University of Washington
Department of Civil and Environmental Engineering

A COMPUTER PROGRAM FOR THE DYNAMIC ANALYSIS OF CONTINUOUS FLOATING STRUCTURES IN SHORT CRESTED WAVES

Constantinos Georgiadis
Billy J. Hartz

Water Resources Series
Technical Report No. 74
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University of Washington
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This report was prepared without the auspices or funding from a specific sponsor; it presents a state of the art dynamic analysis of long, floating structures, which did, however, draw heavily from previously sponsored work. The early, "Mark I" version was developed from a study, completed in 1972, of the Hood Canal Floating Bridge, sponsored by the Washington State Highway Department. Subsequent modifications and improvements led to adapting the analytical methods to predicting the dynamic responses of a series of caisson-type floating breakwaters proposed for sites in Puget Sound (Washington), a project sponsored by the Seattle District, Corps of Engineers. The publication of the report was made possible through the Second Conference on Floating Breakwaters, held at the University of Washington, October 19-20, 1981.

LIST OF SYMBOLS

The following is a list of symbols which are most commonly used in the text. Other symbols used are defined in the text when they first appear.

A Underwater cross-section area, A_c cross-section area

a_o Normalized cross-section area ($a_o = A/(B/2)^2$)(underwater)

B Cross-section width

C Centroid of cross-section

C_F^S, C_F^H, C_F^R Hydrodynamic Force Coefficients defined by Eqs. 3.2a, b, c.

c Distance of centroid to free surface (positive upwards)

D Depth of fluid region

d Normalized depth ($d = D/(B/2)$)

E, E_p, E_c Moduli of elasticity, subscripts for pontoons or connectors

EI Flexural rigidity

e Normalized modulus of elasticity ($e = 2E/\rho_w gB$)

F Cut-off frequency, force

f Frequency in Hz, force per unit length

H Wave height, $H(t) = 2\eta(t)$

H_s Significant wave height ($H_{1/3}$)

I_{xx}, I_{yy} Cross section moment of inertia

i_{xx}, i_{yy} Normalized moment of inertia ($i_{xx} = 192\ I_{xx}/B^4$)

I_o Cross-section polar moments of inertia ($I_o = \iint_{A_c} r^2 dA$)

g Acceleration of gravity

k Wave number ($k = 2\pi/\lambda = \omega^2/g$)

k_j lateral stiffness normalized ($k_j = 4K_j/(\rho_w gB^2)$)

L Bridge length

L_i nodal distance from node i to $i+1$

L_{ij} nodal distance from node i to j

ℓ normalized distance ($\ell = L/(B/2)$)

M Moment

m mass per unit length, moment per unit length

$N_1(z)$, $N_2(z)$, $N_i(z)$ Displacement functions

O Origin of axis on freewater surface

R_i Nodal loads

$R_{R_i R_j}(\tau)$ Correlation between R_i and R_j

$R_f(Z_1, Z_2, \tau)$ Correlation between forces at distances Z_1, and Z_2

r_i Nodal distance

$S(\omega)$, $S(f)$ Spectrum

$S_w(\omega)$, $S_w(f)$ Wave Spectrum

$S_{w(AB)}(\omega)$, $S_{w(Z_1 Z_2)}(\omega)$ Wave cross-spectra between points A and B or Z_1 and Z_2

$S_{f(Z_1 Z_2)}(\omega)$ Force cross-spectra between points Z_1 and Z_2

T Cross-section draft, wave period

t Time variable

X, Y, Z Coordinates

x, y, z Normalized coordinates (i.e., $x = X/(B/2)$)

$\beta_H, \beta_H^S, \beta_H^H, \beta_H^R$ Hydrodynamic mass coefficient, superscript for sway, heave and roll

$\beta_V, \beta_V^S, \beta_V^H, \beta_V^R$ Virtual mass coefficient, superscript for sway, heave and roll

γ Coherence

$\delta, \delta_{(\omega)}$ Hydrodynamic force coefficient - nondimensional

$\overline{\delta}(\omega)$ Non-dimensional hydrodynamic force coefficient including directional effects

η Wave surface height from mean ($\eta = \eta(t)$)

θ Wave direction relative to bridge axis

λ Wave length

$\xi, \xi_H^S, \xi_H^H, \xi_H^R, \xi_V^S, \xi_V^H, \xi_V^R$ Percent of critical damping, subscript for hydrodynamic or virtual mass, superscript for sway, heave and roll

ρ_w Water specific mass

σ Normalized frequence ($\sigma = \omega\sqrt{B/2g}$)

Φ Wave potential

ϕ Nondimensional wave potential

ω Cyclic frequency

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I. Introduction

Although the structural modeling of a floating bridge or breakwater poses no particular difficulty, the implementation of the shortcrested waves in the nodal loads needs to be done carefully.

