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COMPUTER GENERATED RANDOM SEA SURFACES FOR USE WITH THE PROGRAM CABUOY

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30 SEPTEMBER 1977

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Random sea surfaces representative of sea states 3 through 8 have been generated for use with the computer program CABUOY. Output waveforms are presented graphically, along with the frequencies, amplitudes and phases of the component waves. Physical characteristics of the generated waveforms are compared with actual sea state data.

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S U M M A R Y

Random sea surfaces representative of sea states 3 through 8 have been generated for use with the computer program CABUOY. Output waveforms are presented graphically, along with the frequencies, amplitudes and phases of the component waves. Physical characteristics of the generated waveforms are compared with actual sea state data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND

CABUOY is a Fortran computer program which solves for the two dimensional dynamic motions of ocean deployed cable systems.[1] The program calculates the response of a moored, drifting or towed system to a surface wave forcing function, and outputs the position of each suspended body and the resultant cable tensions. Designed as a developmental tool for the evaluation of new sonobuoy systems, CABUOY requires a standardized input for surface motions so that engineering changes can be compared against known designs. Sea surfaces representative of sea states 3 through 8 were desired.

DISCUSSION

CABUOY generates a random surface motion through the superposition of sine waves of the form

$$y = A \sin (kx - \omega t + \theta)$$

where

y = vertical coordinate of wave
A = wave amplitude
$k = 2\pi/\lambda$ = wave number
λ = wave length
x = horizontal coordinate of wave
$\omega = 2\pi/T$ = circular frequency
T = wave period
t = time
θ = wave phase

This effort was concerned with the selection of component amplitudes and periods which would yield motions characteristic of wind driven waves at sea, in terms of significant wave height and period. As CABUOY is limited to 19 component waves, the pattern would not be completely random. It was considered that 1000 seconds of random motion would be sufficient in most cases.

The calculation of component wave amplitudes was based upon a knowledge of the energy content of wind driven waves. According to the Pierson-Moskowitz wave theory,[2] the energy spectral density for a fully developed sea can be defined by

$$S(\omega) = 8.1 \times 10^{-3}\ g^2\ \omega^{-5}\ e^{-.74(g/\mu_\omega \omega)^4}$$

1. *A Fortran IV Computer Program for the Time Domain Analysis of the Two Dimensional Dynamic Motions of General Buoy-Cable-Body Systems, H. T. Wang, DTNSRDC Report 77-0046, June 77.*
2. *Buoy Engineering, H. O. Berteaux, John Wiley & Sons, 1976.*

where

g = acceleration due to gravity
μ_ω = wind velocity

Solutions to this equation are illustrated in figure 1 for several wind velocities. Integration of this curve for a constant wind velocity yields the cocumulative energy function, illustrated in figure 2. This function represents the energy content of a fully developed sea as a function of wave period. For a constant wind velocity, the energy defined by the cocumulative function at a period To represents the total energy for all waves of periods To or less. Therefore, for some interval ΔT, the quantity

$$E(To + \Delta T/2) - E(To - \Delta T/2)$$

represents the total wave energy contained in a period band centered at To with a width of ΔT. Thus, from the cocumulative spectrum, it is possible to calculate the total wave energy existing in discrete period bands.

From statistical theory, the following relationships between wave height and wave energy have been defined:[3]

$$\text{Significant wave height} = 2.83\sqrt{\text{energy}}$$
$$\text{Tenth highest wave} = 3.60\sqrt{\text{energy}}$$
$$\text{Average wave height} = 1.77\sqrt{\text{energy}}$$

For this analysis, the component wave heights were defined according to the definition for average wave height using the energy derived from the cocumulative spectrum. It was found that component waves of average height summed together generated sea states consistent with recorded data, as summarized in the sea state chart, table I.

Component frequencies were determined by dividing the significant period band, defined as the band of periods on the cocumulative distribution function that excludes the top 5 percent and lower 3 percent of the total energy, into equally spaced intervals. The component waves were then assigned the period in the center of the interval. Component periods were shifted slightly, if necessary, to avoid harmonics which would decrease the randomness of the resultant wave pattern.

Tables II through VII list the component wave frequencies and amplitudes as calculated for sea states 3 through 8. The phase shifts were included to eliminate the unnaturally large wave which resulted when all components were summed together beginning at time 0. The phase shift amounts to shifting the initial time 20 seconds, and eliminates the singularity. One thousand seconds of random sea state data can be generated before the pattern repeats.

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3. *Wind Waves, Their Generation and Propagation on the Ocean Surface*, B. Kinsman, Prentice Hall, 1965.

