3 illustrate the selected cargo location points.

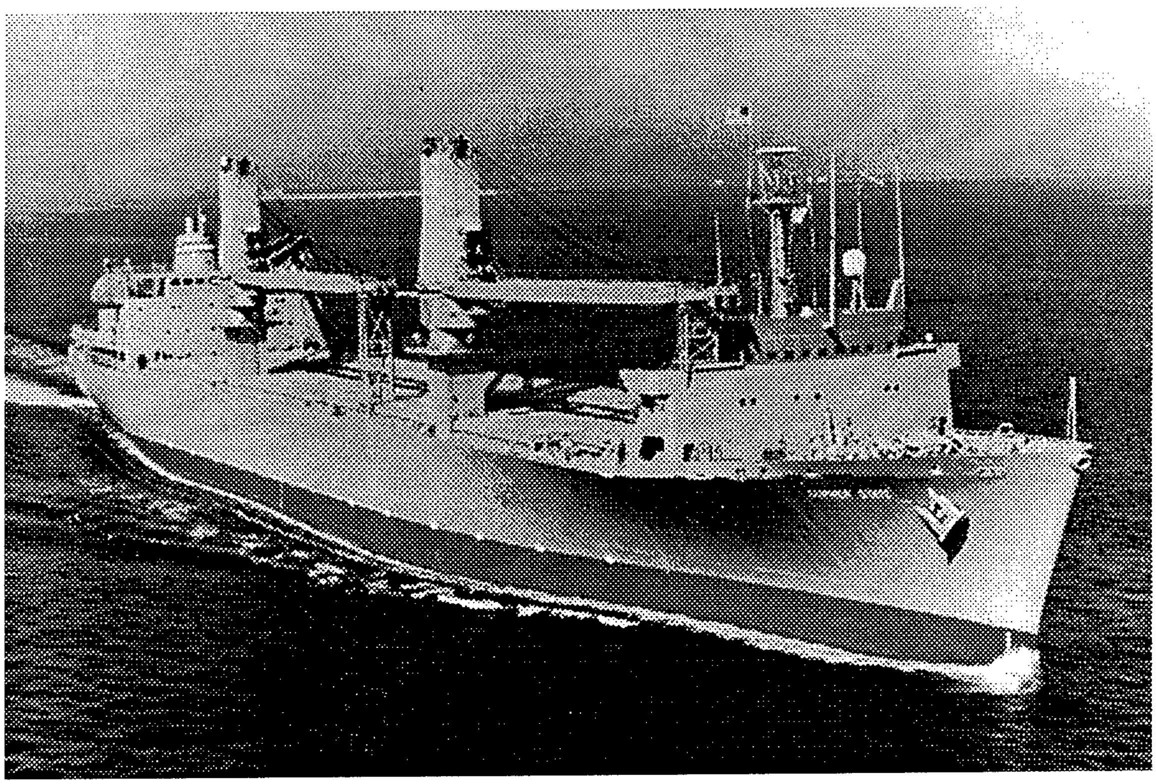
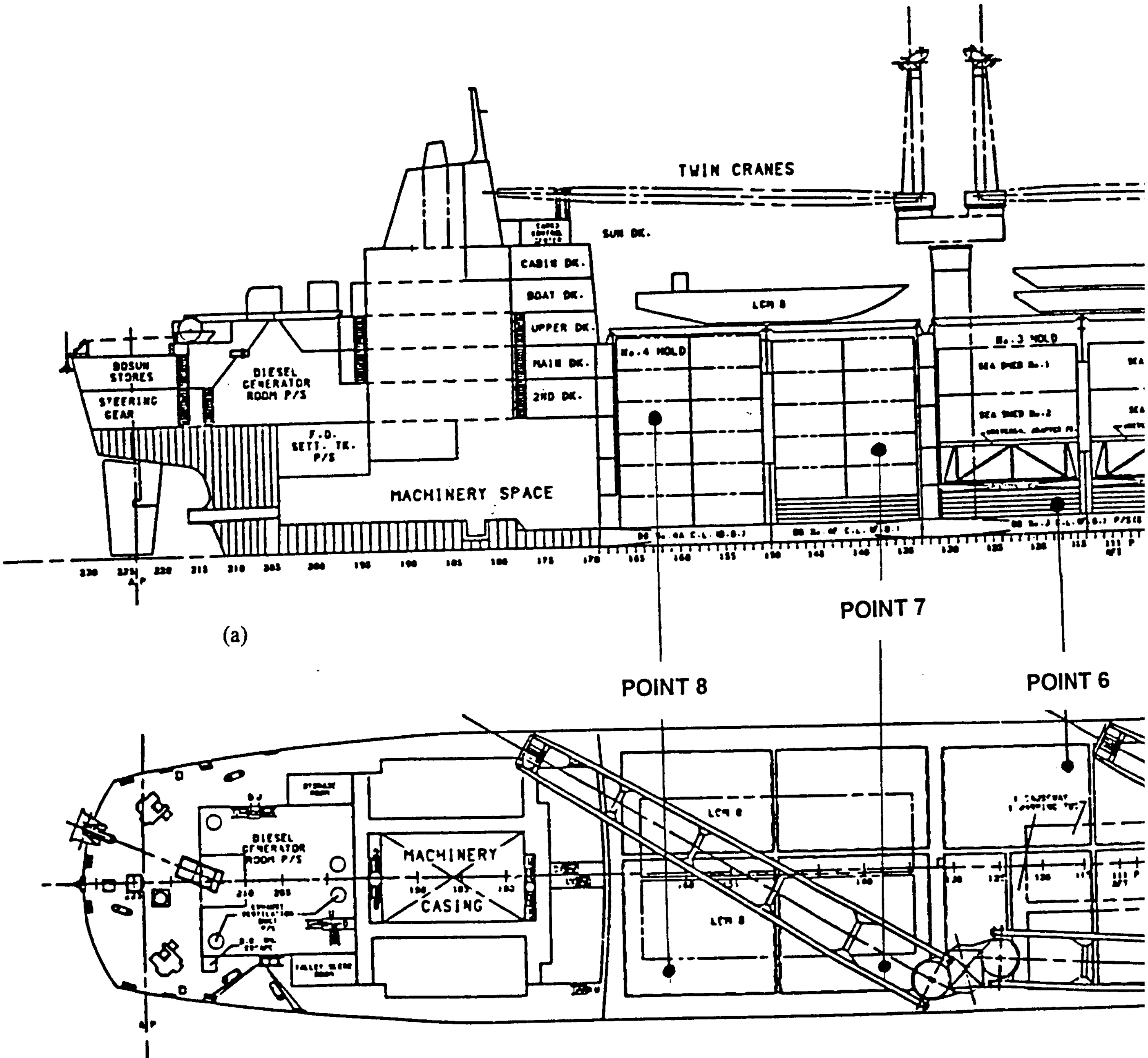


Fig. 1. USS Gopher State, T-ACS 4 Auxiliary Crane Ship.


TWIN CRANES
SUN DK.
CABIN DK.
BOAT DK.
UPPER DK.
MAIN DK.
2ND DK.
BOSUN STORES
STEERING GEAR
DIESEL GENERATOR ROOM P/S
F.O. SETT. TK. P/S
MACHINERY SPACE
No.4 HOLD
No.3 HOLD
SEA SHED No.1
SEA SHED No.2
(a)
POINT 7
POINT 8
POINT 6
DIESEL GENERATOR ROOM P/S
MACHINERY CASING
LCM 8
LCM 8
(b)

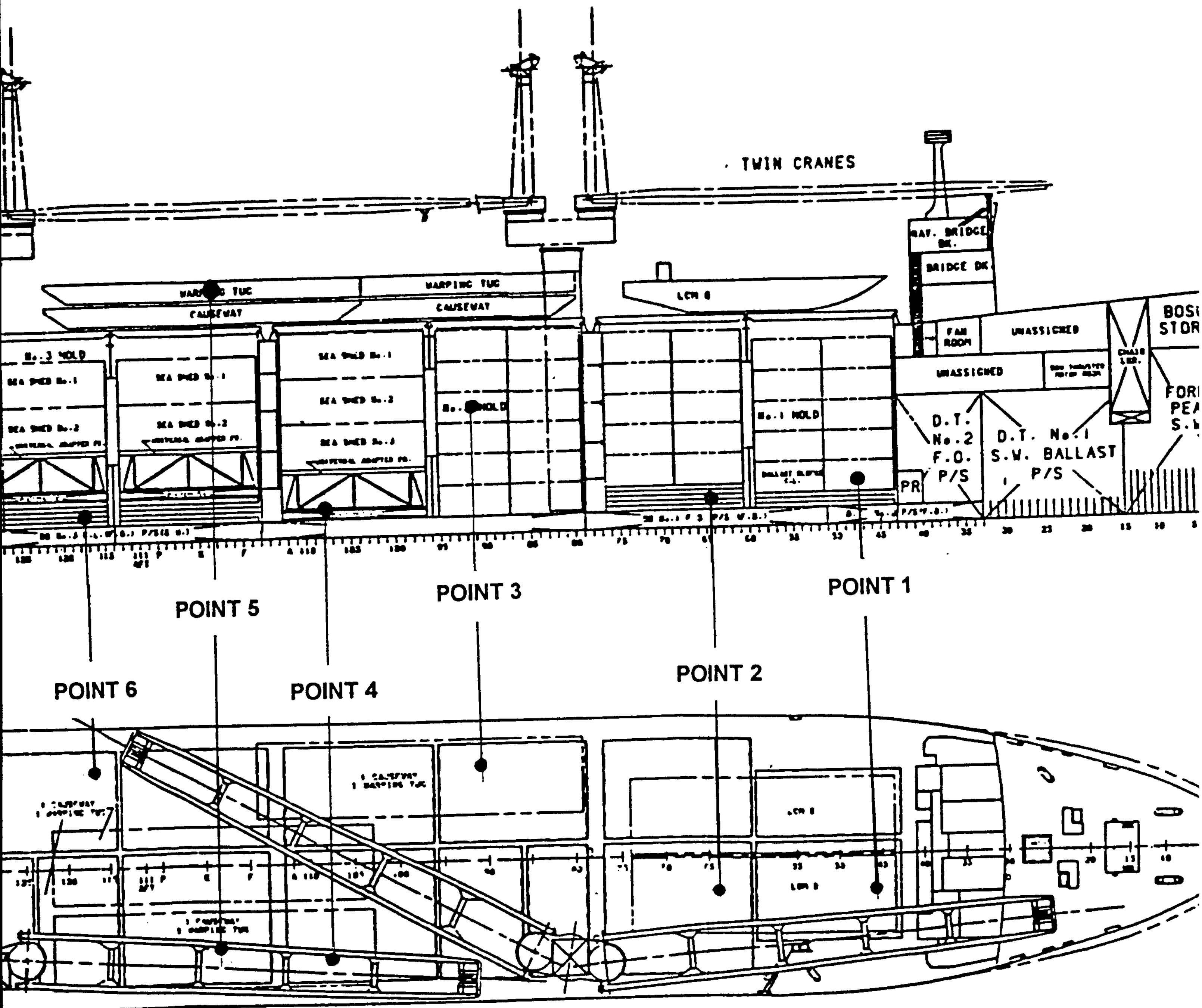


Fig. 2. T-ACS 4 sketches to illustrate the sele
cargo locations. (a) T-ACS 4 inboar
profile sketch showing longitudinal an
vertical point locations. (b) T-ACS 4
view sketch showing lateral and longi
point locations.

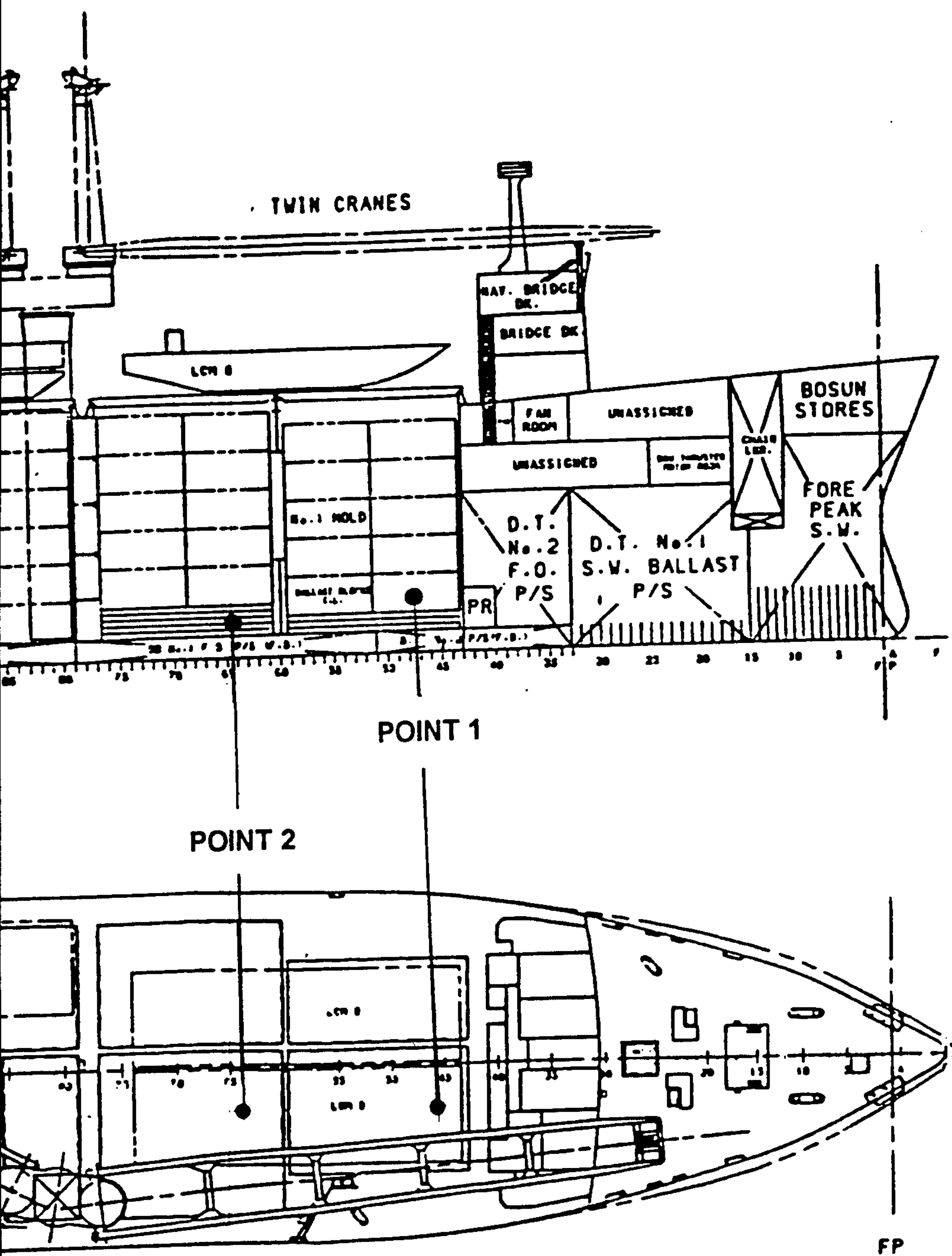


Fig. 2. T-ACS 4 sketches to illustrate the selected cargo locations. (a) T-ACS 4 inboard profile sketch showing longitudinal and vertical point locations. (b) T-ACS 4 plan view sketch showing lateral and longitudinal point locations.

