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SEAKEEPING CHARACTERISTICS OF A U.S. COAST GUARD MEDIUM ENDURANCE CUTTER (WMEC)

by

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and

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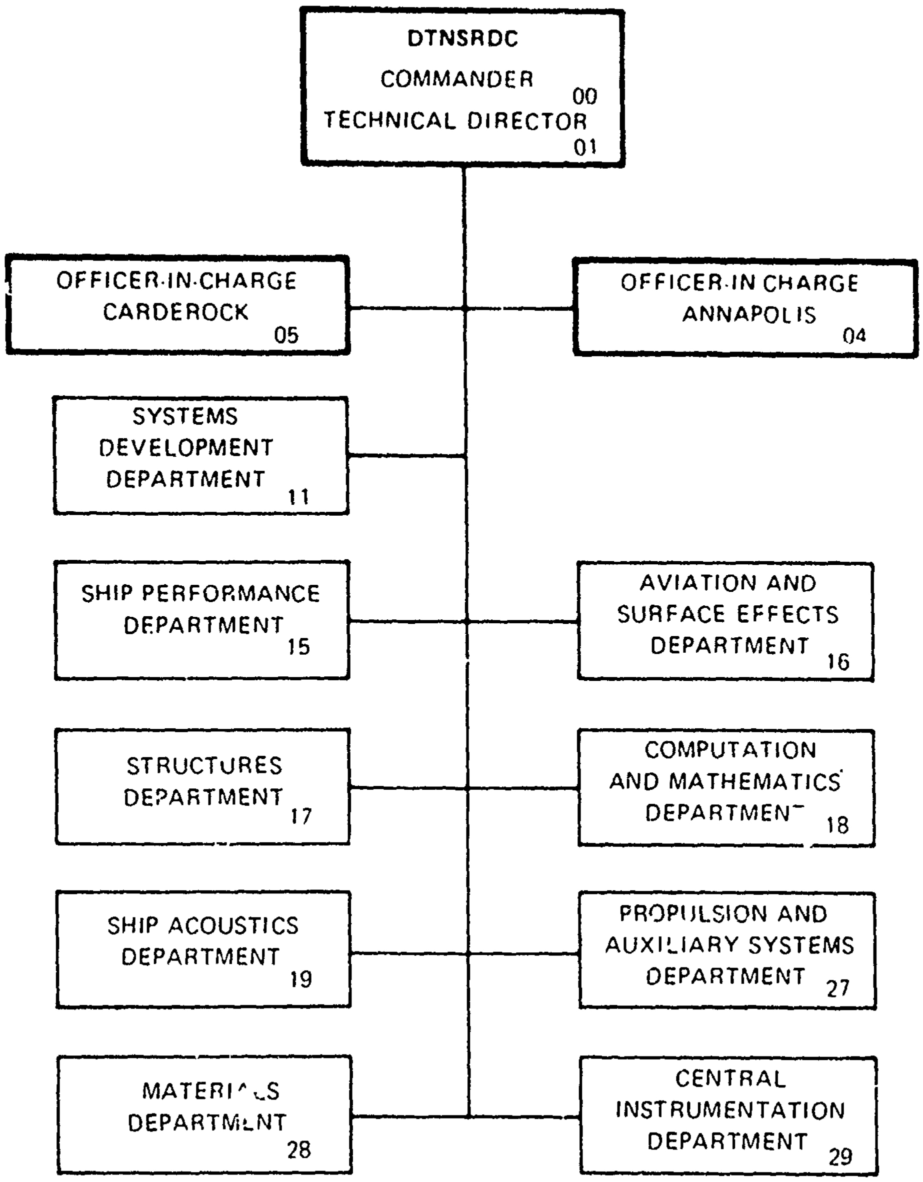

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Model experiments to determine the seakeeping characteristics of a United States Coast Guard Medium Endurance Cutter (WMEC) in head irregular seas are described. Response statistics and response amplitude operators necessary to assess helicopter operations are presented. Slamming and deck wetness are analyzed.

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NOTATION

L	Ship length between perpendiculars
Δ	Salt water displacement
T	Draft (load waterline to bottom of keel)
K_θ	Longitudinal radius of gyration
θ_A	Single amplitude of pitch
Z_A	Single amplitude of heave
$\tilde{\zeta}_A$	Single amplitude of wave height
$\ddot{s}_A$	Absolute acceleration at Station 14
r_A	Ship to wave relative motion at Station 0
$(\tilde{\zeta}_w)_{1/3}$	Significant single amplitude of wave height
λ	Wavelength
G	Acceleration of gravity in ft/sec^2

ABSTRACT

Model experiments to determine the seakeeping characteristics of a United States Coast Guard Medium Endurance Cutter (WMEC) in head irregular seas are described. Response statistics and response amplitude operators necessary to assess helicopter operations are presented. Slamming and deck wetness are analyzed.

ADMINISTRATIVE INFORMATION

The work reported herein was sponsored by the United States Coast Guard (USCG). The funding document was MIPR Z-70099-6-62370. At the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), where the work was performed, it was identified by Work Unit Number 1-1568-022.

INTRODUCTION

This report presents the results of the seakeeping phase of a USCG sponsored program to evaluate the hydrodynamic characteristics of a 270-foot Medium Endurance Cutter (WMEC). The USCG requested that an experiment be conducted with a model of the WMEC in long-crested head waves representing Sea States 3 and 5 at ship speeds of 6, 10, and 15 knots. This experiment was to establish seakeeping characteristics related to helicopter operations and to ship habitability. Pitch angle statistics and absolute vertical acceleration statistics at ship Station 14 were required for helicopter operational considerations. Slamming and deck wetness data were of particular interest with respect to ship habitability.

PRELIMINARY ELEMENTS

Before performing the WMEC cutter experiments, it was necessary to ballast and instrument the model. Pertinent details of these procedures along with the experimental procedure are described in the immediately following sections.

All quantities given at the scale of the prototype were obtained from Froude scaling of model quantities.

MODEL AND BALLASTING

DTNSRDC Model No. 5347, representing the Medium Endurance Cutter at a scale ratio of 14.439 was used for the subject experiment. The model was of wooden lift construction and 5.38 metres (17.66 ft) in length on the waterline. See Figure 1 for body plan, Table 3 for ship particulars.

Prior to the experiment the model was statically ballasted to a full-scale draft of 4.11 metres (13.50 ft) at a displacement of 1706.6 tonnes (1734.0 long tons SW). The Bifilar Pendulum technique was used to experimentally determine the model's longitudinal radius of gyration, and ballast weights were arranged to obtain a radius of gyration of 0.24 L.

INSTRUMENTATION

Measurements of primary concern made during the experiment were:

1. pitch,
2. wave height,
3. heave,
4. ship-to-wave relative motion at Station 0,
5. absolute acceleration at Station 14,
6. keel pressure at Station 3.

Measurements of secondary concern, made for checks on run quality and model control, were:

1. yaw,
2. sway,
3. roll.

Pitch and yaw were measured by gyroscopic transducers mounted near the model's longitudinal center of buoyancy (LCB). Wave height, heave, sway, and relative motion were measured by ultrasonic transducers. Wave height was measured 6.1 metres (20.0 ft) forward of the model LCB, heave and sway were measured at the LCB. The relative motion transducer was suspended over the deck edge at Station 0. The acceleration was measured by a force-balance servomechanism accelerometer located on the model's centerline at Station 14. To measure keel slamming pressures, a strain gauge type pressure transducer was flush mounted in the keel (its sensitive surface in the horizontal plane) at Station 3.

Signals from all transducers were received via an umbilical cable bundle suspended over the model during the experiment. All data were recorded on strip charts, and on analog and digital tapes.

Two video cameras were used to provide a visual record of the model's behavior, particularly in regard to its deck wetness characteristics. Camera 1 gave a direct bow view from forward of the model. Camera 2 showed a side view of the port bow, on which a grid had been marked to facilitate definition of ship-to-wave relative motion.

EXPERIMENTAL PROCEDURE

The experiment was conducted in simulated Sea State 3 and 5 conditions in DTNSRDC's rectangular seakeeping basin.[1] It was decided to represent the Sea State 3 condition by long-crested waves with a significant height of 1.5 metres (5.0 ft) and the Sea State 5 condition by long-crested waves with a significant height of 3.0 metres (10.0 ft). Available random wave programs which most closely approximated fully-developed seas with these significant wave heights in point of modal frequencies were selected (see page 11 and 12 for further information).

The model was powered into head waves at speeds corresponding to 6, 10, and 15 knots full-scale in each of the two sea states. Several passes of the basin were made in each condition until the equivalent of 20-30 minutes of full-scale data had been collected.

[1] Brownell, W.F., "A Rotating Arm and Maneuvering Basin," David W. Taylor Model Basin Report 1053 (Jul 1956).

During all data collection the model was completely free running; restraint ropes were used only before and after each data run to accelerate and decelerate the model. The model was self-powered by twin screws driven by a single electric motor manually controlled from the carriage. Model steering was accomplished automatically by a rudder servomechanism activated by model sway and yaw feedback.

RESULTS

Subsequent to the experiment, a computerized spectral analysis was performed on wave, pitch, heave, relative motion and acceleration data. A less quantitative analysis of slamming and deck wetness was made using strip chart keel pressure records and video tapes, respectively. Following is a discussion of the results.

SPECTRAL ANALYSIS

As mentioned previously, 20-30 minutes (prototype time) of data was collected at each of the six experimental conditions. A spectral analysis was then performed at each condition to define the following:

1. wave spectra,
2. pitch, heave, relative motion, and absolute acceleration spectra,
3. wave, pitch, heave, relative motion, and absolute acceleration significant single amplitudes,
4. pitch, heave, relative motion, and absolute acceleration response amplitude operators,
5. pitch-to-wave and heave-to-wave phase angles.

The measured wave spectra (transformed to the wave frequency domain) are plotted in Figures 2 and 3. Also plotted, for comparison, in these figures are Bretschneider wave spectra[2] of identical modal frequency. In each case, the

[2] "Estuary and Coastline Hydrodynamics," Edited by A.T. Ippen, McGraw-Hill, Inc., "Wave Generation by Wind, Deep and Shallow Water," (C.L. Bretschneider) pp. 133-196 (1966).

attained modal frequency differed from its theoretical, fully-developed value by about 0.1 radians per second.

A sample response spectra (heave at 10 knots, Sea State 5) is included as Figure 4 for inspection, and significant single amplitude values are tabulated in Table 1. Response amplitude operator and phase angle data are presented in Figures 5 through 16 and 17 through 19, respectively.

The pitch and acceleration statistics tabulated in Table 1, and the response amplitude operators of Figures 5 through 7 and 14 through 16 supply the requisite data base for analysis of helicopter operations.

SLAMMING AND DECK WETNESS ANALYSIS

In the basic conditions investigated (fully-developed Sea State 3 and 5 at ship speeds of 6, 10, and 15 knots), no slamming was registered by the pressure gauge on the keel at Station 3; and no instances of severe deck wetness were observed. Forefoot emergences and instances of mild deck wetness were, however, observed. Here the distinction between "severe" and "mild" deck wetness is based upon the lateral extent of the water which rises above the sheer line. If the lateral extent is essentially equal to the length of the causal wave crest, the wetness is said to be severe. If the lateral extent is small with respect to the length of the wave crest, the wetness is said to be mild. Thus, severe wetness can be identified with shipping of green water while mild deck wetness can be identified with bow wave profile overtopping.