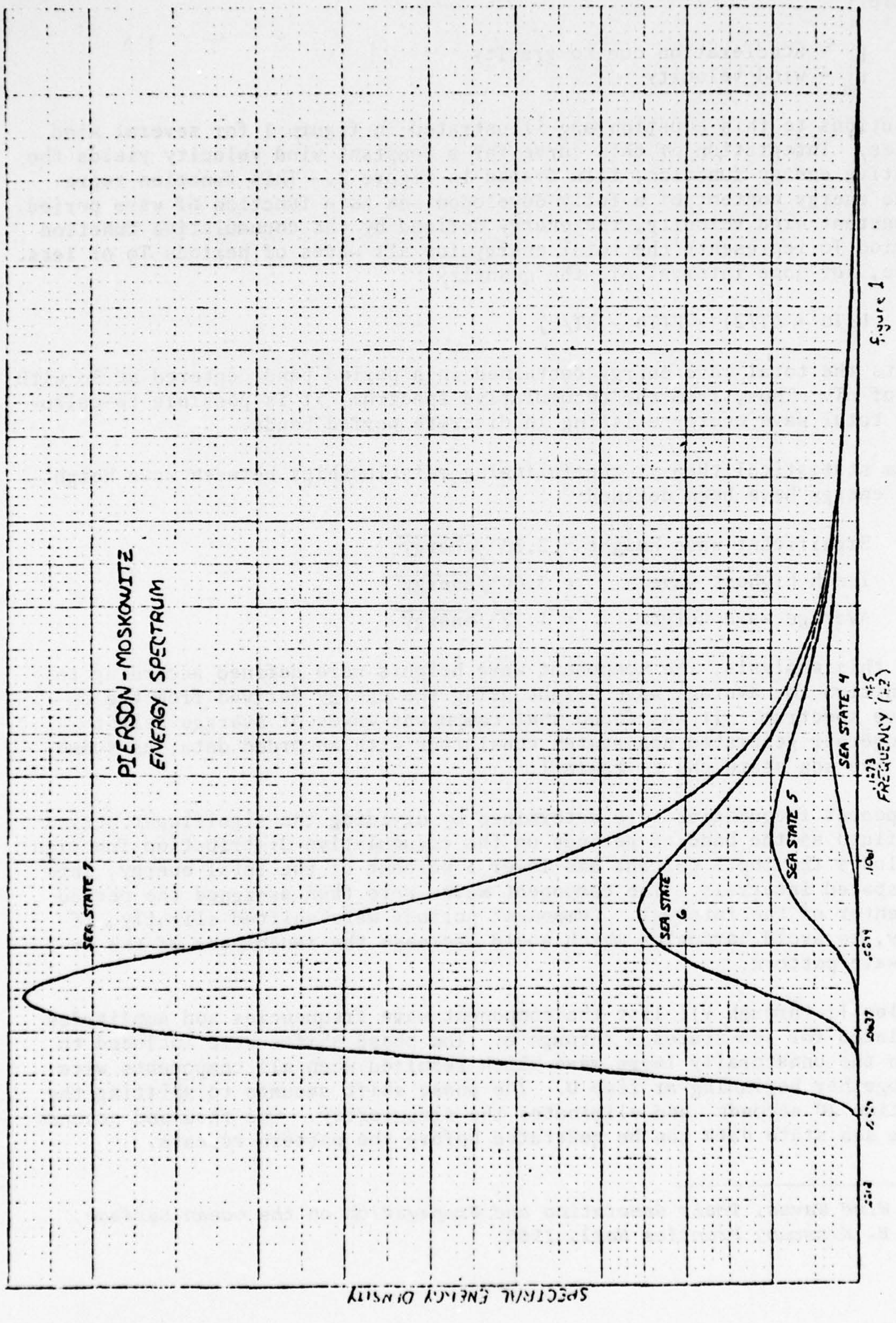

FIGURE 1 - Pierson Moskowitz Energy Spectrum

CO-CUMULATIVE ENERGY FUNCTION

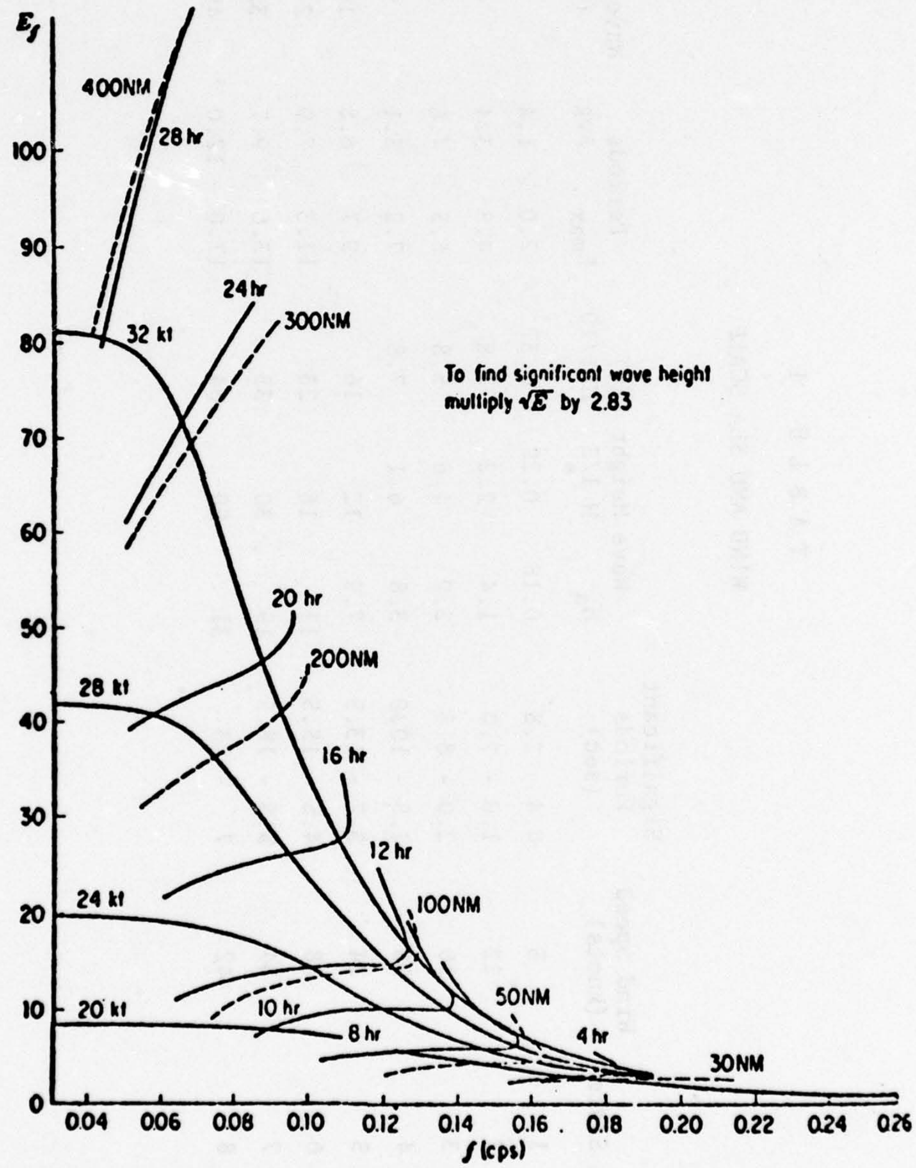

FIGURE 2 - Co-Cumulative Energy Function

TABLE I

WIND AND SEA SCALE

Sea State	Wind Speed (knots)	Significant Periods (sec)	Wave Height (ft) H_a	Wave Height (ft) H 1/3	Wave Height (ft) H 1/10	Periods E_{max}	Periods Avg	Wave Length (ft)	Energy (slug ft^2) Sec^2
1	5	0.4 - 2.8	0.18	0.29	0.37	2.0	1.4	6.7	0.008
2	12	1.0 - 7.0	1.4	2.2	2.8	4.8	3.4	40	0.60
3	16	2.0 - 8.8	2.9	4.6	5.8	6.5	4.6	71	2.54
4	18	2.5 - 10.0	3.8	6.1	7.8	7.2	5.1	90	4.58
5	24	3.7 - 13.5	7.9	12	16	9.7	6.8	160	19.27
6	28	4.5 - 15.5	11	18	23	11.3	7.9	212	41.65
7	34	5.5 - 18.5	19	30	38	13.6	9.7	322	109.95
8	42	7 - 23	31	50	64	17.0	12.0	492	316.27

TABLE II

SINE WAVE COMPONENT INPUTS FOR SEA STATE GENERATOR

SEA STATE 3

Frequency (Hz)	Amplitude (ft)	Phase (deg)
0.459	0.090	64.8
0.394	0.127	316.8
0.345	0.270	324.0
0.307	0.238	50.4
0.277	0.324	194.4
0.252	0.382	14.4
0.231	0.312	223.2
0.213	0.402	93.6
0.198	0.349	345.6
0.185	0.349	252.0
0.174	0.493	172.8
0.164	0.493	100.8
0.154	0.285	28.8
0.146	0.285	331.2
0.139	0.201	280.8
0.133	0.201	237.6
0.127	0.285	194.4
0.121	0.201	151.2
0.116	0.201	115.2

$$\theta_{Time} = 2\pi ft \text{ (sec)}$$

$$\theta_{Space} = 2\pi x/\lambda \text{ (feet)}$$

TABLE III

SINE WAVE COMPONENT INPUTS FOR SEA STATE GENERATOR

SEA STATE 4

Frequency (Hz)	Amplitude (ft)	Phase (deg)
0.371	0.255	151.2
0.323	0.238	165.6
0.287	0.349	266.4
0.258	0.402	57.6
0.234	0.493	244.8
0.214	0.349	100.8
0.197	0.604	338.4