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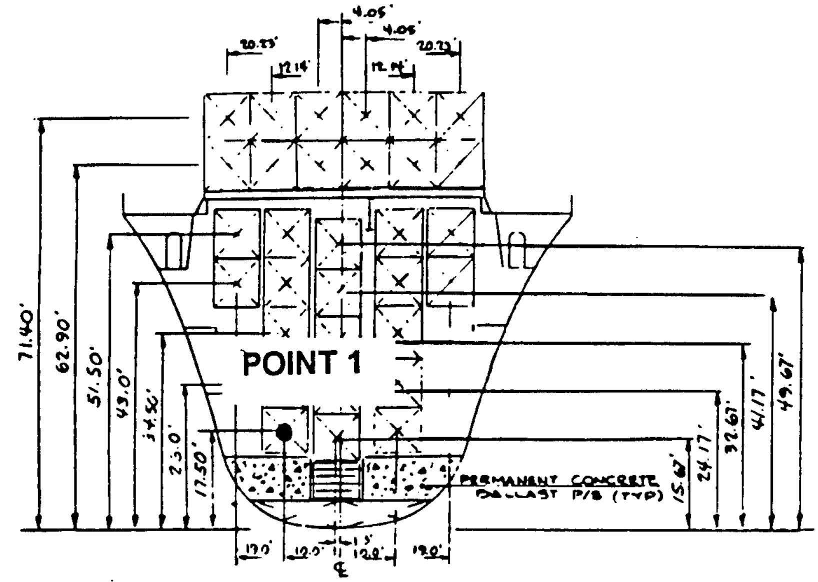

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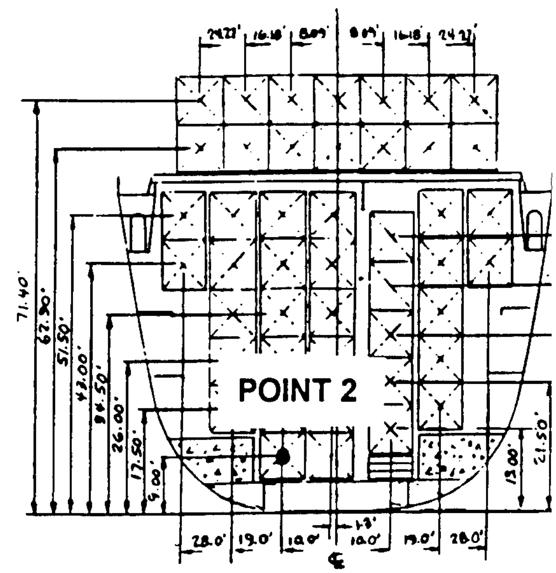

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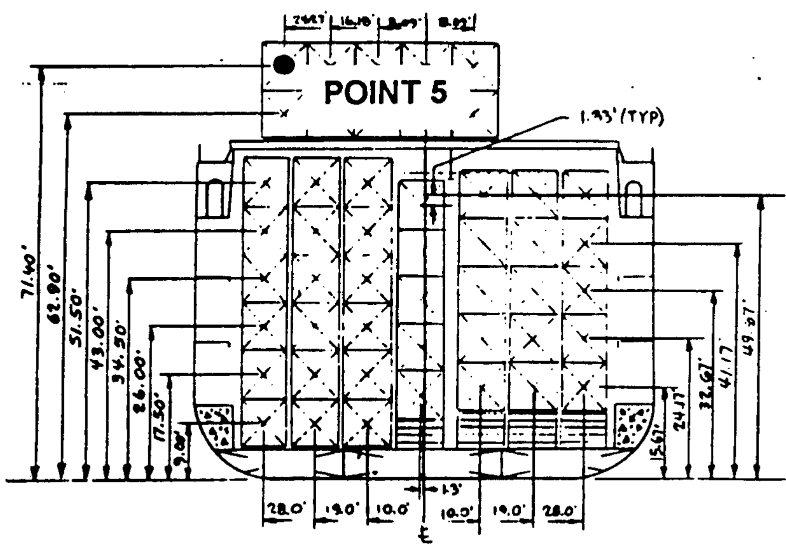

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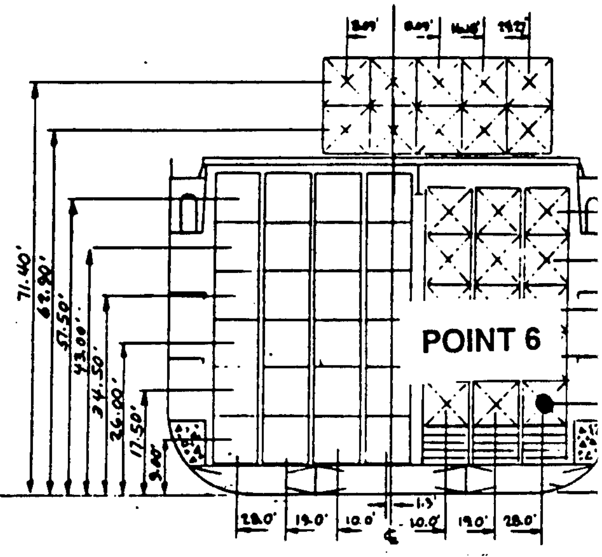

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FR - 120
LKG AFT

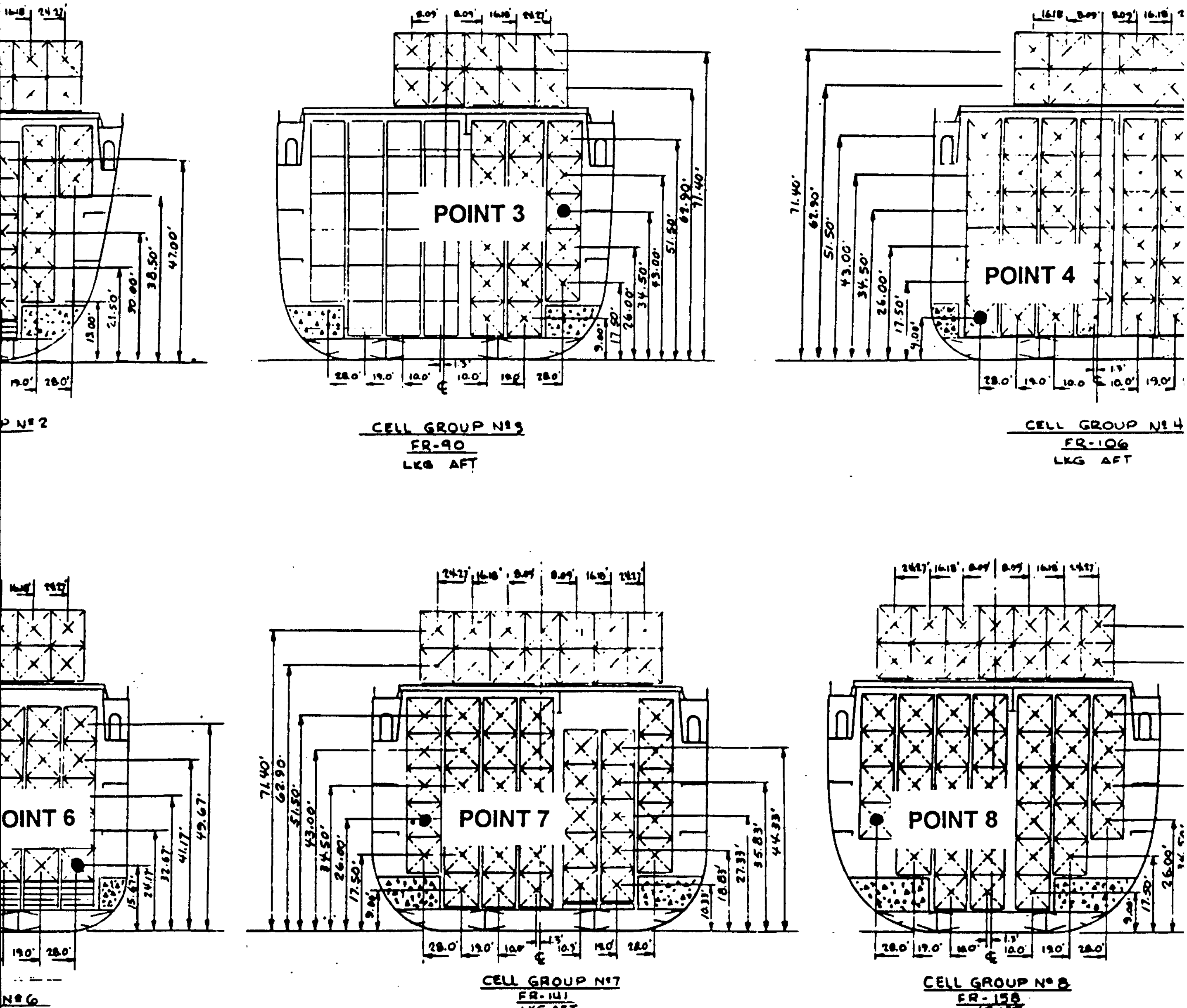

Fig. 3. T-ACS 4 cross-section views to ill
lateral and vertical locations of sel
cargo points.

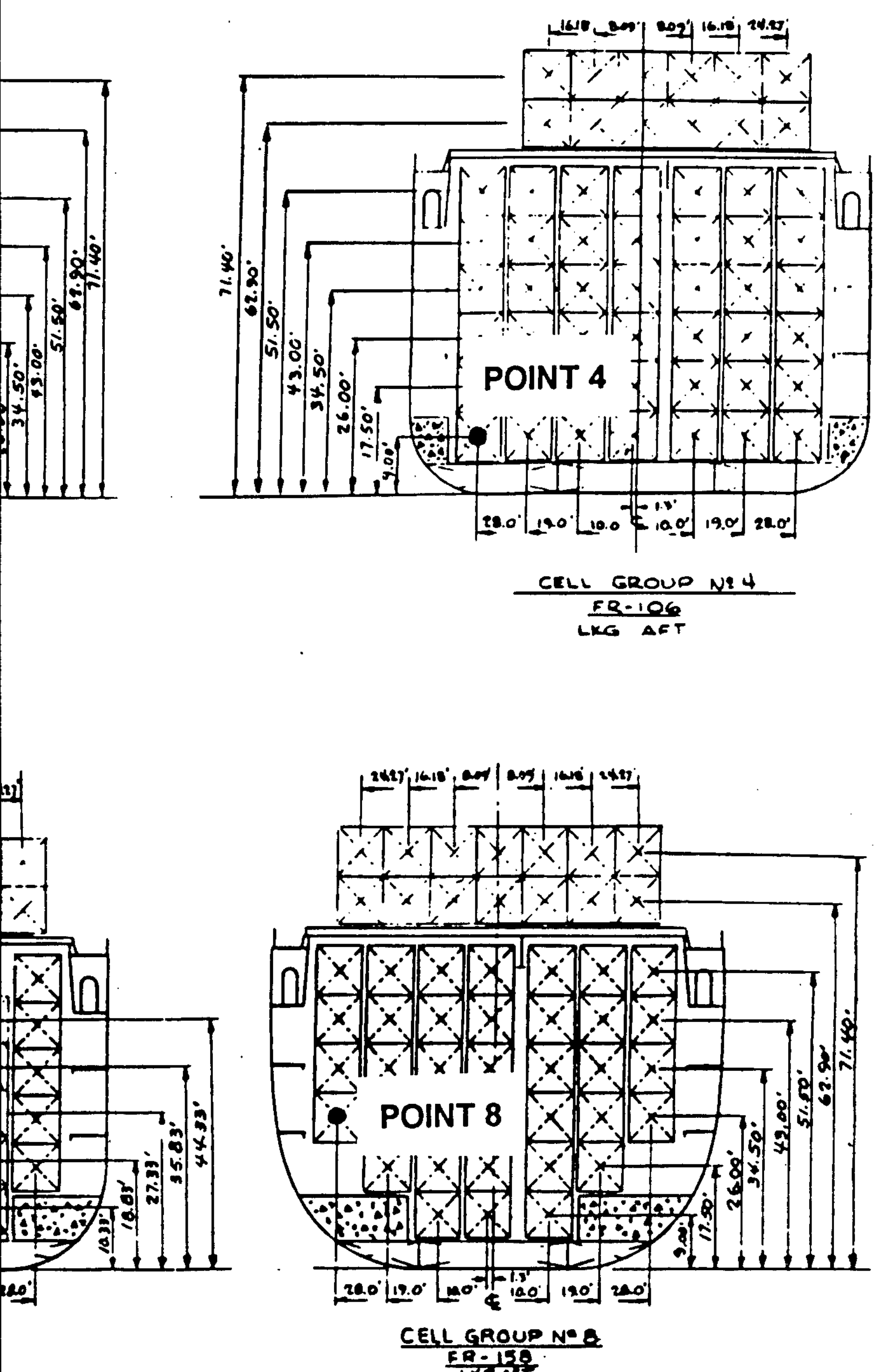

Fig. 3. T-ACS 4 cross-section views to illustrate lateral and vertical locations of selected cargo points.

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Table 2. Cargo locations.

	FRAME NO.	CELL GROUP	LONGITUDINAL	TRANSVERSE	VERTICAL
POINT 1	47	1	106	-10	17.5
POINT 2	68	2	138	-10	9
POINT 3	90	3	208	28	43
POINT 4	108	4	256	-28	9
POINT 5	H	5	284	-24.27	71.4
POINT 6	118	6	341	28	15.67
POINT 7	138	7	376	-28	26
POINT 8	162	8	437	-28	34.5

The origin of the reference system for importing these locations into the ship motion prediction computer programs is defined as the intersection of the ship's forward perpendicular (FP), centerline and baseline. The x-coordinate (longitudinal location) is measured from the FP to the aft perpendicular (AP). The y-coordinate (transverse location) is measured from the ship's centerline with y positive to port. The z-coordinate (vertical location) is measured from the baseline with z positive up. In Table 2 the units are expressed in feet.

OUTPUT FORMAT

The computer programs (discussed below) used in this analysis are able to predict ship responses in six degrees of freedom (6DOF); they are surge, sway, heave, roll, pitch and yaw. Absolute longitudinal displacement has components of surge, pitch and yaw. Absolute lateral displacement has components of sway, roll and yaw. Absolute vertical displacement has components of heave, roll and pitch. By combining the various motion components and phase angles, the computer programs are able to determine absolute displacement, velocity and acceleration in longitudinal, lateral and vertical directions of any point on the ship in an earth reference frame.

In addition the output can be expressed in the form of a significant value, statistically corresponding to significant wave height; this value is also referred to as twice the root mean square (rms) amplitude. Absolute displacement responses for each point selected can be provided as a function of heading and modal period, given a specific significant wave height. These absolute displacement responses can then be used to generate motion envelopes within a range of headings.

BACKGROUND

SHIP MOTION PREDICTION PROGRAMS

Three mooring cases for the T-ACS 4 Auxiliary Crane Ship were considered; free floating, moored to the lee side of the Mobile Offshore Base (MOB) and moored to the weather side of the MOB. For the free floating case, only the standard ship motion program (SMP) computer model was used. For the moored cases, WAMIT was used to model the interactions between the floating bodies. Then SMP was used to provide an output format consistent with the free floating case. For each of these cases, the same eight points were examined for absolute displacement, velocity and acceleration. The following is a brief description of SMP[5] and WAMIT,[6] the computer programs used in this analysis. More detailed information can be obtained from the respective user manuals for each of these programs.

SMP[5]

The Standard Ship Motion Program (SMP) was developed at the David W. Taylor Naval Ship Research and Development Center. SMP provides predictions of translational and angular ship statistical responses in irregular seas. These predictions are obtained from the product of ship Response Amplitude Operators (RAOs) and sea spectra. Ship motion predictions in irregular seas are based on two assumptions of the principle of superposition. The first assumption is that the irregular sea can be represented as a superposition or sum of simple sine waves whose amplitudes are obtained from specified spectral densities with random and uniformly distributed phases. The second assumption is that the irregular responses of a ship are the superposition or sum of the ship responses to these individual sine waves. Based on these assumptions, predictions of ship responses in regular sinusoidal waves provide the data base from which ship responses in irregular waves can be predicted.

The six degree of freedom (6DOF) transfer functions are obtained as solutions of two independent sets of three coupled equations of motion. Because the ship is assumed to have lateral symmetry, surge and the vertical mode responses of heave and pitch are solved independently of the lateral mode responses, sway, roll and yaw. The roll motion has been shown to exhibit nonlinear behavior due to viscous roll damping. This indirectly affects the motions of sway and yaw when they are coupled with roll. A subroutine in SMP calculates the nonlinear component of roll damping and incorporates these calculations into the coupled motion equations.

Seaway descriptions of significant wave height, modal period and long or short-crested response spectra are used as inputs to SMP. The 6DOF transfer functions are computed for various ship speeds, heading angles, wave frequencies and mean roll angles. A procedure has been developed to use these transfer functions in determining translational displacements of any point on the ship with respect to an earth reference frame. The motions at a point involve combinations of vertical and lateral mode responses and must be treated as nonlinear and solved for a set of mean roll angles previously calculated in the roll damping subroutine.

Output from SMP can be configured to suit the user's requirements. In this analysis the output was configured to include absolute displacements, velocities and accelerations of selected points in longitudinal, lateral and vertical directions for each heading, modal period and spectral function.

WAMIT[6]

WAMIT is a radiation-diffraction panel program for wave-body interactions at zero speed developed by the Massachusetts Institute of Technology for the linear analysis of the interaction of surface waves with offshore structures. Its computing capabilities include the removal of the effects of irregular frequencies, the analysis of second-order forces on fixed structures in bichromatic and bidirectional waves, including difference-frequency and sum-frequency components.

WAMIT was used in this analysis because it can analyze the interactions between waves and one or more bodies which interact hydrodynamically and mechanically. Each of the separate bodies may oscillate independently with up to six degrees of freedom. The bodies may be free floating, fixed, or constrained by external forces, such as mooring forces. The basic theory for multibody interactions with waves is similar to that of a single body and is described in Chapter 11 of the WAMIT User Manual. The principal extension is to increase the maximum number of degrees of freedom from six for a single body to 6N for N bodies. In this analysis two bodies are present and the maximum possible number of degrees of freedom becomes twelve, six for each body.

For the two mooring cases (T-ACS 4 moored to the lee side of the MOB and the T-ACS 4 moored to the weather side of the MOB), WAMIT provides the transfer functions for the motion of the ship. The SMP program then uses this information to determine absolute displacement, velocity and acceleration in the same output format as for the free floating ship.