Table 2 presents the statistics of forefoot emergence and mild deck wetness obtained by analysis of the video tape records of the cutter experiment. Deck wetnesses occurred in the vicinity of Stations 0 through 2. The vertical extent of the overtopping water appeared to be limited to about 1.5 metres (5.0 ft), and its lateral extent at the sheer line was at most 0.6 metres (2.0 ft).

Since no bottom slamming or severe deck wetness occurred under the basic conditions investigated, some exploratory runs were made under other conditions in an attempt to induce these phenomena.

Initially, waves equivalent to a fully-developed Sea State 6 were tried at ship speeds of 10 and 15 knots. These runs failed to produce any bottom slamming, and the deck wetness experienced by the model continued to be limited to mild cases. It appeared that the increase in wavelengths associated with the increase in sea state had produced a subcritical situation in which the model responded primarily in heave. Hence, it was decided to attempt to generate waves equivalent to a partially-developed sea which had the same frequency content as the fully-developed Sea State 5 but a greater significant wave height; and to run into these waves at 15 knots. This attempt failed. The scale ratio of the model was such that the random wave program with the desired frequency content could not produce waves of significant height more than about 3.6 metres (12 ft).

The spectral analysis results ultimately obtained indicate that the general hypothesis as to the critical nature of partially-developed seas for slamming and deck wetness is correct. The measured relative motion response amplitude operators are maximized for wave frequencies in the 0.8 to 0.9 radian per second range. Fully-developed seas with modal frequencies in this range would have significant heights of only 1.8 to 2.4 metres (6 to 8 ft). Hence, the critical condition for slamming and deck wetness of the cutter under consideration occurs in severe, partially-developed seas with modal frequencies in the 0.8 to 0.9 radian per second range. Though these critical conditions could not be simulated in the basin at the scale ratio of the model used, they can occur. Wave statistics from reference 3 indicate that, on a worldwide basis, waves with modal frequencies in the specified range will attain significant heights of 6 to 7 metres (20 to 23 ft) with a probability on the order of 0.001.

CONCLUSIONS

1. Assessment of the cutter's seakeeping characteristics, regarding helicopter operations, can be made from the pitch and acceleration data presented in this report.

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[3]Hogben, N. and F.E. Lumb, "Ocean Wave Statistics," Her Majesty's Stationery Office, London (1967).

2. Slamming and severe wetness (shipping of green water) should not occur in either fully-developed Sea State 3 [$(\tilde{\zeta}_w)_{1/3}$ = 1.5 m] or 5 [$(\tilde{\zeta}_w)_{1/3}$ = 3.0 m] at speeds to 15 knots. However, these phenomena may occur in severe, partially-developed seas with modal frequencies in the 0.8 to 0.9 radian per second range.

TABLE 1 SIGNIFICANT SINGLE AMPLITUDES FROM SPECTRAL ANALYSIS

SIGNIFICANT SINGLE AMPLITUDE OF	6 KNOTS AT		10 KNOTS AT		15 KNOTS AT	
	$(\tilde{\zeta}_w)_{1/3}$ = 1.55 m (5.1 FT)	$(\tilde{\zeta}_w)_{1/3}$ = 3.00 m (9.9 FT)	$(\tilde{\zeta}_w)_{1/3}$ = 1.58 m (5.2 FT)	$(\tilde{\zeta}_w)_{1/3}$ = 3.12 m (10.2 FT)	$(\tilde{\zeta}_w)_{1/3}$ = 1.68 m (5.5 FT)	$(\tilde{\zeta}_w)_{1/3}$ = 3.17 m (10.4 FT)
PITCH IN DEGREES	1.3	2.7	1.4	3.1	1.5	3.2
HEAVE IN METRES	0.34 (1.1 FT)	1.07 (3.5 FT)	0.40 (1.3 FT)	1.19 (3.9 FT)	0.46 (1.5 FT)	1.25 (4.1 FT)
RELATIVE MOTION AT STATION 0 IN METRES	1.46 (4.8 FT)	2.38 (7.8 FT)	1.55 (5.1 FT)	2.44 (8.0 FT)	1.77 (5 8 FT)	2.83 (9.3 FT)
ABSOLUTE VERTICAL ACCELERATION AT STATION 14 IN METRES/(SECOND)^2	0.30 (1.0 FT/SEC^2)	0.64 (2.1 FT/SEC^2)	0.37 (1.2 FT/SEC^2)	0.82 (2.7 FT/SEC^2)	0.55 (1.8 FT/SEC^2)	1.10 (3.6 FT/SEC^2)

TABLE 2 FOREFOOT EMERGENCE AND DECK WETNESS STATISTICS

SEA STATE	SPEED (KNOTS)	NUMBER PER HOUR OF	
		EMERGENCES	WETNESSES*
3	6	0	0
	10	0	0
	15	0	7
5	6	11	0
	10	16	13
	15	21	86

*MILD WETNESS DUE TO BOW WAVE PROFILE OVERTOPPING

TABLE 3 PARTICULARS OF CUTTER (WMEC)

PARAMETER	FULL SCALE	MODEL SCALE
L	77.72m (255 ft)	5.38m (17.66 ft)
T	4.11m (13.50 ft)	0.28m (0.93 ft)
Δ	1706.6 TONNES (1734 LONGTONS SW)	570.49 Kg (1257.7 lb.)
K_θ	0.24 L	0.24 L