0.183	0.569	237.6
0.171	0.402	151.2
0.160	0.569	72.0
0.151	0.636	7.2
0.142	0.402	302.4
0.135	0.569	252.0
0.128	0.402	201.6
0.122	0.285	158.4
0.116	0.285	115.2
0.111	0.285	79.2
0.106	0.569	43.2
0.069	0.402	136.8

TABLE IV

SINE WAVE COMPONENT INPUTS FOR SEA STATE GENERATOR

SEA STATE 5

Frequency (Hz)	Amplitude (ft)	Phase (deg)
0.253	0.604	21.6
0.224	0.667	172.8
0.2	0.753	0.0
0.182	0.944	230.4
0.166	0.9	115.2
0.153	1.026	21.6
0.142	1.065	302.4
0.132	0.986	230.4
0.124	1.365	172.8
0.116	1.102	115.2
0.110	0.805	36.0
0.104	1.026	28.8
0.099	0.854	352.8
0.094	0.9	316.8
0.089	0.697	280.8
0.086	0.753	259.2
0.082	0.753	230.4
0.079	0.493	208.8
0.076	0.402	187.2

TABLE V

SINE WAVE COMPONENT INPUTS FOR SEA STATE GENERATOR

SEA STATE 6

Frequency (Hz)	Amplitude (ft)	Phase (deg)
0.209	0.944	64.8
0.186	1.138	259.2
0.168	1.102	129.6
0.153	1.273	21.6
0.141	1.273	295.2
0.130	1.365	216.0
0.121	1.777	151.2
0.113	1.635	93.6
0.106	1.559	43.2
0.1	1.304	0.0
0.095	1.61	324.0
0.09	1.479	288.0
0.085	0.9	252.0
0.081	1.207	223.2
0.078	1.173	201.6
0.074	1.102	172.8
0.071	0.9	151.2
0.068	0.9	129.6
0.066	1.273	115.2

TABLE VI

SINE WAVE COMPONENT INPUTS FOR SEA STATE GENERATOR

SEA STATE 7

Frequency (Hz)	Amplitude (ft)	Phase (deg)
0.171	1.423	151.2
0.153	1.635	21.6
0.139	1.660	280.8
0.127	2.347	194.4
0.117	2.205	122.4
0.108	2.546	57.6
0.101	2.381	7.2
0.094	2.546	316.8
0.088	2.514	273.6
0.083	2.432	237.6
0.079	2.546	208.8
0.075	2.530	180.0
0.071	2.012	151.2
0.068	2.012	129.6
0.065	1.684	108.0
0.062	1.909	86.4
0.060	1.273	72.0
0.057	1.559	50.4
0.055	1.273	36.0