MODELING OF OCEAN WAVES

As stated previously, prediction of ship motion responses to irregular seas assumes the principle of superposition in that an irregular sea can be modeled as a sum of regular seas. In SMP, regular sinusoidal spectra are used to generate a bank of RAOs, or transfer functions. Using this bank of RAOs with an input of an irregular sea spectrum, ship motion responses are determined. Selection of the appropriate input spectra becomes critical for design purposes.

Spectral Families

The complex nature of ambient ocean waves is evident. Waves are constantly changing in time and space, they are dispersive and random. In fact, their primary generating mechanism - the wind - is itself random. Therefore it is appropriate to describe waves stochastically. For a deterministic solution, the wave environment cannot be confined to a specific instant in time, but rather should be represented as a situation that might be expected over a representative period of time[2].

Several idealized wave spectral families have been devised to represent these expected situations, each of which may be useful for specific applications in ship design. The following is a discussion of the idealized spectra used in this analysis including the advantages and limitations of each.

Bretschneider[7]

The Bretschneider spectrum is a single-peaked, two-parameter spectrum which uses modal period and wave height as independent variables. The Bretschneider family therefore can be used to represent rising, falling and fully developed seas. Use of the Bretschneider family permits analysis of ship motion responses to a specific significant wave height coupled with many possible peak modal periods. The Bretschneider spectrum has limitations in that its form provides a poor fit in the presence of a sufficiently dominant swell from a distant storm. Depending on the distance from the storm, the shape of a spectrum of actual wave conditions may have a severely diminished tail. The idealized Bretschneider spectrum shape has a well defined tail which could lead to a prediction of ship motion responses to higher frequency waves much greater than would actually occur.

Ochi-Hubble[7]

Another theoretical family of spectra was developed by Ochi and Hubble (1976). The Ochi-Hubble spectrum is a double-peaked spectrum which includes components of swell and can provide a fit to most spectra derived from actual wave measurement. The Ochi-Hubble spectrum is sometimes referred to as the Ochi six-parameter spectrum. It is a modification of the two-parameter Bretschneider spectrum and includes a shape factor as a third parameter. A six-parameter spectrum is obtained by adding two of these three-parameter forms together to represent both a sea and swell component.

Ochi developed a set of 11 specific spectra using significant wave height as an independent variable. One of these 11 spectra corresponds to the most probable spectrum; the 11 spectra combine to provide a 95% probability confidence band. Coincidentally, the Ochi-Hubble sea and swell modal period of spectrum number 4 for this significant wave height corresponds to the natural roll period of the T-ACS 4 Auxiliary Crane Ship. The estimated natural roll period for the T-ACS 4 in the fully loaded departure condition is approximately 15.3 seconds. This means that there is a probability that a worst case ocean environment might be encountered. It should also be noted that the Ochi-Hubble spectrum is not a statistical representation of all seas, but it can be used to determine ship motion responses for engineering purposes.

Input Spectra

For either of these spectral families a broad range of modal periods is possible. Analysis to include all the possible combinations including swell is beyond the scope of this report. However, McCreight[3] suggests that when a general analysis is desired for operation in any sea the following three spectra should be considered:

1. A Bretschneider spectrum that is most probable for the significant wave height of interest.
2. The six-parameter Ochi-Hubble spectrum that is most probable for the significant wave height of interest.
3. A spectrum with its peak closely matching the natural roll period of the vessel. This spectrum should be considered if, in fact, there is a likelihood of its occurrence.

METHOD

The following describes the methods used to predict T-ACS 4 ship motion responses and to determine an envelope of motion that might likely be encountered during cargo transfer operations. The background section of this report already addresses much of the justification for selection of ship motion prediction programs, input spectra and cargo locations, but for clarity, some of those justifications are repeated here.

CARGO LOCATION SELECTION

The cargo locations selected for analysis are listed in Table 2. The specific locations represent extreme cargo placement locations along longitudinal, transverse and vertical axes under full load departure conditions for the T-ACS 4 Auxiliary Crane Ship. For example, cargo point 1 represents the cargo location longitudinally farthest from the center of floatation of the ship. This point will likely provide a prediction of extreme longitudinal displacement. Cargo point 5 represents the cargo location highest above the baseline of the ship. This point will likely provide a prediction of extreme lateral displacement, especially when sway motion is coupled with an in-phase roll motion. The other points provide representative cargo locations from all eight cargo cells along the ship. Since the scope of this report does not allow examination of all possible cargo locations, the points selected for investigation are those points most likely to provide extreme motion responses.

SELECTION OF INPUT SPECTRA

Although the data provided as output from the SMP and WAMIT programs included ship motion response predictions to Bretschneider spectra of 6, 7, 8, 9, 11, 13, 15 and 17 second modal periods and the 11 member Ochi-Hubble family of spectra, this report presents results from only the following input spectra:

1. A Bretschneider spectrum of 6.17 ft significant wave height and 8 second modal period.

2. A Bretschneider spectrum of 6.17 ft significant wave height and 9 second modal period.

3. An Ochi-Hubble spectrum identified as the most probable occurring at a significant wave height of 6.17 ft.

4. An Ochi-Hubble spectrum identified as coinciding with the natural roll period of the vessel corresponding to a significant wave height of 6.17 ft.

As suggested in the Background/Input Spectra section of this report a Bretschneider spectra of the most probable modal period should be considered. The most probable modal period for a significant wave height of 6.17 ft is 8.8 seconds (Table 1). Since Bretschneider data for both 8 and 9 second modal periods exists, this report presents results for both.

MOORING

For each of the spectra selected as input, three mooring cases were considered; free floating, moored to the lee side of the MOB, and moored to the weather side of the MOB.The free floating case represents the motion of the T-ACS 4 unconstrained by mooring forces and free of interactions with other bodies. For the lee side mooring case, the T-ACS 4 was moored alongside the MOB with its bow in the direction of the MOB's bow. The MOB was situated such that the waves encountered the MOB before reaching the ship. For the weather side mooring case, the T-ACS was again moored alongside the MOB with its bow in the direction of the MOB's bow. The MOB was situated such that the waves encountered the T-ACS 4 before reaching the MOB. For both mooring cases a series of springs and dashpots modeled the mooring lines and fendering; the mooring configuration was the same for both moored cases.

COMPUTER PROGRAMS

The appropriate input spectra were used with SMP and WAMIT RAO files to generate absolute displacement, velocity and acceleration data for the three different ship mooring configurations. Note that the data generated by these programs included many more spectra than this report analyzes. The results section of this report includes only the data from the Bretschneider spectra of 8 and 9 second modal periods, the Ochi-Hubble most probable spectrum and the Ochi-Hubble spectrum corresponding to the natural roll period of the T-ACS 4.

RESULTS

Appendix A contains spreadsheets of displacement, velocity and acceleration data, arranged by input spectra. Appendix B displays single amplitude graphical representation of this data. It should be noted that the graphical values may be either plus or minus from the origin.

When transferring cargo at sea, typically, a ship will be positioned such that the waves encounter the bow of the ship head on. And although the spreadsheets in Appendix A present data for headings of 0 to 180 degrees in 15 degree increments, it is not reasonable to assume that cargo transfer operations are likely to proceed in quarter or beam sea conditions. It is more probable that the ship will maneuver, whenever possible, to achieve optimal wave encounter conditions. Therefore, motion envelopes were developed for headings of 0 to 30 degrees and for a margin of error, for headings from 0 to 45 degrees.

Table 3 shows the maximum displacement values from which the motion envelopes (Appendix C) were developed. Table 4 shows the maximum acceleration values for these same headings. In the context of this report, a maximum value represents twice the rms value. It corresponds to the statistical definition of significant wave height. Theoretically, statistics predict that this value will be exceeded a certain percentage of the time depending on N, the number of waves encountered. The probability that these values will be exceeded is left for future analysis.

Table 3. Maximum longitudinal, lateral and vertical displacements. Units are in feet.

SPECTRA	MAXIMUM DISPLACEMENT			MAXIMUM DISPLACEMENT		
	Heading From 0 to 30 Degrees			Heading from 0 to 45 Degrees		
Free Floating Case	Longitudinal	Lateral	Vertical	Longitudinal	Lateral	Vertical
Ochi-Hubble Most Probable Spectra	+/-0.70	+/-0.62	+/-2.80	+/-0.79	+/-1.09	+/-3.51
Ochi-Hubble Spectra Corresponding to Natural Roll	+/-1.67	+/-2.83	+/-3.42	+/-1.67	+/-3.69	+/-3.66
Bretschneider Spectrum (8 & 9 Second Modal Periods)	+/-0.59	+/-0.53	+/-2.44	+/-0.67	+/-0.94	+/-3.16

Table 4. Maximum longitudinal, lateral and vertical accelerations. Units are in g x 100.

SPECTRA	MAXIMUM ACCELERATION			MAXIMUM ACCELERATION		
	Heading From 0 to 30 Degrees			Heading from 0 to 45 Degrees		
Free Floating Case	Longitudinal	Lateral	Vertical	Longitudinal	Lateral	Vertical
Ochi-Hubble Most Probable Spectra	0.79	0.77	3.68	0.96	1.44	4.93
Ochi-Hubble Spectra Corresponding to Natural Roll	0.94	1.62	2.71	0.94	2.16	3.21
Bretschneider Spectrum (8 & 9 Second Modal Periods)	0.665	0.694	3.445	0.96	1.321	4.746

DISCUSSION OF RESULTS

As expected, the longcrested Ochi-Hubble spectra corresponding to the ship's natural roll period provided the most extreme predictions of ship motion responses. It was surprising though, that in the moored cases for both the Bretschneider and Ochi-Hubble spectra, motion response predictions were significantly greater than in the free floating cases; the mooring forces were expected to constrain motion. Factors such as resonant horizontal motions resulting from elastic mooring may be partially responsible for the greater motion responses. It is more likely, however, that the mooring forces were not optimally modeled in WAMIT. For this reason, the results of the moored cases are considered inconclusive and are not presented. Further analysis with variations in the mooring forces are required to determine a more realistic simulation of those forces.

PROBABILITY OF EXTREMES

The results of ship motion presented here do not address the probability of their occurrence. Instead the analysis focuses on the possibility of extreme displacements occurring, and chooses those values to describe an envelope of motion. Further analysis incorporating environmental probabilities could be useful in determining a smaller but acceptable envelope of motion and corresponding system availability.

CONCLUSION

The ship motion responses presented here for the free floating case provide reasonable predictions for an envelope of motion. The moored responses, however, are questionable, not just because they are greater than the free floating responses, but because in some instances they are nearly double. Clearly more investigation of the mooring forces and how they are represented in WAMIT are necessary. With that noted, the values derived for the free floating case from the Ochi-Hubble most probable spectrum, the Ochi-Hubble spectrum corresponding to the natural roll of the vessel and the Bretschneider mean modal period spectrum, have been used to determine an envelope of motion presented in Figure C.1.

The method for determining this envelope of motion can be easily duplicated for other significant wave heights and modal periods. By choosing an appropriate Ochi-Hubble spectrum, sea and swell conditions can be combined. The T-ACS 4 auxiliary crane ship was selected as representative of a typical military container ship for this analysis, but once a particular ship has been defined as SMP or WAMIT input, its unique motion responses can be determined using the methods set forth in this report.

FURTHER ANALYSIS

Recommendations for further analysis of ship motion responses include analyzing the motion responses at other significant wave heights and modal periods using both the Bretschneider and Ochi-Hubble input spectra. Probability of occurrence statistics for wave data exist in various forms. For example in Principles of Naval Architecture (PNA)[7] there are tables of observed percentage frequency of occurrence of wave heights and periods both for specific ocean areas and worldwide. Databases such as the Spectral Ocean Wave Model (SOWM) and the Global Spectral Ocean Wave Model (GSOWM)[3] have been developed and provide a hindcasting model. By selecting a particular set of motion criteria in which cargo transfer equipment would be designed to operate and using the databases for probability of occurrence, it would be possible to predict when the equipment would be able to operate and when the equipment might fail. This information could be used to predict an availability of the cargo transfer system.

Alternatively, SMP is capable of providing a time history of absolute displacement at a point. A three dimensional plot of this information, with each point representing an instant in time, could provide an envelope of motion corresponding to extreme displacements. In addition, this graphical method would provide visualization of the frequency that these extreme displacements were occurring. It could also be seen if there was a smaller more densely populated region of occurrence, thereby addressing the probability of occurrence of motion and not simply the extremes. The drawback in this method is that theoretically there are an infinite number of time histories that produce the same spectra in the frequency domain. A large time sample would be required to gain a measure of confidence in time history results.

Lastly, since mooring has proven to be a critical issue, modeling of the mooring forces can not be arbitrary. The ship motion response prediction programs provide results which are extremely sensitive to how the mooring forces are represented. The stiffness and damping coefficients considered in the mooring cases may even change the natural frequencies of the vessel (when considered as a system including the vessel, the mooring lines and the fendering) and cause the responses to be excited at even the most probable input spectra. Investigation into accurately modeling these mooring forces in WAMIT may include model testing.

ACKNOWLEDGEMENTS

I wish to acknowledge the contributions of Dr. William R. McCreight and Mr. Tim C. Smith (both of NSWCCD), who provided vast quantities of data from SMP and WAMIT along with basic theoretical information on these programs. Similarly, the efforts of Mrs. Kathy K. McCreight (of NSWCCD) in defining the appropriate spectra for analysis is gratefully acknowledged. Lastly, I wish to express my gratitude for the direction and guidance provided by Mr. Keith R. McAllister (of NSWCCD).

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APPENDIX A

DISPLACEMENT, VELOCITY AND ACCELERATION DATA TABLES

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Table A.1. Longcrested Ochi-Hubble displacement data. Free floating case.

T-ACS 4 free floating/ Significant Wave Height 6.17/Ochi-Hubble														
LONGITUDINAL DISPLACEMENT (FT)					HEADING (DEGREES)									
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	0.53	0.55	0.61	0.68	0.67	0.44	0.08	0.54	0.72	0.69	0.59	0.52	0.49
4	Point 1	1.57	1.55	1.45	1.25	0.94	0.51	0.1	0.64	1.05	1.34	1.51	1.6	1.62
MP	Point 2	0.6	0.62	0.69	0.77	0.77	0.5	0.1	0.63	0.83	0.79	0.68	0.6	0.57
4	Point 2	1.67	1.64	1.54	1.34	1.01	0.55	0.11	0.69	1.13	1.42	1.61	1.7	1.72
MP	Point 3	0.38	0.37	0.39	0.4	0.36	0.22	0.07	0.24	0.3	0.31	0.29	0.28	0.29
4	Point 3	1.3	1.26	1.15	0.98	0.71	0.37	0.12	0.47	0.79	1.03	1.19	1.28	1.33
MP	Point 4	0.6	0.62	0.7	0.79	0.79	0.53	0.1	0.67	0.89	0.84	0.71	0.61	0.57
4	Point 4	1.67	1.65	1.55	1.36	1.04	0.57	0.1	0.71	1.16	1.46	1.63	1.71	1.72
MP	Point 5	0.37	0.41	0.5	0.64	0.76	0.61	0.18	0.61	0.54	0.39	0.28	0.23	0.21
4	Point 5	1.03	1.03	0.97	0.87	0.74	0.51	0.16	0.6	0.75	0.9	0.99	1.03	1.03
MP	Point 6	0.54	0.57	0.63	0.7	0.68	0.44	0.09	0.51	0.66	0.63	0.56	0.51	0.51
4	Point 6	1.6	1.55	1.44	1.25	0.94	0.5	0.12	0.62	1.01	1.3	1.48	1.59	1.64
MP	Point 7	0.47	0.5	0.56	0.64	0.65	0.45	0.06	0.52	0.68	0.64	0.54	0.46	0.42
4	Point 7	1.48	1.46	1.38	1.2	0.92	0.51	0.09	0.62	1.02	1.29	1.45	1.52	1.52
MP	Point 8	0.42	0.45	0.51	0.59	0.61	0.44	0.07	0.48	0.6	0.55	0.46	0.39	0.35
4	Point 8	1.39	1.37	1.29	1.13	0.87	0.49	0.09	0.59	0.96	1.21	1.36	1.42	1.42
LATERAL DISPLACEMENT (FT)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	0	0.28	0.62	1.09	1.6	1.93	1.87	1.78	1.49	1.03	0.61	0.28	0
4	Point 1	0	0.55	1.09	1.57	2	2.35	2.5	2.55	2.37	1.98	1.43	0.76	0
MP	Point 2	0	0.24	0.55	0.96	1.43	1.77	1.76	1.64	1.35	0.93	0.54	0.25	0
4	Point 2	0	0.63	1.17	1.65	2.1	2.52	2.8	2.91	2.77	2.37	1.75	0.97	0
MP	Point 3	0	0.15	0.35	0.67	1.17	1.77	2.08	1.69	1.1	0.63	0.34	0.15	0
4	Point 3	0	0.83	1.51	2.08	2.53	2.82	2.84	2.46	1.97	1.48	1.03	0.57	0
MP	Point 4	0	0.11	0.26	0.5	0.91	1.42	1.69	1.36	0.89	0.52	0.28	0.12	0
4	Point 4	0	0.65	1.17	1.65	2.1	2.54	2.84	2.82	2.59	2.16	1.58	0.88	0
MP	Point 5	0	0.19	0.41	0.76	1.31	1.96	2.36	1.96	1.28	0.73	0.4	0.19	0
4	Point 5	0	1.67	2.83	3.69	4.29	4.6	4.61	4.25	3.75	3.16	2.43	1.47	0
MP	Point 6	0	0.13	0.29	0.53	0.91	1.41	1.71	1.4	0.91	0.52	0.28	0.12	0
4	Point 6	0	0.56	1.07	1.53	1.96	2.35	2.58	2.48	2.18	1.76	1.25	0.67	0
MP	Point 7	0	0.18	0.4	0.7	1.1	1.54	1.81	1.56	1.09	0.66	0.36	0.16	0
4	Point 7	0	0.47	0.94	1.4	1.83	2.18	2.35	2.21	1.87	1.44	0.97	0.49	0
MP	Point 8	0	0.27	0.59	1	1.44	1.74	1.87	1.79	1.41	0.94	0.54	0.24	0
4	Point 8	0	0.58	1.12	1.61	2.01	2.28	2.38	2.29	2	1.6	1.12	0.58	0

MP = Most probable Ochi-Hubble spectra

4 = Ochi-Hubble spectra which corresponds to the natural roll period of the T-ACS 4

Table A.1 Continued.