The response calculation can be done with existing computer programs (SAPIV, STRUDL, NASTRAN,...) with additional help from other programs, to simulate the sea state and process the results. This procedure can prove to be time and money consuming, risking the opportunity of errors in the handling and transformation of the data.

The program presented here combines fluid structure and stochastic process theories in one program. In this way the response computation of floating structures is reduced to a routine problem.

The following aspects have been implemented in the program:

1) Flexibility and ease of modeling with reduction of input data for floating bridges and breakwaters.
2) Continuous structures as well as structures with flexible connectors.
3) Frequency and time domain analysis.
4) Boat wake analysis.
5) Frequency dependent hydrodynamic coefficients.
6) Short-crested waves.
7) Wave Time series simulation from wave spectra.
8) Monte Carlo simulation of random sea state.
9) Programming optimization for reduced cost and central memory requirements.
10) Graphical output of results in convenient format.

Following is a brief theoretical background of the program operations (more on this can be found in ref. 6).

Verification of the accuracy of the program has been done with the response of the original Hood-Canal bridge for which there exist actual field measurements under various wave loadings, [9, 10, 18].

The program is written in FORTRAN IV language and can be adapted to most computers. For the moment it is available for C.D.C. and VAXII machines.

II. Structural Model

The program computes the response of straight floating bridges and breakwaters. In such cases neglecting the small coupling between sway and roll due to hydrodynamic mass and damping, the response can be considered uncoupled for the three directions of motion; sway, heave, roll. A future extension of the program will be for the case of curved bridges, where the response is three dimensional.

Finite beam elements of half pontoon length, and linear elastic springs for the lateral anchoring are used in the structural modeling. A consistent mass and bouyancy matrix is used, based on a third degree polynomial element displacement field [5], [24]. The structural idealization as well as the stiffness and mass matrices are shown in Figures 2.1 a,b. In the same figures are shown the stiffness matrices for flexible connectors (if any exist between the pontoons), based on a constant curvature displacement field due to their smaller length.

Elastic springs for the lateral anchoring can be specified at the ends and middle of each pontoon. The nodal point spacing can be chosen closer than half pontoon length by specifying pontoons shorter than the actual ones. In the later case and in case of a structure with rigid connectors, very stiff connectors should be specified to simulate the rigid connections between the shorter pontoons (see Fig 2.2).

Assembling the structure stiffness and mass matrices and condensing the rotational degrees of freedom, the equations of motion are:

$$[m]\{\ddot{r}(t)\} + [c]\{\dot{r}(t)\} + [k]\{r(t)\} = \{R(t)\} \qquad (2.1)$$

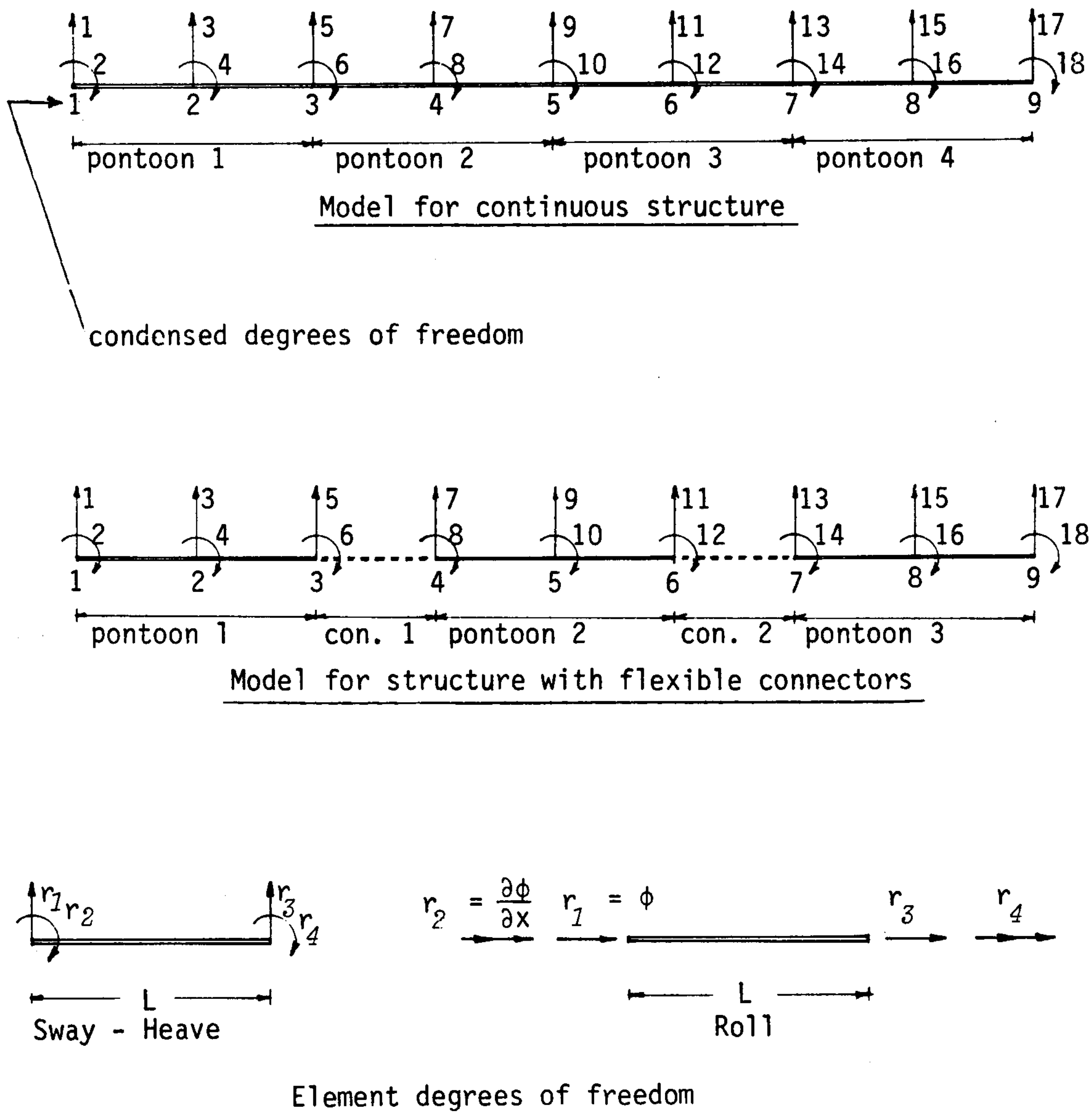


Fig. 2.1.a

Structure Idealization

$$[K_B^p] = \frac{E_p I_p}{L^3}\begin{bmatrix} 12 & -6L & -12 & -6L \\ -6L & 4L^2 & 6L & 2L^2 \\ -12 & 6L & 12 & 6L \\ -6L & 2L^2 & 6L & 4L^2 \end{bmatrix}$$

Bending stiffness for pontoons

$$[K_T^p] = \frac{G_p J_p}{30L}\begin{bmatrix} 36 & -3L & -36 & -3L \\ -3L & 4L^2 & 3L & -L^2 \\ -36 & 3L & 36 & 3L \\ -3L & -L^2 & 3L & 4L^2 \end{bmatrix}$$

Torsional stiffness for pontoons

$$[K_W^p] = \frac{sL}{420}\begin{bmatrix} 156 & -22L & 54 & 13L \\ -22L & 4L^2 & -13L & -3L^2 \\ 54 & -13L & 156 & 22L \\ 13L & -3L^2 & 22L & 4L^2 \end{bmatrix}$$

Bouyancy stiffness

$s = wb$ Heave

$s = wb^3/12$ Roll

w: water specific weight

b: cross-section width

$$[M^p] = \beta \frac{m L}{420}\begin{bmatrix} 156 & -22L & 54 & 13L \\ -22L & 4L^2 & -13L & -3L^2 \\ 54 & -13L & 156 & 22L \\ 13L & -3L^2 & 22L & 4L^2 \end{bmatrix}$$