TABLE VII

SINE WAVE COMPONENT INPUTS FOR SEA STATE GENERATOR

SEA STATE 8

Frequency (Hz)	Amplitude (ft)	Phase (deg)
0.135	2.347	252.0
0.121	3.509	151.2
0.110	3.745	72.0
0.101	3.656	7.2
0.093	3.84	216.0
0.086	3.711	259.2
0.080	4.316	216.0
0.075	4.5	180.0
0.071	4.124	151.2
0.067	4.316	122.4
0.063	4.589	93.6
0.060	3.711	72.0
0.057	4.124	50.4
0.054	3.486	28.8
0.052	3.367	14.4
0.050	2.846	0.0
0.048	2.7	345.6
0.046	1.8	331.2
0.044	1.559	316.8

Figures 3 through 8 present 600 seconds of wave data for sea states 3 through 8 which were generated using the previously defined component waves. These waves compare favorably with the sea state chart in table I. Figure 9 presents actual wave data recorded at sea north of St. Croix in the U.S. Virgin Islands. In general, the computed sea data compare favorably with actual data.

CONCLUSION

Random sea surfaces composed of discrete sine waves whose amplitudes and frequencies are derived from the cocumulative sea spectrum can be generated which compare favorably to actual sea surface date. These computer sea states should be used with the program CABUOY when it is necessary to evaluate the response of a cable suspended system to a random sea state forcing function.