VERTICAL DISPLACEMENT (FT)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	2.29	2.41	2.8	3.51	4.28	4.23	3.7	4.11	3.73	2.98	2.42	2.13	2.04
4	Point 1	3.36	3.39	3.42	3.48	3.61	3.46	3.13	3.42	3.26	3.18	3.22	3.25	3.28
MP	Point 2	1.99	2.09	2.43	3.07	3.81	3.96	3.62	3.74	3.26	2.57	2.08	1.83	1.76
4	Point 2	3.03	3.05	3.1	3.18	3.33	3.31	3.09	3.2	3	2.9	2.91	2.92	2.95
MP	Point 3	1.37	1.43	1.62	1.98	2.55	3.21	3.62	3.38	2.63	1.89	1.45	1.24	1.16
4	Point 3	2.39	2.7	3.18	3.66	4.13	4.56	4.8	4.67	4.26	3.79	3.29	2.76	2.32
MP	Point 4	1	1.05	1.23	1.65	2.43	3.26	3.34	2.53	1.65	1.12	0.89	0.8	0.8
4	Point 4	2.06	2.1	2.39	2.65	2.91	3.19	3.18	2.83	2.56	2.39	2.18	1.93	2.01
MP	Point 5	0.83	0.86	0.99	1.35	2.13	3.1	3.3	2.43	1.47	0.93	0.72	0.65	0.65
4	Point 5	1.94	1.92	2.14	2.38	2.64	2.99	3.05	2.64	2.35	2.18	1.98	1.78	1.89
MP	Point 6	0.73	0.76	0.82	0.98	1.62	2.8	3.38	2.72	1.77	1.16	0.86	0.7	0.63
4	Point 6	1.89	2.46	3.05	3.56	4	4.48	4.72	4.47	4.1	3.65	3.1	2.47	1.86
MP	Point 7	0.86	0.87	0.93	1.15	1.84	2.88	3.15	2.43	1.66	1.2	0.95	0.83	0.81
4	Point 7	1.99	1.83	2.05	2.3	2.58	3	3.11	2.78	2.51	2.29	2.05	1.82	1.97
MP	Point 8	1.3	1.32	1.45	1.71	2.24	2.94	3.08	2.83	2.37	1.88	1.53	1.33	1.28
4	Point 8	2.38	2.14	2.27	2.45	2.69	3.03	3.09	2.97	2.76	2.55	2.36	2.2	2.37

Ochi-Hubble Spectra Corresponding to the Natural Roll Period of the T-ACS 4

MAXIMUM DISPLACEMENTS		UNITS OF FEET	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	1.67	Longitudinal	1.67
Lateral	2.83	Lateral	3.69
Vertical	3.42	Vertical	3.66

Ochi-Hubble Most-Probable Spectra

MAXIMUM DISPLACEMENTS		UNITS OF FEET	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	0.7	Longitudinal	0.79
Lateral	0.62	Lateral	1.09
Vertical	2.8	Vertical	3.51

Table A.2. Longcrested Bretschneider displacement data. Free floating case.

T-ACS 4 free floating/ Significant Wave Height 6.17/Bretschneider Longcrested														
LONGITUDINAL DISPLACEMENT (FT)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	0.262	0.275	0.318	0.395	0.454	0.346	0.071	0.436	0.489	0.391	0.308	0.268	0.254
9	Point 1	0.459	0.475	0.521	0.582	0.592	0.407	0.078	0.508	0.637	0.584	0.508	0.457	0.437
8	Point 2	0.297	0.31	0.361	0.454	0.527	0.392	0.105	0.532	0.588	0.461	0.361	0.315	0.301
9	Point 2	0.514	0.532	0.586	0.661	0.68	0.464	0.109	0.607	0.748	0.674	0.582	0.523	0.501
8	Point 3	0.208	0.204	0.215	0.238	0.261	0.196	0.079	0.186	0.175	0.163	0.147	0.14	0.146
9	Point 3	0.337	0.332	0.34	0.349	0.331	0.215	0.077	0.224	0.265	0.274	0.265	0.259	0.268
8	Point 4	0.297	0.31	0.362	0.459	0.537	0.417	0.101	0.565	0.634	0.493	0.377	0.322	0.301
9	Point 4	0.514	0.532	0.589	0.671	0.697	0.49	0.105	0.644	0.801	0.715	0.605	0.533	0.501
8	Point 5	0.268	0.285	0.338	0.499	0.736	0.695	0.235	0.732	0.512	0.312	0.219	0.194	0.184
9	Point 5	0.342	0.372	0.439	0.589	0.781	0.68	0.217	0.707	0.551	0.366	0.271	0.234	0.216
8	Point 6	0.269	0.283	0.329	0.414	0.483	0.363	0.091	0.421	0.439	0.351	0.29	0.265	0.264
9	Point 6	0.47	0.487	0.534	0.599	0.614	0.417	0.098	0.486	0.58	0.536	0.482	0.452	0.45
8	Point 7	0.234	0.248	0.292	0.373	0.456	0.396	0.057	0.434	0.463	0.364	0.277	0.231	0.21
9	Point 7	0.41	0.429	0.478	0.546	0.58	0.438	0.062	0.498	0.604	0.547	0.464	0.405	0.375
8	Point 8	0.215	0.23	0.272	0.357	0.46	0.424	0.073	0.423	0.404	0.313	0.235	0.193	0.173
9	Point 8	0.368	0.389	0.437	0.509	0.562	0.448	0.071	0.468	0.529	0.473	0.4	0.347	0.318
LATERAL DISPLACEMENT (FT)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	0	0.158	0.358	0.686	1.195	1.681	1.602	1.448	1.04	0.625	0.335	0.15	0
9	Point 1	0	0.242	0.534	0.938	1.456	1.863	1.793	1.683	1.329	0.888	0.519	0.238	0
8	Point 2	0	0.146	0.319	0.599	1.058	1.537	1.529	1.333	0.936	0.558	0.302	0.138	0
9	Point 2	0	0.218	0.475	0.83	1.301	1.709	1.699	1.554	1.206	0.804	0.473	0.219	0
8	Point 3	0	0.086	0.195	0.382	0.742	1.339	1.709	1.21	0.663	0.354	0.199	0.091	0
9	Point 3	0	0.144	0.325	0.598	1.037	1.643	1.978	1.539	0.965	0.563	0.316	0.143	0
8	Point 4	0	0.082	0.166	0.289	0.584	1.121	1.46	1.026	0.563	0.295	0.162	0.077	0
9	Point 4	0	0.115	0.246	0.441	0.795	1.325	1.629	1.253	0.783	0.46	0.262	0.121	0
8	Point 5	0	0.139	0.266	0.422	0.751	1.362	1.858	1.342	0.725	0.419	0.283	0.148	0
9	Point 5	0	0.22	0.454	0.745	1.19	1.814	2.24	1.796	1.157	0.72	0.449	0.221	0
8	Point 6	0	0.079	0.176	0.317	0.582	1.068	1.457	1.056	0.577	0.293	0.151	0.066	0
9	Point 6	0	0.118	0.261	0.463	0.794	1.294	1.639	1.286	0.794	0.451	0.245	0.108	0
8	Point 7	0	0.097	0.224	0.421	0.732	1.168	1.507	1.184	0.704	0.372	0.186	0.077	0
9	Point 7	0	0.153	0.342	0.604	0.97	1.416	1.716	1.434	0.952	0.565	0.308	0.135	0
8	Point 8	0	0.146	0.334	0.623	1.025	1.375	1.534	1.415	0.957	0.546	0.282	0.122	0
9	Point 8	0	0.23	0.505	0.868	1.298	1.628	1.765	1.675	1.252	0.802	0.456	0.205	0

Table A.2. Continued.

VERTICAL DISPLACEMENT (FT)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	1.535	1.588	1.832	2.549	3.659	3.916	3.48	4.042	3.11	2.019	1.518	1.402	1.387
9	Point 1	2.041	2.129	2.441	3.157	4.131	4.243	3.751	4.259	3.553	2.599	2.083	1.89	1.845
8	Point 2	1.364	1.41	1.616	2.227	3.229	3.635	3.39	3.599	2.684	1.729	1.307	1.211	1.201
9	Point 2	1.791	1.868	2.138	2.764	3.667	3.957	3.665	3.834	3.092	2.239	1.794	1.63	1.593
8	Point 3	1.02	1.07	1.224	1.551	2.159	2.939	3.351	2.915	1.906	1.199	0.964	0.88	0.819
9	Point 3	1.276	1.324	1.496	1.844	2.456	3.221	3.65	3.3	2.39	1.666	1.321	1.154	1.069
8	Point 4	0.832	0.842	0.892	1.109	1.856	2.871	3.052	2.124	1.2	0.762	0.623	0.585	0.605
9	Point 4	0.979	1.02	1.151	1.483	2.257	3.205	3.34	2.435	1.5	1.008	0.816	0.749	0.765
8	Point 5	0.754	0.757	0.778	0.886	1.565	2.723	3.011	1.938	0.973	0.632	0.552	0.513	0.523
9	Point 5	0.852	0.879	0.969	1.213	1.949	3.043	3.295	2.28	1.293	0.848	0.692	0.629	0.64
8	Point 6	0.705	0.759	0.803	0.753	1.122	2.516	3.101	2.121	1.178	0.861	0.712	0.586	0.526
9	Point 6	0.775	0.829	0.896	0.952	1.464	2.791	3.387	2.535	1.581	1.122	0.876	0.708	0.627
8	Point 7	0.757	0.743	0.744	0.73	1.281	2.557	2.869	1.929	1.173	0.889	0.764	0.67	0.637
9	Point 7	0.871	0.869	0.915	1.034	1.658	2.842	3.141	2.273	1.499	1.121	0.926	0.81	0.78
8	Point 8	0.963	0.956	1.018	1.181	1.728	2.689	2.821	2.474	1.878	1.386	1.121	0.983	0.93
9	Point 8	1.21	1.216	1.312	1.53	2.079	2.937	3.075	2.757	2.222	1.723	1.41	1.239	1.183

MAXIMUM DISPLACEMENTS		UNITS OF FEET	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	0.589	Longitudinal	0.671
Lateral	0.534	Lateral	0.938
Vertical	2.441	Vertical	3.157

Table A.3. Longcrested Ochi-Hubble velocity data. Free floating case.

T-ACS 4 free floating/ Significant Wave Height 6.17/Ochi-Hubble														
LONGITUDINAL VELOCITY (FT/SEC)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	0.31	0.32	0.37	0.42	0.43	0.3	0.06	0.37	0.46	0.42	0.35	0.31	0.29
4	Point 1	0.65	0.64	0.61	0.54	0.43	0.25	0.05	0.32	0.47	0.57	0.63	0.66	0.67
MP	Point 2	0.35	0.37	0.41	0.48	0.5	0.34	0.08	0.44	0.54	0.49	0.41	0.35	0.34
4	Point 2	0.7	0.69	0.65	0.58	0.47	0.28	0.06	0.36	0.52	0.61	0.68	0.71	0.71
MP	Point 3	0.22	0.22	0.23	0.25	0.24	0.16	0.06	0.16	0.19	0.18	0.17	0.16	0.17
4	Point 3	0.53	0.51	0.47	0.41	0.31	0.18	0.06	0.21	0.33	0.42	0.48	0.52	0.53
MP	Point 4	0.35	0.37	0.42	0.49	0.51	0.36	0.08	0.47	0.58	0.52	0.43	0.36	0.34
4	Point 4	0.7	0.69	0.66	0.59	0.48	0.29	0.06	0.37	0.54	0.63	0.69	0.71	0.71
MP	Point 5	0.24	0.26	0.32	0.43	0.56	0.5	0.16	0.51	0.39	0.27	0.19	0.16	0.14
4	Point 5	0.42	0.43	0.41	0.4	0.43	0.39	0.13	0.42	0.37	0.38	0.4	0.41	0.41
MP	Point 6	0.32	0.33	0.38	0.43	0.45	0.3	0.07	0.35	0.42	0.38	0.33	0.3	0.3
4	Point 6	0.66	0.65	0.61	0.54	0.43	0.26	0.06	0.31	0.45	0.55	0.62	0.66	0.68
MP	Point 7	0.27	0.29	0.33	0.39	0.42	0.33	0.05	0.36	0.44	0.39	0.32	0.27	0.24
4	Point 7	0.61	0.6	0.58	0.52	0.42	0.27	0.04	0.31	0.46	0.55	0.6	0.62	0.62
MP	Point 8	0.24	0.26	0.31	0.37	0.41	0.34	0.06	0.34	0.38	0.34	0.27	0.23	0.2
4	Point 8	0.57	0.57	0.54	0.48	0.4	0.28	0.05	0.31	0.42	0.51	0.56	0.58	0.58
LATERAL VELOCITY (FT/SEC)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	0	0.17	0.38	0.69	1.07	1.4	1.34	1.22	0.97	0.65	0.37	0.17	0
4	Point 1	0	0.24	0.47	0.7	0.94	1.21	1.24	1.2	1.05	0.86	0.61	0.32	0
MP	Point 2	0	0.15	0.34	0.61	0.96	1.28	1.28	1.13	0.88	0.58	0.33	0.15	0
4	Point 2	0	0.27	0.5	0.71	0.94	1.21	1.31	1.3	1.19	1	0.74	0.41	0
MP	Point 3	0	0.09	0.21	0.41	0.74	1.2	1.47	1.1	0.68	0.38	0.21	0.09	0
4	Point 3	0	0.35	0.64	0.9	1.12	1.33	1.42	1.16	0.88	0.65	0.44	0.24	0
MP	Point 4	0	0.07	0.16	0.31	0.58	0.97	1.22	0.91	0.57	0.32	0.17	0.08	0
4	Point 4	0	0.26	0.47	0.66	0.86	1.11	1.31	1.21	1.07	0.89	0.65	0.36	0
MP	Point 5	0	0.12	0.25	0.45	0.8	1.27	1.63	1.26	0.78	0.44	0.25	0.12	0
4	Point 5	0	0.71	1.21	1.59	1.86	2.05	2.14	1.91	1.64	1.36	1.04	0.62	0
MP	Point 6	0	0.08	0.18	0.33	0.58	0.94	1.23	0.94	0.58	0.32	0.17	0.07	0
4	Point 6	0	0.23	0.43	0.62	0.81	1.03	1.22	1.08	0.91	0.72	0.51	0.27	0
MP	Point 7	0	0.11	0.24	0.43	0.7	1.03	1.29	1.04	0.69	0.41	0.22	0.09	0
4	Point 7	0	0.19	0.39	0.59	0.8	1.01	1.17	1.02	0.81	0.6	0.4	0.2	0
MP	Point 8	0	0.16	0.36	0.63	0.94	1.19	1.32	1.22	0.91	0.58	0.32	0.14	0
4	Point 8	0	0.25	0.49	0.72	0.93	1.12	1.2	1.13	0.92	0.71	0.48	0.25	0

MP = Most probable Ochi-Hubble spectra

4 = Ochi-Hubble spectra which corresponds to the natural roll period of the T-ACS 4

Table A.3. Continued.