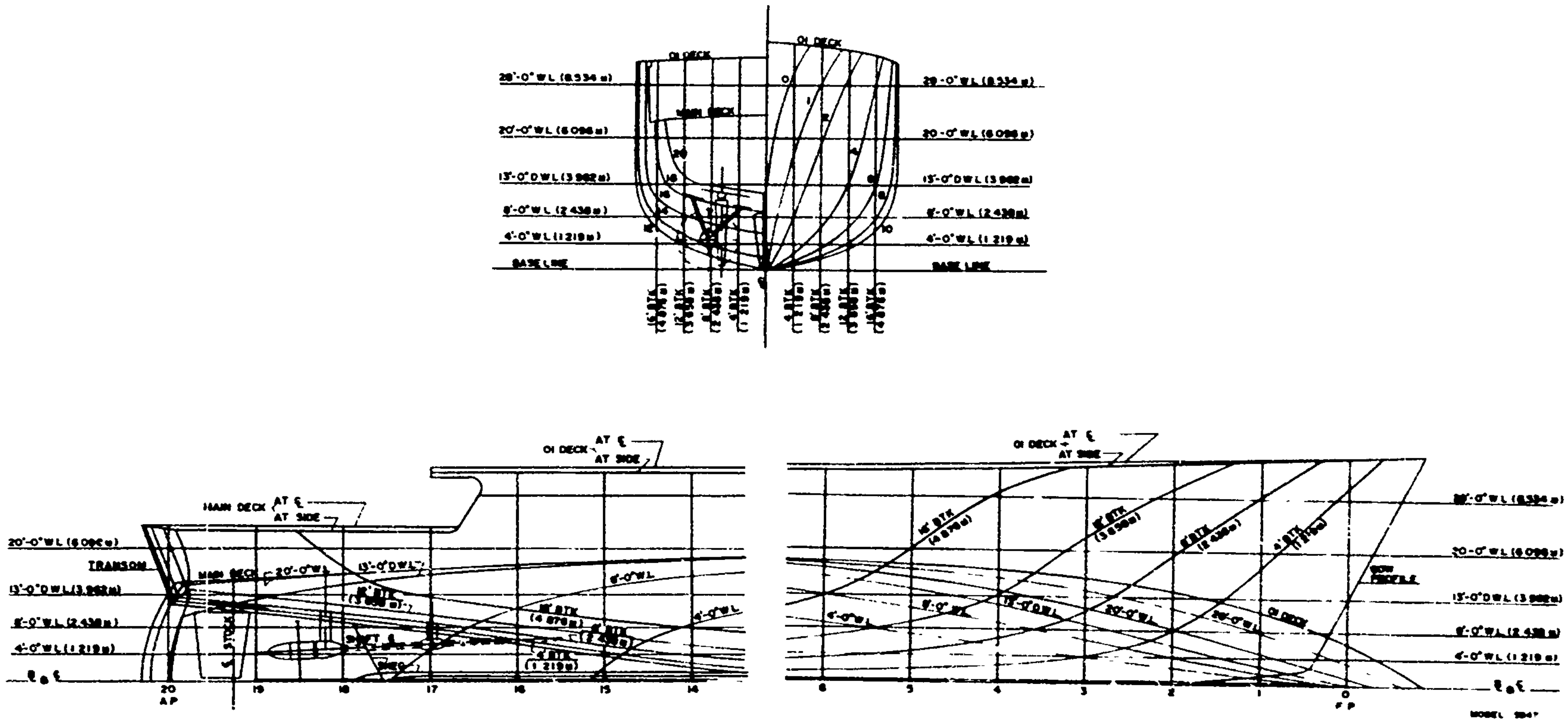

FIGURE 1 - BODY PLAN OF WMEC CUTTER

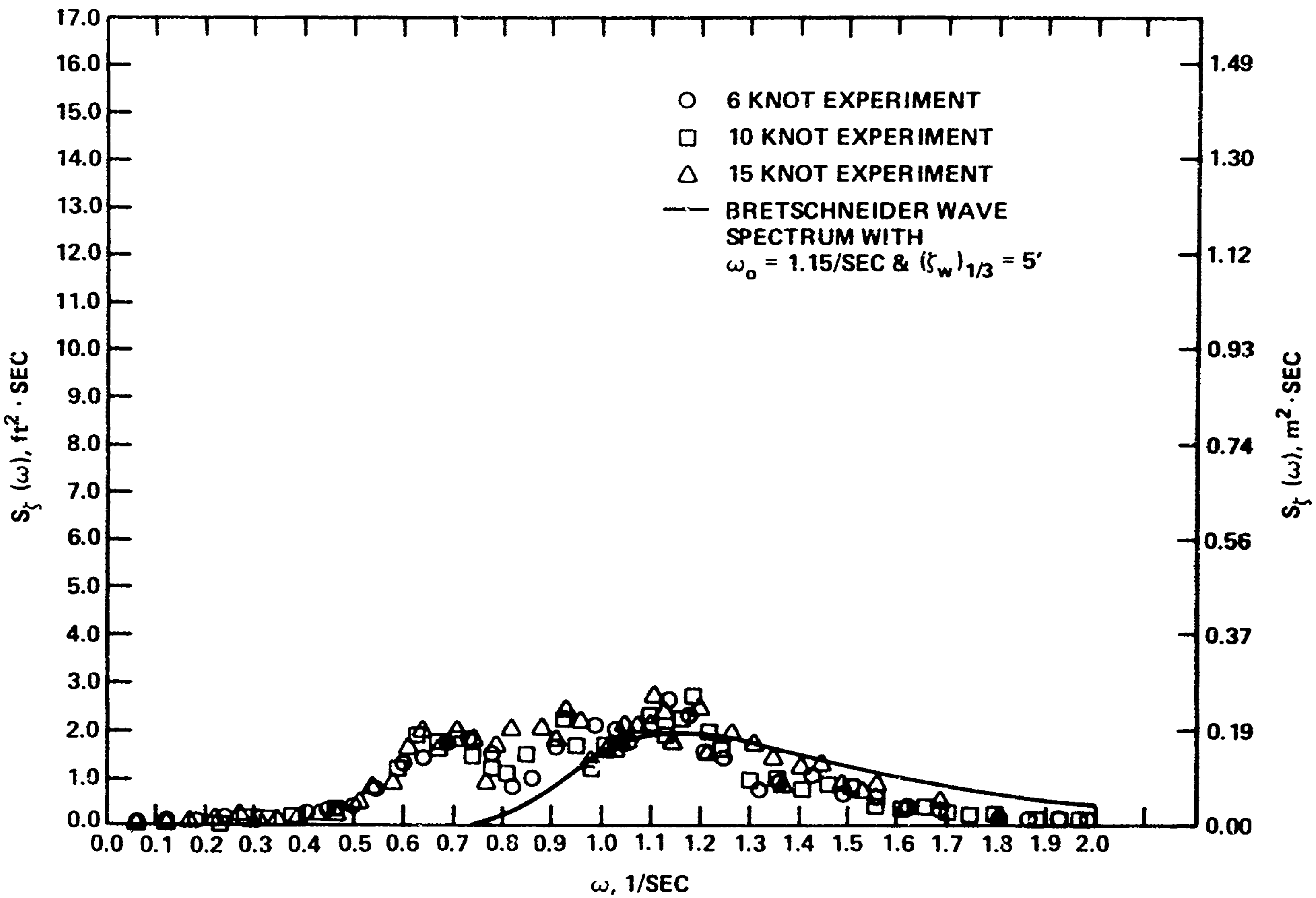

FIGURE 2 MEASURED AND BRETSCHNEIDER WAVE SPECTRA: SEA STATE 3

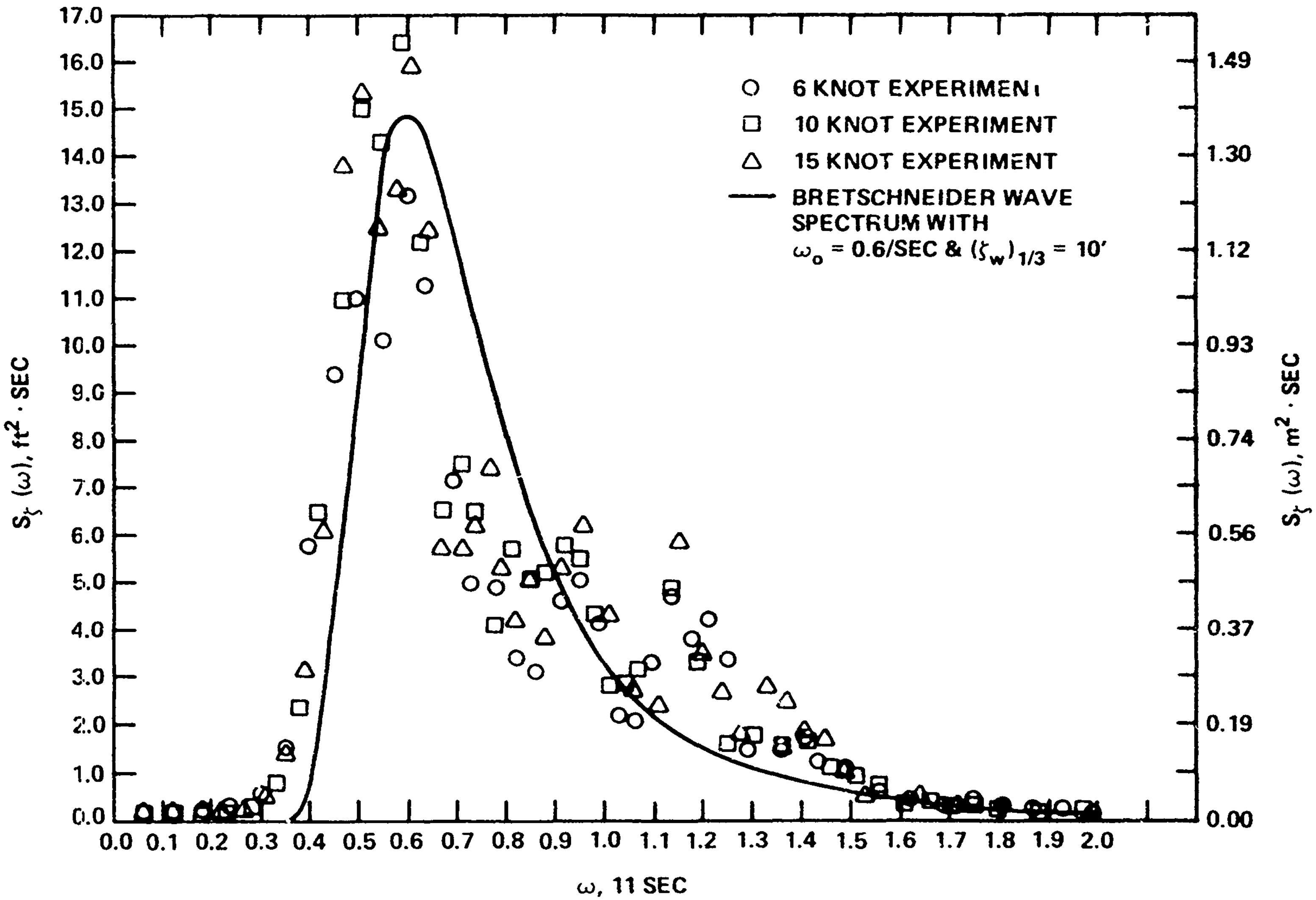

FIGURE 3 MEASURED AND BRETSCHNEIDER WAVE SPECTRA: SEA STATE 5

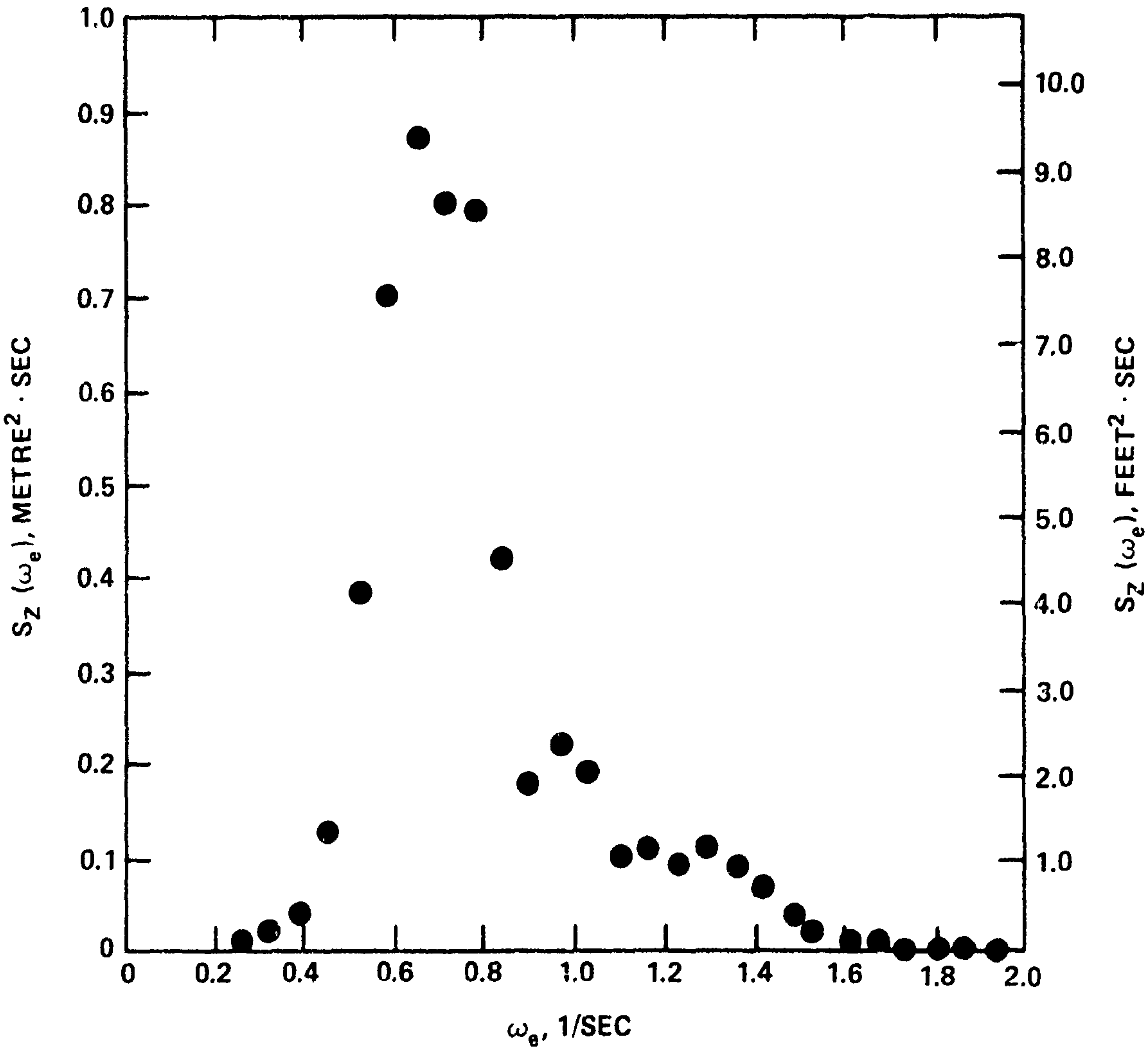