Mass matrix

$$\beta = \left(\frac{\text{hydr. + struct. mass}}{\text{struct. mass}}\right)$$

$$m = \iint_{A_c} \rho \, g \, dA \text{ (Heave, Sway)}; \quad m = \iint_{A_c} \rho \, g r^2 \, dA \text{ (Roll}$$

$$[K_T^c] = \begin{bmatrix} \frac{G_c J_c}{L_c} & 0 & \frac{-G_c J_c}{L_c} & 0 \\ 0 & 0 & 0 & 0 \\ \frac{-G_c J_c}{L_c} & 0 & \frac{G_c J_c}{L_c} & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Torsional stiffness connectors

$$[K_B^c] = \begin{bmatrix} \frac{G_c A_c}{L_c} & 0 & \frac{-G_c A_c}{L_c} & 0 \\ 0 & \frac{E_c I_c}{L_c} & 0 & \frac{-E_c I_c}{L_c} \\ \frac{-G_c A_c}{L_c} & 0 & \frac{G_c A_c}{L_c} & 0 \\ 0 & \frac{-E_c I_c}{L_c} & 0 & \frac{E_c I_c}{L_c} \end{bmatrix}$$

Bending stiffness connectors

Fig. 2.1.b

Stiffness and Mass Matrices

where: [m], [c] virtual mass and damping matrices (structure + Hydro-dynamic).

[k] structure stiffness + bouyancy matrix

{R(t)} exciting wave forces

{r(t)} nodal displacements

The above equation is solved in frequency and time domain as discussed in paragraphs 6 and 7 below.

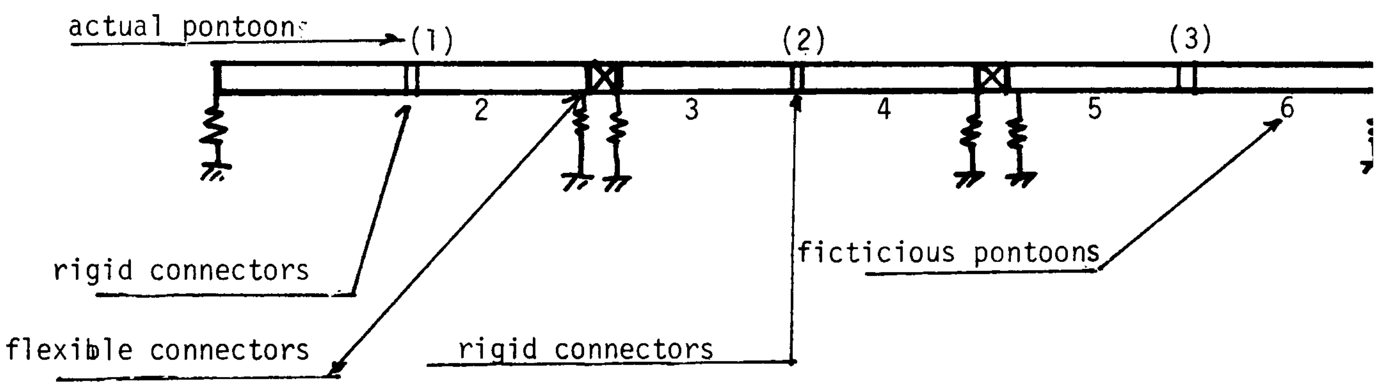


Fig. 2.2
Connector Idealizations

III. Hydrodynamic Coefficients

The hydrodynamic forces on the oscillating structure are: added mass (proportional to the structure acceleration), added damping (proportional to the structure velocity), and exciting force (proportional to the incident wave). The way these forces are computed is described in ref. 6. Here are presented in summary some results in tables and graphs for practical use obtained using program HYDRO. Detailed description of the theory behind this program and its use can be found in ref. 6

In the graphs and tables following are presented the coefficients:

β_1, β_2, β_3, for the Hydrodynamic mass.

ξ_1, ξ_2, ξ_3, for the Hydrodynamic damping.

δ_1, δ_2, δ_3, for the Hydrodynamic exciting forces.

(where subscripts 1, 2, 3 are used for the three directions of motion: sway, heave, roll).