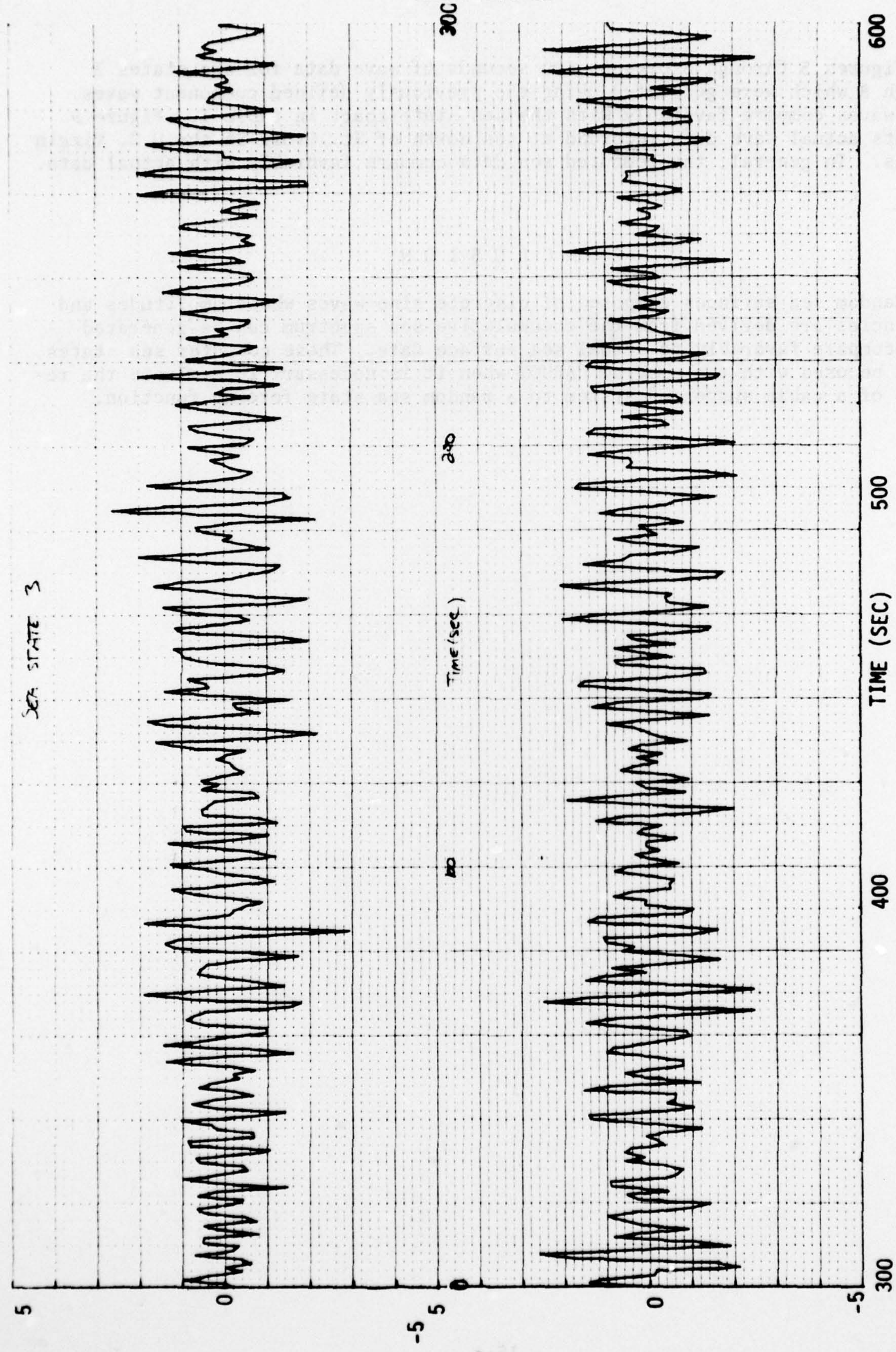

FIGURE 3 - Computer Generated Sea State 3 Wave

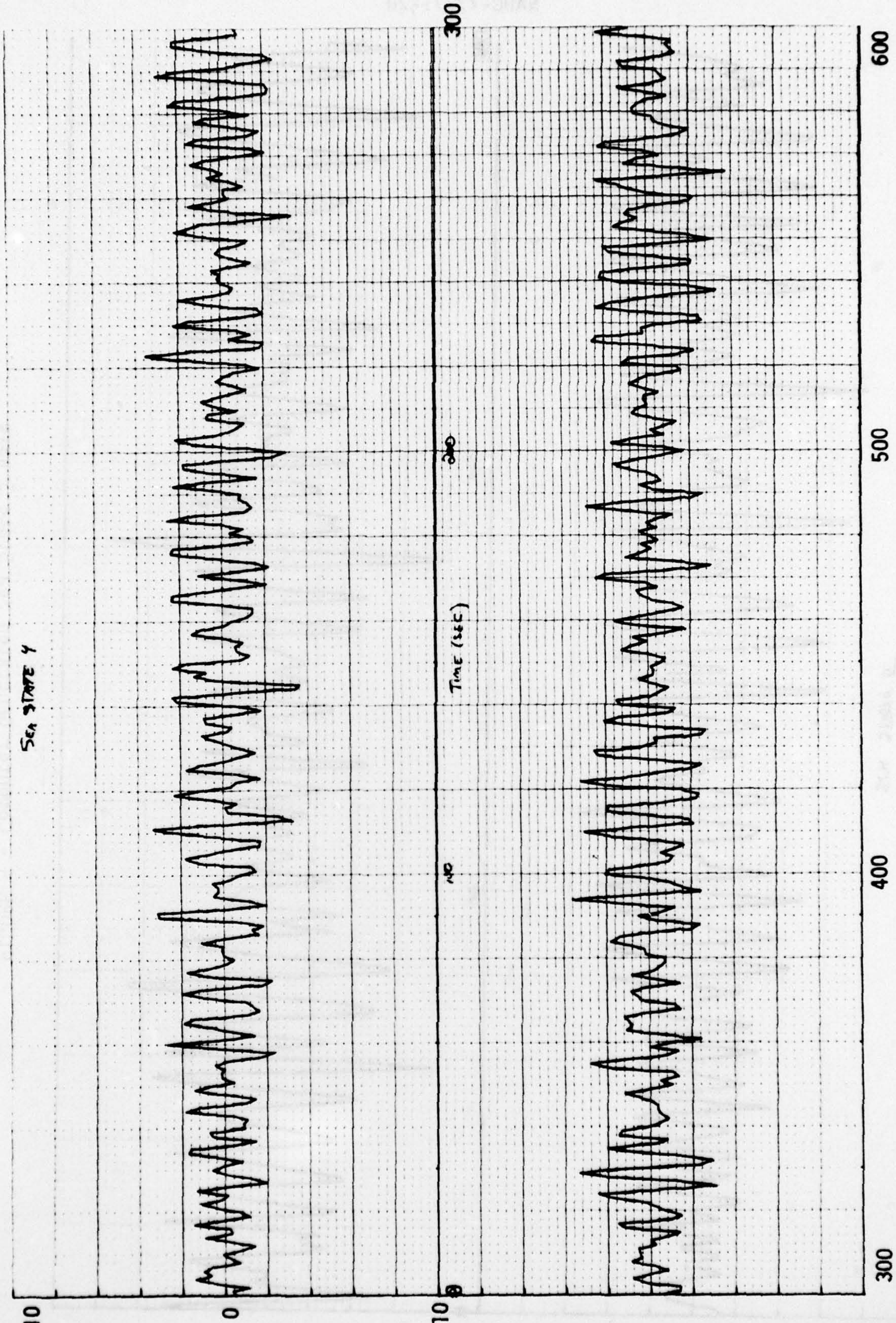

FIGURE 4 - Computer Generated Sea State 4 Wave