VERTICAL VELOCITY (FT/SEC)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	1.45	1.53	1.79	2.32	2.98	3.05	2.67	3.03	2.58	1.94	1.52	1.34	1.3
4	Point 1	1.55	1.58	1.63	1.77	2.09	2.15	1.91	2.2	1.79	1.53	1.47	1.48	1.5
MP	Point 2	1.27	1.33	1.56	2.03	2.65	2.84	2.61	2.73	2.24	1.67	1.31	1.16	1.12
4	Point 2	1.39	1.41	1.46	1.59	1.88	2.02	1.88	1.99	1.6	1.36	1.32	1.32	1.34
MP	Point 3	0.9	0.94	1.08	1.34	1.77	2.29	2.6	2.36	1.73	1.2	0.92	0.79	0.74
4	Point 3	1.07	1.18	1.39	1.62	1.9	2.23	2.42	2.28	1.95	1.68	1.45	1.22	1.01
MP	Point 4	0.68	0.7	0.79	1.06	1.63	2.29	2.39	1.75	1.09	0.72	0.58	0.52	0.52
4	Point 4	0.9	0.94	1.07	1.21	1.43	1.76	1.81	1.42	1.12	0.99	0.9	0.8	0.85
MP	Point 5	0.58	0.59	0.65	0.85	1.41	2.17	2.36	1.65	0.94	0.59	0.47	0.43	0.44
4	Point 5	0.84	0.84	0.95	1.07	1.27	1.66	1.76	1.31	1.02	0.9	0.81	0.73	0.79
MP	Point 6	0.52	0.55	0.59	0.65	1.05	1.98	2.43	1.84	1.14	0.75	0.58	0.48	0.43
4	Point 6	0.81	1.05	1.3	1.52	1.72	2.13	2.35	2.05	1.8	1.58	1.33	1.05	0.77
MP	Point 7	0.6	0.59	0.62	0.72	1.2	2.03	2.26	1.66	1.09	0.79	0.64	0.56	0.54
4	Point 7	0.86	0.8	0.9	1.01	1.19	1.63	1.75	1.38	1.14	1.01	0.89	0.78	0.84
MP	Point 8	0.85	0.86	0.94	1.11	1.5	2.1	2.22	2.01	1.62	1.25	1	0.87	0.83
4	Point 8	1.06	0.96	1.02	1.11	1.3	1.69	1.75	1.62	1.38	1.21	1.09	1	1.05

MAXIMUM VELOCITIES		UNITS OF FEET/SEC	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	0.7	Longitudinal	0.7
Lateral	1.21	Lateral	1.59
Vertical	1.79	Vertical	2.32

Table A.4. Longcrested Bretschneider velocity data. Free floating case.

T-ACS 4 free floating/ Significant Wave Height 6.17/Bretschneider Longcrested														
LONGITUDINAL VELOCITY (FT/SEC)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	0.165	0.172	0.201	0.26	0.32	0.266	0.056	0.331	0.345	0.257	0.197	0.174	0.167
9	Point 1	0.266	0.276	0.309	0.361	0.391	0.291	0.059	0.363	0.421	0.36	0.301	0.268	0.256
8	Point 2	0.187	0.195	0.228	0.301	0.372	0.296	0.086	0.407	0.42	0.306	0.233	0.208	0.2
9	Point 2	0.299	0.31	0.348	0.412	0.452	0.328	0.086	0.44	0.502	0.42	0.348	0.311	0.297
8	Point 3	0.143	0.141	0.15	0.167	0.197	0.168	0.074	0.156	0.126	0.113	0.1	0.093	0.097
9	Point 3	0.203	0.2	0.208	0.22	0.227	0.168	0.068	0.164	0.166	0.164	0.154	0.148	0.154
8	Point 4	0.187	0.198	0.235	0.318	0.408	0.337	0.099	0.405	0.374	0.271	0.216	0.201	0.2
9	Point 4	0.299	0.313	0.353	0.425	0.479	0.359	0.098	0.429	0.451	0.377	0.323	0.299	0.297
8	Point 5	0.204	0.214	0.251	0.374	0.584	0.609	0.216	0.641	0.408	0.252	0.175	0.155	0.147
9	Point 5	0.234	0.251	0.296	0.417	0.597	0.575	0.196	0.602	0.419	0.267	0.191	0.167	0.156
8	Point 6	0.17	0.179	0.21	0.276	0.345	0.281	0.073	0.323	0.308	0.23	0.186	0.173	0.174
9	Point 6	0.273	0.284	0.318	0.374	0.412	0.303	0.075	0.35	0.38	0.327	0.285	0.265	0.265
8	Point 7	0.15	0.158	0.187	0.25	0.33	0.327	0.053	0.34	0.327	0.242	0.177	0.149	0.136
9	Point 7	0.238	0.25	0.284	0.34	0.391	0.334	0.051	0.363	0.4	0.337	0.273	0.235	0.217
8	Point 8	0.142	0.151	0.179	0.245	0.344	0.361	0.07	0.345	0.288	0.21	0.151	0.125	0.112
9	Point 8	0.216	0.229	0.262	0.322	0.39	0.356	0.064	0.354	0.351	0.292	0.235	0.2	0.182
LATERAL VELOCITY (FT/SEC)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	0	0.11	0.248	0.487	0.9	1.395	1.323	1.121	0.745	0.43	0.225	0.104	0
9	Point 1	0	0.149	0.334	0.611	1.016	1.424	1.359	1.214	0.891	0.564	0.317	0.145	0
8	Point 2	0	0.106	0.228	0.429	0.795	1.268	1.267	1.028	0.67	0.385	0.206	0.098	0
9	Point 2	0	0.137	0.299	0.538	0.903	1.3	1.295	1.117	0.805	0.507	0.288	0.134	0
8	Point 3	0	0.06	0.135	0.266	0.53	1.032	1.391	0.884	0.452	0.239	0.141	0.065	0
9	Point 3	0	0.085	0.193	0.365	0.668	1.151	1.462	1.039	0.604	0.34	0.192	0.087	0
8	Point 4	0	0.065	0.128	0.209	0.417	0.868	1.207	0.764	0.393	0.204	0.119	0.059	0
9	Point 4	0	0.075	0.157	0.276	0.518	0.947	1.238	0.868	0.502	0.281	0.159	0.075	0
8	Point 5	0	0.108	0.203	0.303	0.515	0.992	1.495	0.97	0.494	0.305	0.218	0.114	0
9	Point 5	0	0.134	0.268	0.434	0.719	1.195	1.61	1.178	0.696	0.424	0.273	0.138	0
8	Point 6	0	0.056	0.122	0.217	0.405	0.801	1.201	0.791	0.401	0.195	0.103	0.046	0
9	Point 6	0	0.074	0.162	0.29	0.513	0.903	1.239	0.895	0.511	0.275	0.147	0.065	0
8	Point 7	0	0.064	0.148	0.285	0.517	0.88	1.237	0.895	0.49	0.244	0.119	0.049	0
9	Point 7	0	0.093	0.209	0.38	0.637	0.989	1.286	1.004	0.618	0.346	0.182	0.078	0
8	Point 8	0	0.096	0.221	0.427	0.744	1.07	1.257	1.093	0.678	0.366	0.18	0.078	0
9	Point 8	0	0.139	0.31	0.554	0.877	1.166	1.314	1.196	0.828	0.499	0.272	0.121	0

Table A.4. Continued.

VERTICAL VELOCITY (FT/SEC)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	1.11	1.139	1.3	1.841	2.777	3.08	2.723	3.234	2.326	1.434	1.064	1.01	1.013
9	Point 1	1.348	1.398	1.604	2.153	2.997	3.195	2.824	3.281	2.548	1.735	1.348	1.24	1.221
8	Point 2	0.992	1.018	1.153	1.61	2.445	2.845	2.65	2.857	1.998	1.224	0.916	0.873	0.877
9	Point 2	1.191	1.235	1.411	1.883	2.65	2.965	2.754	2.925	2.204	1.489	1.16	1.069	1.055
8	Point 3	0.758	0.795	0.912	1.165	1.643	2.284	2.625	2.223	1.372	0.843	0.699	0.649	0.601
9	Point 3	0.872	0.91	1.036	1.299	1.776	2.396	2.733	2.394	1.616	1.071	0.86	0.769	0.713
8	Point 4	0.633	0.638	0.664	0.794	1.363	2.21	2.385	1.6	0.864	0.54	0.45	0.429	0.449
9	Point 4	0.695	0.712	0.775	0.972	1.558	2.351	2.493	1.747	1.016	0.662	0.541	0.504	0.519
8	Point 5	0.582	0.584	0.594	0.639	1.135	2.096	2.359	1.433	0.685	0.458	0.416	0.386	0.393
9	Point 5	0.62	0.63	0.668	0.789	1.325	2.231	2.462	1.604	0.847	0.557	0.473	0.435	0.442
8	Point 6	0.552	0.6	0.647	0.618	0.813	1.964	2.457	1.589	0.878	0.663	0.547	0.446	0.401
9	Point 6	0.576	0.62	0.667	0.67	0.974	2.067	2.547	1.779	1.05	0.759	0.607	0.494	0.442
8	Point 7	0.586	0.575	0.575	0.534	0.916	1.997	2.272	1.468	0.881	0.686	0.597	0.515	0.482
9	Point 7	0.629	0.622	0.638	0.666	1.103	2.102	2.359	1.616	1.021	0.774	0.654	0.569	0.542
8	Point 8	0.723	0.712	0.754	0.861	1.284	2.143	2.261	1.976	1.439	1.051	0.853	0.743	0.696
9	Point 8	0.828	0.826	0.885	1.025	1.449	2.213	2.328	2.059	1.581	1.192	0.971	0.849	0.805

MAXIMUM VELOCITIES		UNITS OF FEET/SEC	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	0.353	Longitudinal	0.425
Lateral	0.334	Lateral	0.611
Vertical	1.604	Vertical	2.153

Table A.5. Longcrested Ochi-Hubble acceleration data. Free floating case.

T-ACS 4 free floating/ Significant Wave Height 6.17/Ochi-Hubble														
LONGITUDINAL ACCELERATION (g x 100)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	0.57	0.6	0.69	0.83	0.9	0.68	0.14	0.82	0.96	0.82	0.67	0.58	0.54
4	Point 1	0.88	0.87	0.83	0.77	0.68	0.48	0.1	0.59	0.74	0.81	0.86	0.89	0.89
MP	Point 2	0.65	0.68	0.78	0.94	1.03	0.75	0.2	0.98	1.14	0.96	0.78	0.67	0.64
4	Point 2	0.94	0.93	0.9	0.84	0.75	0.52	0.14	0.7	0.84	0.88	0.93	0.96	0.96
MP	Point 3	0.43	0.43	0.46	0.5	0.52	0.41	0.17	0.39	0.38	0.35	0.32	0.3	0.31
4	Point 3	0.71	0.69	0.65	0.57	0.48	0.34	0.15	0.37	0.47	0.57	0.64	0.67	0.7
MP	Point 4	0.65	0.68	0.79	0.96	1.06	0.82	0.21	1.05	1.22	1.03	0.81	0.69	0.64
4	Point 4	0.94	0.94	0.91	0.85	0.77	0.57	0.15	0.73	0.89	0.92	0.95	0.97	0.96
MP	Point 5	0.51	0.56	0.68	0.96	1.34	1.38	0.48	1.38	0.95	0.63	0.42	0.36	0.33
4	Point 5	0.6	0.61	0.63	0.7	0.95	1.06	0.39	1.11	0.72	0.61	0.57	0.56	0.55
MP	Point 6	0.59	0.62	0.72	0.86	0.93	0.69	0.16	0.78	0.86	0.75	0.63	0.57	0.56
4	Point 6	0.89	0.88	0.84	0.78	0.7	0.5	0.13	0.58	0.69	0.77	0.84	0.89	0.91
MP	Point 7	0.51	0.54	0.63	0.78	0.9	0.81	0.16	0.83	0.91	0.77	0.6	0.5	0.45
4	Point 7	0.82	0.81	0.79	0.74	0.69	0.6	0.11	0.62	0.71	0.78	0.81	0.83	0.82
MP	Point 8	0.46	0.49	0.59	0.74	0.89	0.87	0.19	0.82	0.8	0.67	0.51	0.42	0.38
4	Point 8	0.76	0.76	0.74	0.7	0.69	0.66	0.14	0.64	0.66	0.72	0.75	0.77	0.76
LATERAL ACCELERATION (g x 100)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	0	0.33	0.77	1.44	2.39	3.51	3.35	2.75	2.04	1.32	0.73	0.33	0
4	Point 1	0	0.35	0.7	1.11	1.7	2.59	2.52	2.16	1.64	1.24	0.86	0.45	0
MP	Point 2	0	0.3	0.68	1.27	2.14	3.18	3.19	2.53	1.86	1.18	0.65	0.3	0
4	Point 2	0	0.38	0.72	1.07	1.59	2.42	2.51	2.16	1.74	1.39	1	0.55	0
MP	Point 3	0	0.18	0.41	0.81	1.54	2.71	3.57	2.34	1.37	0.75	0.42	0.19	0
4	Point 3	0	0.47	0.87	1.25	1.65	2.27	2.78	1.91	1.31	0.93	0.62	0.33	0
MP	Point 4	0	0.16	0.34	0.65	1.24	2.21	3.06	1.96	1.17	0.63	0.35	0.17	0
4	Point 4	0	0.35	0.63	0.89	1.21	1.83	2.44	1.82	1.45	1.17	0.85	0.47	0
MP	Point 5	0	0.26	0.52	0.9	1.61	2.69	3.91	2.65	1.55	0.86	0.54	0.27	0
4	Point 5	0	0.94	1.62	2.16	2.58	3.03	3.6	2.84	2.3	1.88	1.42	0.84	0
MP	Point 6	0	0.17	0.36	0.66	1.18	2.04	3.07	2.04	1.18	0.63	0.33	0.14	0
4	Point 6	0	0.29	0.56	0.82	1.14	1.67	2.36	1.72	1.25	0.94	0.66	0.35	0
MP	Point 7	0	0.21	0.47	0.86	1.44	2.25	3.19	2.29	1.42	0.79	0.41	0.17	0
4	Point 7	0	0.26	0.54	0.84	1.21	1.74	2.38	1.77	1.21	0.84	0.54	0.27	0
MP	Point 8	0	0.31	0.7	1.27	1.99	2.69	3.28	2.75	1.89	1.15	0.61	0.27	0
4	Point 8	0	0.35	0.7	1.08	1.54	2.07	2.44	2.09	1.46	1.04	0.68	0.35	0

MP = Most probable Ochi-Hubble spectra

4 = Ochi-Hubble spectra which corresponds to the natural roll period of the T-ACS 4

Table A.5. Continued.

VERTICAL ACCELERATION (g x 100)						HEADING (DEGREES)								
	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
MP	Point 1	2.99	3.13	3.68	4.93	6.69	7.15	6.19	7.24	5.72	4.05	3.08	2.75	2.68
4	Point 1	2.52	2.56	2.71	3.21	4.39	4.91	4.3	5.18	3.64	2.64	2.37	2.36	2.4
MP	Point 2	2.64	2.75	3.22	4.3	5.92	6.62	6.05	6.45	4.95	3.47	2.65	2.37	2.31
4	Point 2	2.24	2.29	2.43	2.86	3.91	4.54	4.19	4.57	3.16	2.31	2.08	2.07	2.11
MP	Point 3	1.91	2.01	2.32	2.93	3.99	5.29	6.04	5.29	3.66	2.44	1.88	1.66	1.55
4	Point 3	1.7	1.83	2.13	2.55	3.2	4.11	4.65	4.08	3.05	2.48	2.14	1.82	1.54
MP	Point 4	1.5	1.53	1.68	2.19	3.49	5.2	5.52	3.88	2.3	1.49	1.2	1.11	1.12
4	Point 4	1.42	1.48	1.67	1.91	2.52	3.63	3.89	2.68	1.76	1.42	1.26	1.15	1.24
MP	Point 5	1.33	1.34	1.42	1.76	2.98	4.92	5.47	3.59	1.94	1.22	1.02	0.94	0.95
4	Point 5	1.31	1.33	1.49	1.65	2.17	3.43	3.83	2.41	1.54	1.29	1.16	1.04	1.13
MP	Point 6	1.22	1.3	1.38	1.48	2.24	4.56	5.73	4.08	2.43	1.63	1.28	1.06	0.96
4	Point 6	1.26	1.56	1.91	2.18	2.46	3.78	4.5	3.35	2.66	2.28	1.88	1.47	1.11
MP	Point 7	1.35	1.34	1.36	1.49	2.5	4.65	5.31	3.71	2.37	1.73	1.42	1.25	1.19
4	Point 7	1.35	1.28	1.41	1.52	1.92	3.37	3.8	2.62	1.9	1.62	1.41	1.21	1.25
MP	Point 8	1.82	1.83	1.99	2.35	3.27	4.93	5.29	4.73	3.63	2.73	2.16	1.88	1.78
4	Point 8	1.68	1.56	1.66	1.83	2.33	3.64	3.84	3.45	2.62	2.13	1.85	1.64	1.66

MAXIMUM ACCELERATIONS		UNITS OF g x 100	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	0.94	Longitudinal	0.96
Lateral	1.62	Lateral	2.16
Vertical	3.68	Vertical	4.93

Table A.6. Longcrested Bretschneider acceleration data. Free floating case.