Using the above coefficients we can get (per unit length of structure):

Added Mass:

sway $$M_S = \beta_1(\rho_w A) \quad (3.1.a)$$

heave $$M_H = \beta_2(\rho_w A) \quad (3.1.b)$$

roll $$M_R = \beta_3\left\{\rho_w\ (B/2)^4 + c^2\beta_1(\rho_w A)\right\} \quad (3.1.c)$$

Added Damping:

The above coefficient ξ represent percent of critical damping in respect to the virtual mass.

Exciting Forces:

sway $$F_{sway} = \delta_1(\rho_w g)(B/2)(\eta(t)) = C_F^S \eta(t) \tag{3.2.a}$$

heave $$F_{heave} = \delta_2(\rho_w g)(B/2)(\eta(t)) = C_F^H \eta(t) \tag{3.2.b}$$

roll $$F_{roll} = \delta_3(\rho_w g)(B/2)^2(\eta(t)) + c * F_{sway}$$
$$= C_F^R \eta(t) + c * F_{sway} \tag{3.2.c}$$

To take into account the directional wave spectrum the coefficients δ have been modified to $\bar{\delta}$, (Table 3.2) for directional spectrum of the form $S(f,\theta) = S(f)*\cos^n(\theta-\theta_o)$.

A note should be made that all, the above coefficients are frequency dependent and in the graphs and plots the normalized frequency has been used ($\sigma = \omega\sqrt{B/2g}$).