FIGURE 4 SAMPLE RESPONSE SPECTRUM: HEAVE AT 10 KNOTS SEA STATE 5

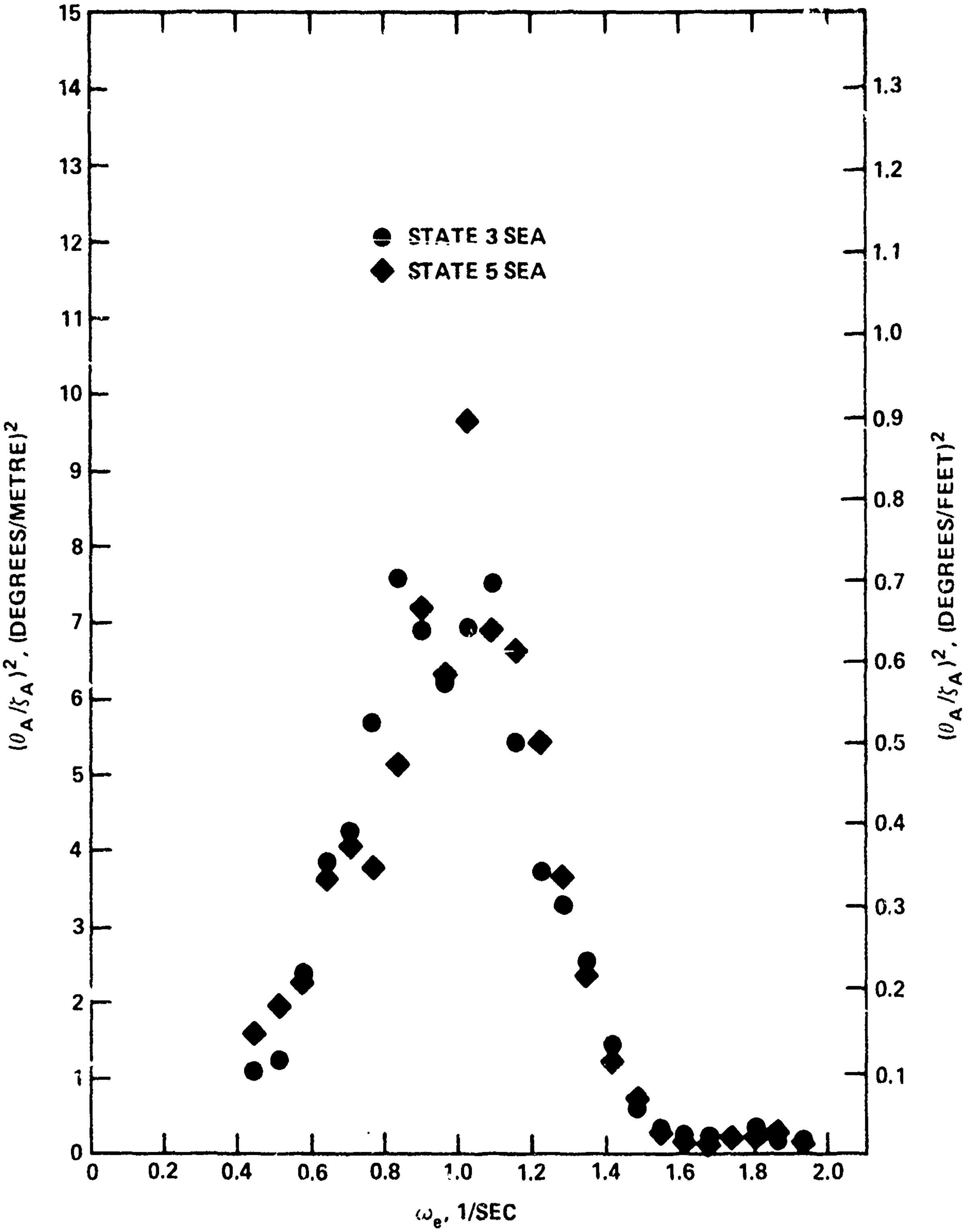

FIGURE 5 PITCH RESPONSE AMPLITUDE OPERATOR @ 6 KNOTS

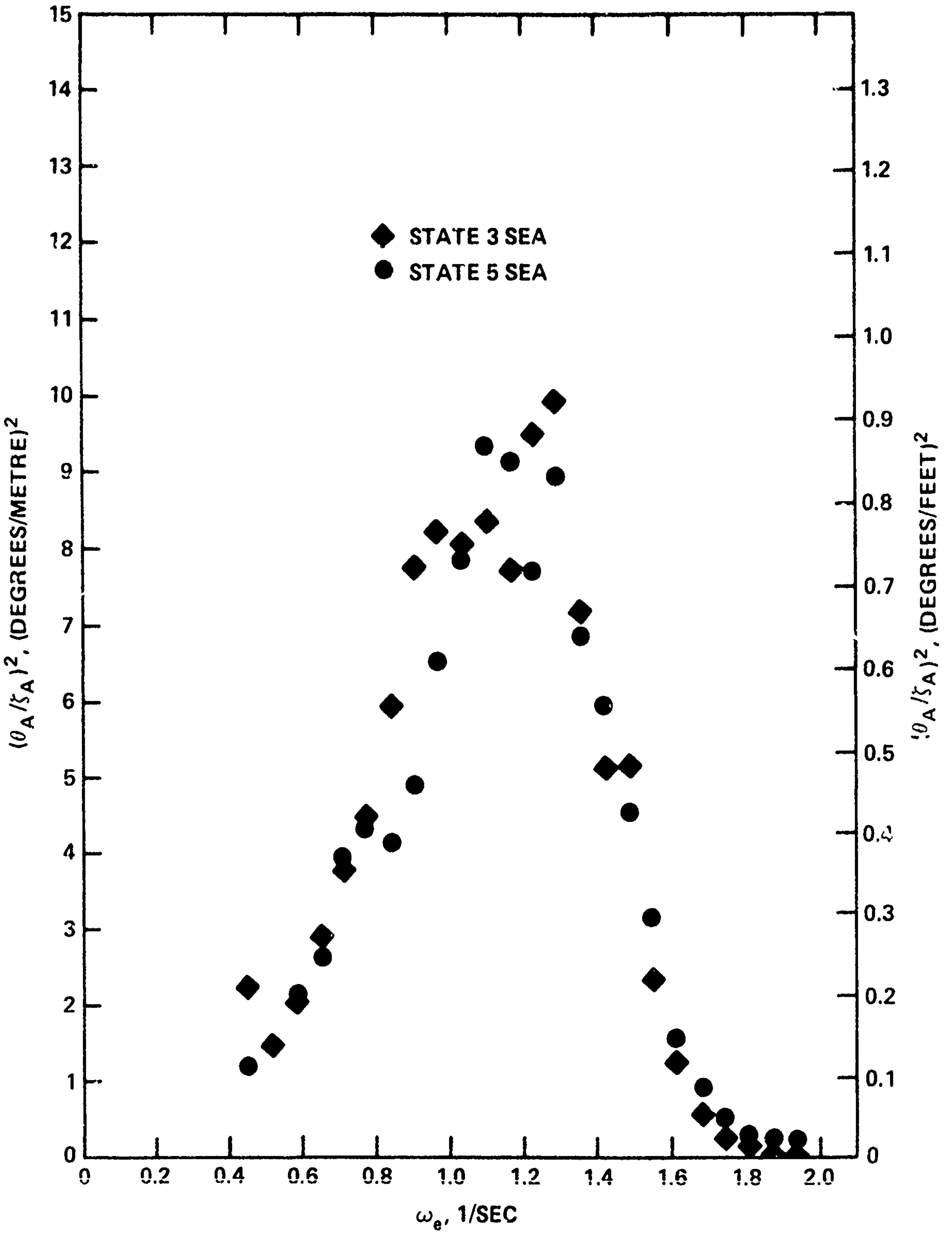

FIGURE 6 PITCH RESPONSE AMPLITUDE OPERATOR
@ 10 KNOTS

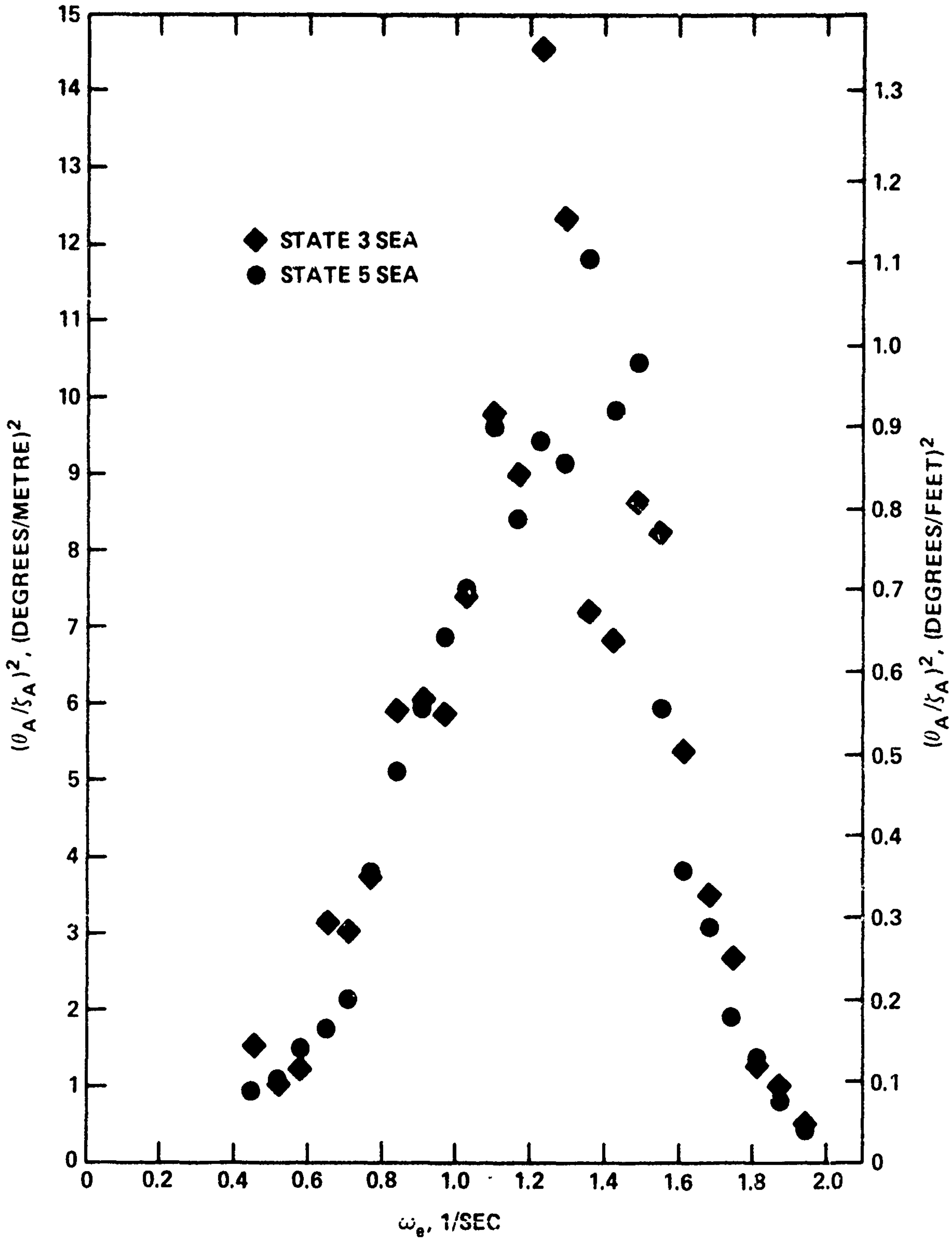

FIGURE 7 PITCH RESPONSE AMPLITUDE OPERATOR
@ 15 KNOTS