T-ACS 4 free floating/ Significant Wave Height 6.17/Bretschneider Longcrested														
LONGITUDINAL ACCELERATION (g x 100)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	0.339	0.35	0.407	0.55	0.725	0.675	0.152	0.812	0.779	0.546	0.409	0.372	0.361
9	Point 1	0.497	0.516	0.585	0.716	0.837	0.691	0.148	0.846	0.9	0.714	0.574	0.512	0.49
8	Point 2	0.382	0.393	0.459	0.633	0.839	0.724	0.229	1.001	0.957	0.656	0.49	0.45	0.44
9	Point 2	0.559	0.58	0.66	0.821	0.967	0.76	0.22	1.033	1.086	0.841	0.672	0.602	0.579
8	Point 3	0.33	0.325	0.358	0.395	0.496	0.478	0.225	0.437	0.319	0.272	0.234	0.209	0.218
9	Point 3	0.408	0.402	0.428	0.462	0.521	0.447	0.2	0.419	0.358	0.331	0.301	0.282	0.293
8	Point 4	0.382	0.39	0.457	0.634	0.855	0.813	0.239	1.063	1.037	0.705	0.51	0.456	0.44
9	Point 4	0.559	0.578	0.662	0.828	0.988	0.832	0.224	1.097	1.172	0.898	0.7	0.613	0.579
8	Point 5	0.508	0.525	0.617	0.911	1.491	1.741	0.642	1.805	1.051	0.679	0.456	0.4	0.376
9	Point 5	0.534	0.564	0.665	0.96	1.475	1.593	0.572	1.655	1.037	0.665	0.458	0.401	0.376
8	Point 6	0.347	0.364	0.428	0.589	0.791	0.712	0.187	0.797	0.69	0.485	0.39	0.374	0.377
9	Point 6	0.509	0.532	0.606	0.752	0.895	0.723	0.184	0.823	0.806	0.643	0.544	0.509	0.509
8	Point 7	0.313	0.326	0.387	0.539	0.781	0.906	0.178	0.874	0.745	0.521	0.365	0.315	0.292
9	Point 7	0.447	0.47	0.542	0.685	0.864	0.865	0.156	0.879	0.857	0.672	0.518	0.444	0.409
8	Point 8	0.142	0.151	0.179	0.245	0.344	0.361	0.07	0.345	0.288	0.21	0.151	0.125	0.112
9	Point 8	0.216	0.229	0.262	0.322	0.39	0.356	0.064	0.354	0.351	0.292	0.235	0.2	0.182
LATERAL ACCELERATION (g x 100)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	0	0.26	0.582	1.166	2.261	3.913	3.691	2.833	1.728	0.984	0.509	0.252	0
9	Point 1	0	0.31	0.694	1.321	2.363	3.718	3.523	2.889	1.943	1.176	0.639	0.301	0
8	Point 2	0	0.26	0.557	1.046	2.002	3.529	3.544	2.589	1.565	0.892	0.479	0.248	0
9	Point 2	0	0.293	0.637	1.172	2.096	3.368	3.372	2.649	1.757	1.06	0.587	0.284	0
8	Point 3	0	0.144	0.313	0.628	1.275	2.679	3.844	2.093	1.001	0.536	0.341	0.155	0
9	Point 3	0	0.173	0.386	0.751	1.442	2.735	3.717	2.299	1.232	0.677	0.399	0.181	0
8	Point 4	0	0.17	0.339	0.537	1.014	2.229	3.378	1.843	0.913	0.478	0.301	0.161	0
9	Point 4	0	0.174	0.356	0.598	1.133	2.265	3.219	1.972	1.064	0.576	0.338	0.169	0
8	Point 5	0	0.272	0.517	0.747	1.193	2.374	4.108	2.294	1.128	0.75	0.551	0.284	0
9	Point 5	0	0.291	0.569	0.882	1.458	2.625	4.019	2.562	1.398	0.871	0.594	0.303	0
8	Point 6	0	0.132	0.279	0.488	0.913	1.953	3.367	1.931	0.91	0.426	0.24	0.114	0
9	Point 6	0	0.155	0.335	0.595	1.078	2.068	3.214	2.048	1.075	0.548	0.296	0.134	0
8	Point 7	0	0.136	0.313	0.621	1.177	2.164	3.465	2.219	1.106	0.517	0.249	0.104	0
9	Point 7	0	0.181	0.412	0.773	1.359	2.278	3.319	2.324	1.302	0.682	0.348	0.148	0
8	Point 8	0	0.206	0.472	0.944	1.748	2.749	3.529	2.784	1.549	0.803	0.373	0.168	0
9	Point 8	0	0.272	0.615	1.145	1.934	2.789	3.385	2.842	1.777	1.01	0.521	0.231	0

Table A.6. Continued.

VERTICAL ACCELERATION (g x 100)						HEADING (DEGREES)								
MODAL PERIOD	CARGO	0	15	30	45	60	75	90	105	120	135	150	165	180
8	Point 1	2.605	2.659	3.01	4.274	6.732	7.788	6.788	8.287	5.539	3.317	2.438	2.367	2.398
9	Point 1	2.926	3.015	3.445	4.746	7.003	7.786	6.829	8.149	5.862	3.764	2.851	2.676	2.667
8	Point 2	2.336	2.386	2.68	3.742	5.914	7.151	6.603	7.252	4.733	2.815	2.093	2.043	2.075
9	Point 2	2.602	2.681	3.045	4.153	6.172	7.185	6.651	7.191	5.04	3.215	2.451	2.309	2.306
8	Point 3	1.808	1.898	2.194	2.826	4.014	5.663	6.577	5.403	3.163	1.943	1.648	1.541	1.418
9	Point 3	1.954	2.047	2.348	2.984	4.162	5.743	6.613	5.602	3.538	2.264	1.855	1.693	1.566
8	Point 4	1.532	1.544	1.592	1.844	3.198	5.435	5.972	3.835	1.986	1.229	1.048	1.01	1.064
9	Point 4	1.604	1.629	1.726	2.094	3.484	5.569	6.016	4.034	2.223	1.415	1.176	1.112	1.156
8	Point 5	1.424	1.432	1.451	1.51	2.633	5.148	5.931	3.369	1.562	1.077	1.003	0.925	0.938
9	Point 5	1.462	1.476	1.527	1.703	2.92	5.279	5.96	3.627	1.807	1.207	1.071	0.986	1.001
8	Point 6	1.366	1.496	1.654	1.673	1.934	4.911	6.296	3.878	2.21	1.666	1.342	1.085	0.977
9	Point 6	1.38	1.499	1.634	1.644	2.143	4.965	6.252	4.094	2.367	1.741	1.399	1.137	1.021
8	Point 7	1.446	1.42	1.431	1.307	2.112	5.003	5.821	3.651	2.216	1.741	1.511	1.281	1.18
9	Point 7	1.483	1.46	1.482	1.451	2.39	5.053	5.784	3.785	2.339	1.801	1.543	1.327	1.243
8	Point 8	1.755	1.723	1.828	2.063	3.081	5.504	5.896	5.169	3.62	2.633	2.126	1.828	1.695
9	Point 8	1.874	1.856	1.979	2.268	3.294	5.446	5.79	5.096	3.726	2.755	2.231	1.936	1.816

MAXIMUM ACCELERATIONS		UNITS OF g x 100	
Headings from 0 to 30 degrees		Headings from 0 to 45 degrees	
Longitudinal	0.665	Longitudinal	0.96
Lateral	0.694	Lateral	1.321
Vertical	3.445	Vertical	4.746

APPENDIX B

DISPLACEMENT CHARTS

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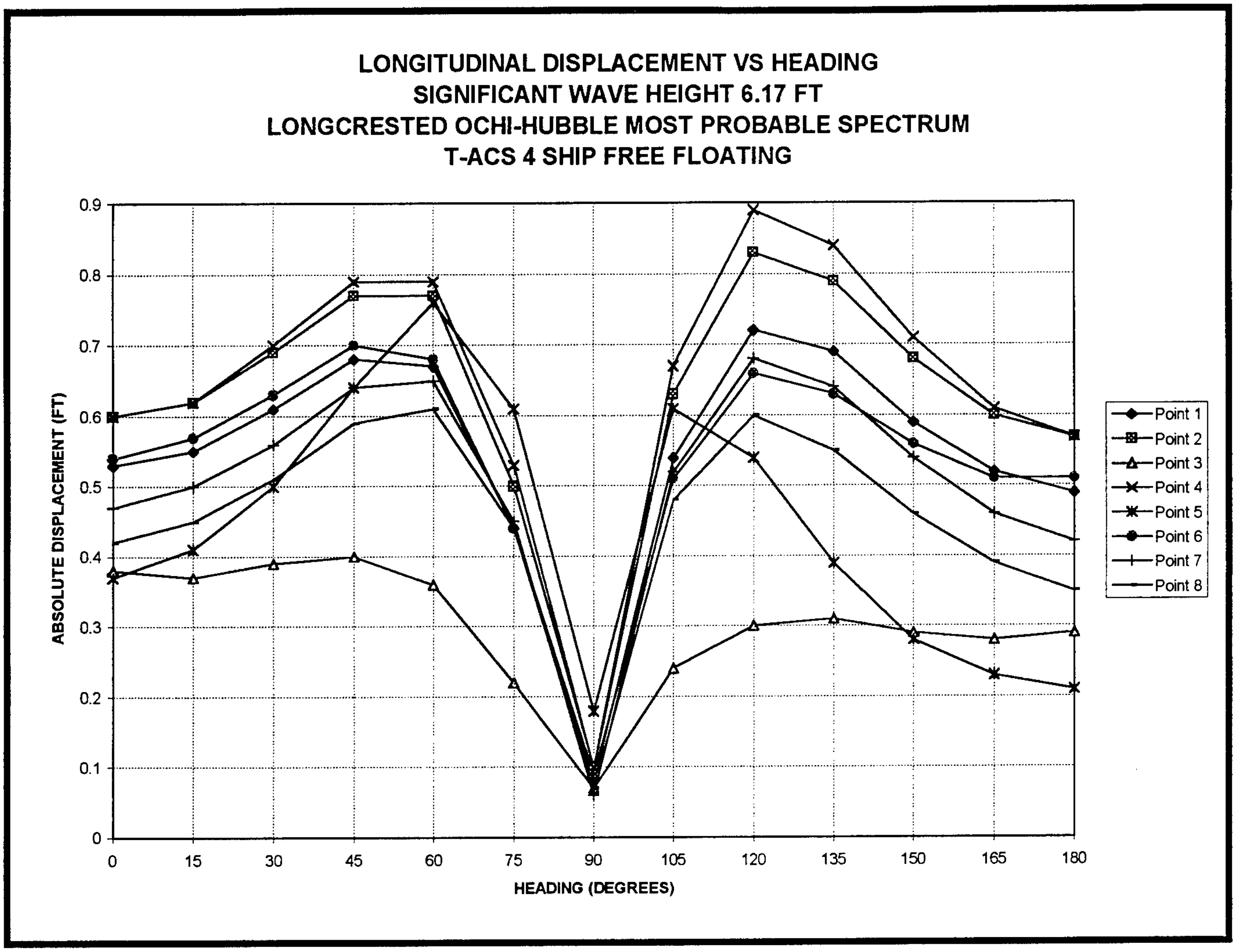

Fig. B.1. Absolute longitudinal displacement vs. heading for the most probable Ochi-Hubble spectrum. Significant wave height 6.17 ft. Free floating case.

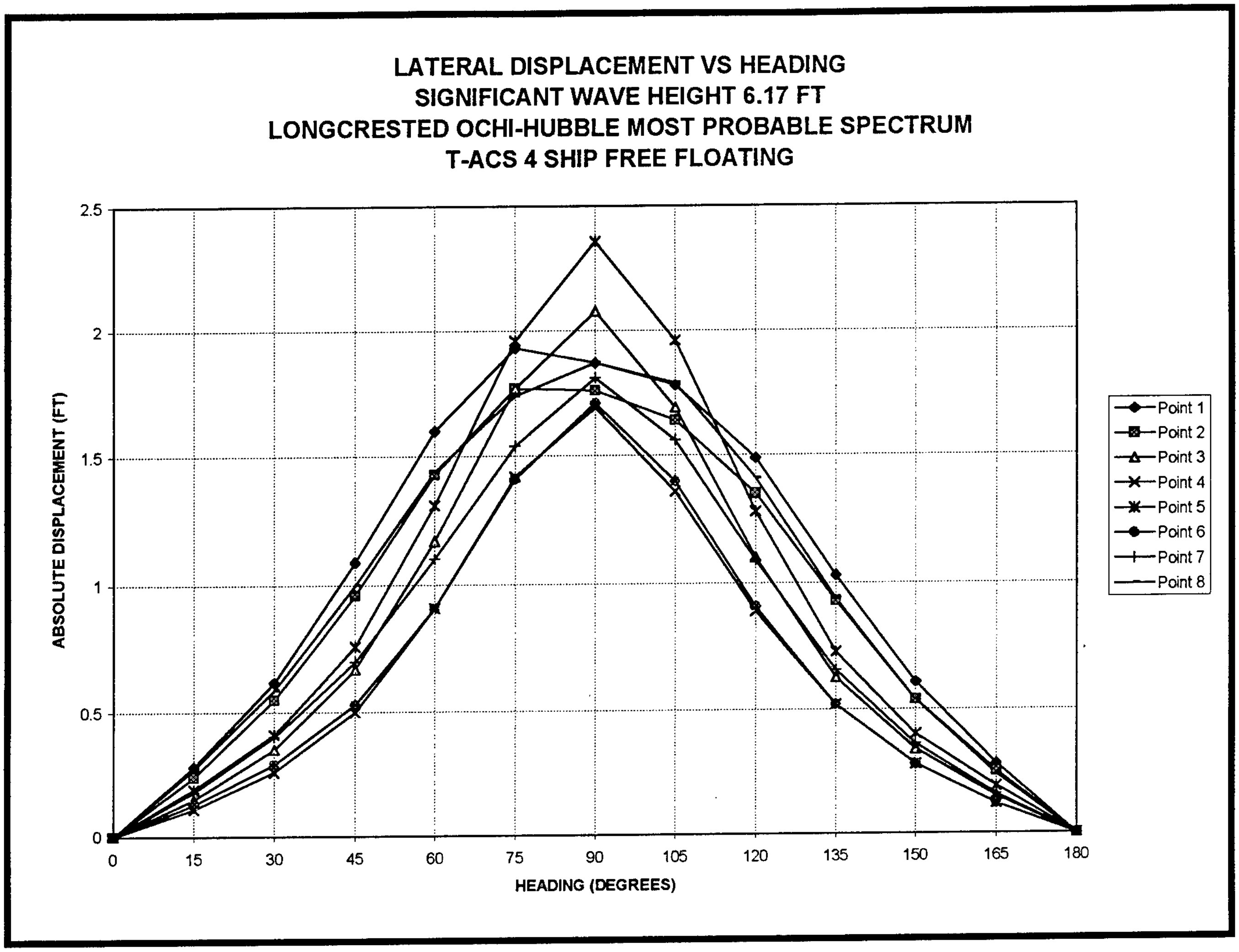

Fig. B.2. Absolute lateral displacement vs. heading for the most probable Ochi-Hubble spectrum. Significant wave height is 6.17 ft. Free floating case.