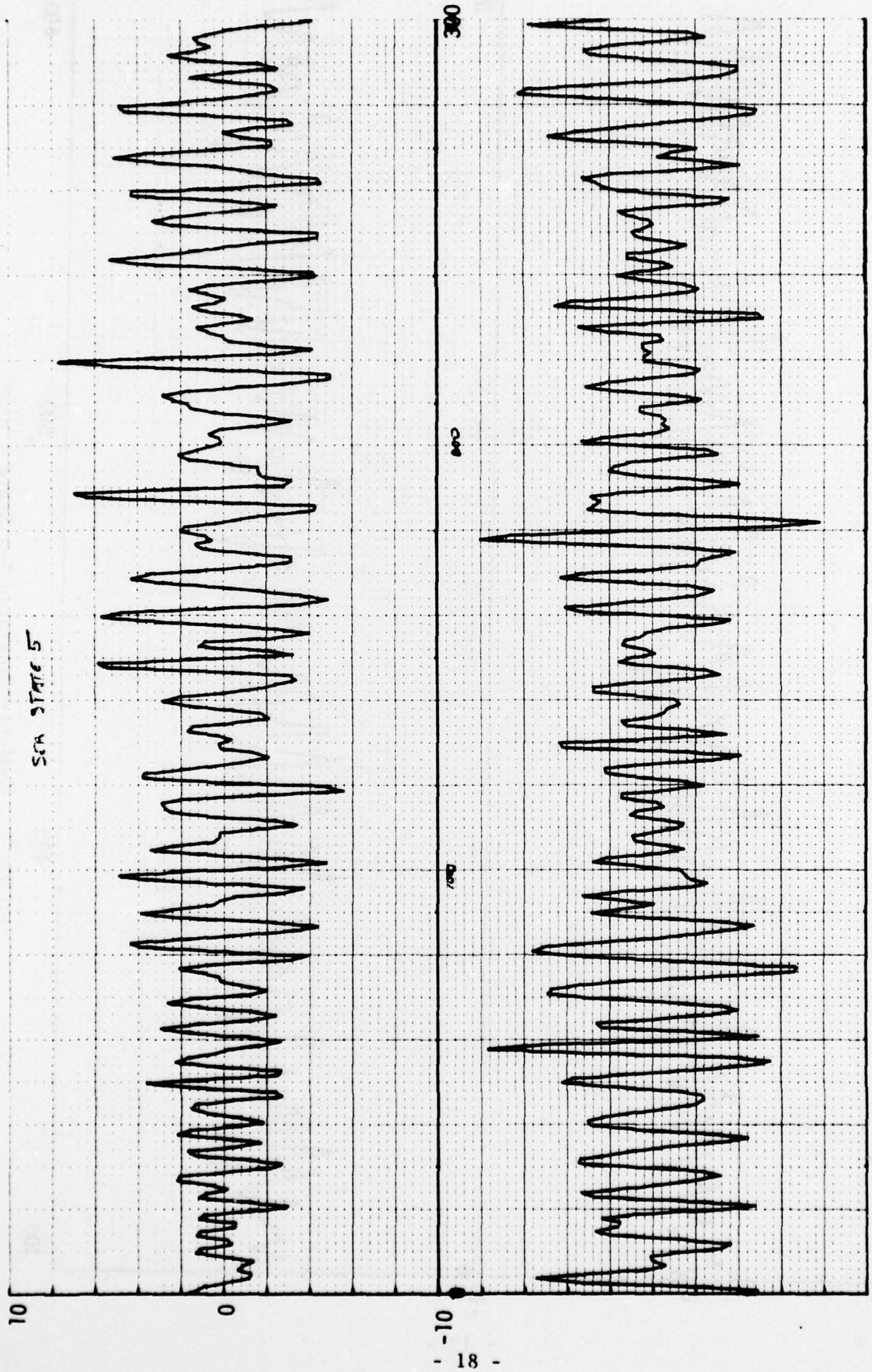

FIGURE 5 - Computer Generated Sea State 5 Wave

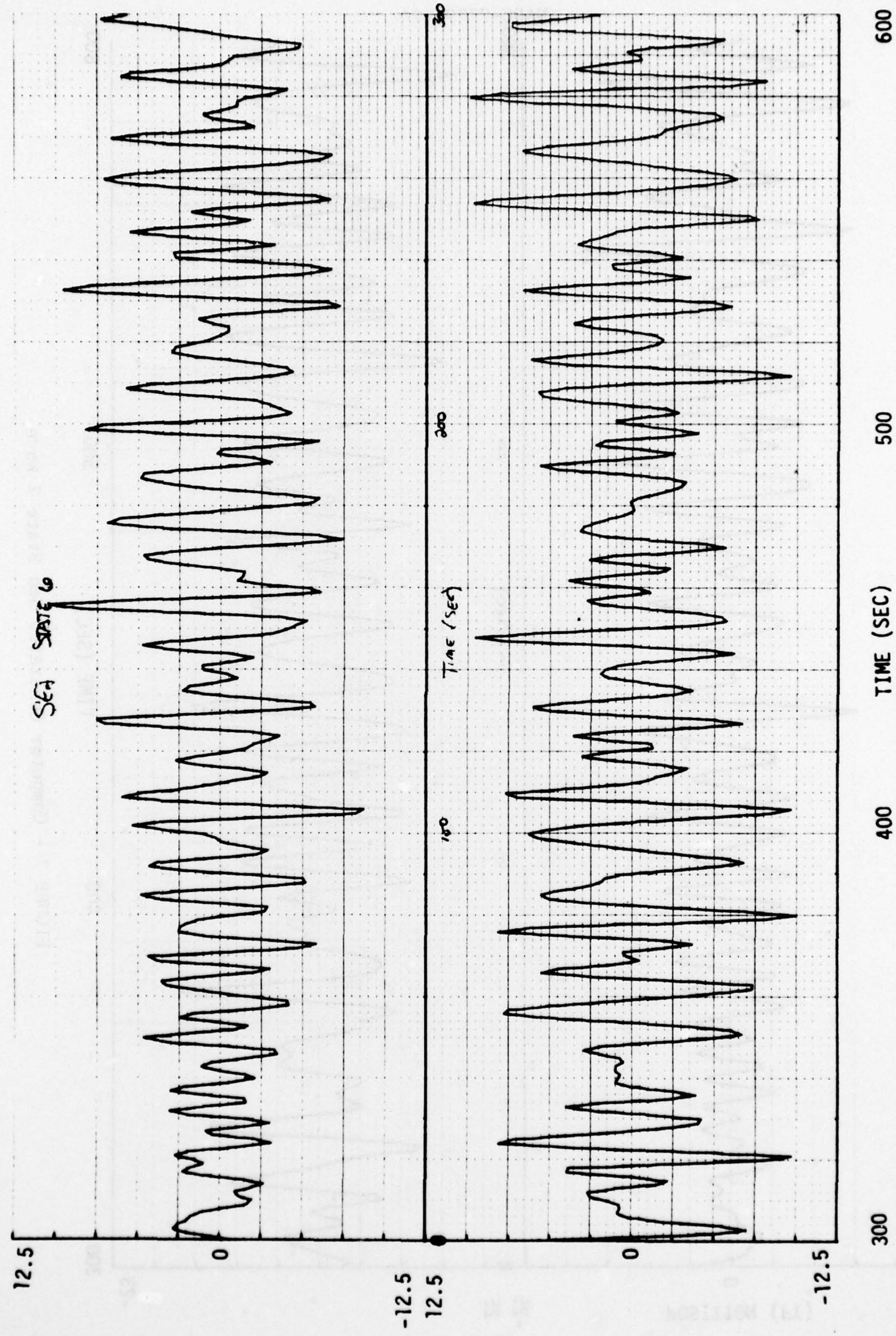

FIGURE 6 - Computer Generated Sea State 6 Wave