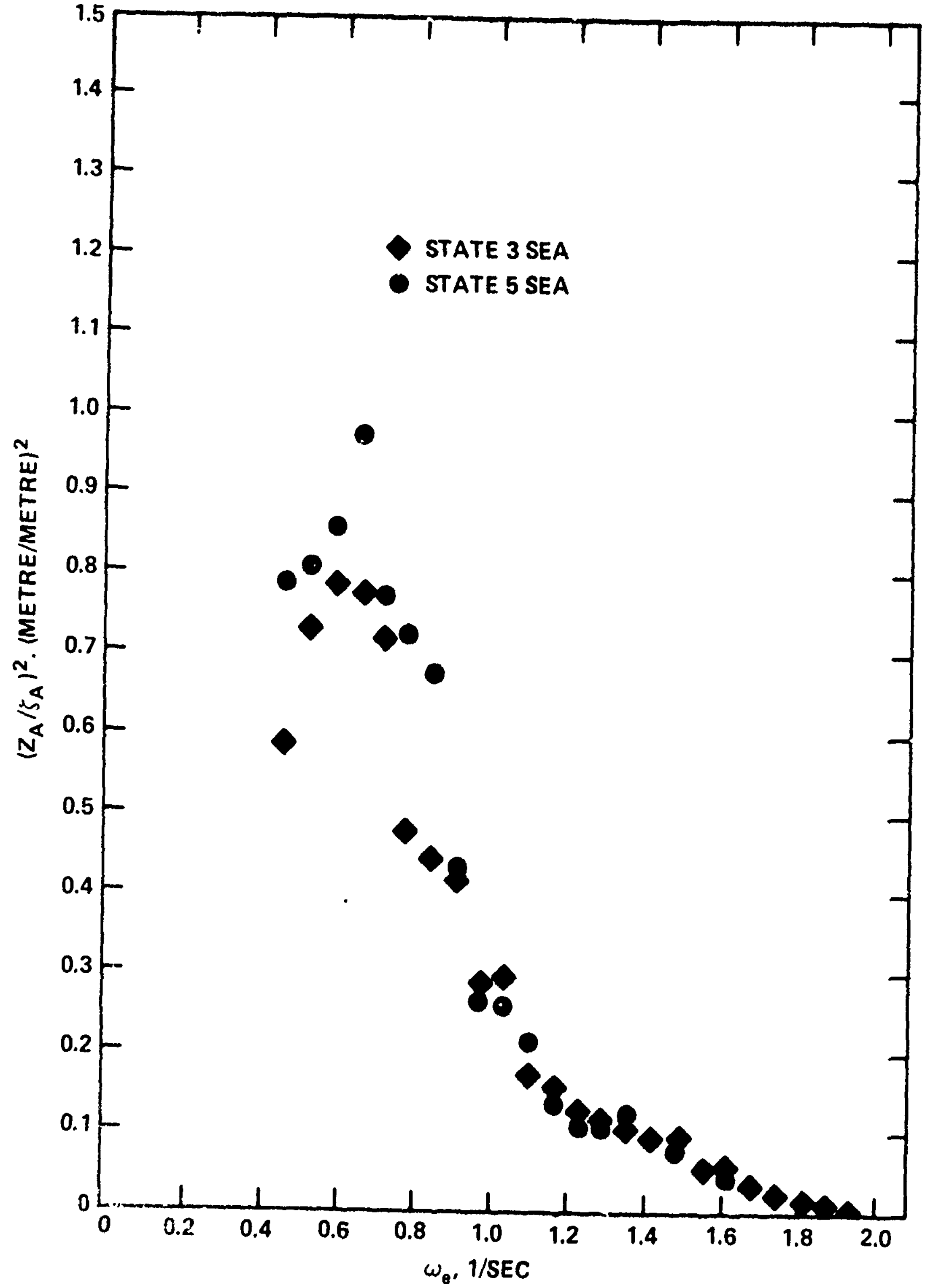

FIGURE 8 HEAVE RESPONSE AMPLITUDE OPERATOR @ 6 KNOTS

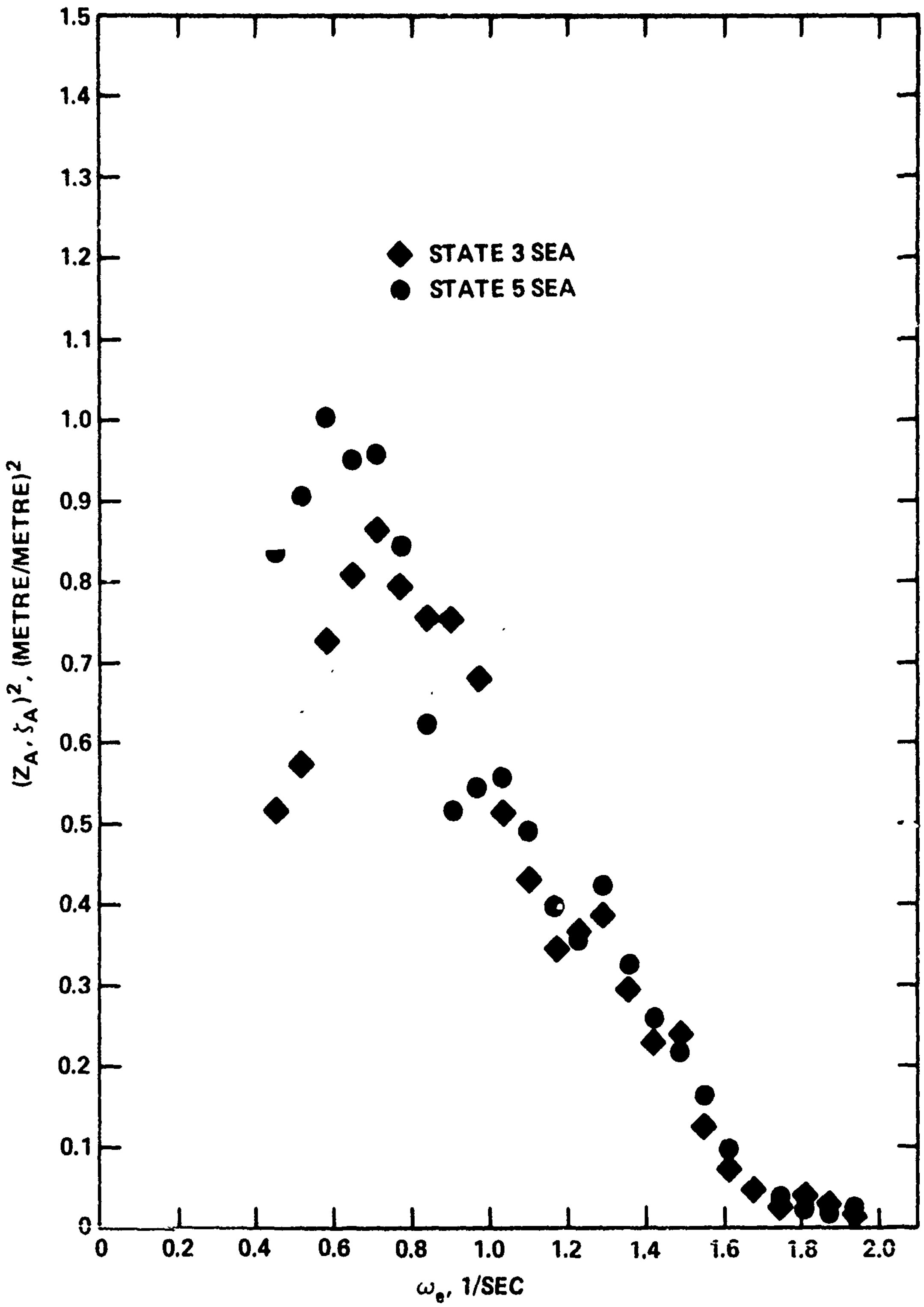

FIGURE 9 HEAVE RESPONSE AMPLITUDE OPERATOR @ 10 KNOTS

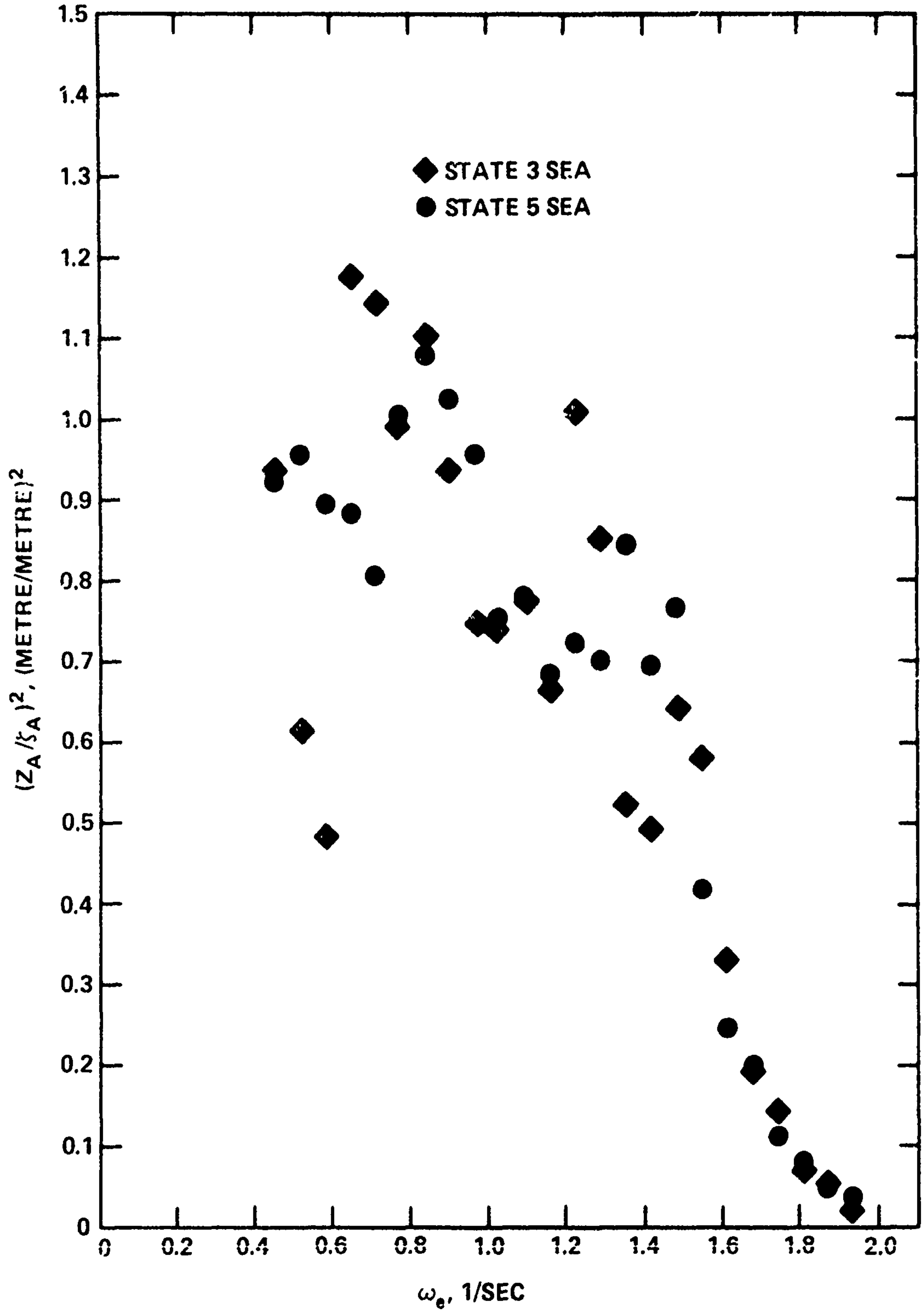

FIGURE 10 HEAVE RESPONSE AMPLITUDE OPERATOR @ 15 KNOTS

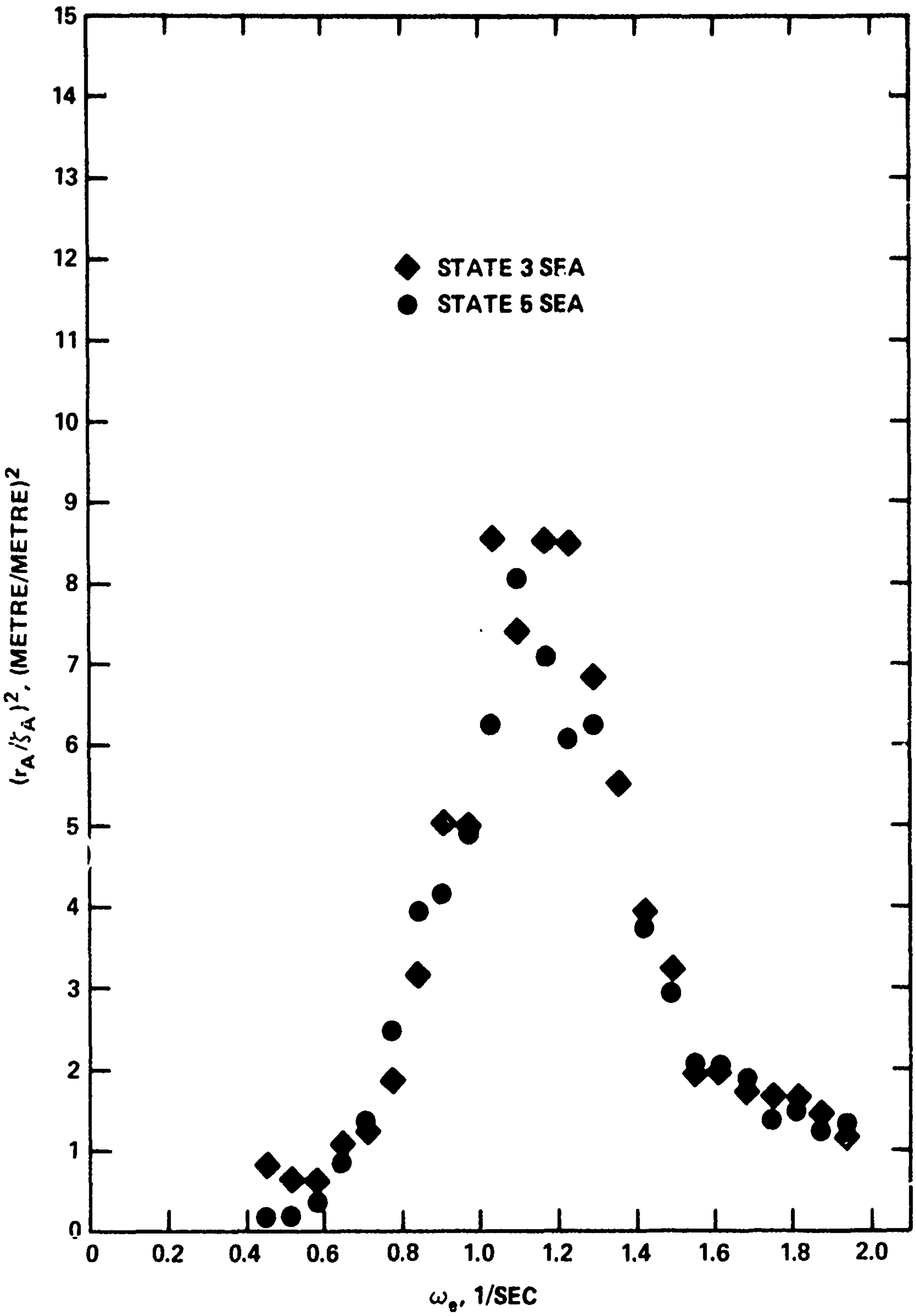