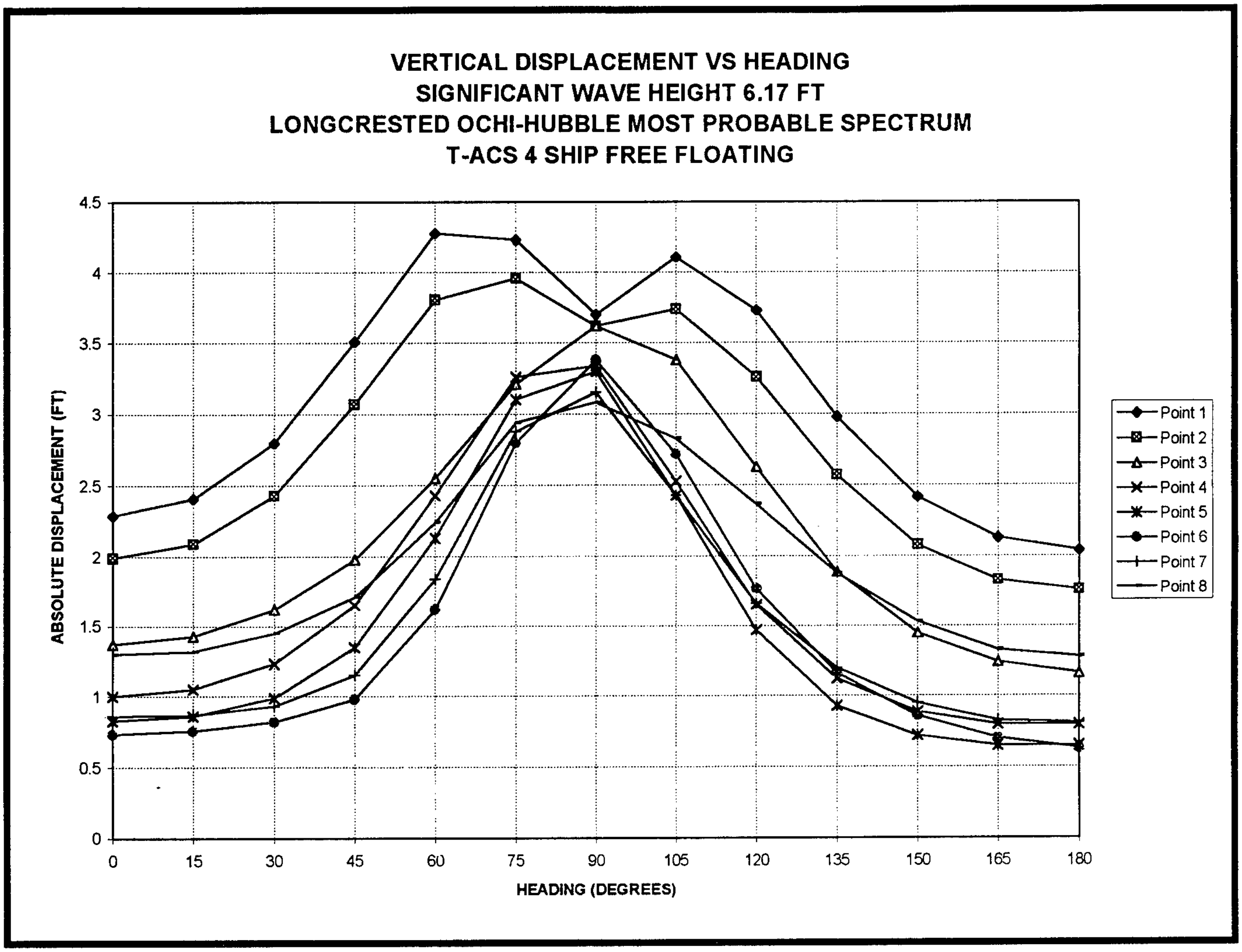

Fig. B.3. Absolute vertical displacement vs. heading for the most probable Ochi-Hubble spectrum. Significant wave height 6.17 ft. Free floating case.

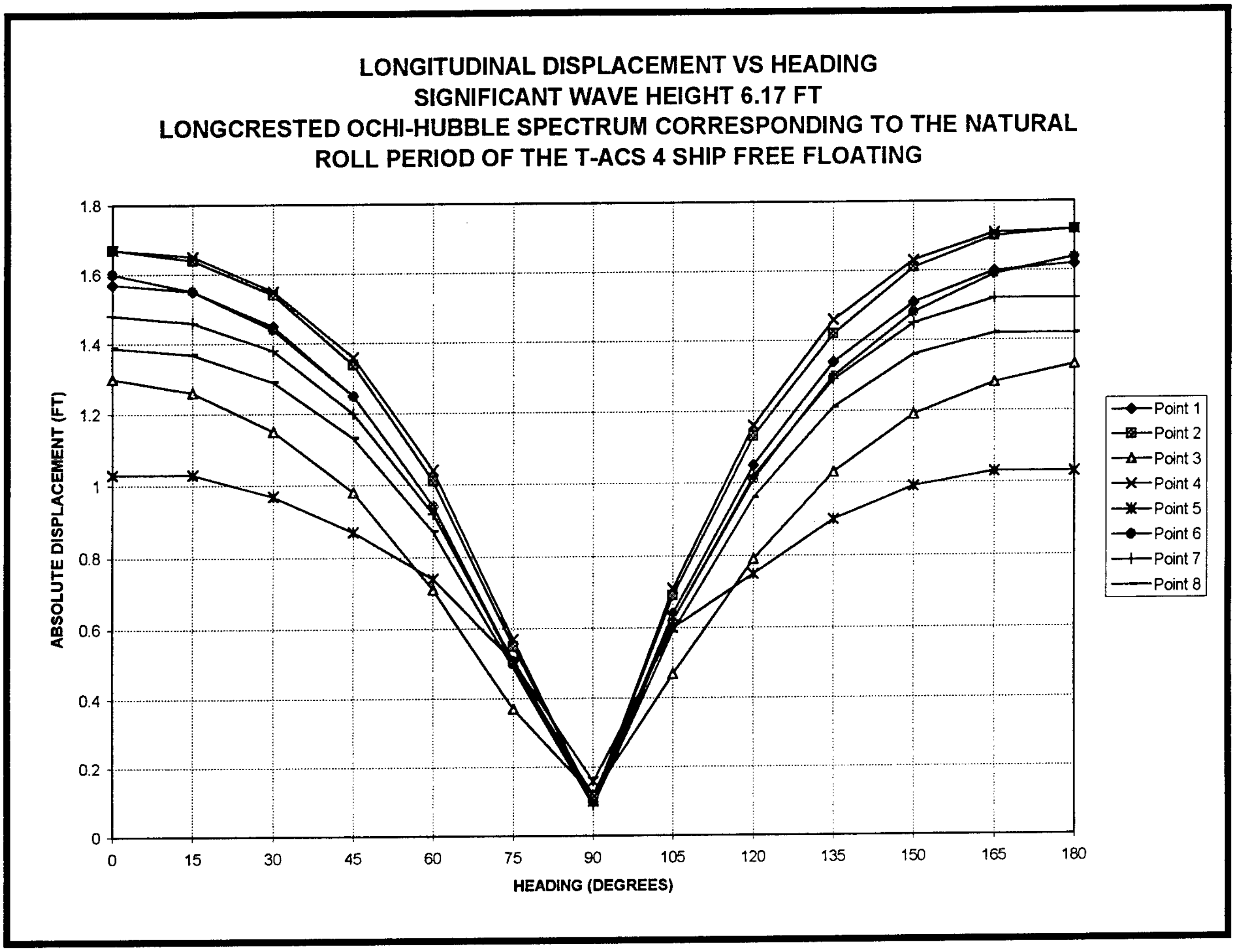

Fig. B.4. Absolute longitudinal displacement vs. heading for the Ochi-Hubble spectrum corresponding to the natural roll period of the T-ACS 4 ship. Significant wave height 6.17 ft. Free floating case.

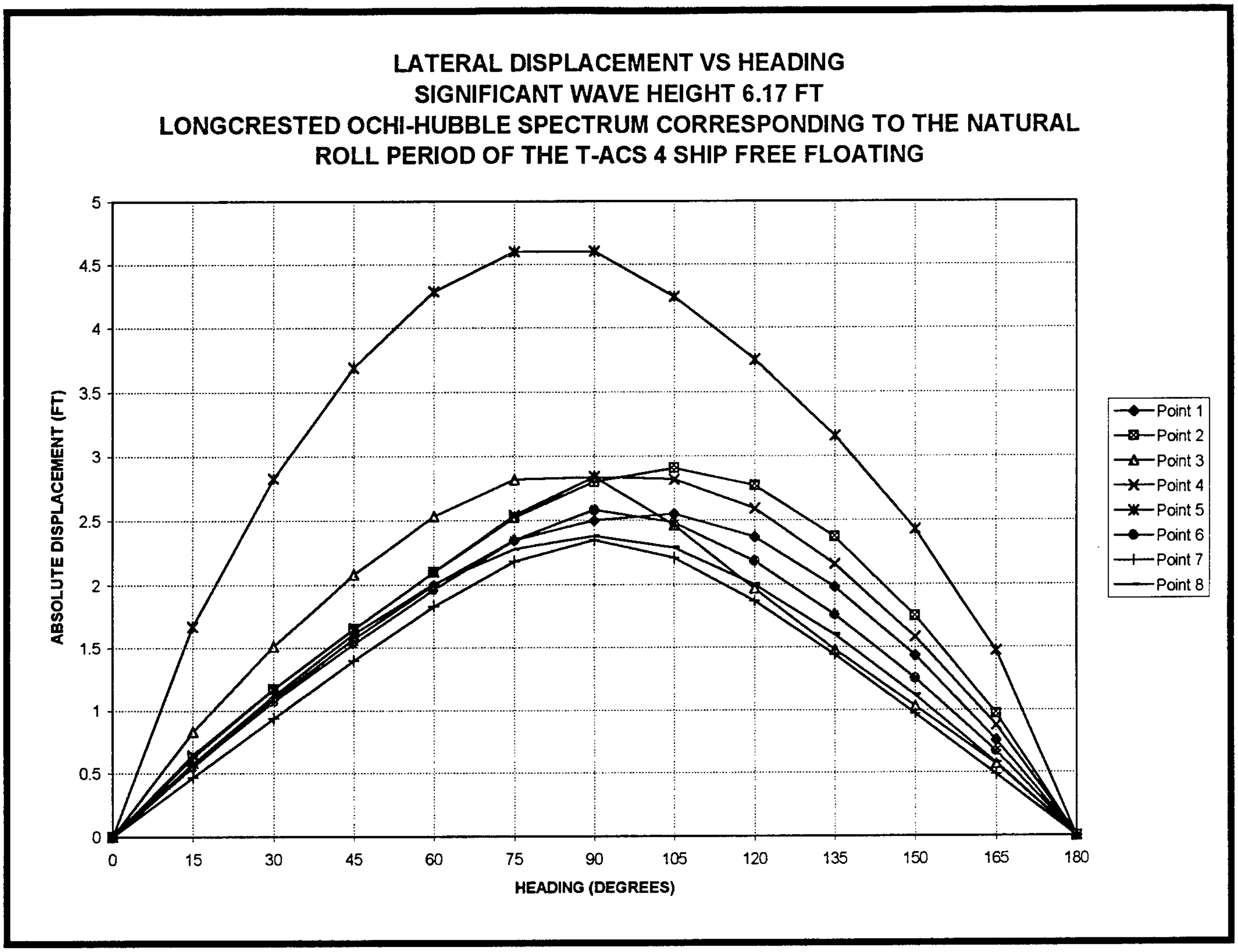

Fig. B.5. Absolute lateral displacement vs. heading for the Ochi-Hubble spectrum corresponding to the natural roll period of the T-ACS 4 ship. Significant wave height 6.17 ft. Free floating case.

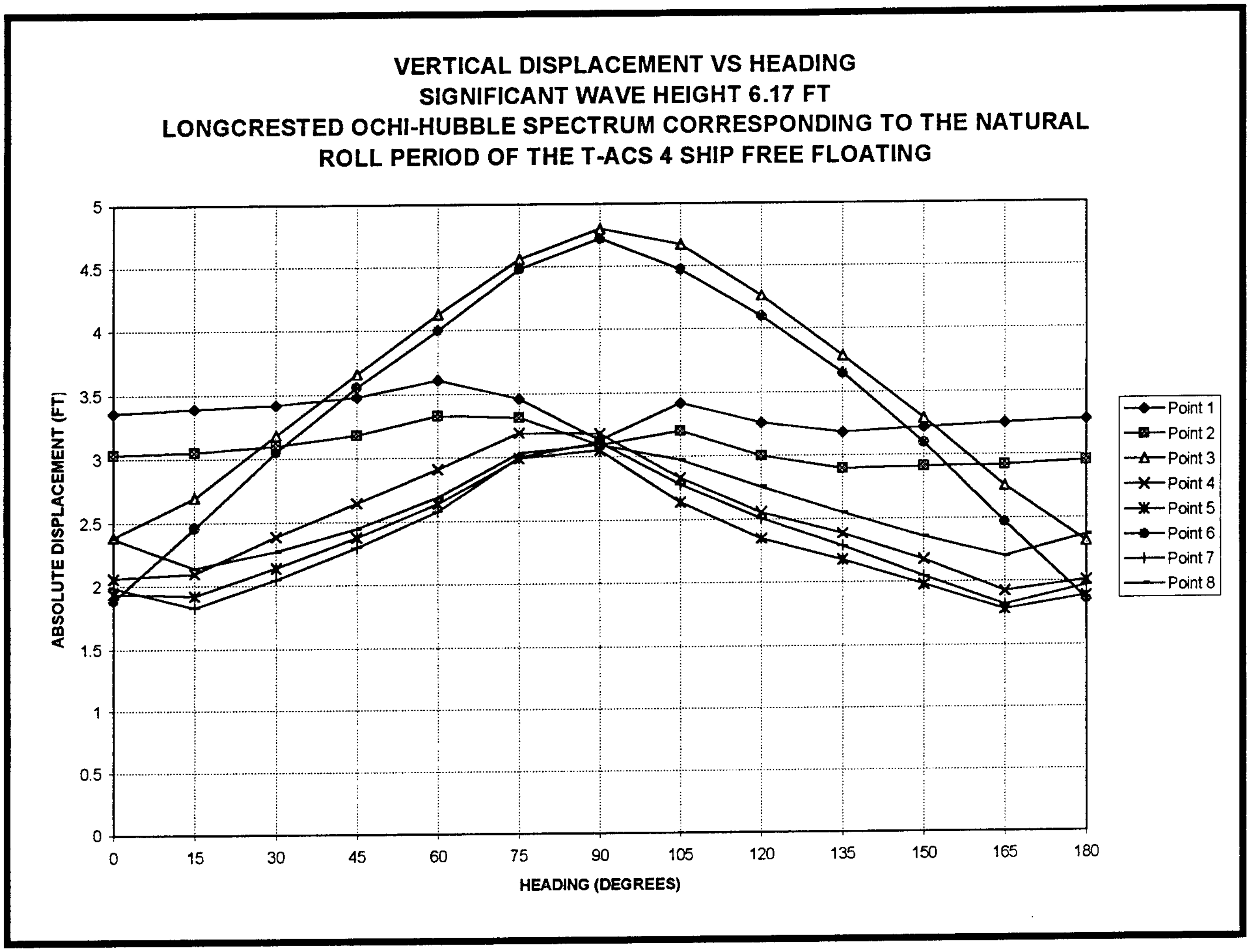

Fig. B.6. Absolute vertical displacement vs. heading for the Ochi-Hubble spectrum corresponding to the natural roll period of the T-ACS 4 ship. Significant wave height 6.17 ft. Free floating case.

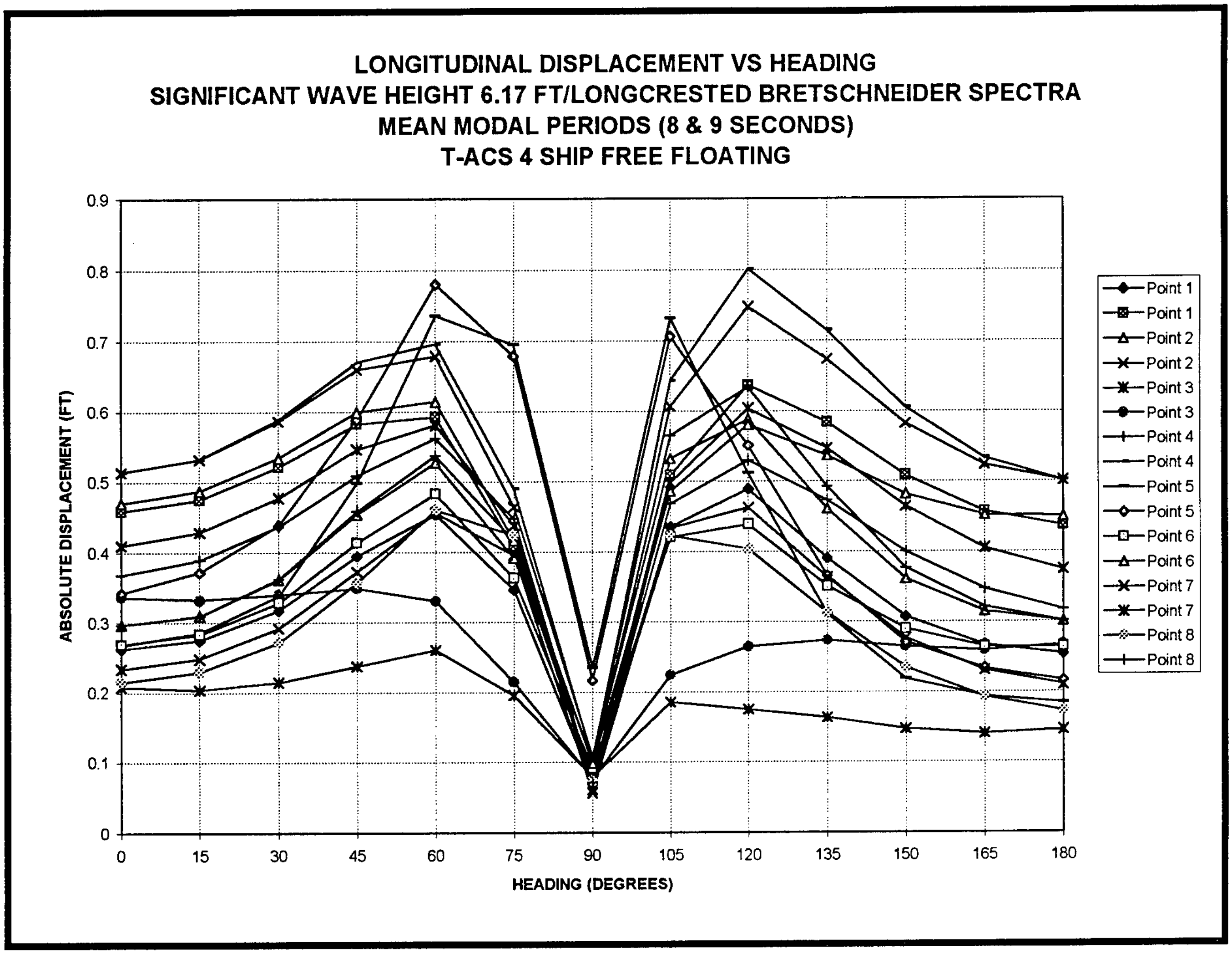

Fig. B.7. Absolute longitudinal displacement vs. heading for Bretschneider spectra of 8 and 9 second modal periods. Significant wave height 6.17 ft. Free floating case.