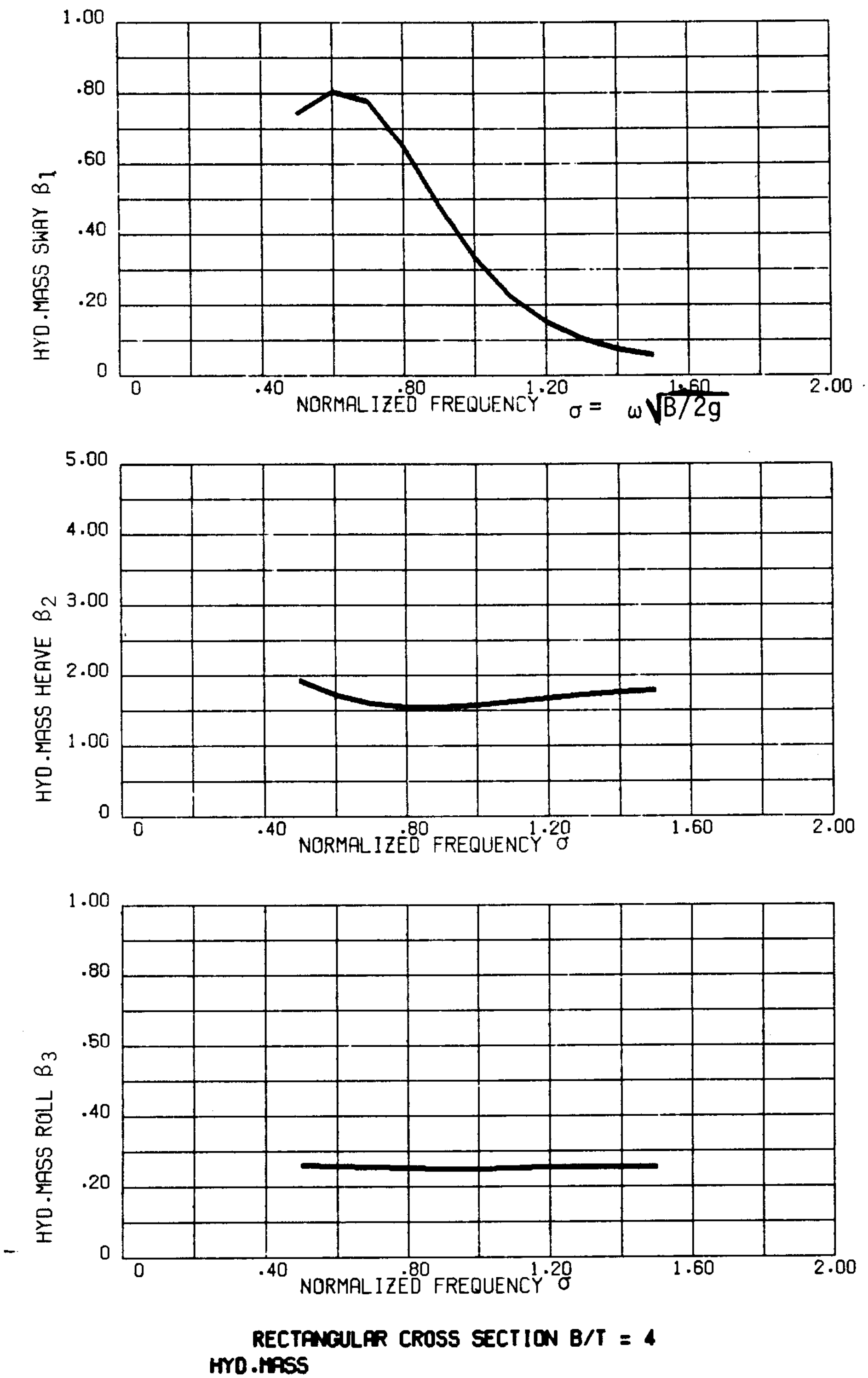


Fig. 3.1.a

Hydrodynamic Mass Coefficients (rectangular cross section B/T = 4)

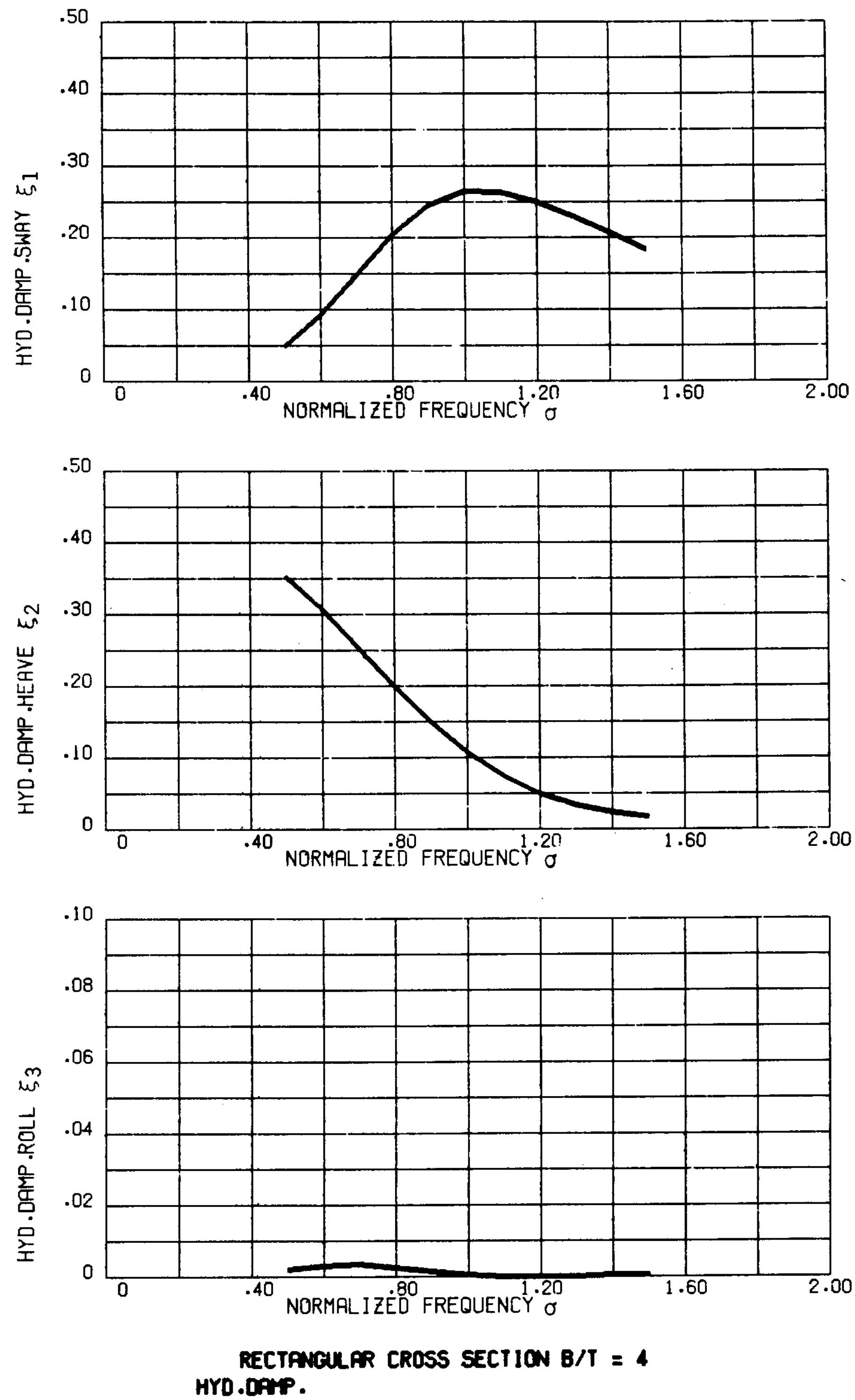


Fig. 3.1.b

Hydrodynamic Damping (rectangular cross section B/T = 4)