FIGURE 11 STATION 0 RELATIVE MOTION RESPONSE AMPLITUDE OPERATOR @ 6 KNOTS

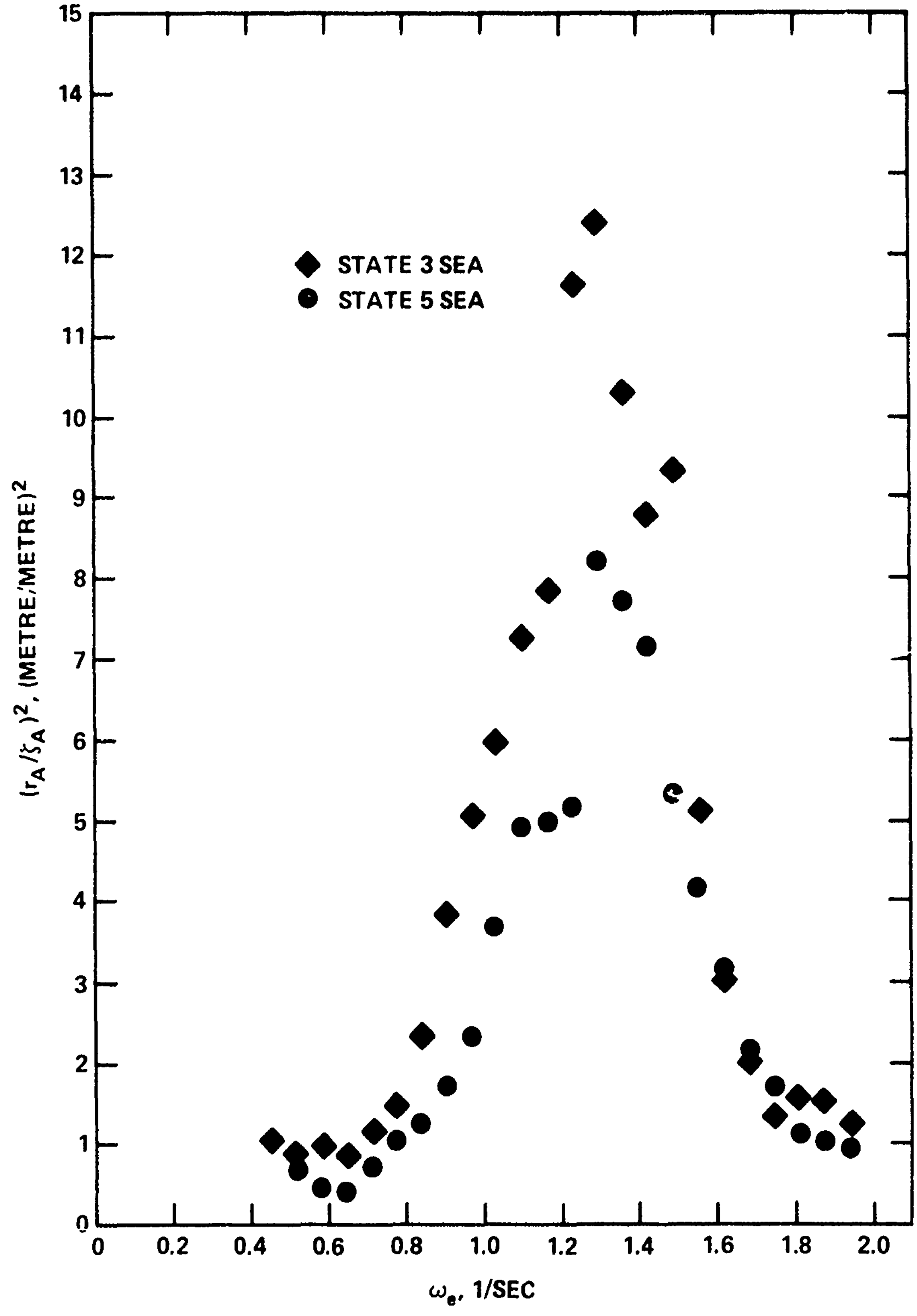

FIGURE 12 STATION 0 RELATIVE MOTION RESPONSE AMPLITUDE OPERATOR @ 10 KNOTS

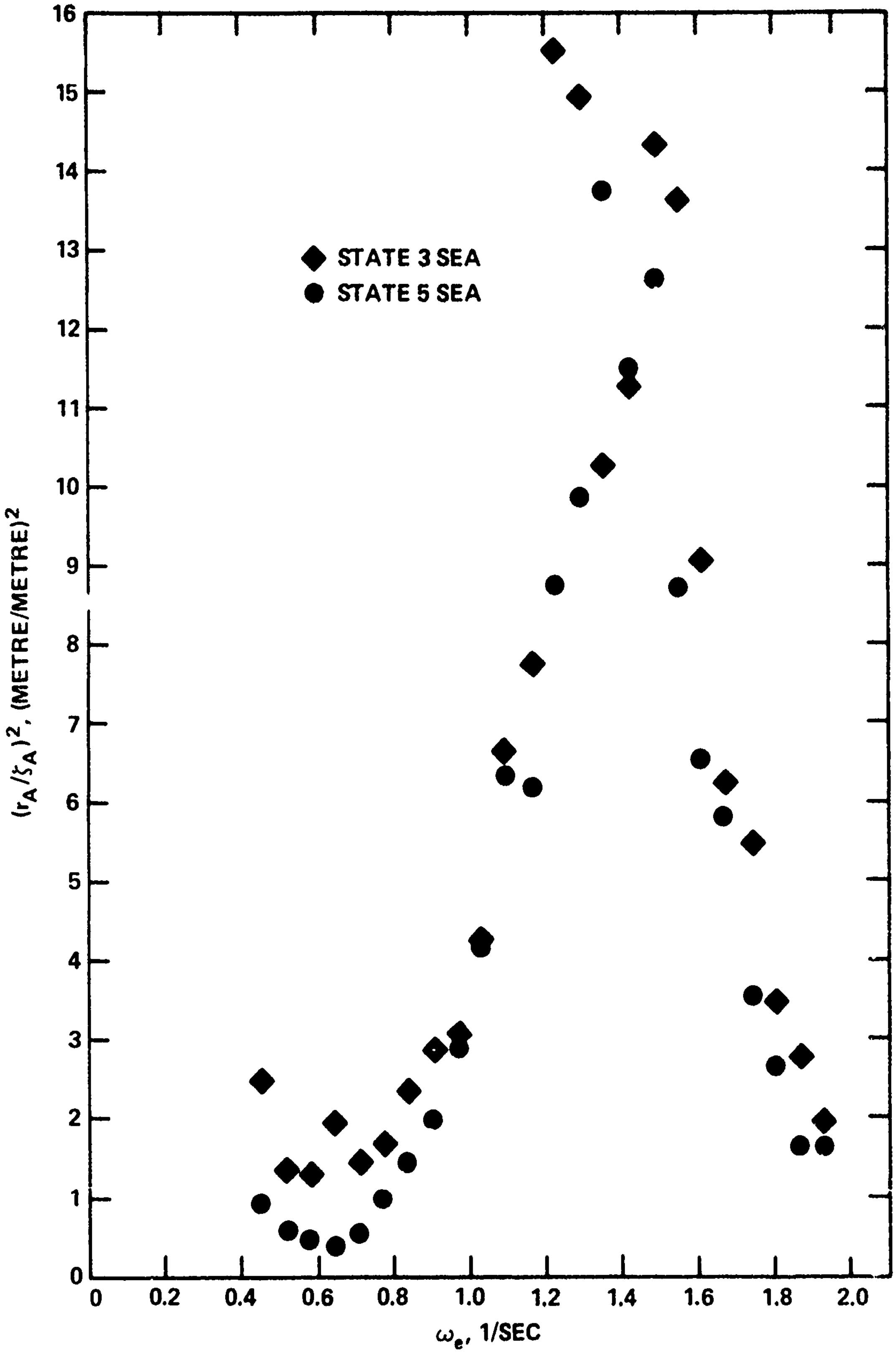

FIGURE 13 STATION 0 RELATIVE MOTION RESPONSE AMPLITUDE OPERATOR @ 15 KNOTS

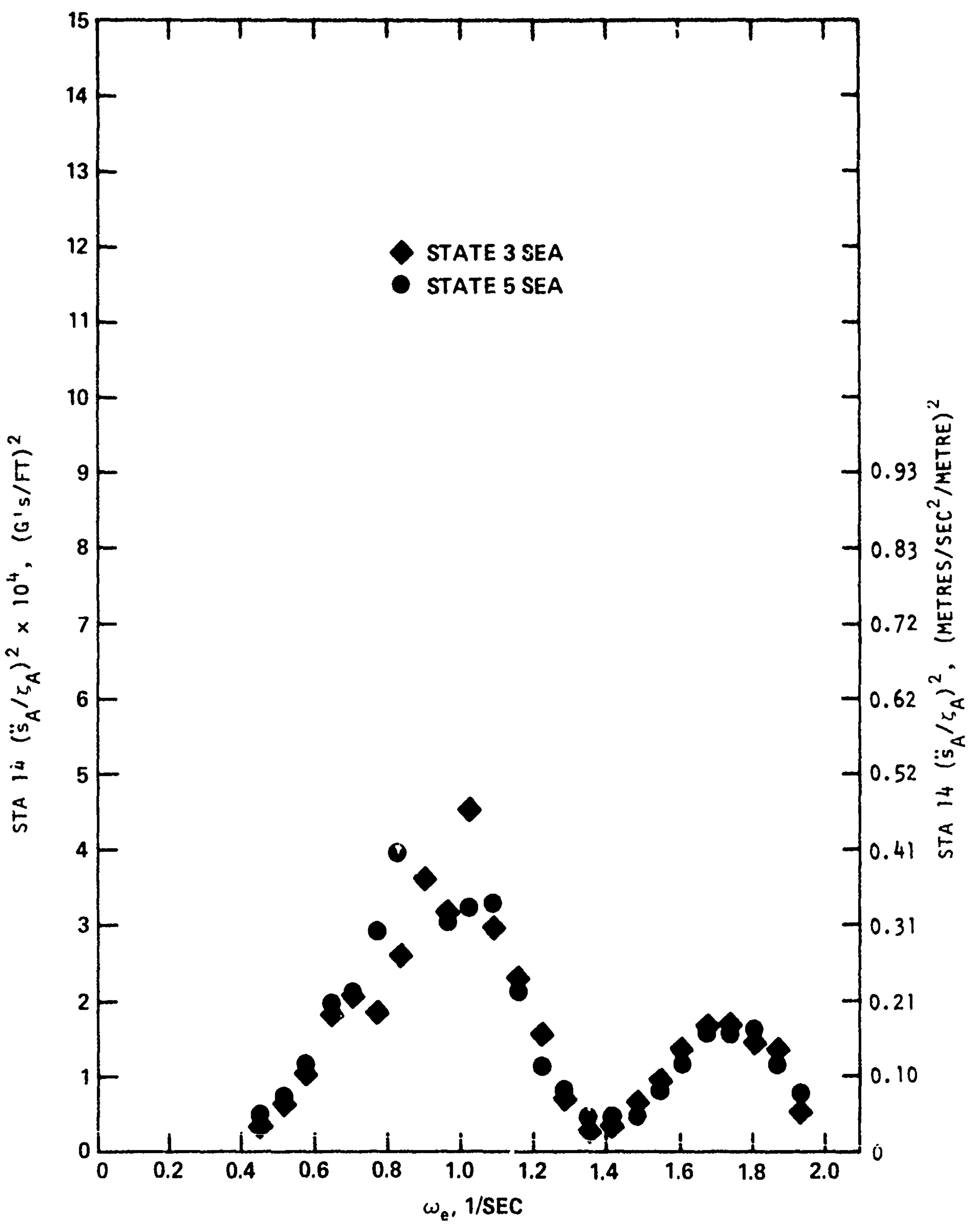