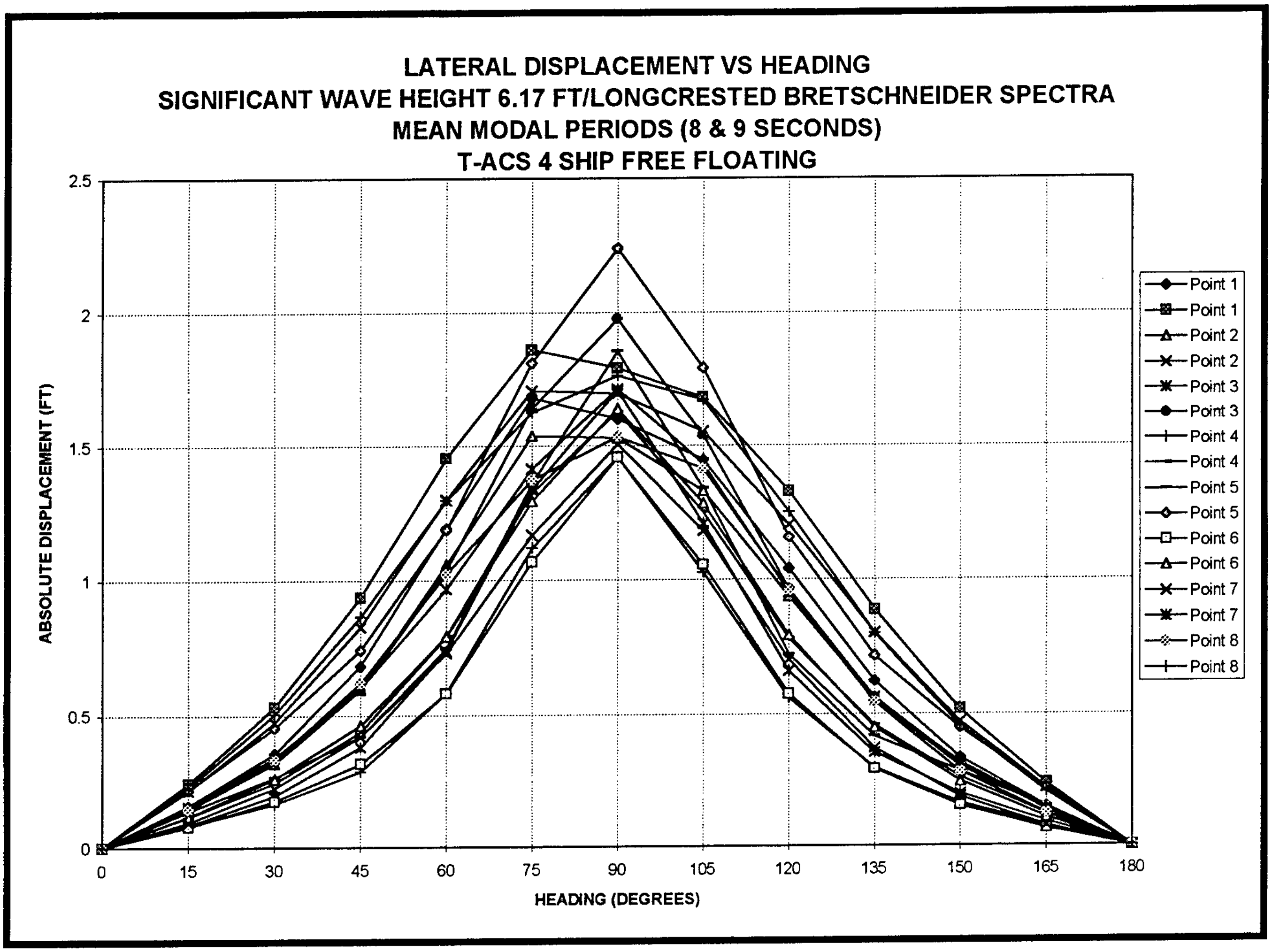

Fig. B.8. Absolute lateral displacement vs. heading for Bretschneider spectra of 8 and 9 second modal periods. Significant wave height 6.17 ft. Free floating case.

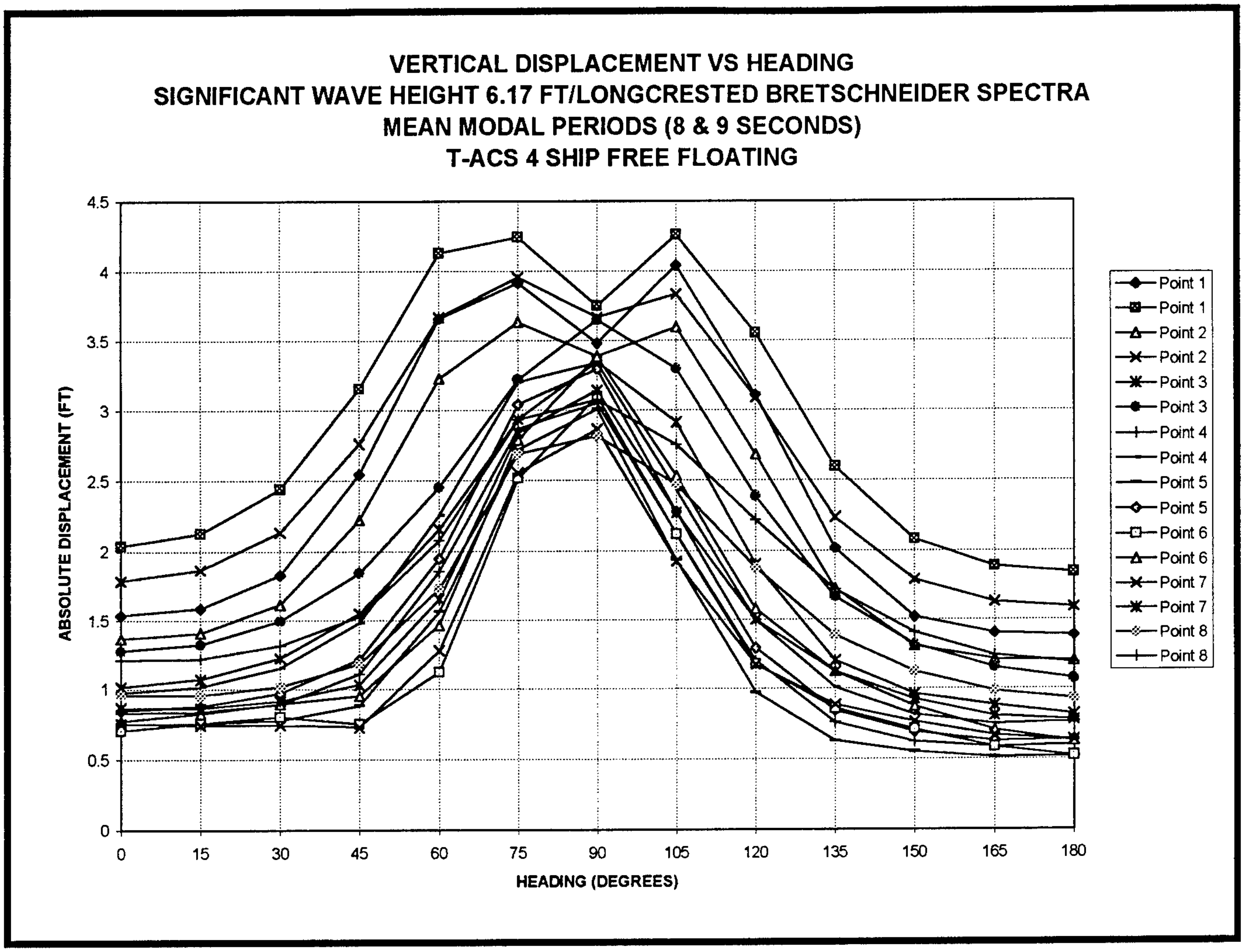

Fig. B.9. Absolute vertical displacement vs. heading for Bretschneider spectra of 8 and 9 second modal periods. Significant wave height 6.17 ft. Free floating case.

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APPENDIX C

MOTION ENVELOPE

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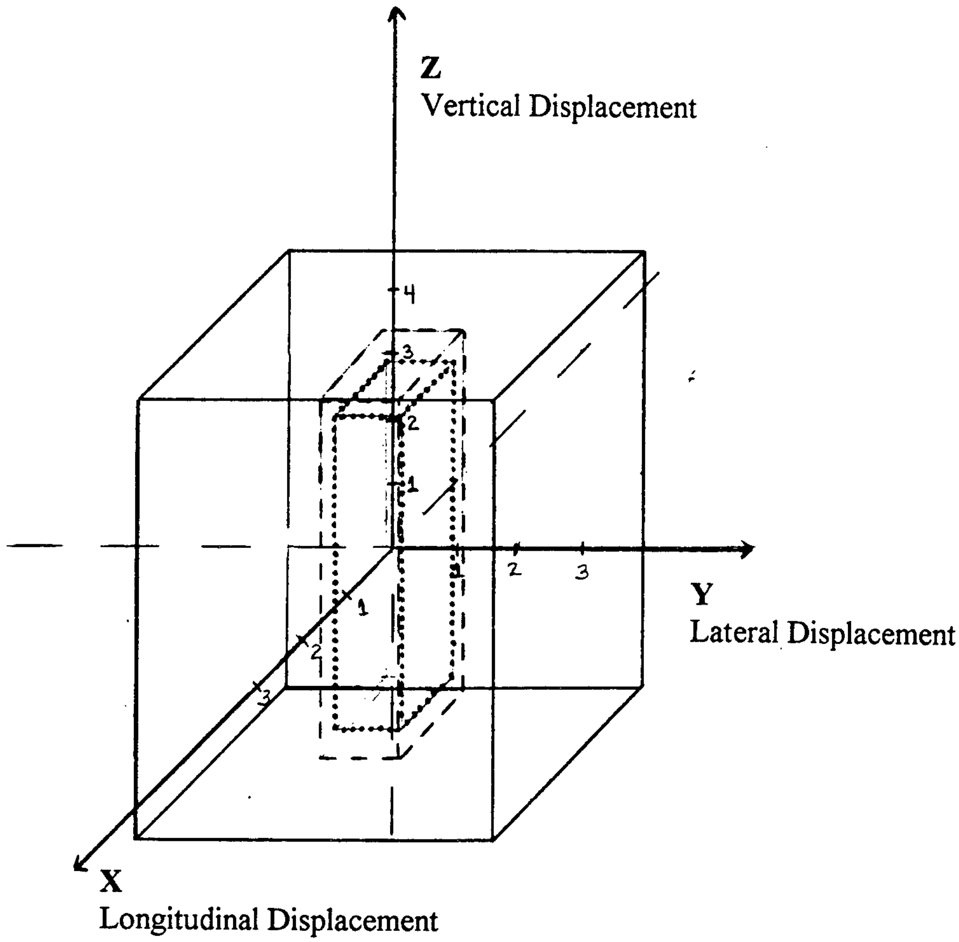
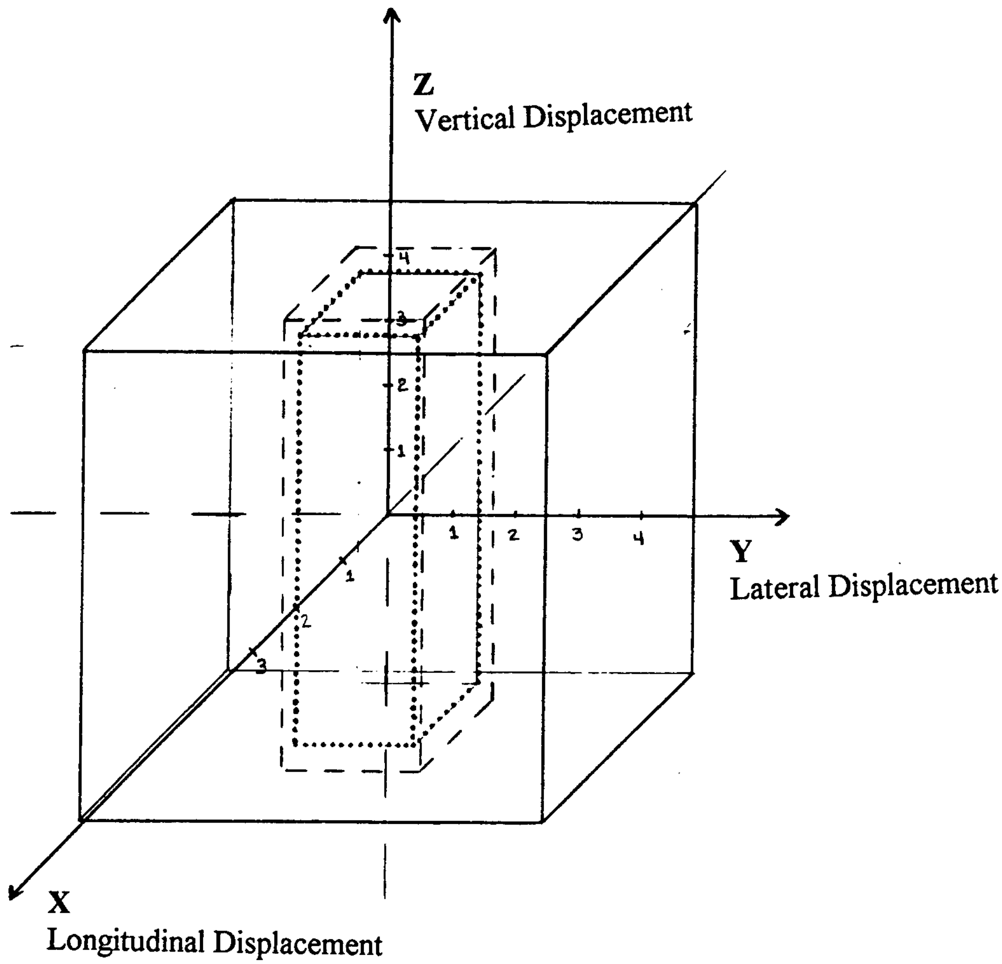


LEGEND		BOX DIMENSIONS (FT)		
LINE STYLE	SPECTRA	X	Y	Z
————	Ochi-Hubble spectrum corresponding to the natural roll period of the T-ACS 4	+/-1.67	+/-2.83	+/-3.42
- - - - - - -	Ochi-Hubble most probable spectrum	+/-0.70	+/-0.62	+/-2.80
....	Bretschneider spectrum of the most probable modal period	+/-0.59	+/-0.53	+/-2.44

Fig. C.1. Maximum predicted ship motion response envelope for the T-ACS 4 in irregular seas of 6.17 ft. significant wave height, for wave headings from 0 to 30 degrees.



LEGEND		BOX DIMENSIONS (FT)		
LINE STYLE	SPECTRA	X	Y	Z
————	Ochi-Hubble spectrum corresponding to the natural roll period of the T-ACS 4	+/-1.67	+/-3.69	+/-3.66
- - - - - - -	Ochi-Hubble most probable spectrum	+/-0.79	+/-1.09	+/-3.51
....	Bretschneider spectrum of the most probable modal period	+/-0.67	+/-0.94	+/-3.16

Fig. C.2. Maximum predicted ship motion response envelope for the T-ACS 4 in irregular seas of 6.17 ft. significant wave height for wave headings from 0 to 45 degrees.

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