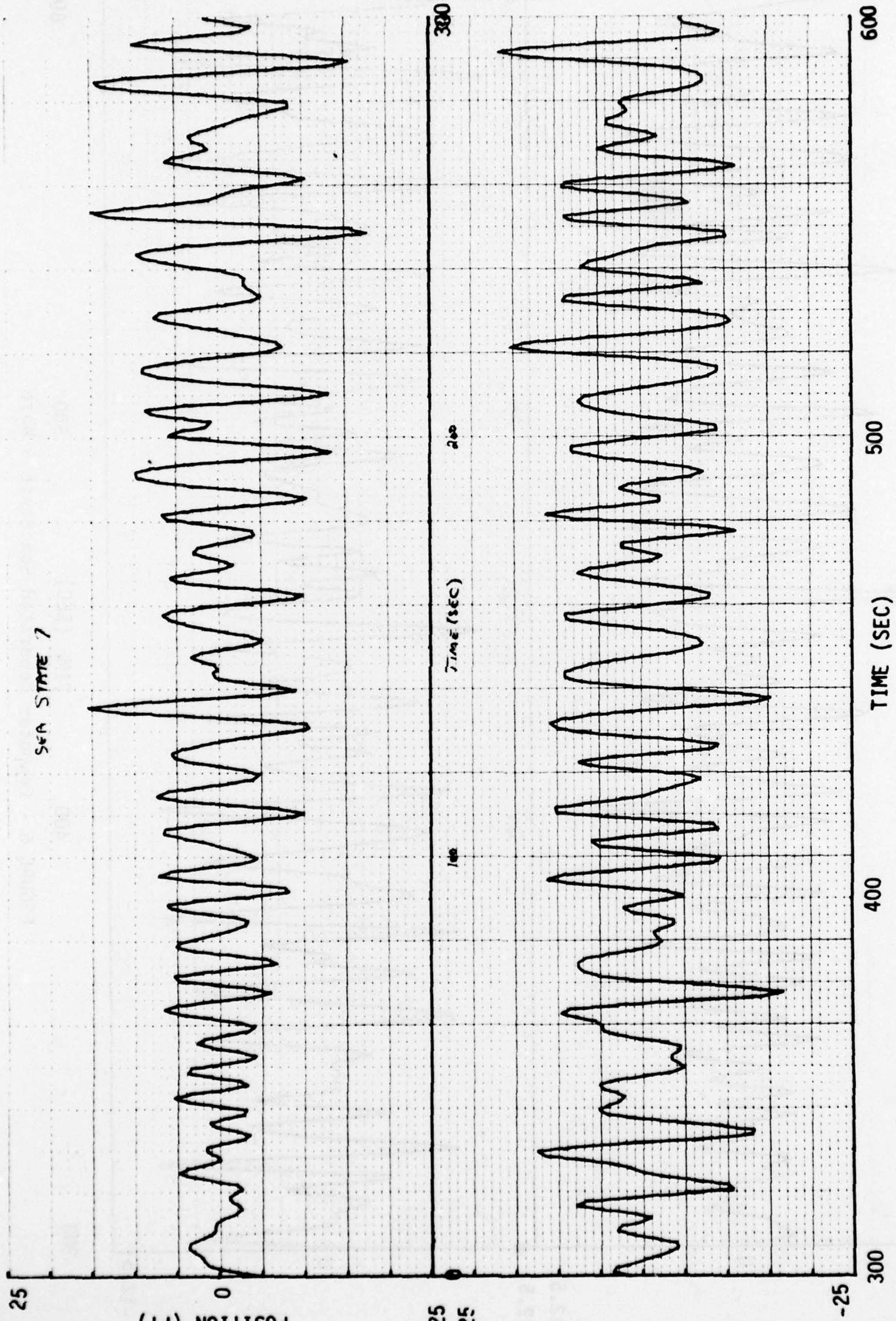

FIGURE 7 - Computer Generated Sea State 7 Wave

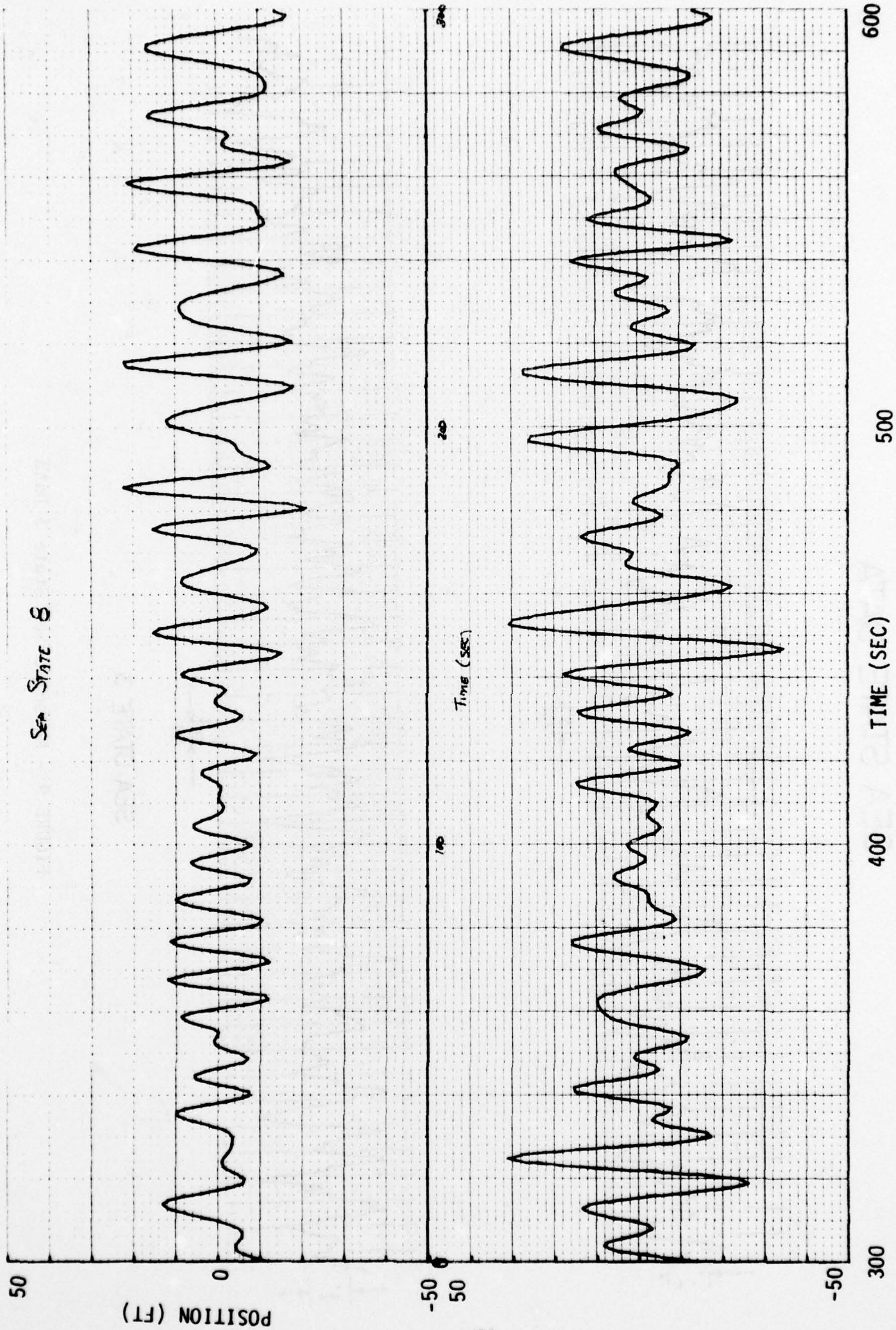