FIGURE 14 STATION 14 ACCELERATION RESPONSE AMPLITUDE OPERATOR @ 6 KNOTS

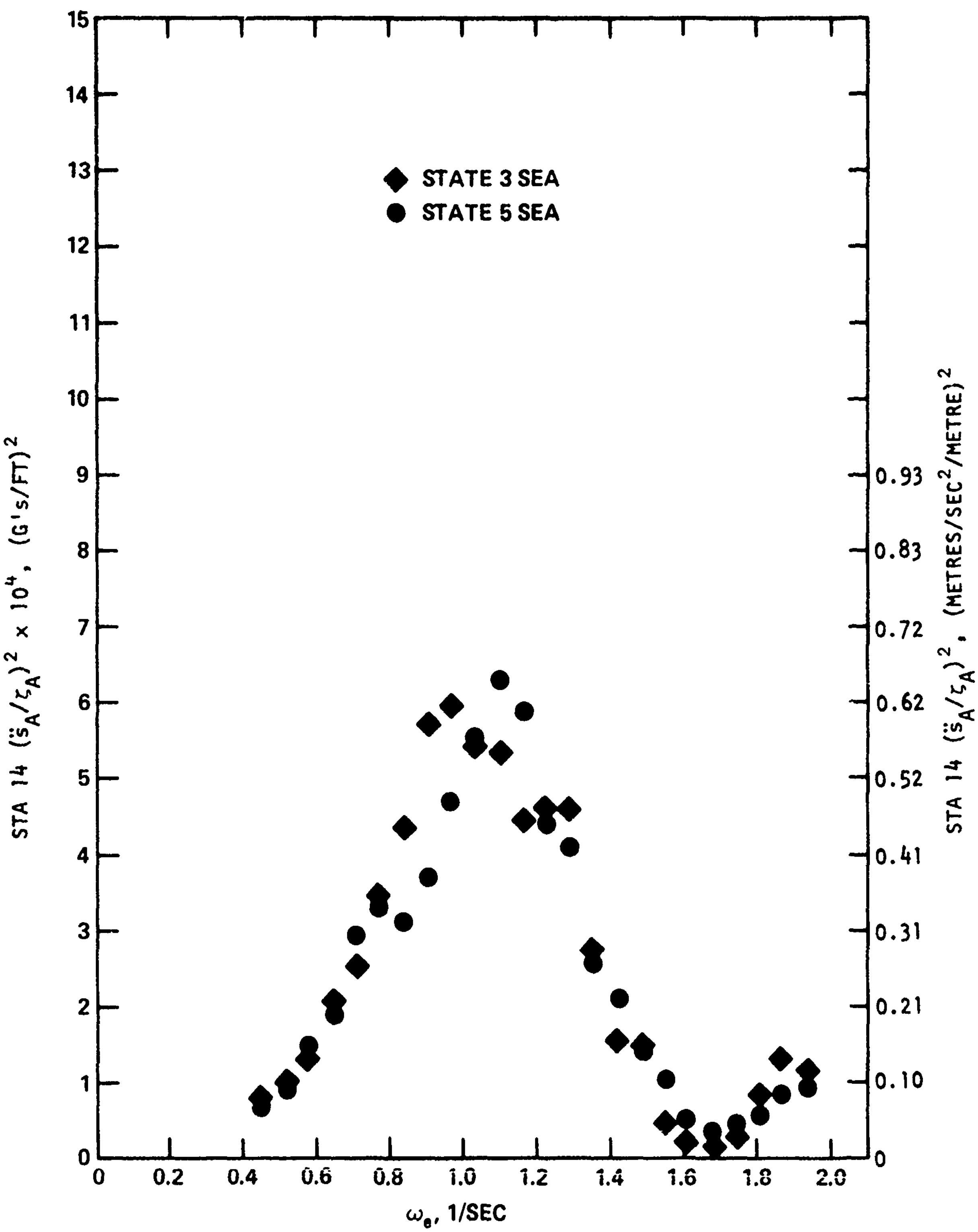

FIGURE 15 STATION 14 ACCELERATION RESPONSE AMPLITUDE OPERATOR @ 10 KNOTS

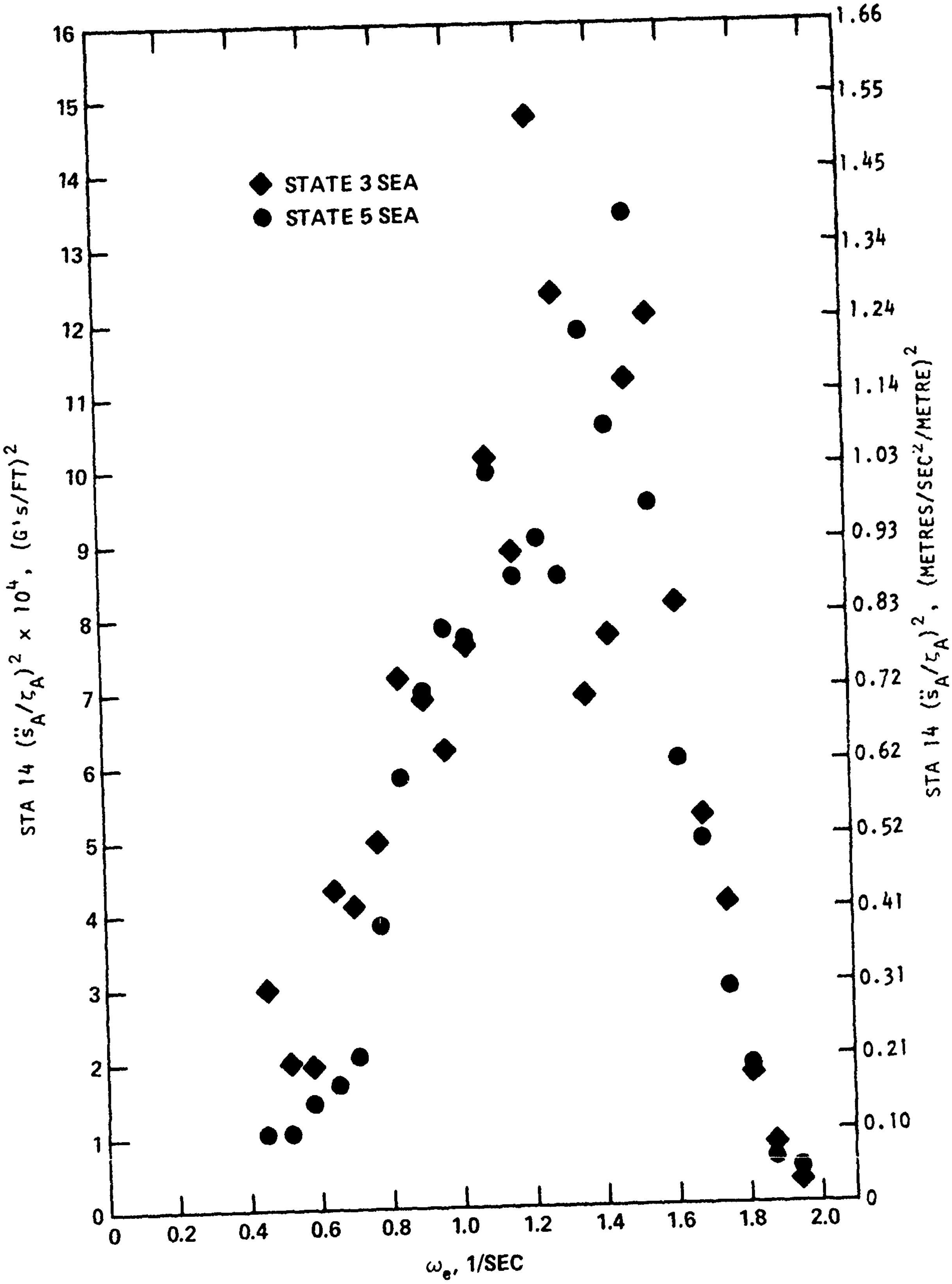

FIGURE 16 STATION 14 ACCELERATION RESPONSE AMPLITUDE OPERATOR @ 15 KNOTS

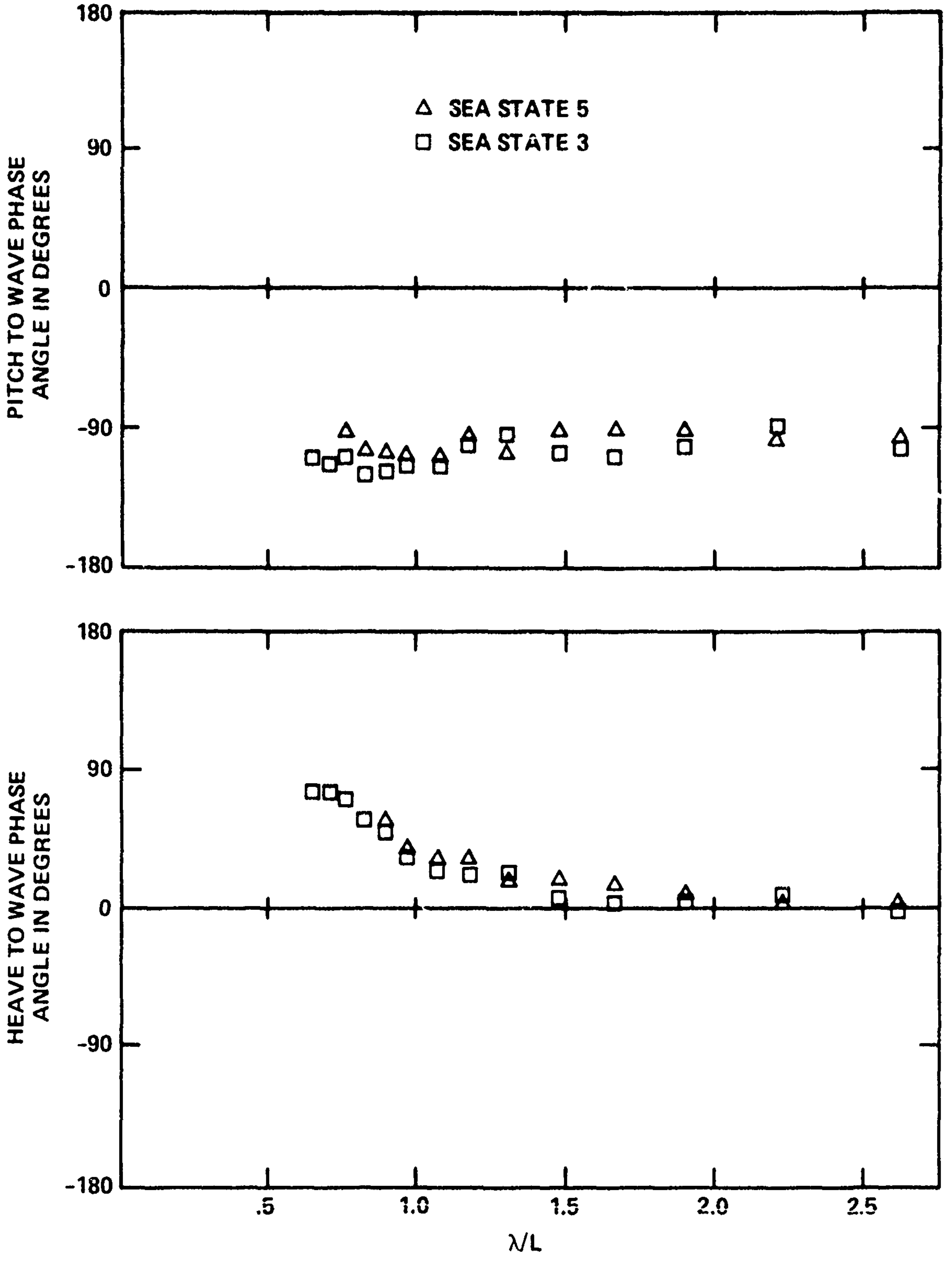