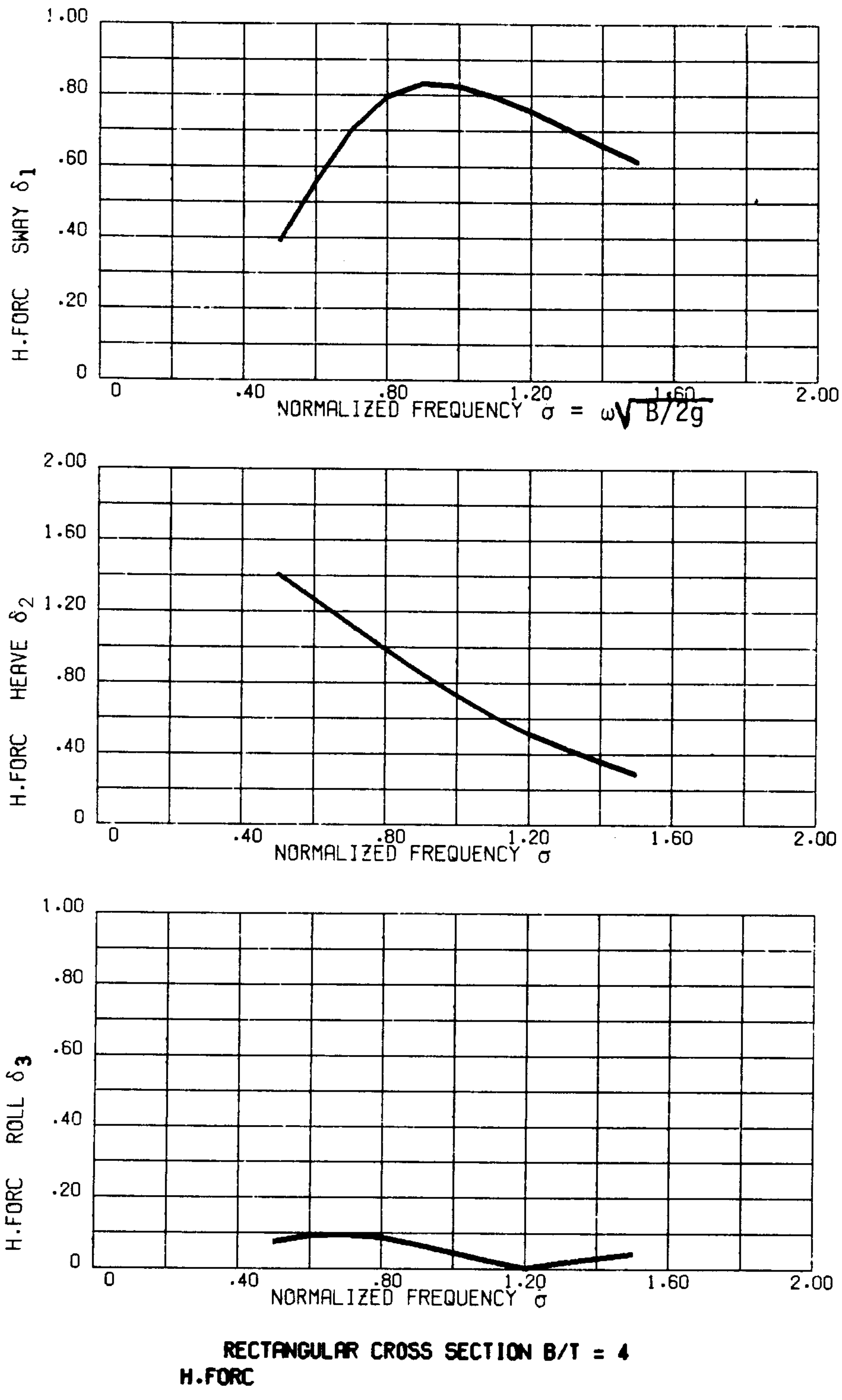


Fig. 3.1.c

Hydrodynamic Exciting Force (rectangular cross section B/T = 4)