FIGURE 8 - Computer Generated Sea State 8 Wave

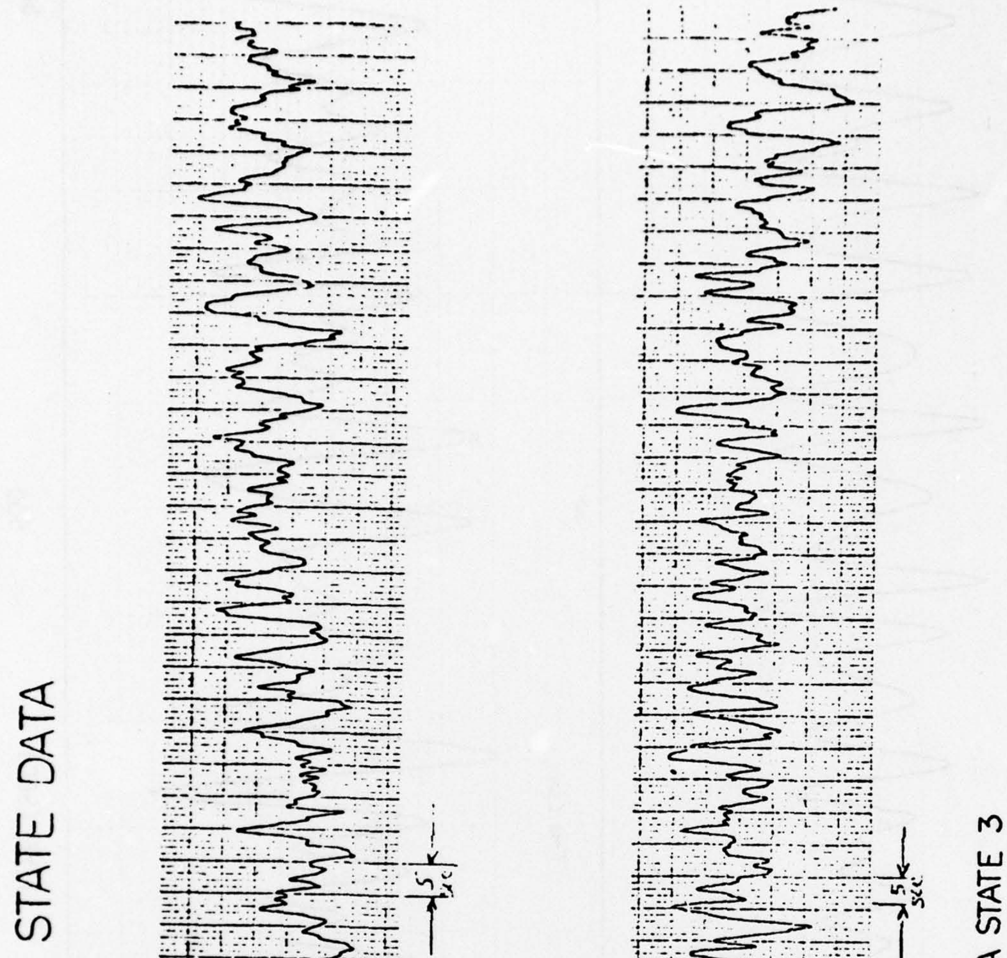

FIGURE 9 - Measured Sea State 3 Data

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