FIGURE 17 PITCH TO WAVE AND HEAVE TO WAVE PHASE ANGLES @ 6 KNOTS

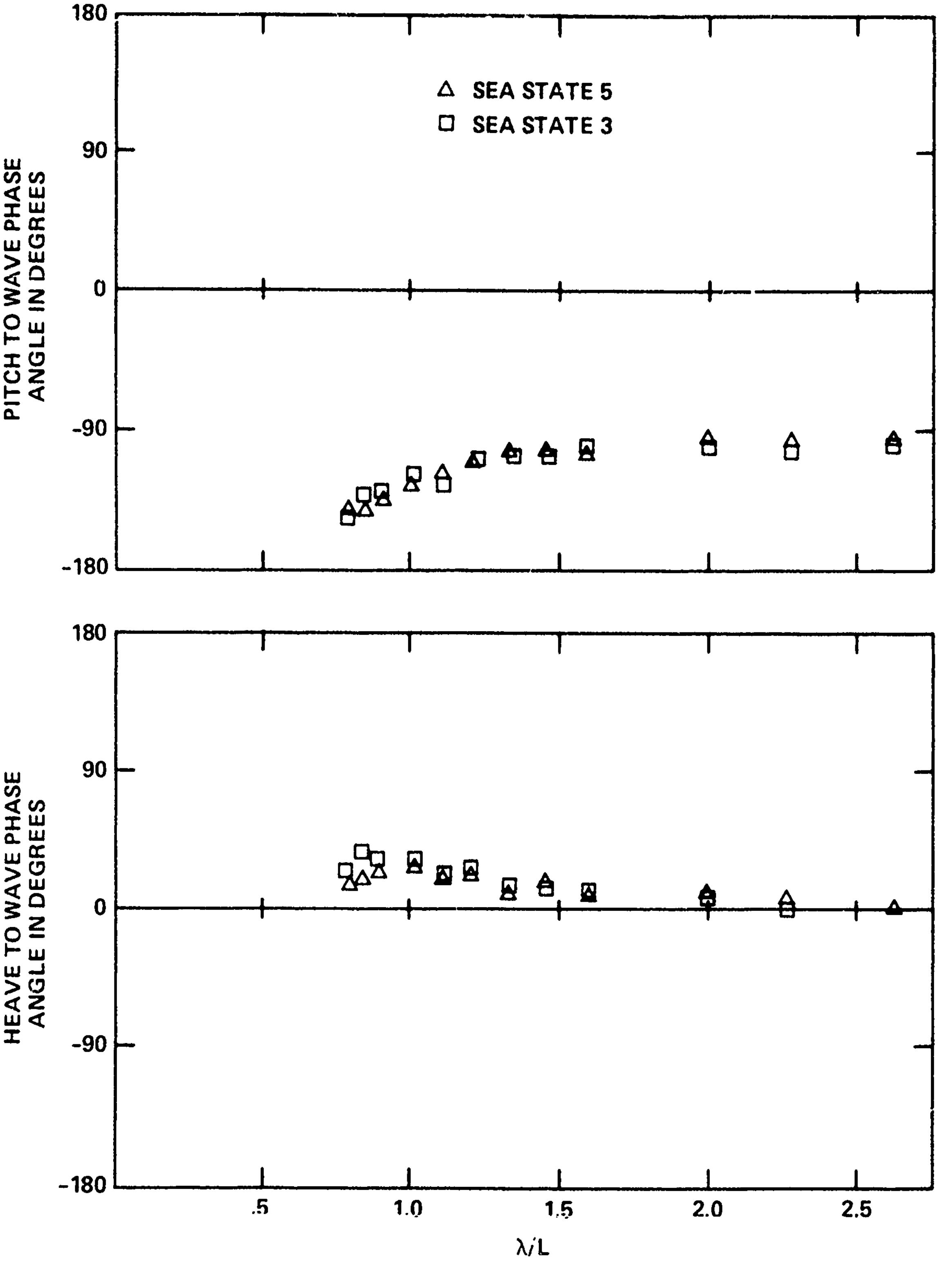

FIGURE 18 PITCH TO WAVE AND HEAVE TO WAVE PHASE ANGLES @ 10 KNOTS

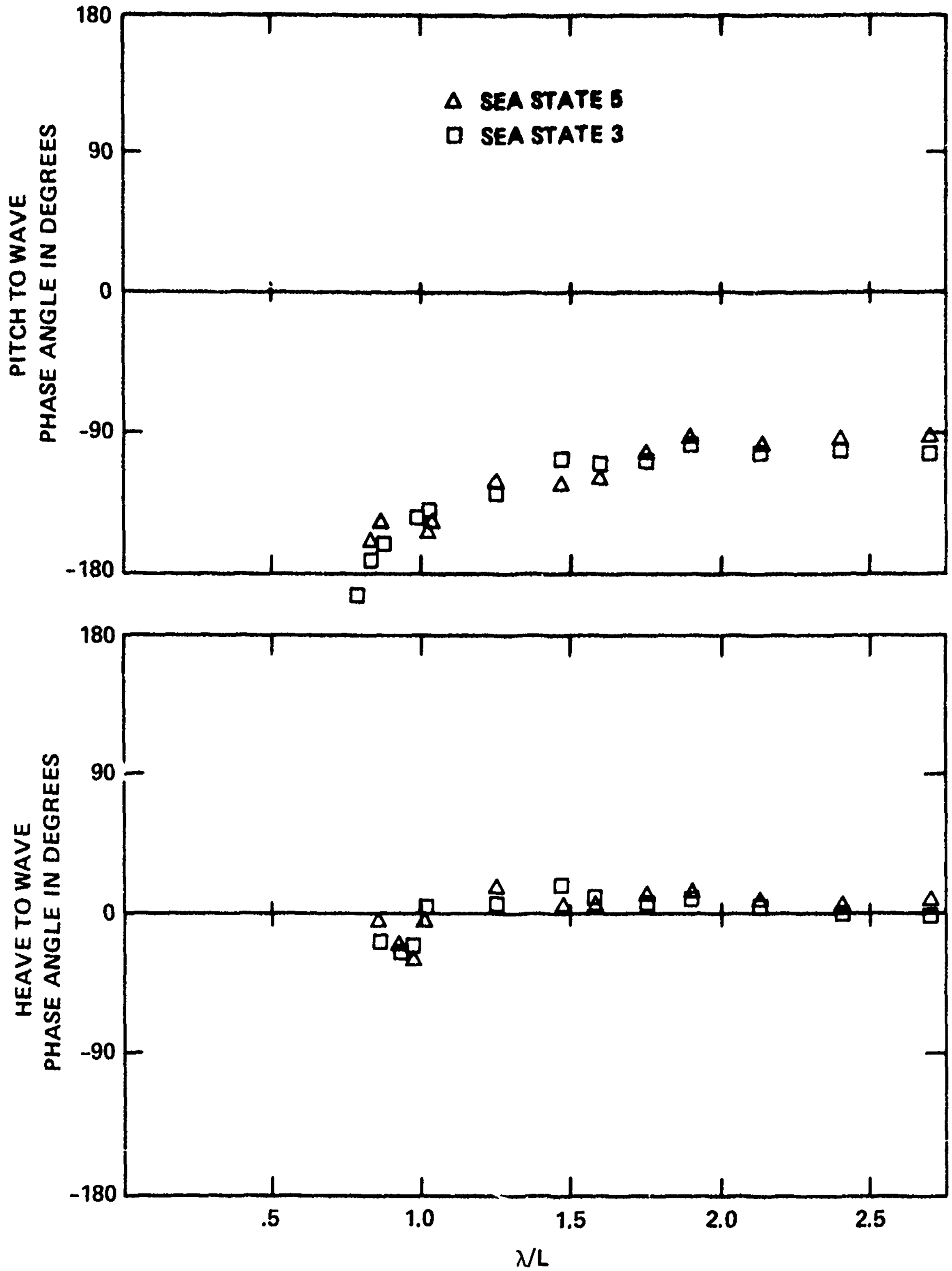

FIGURE 19 PITCH TO WAVE AND HEAVE TO WAVE PHASE ANGLES @ 15 KNOTS

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