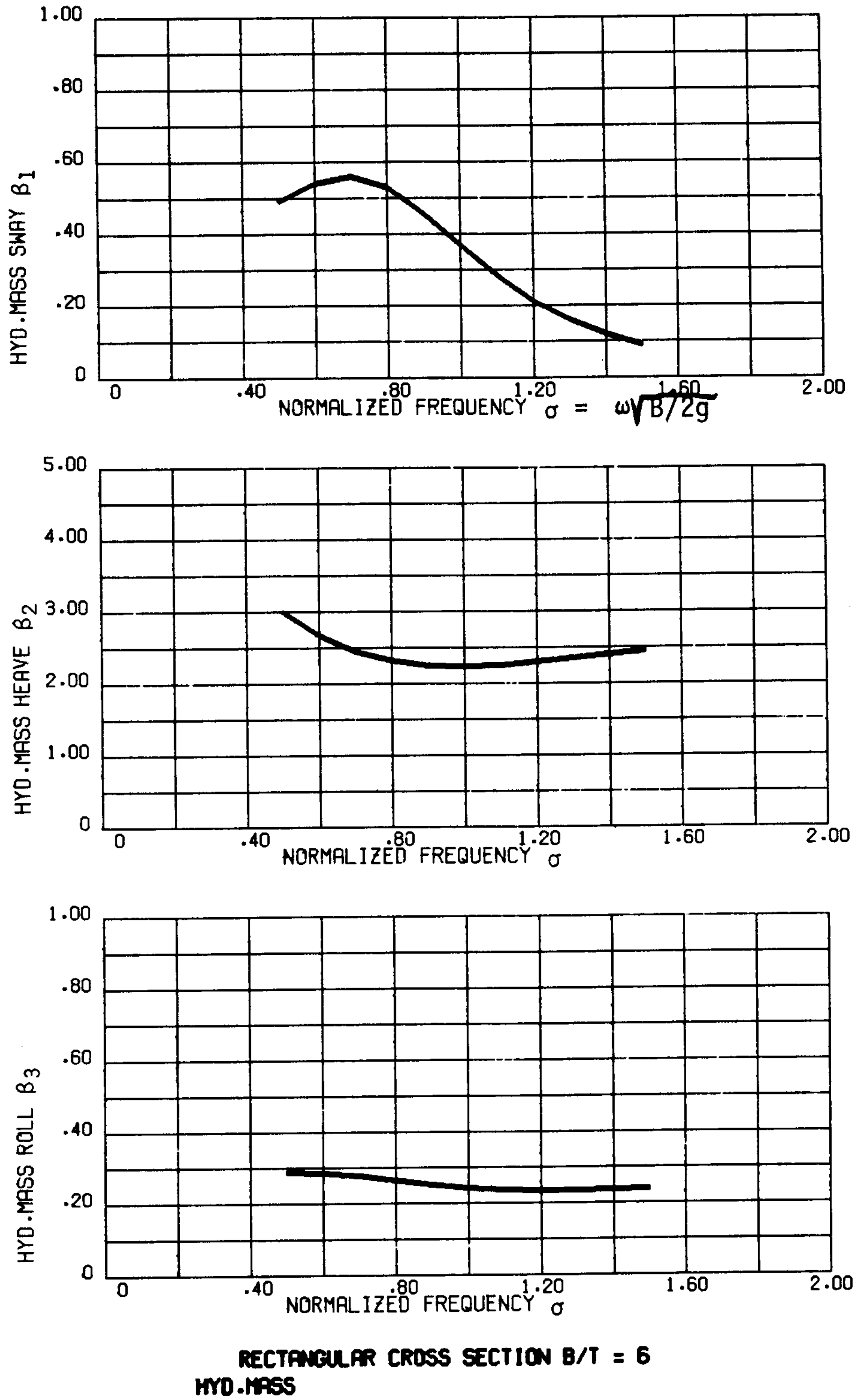


Fig. 3.2.a

Hydrodynamic Mass (rectangular cross section B/T = 6)

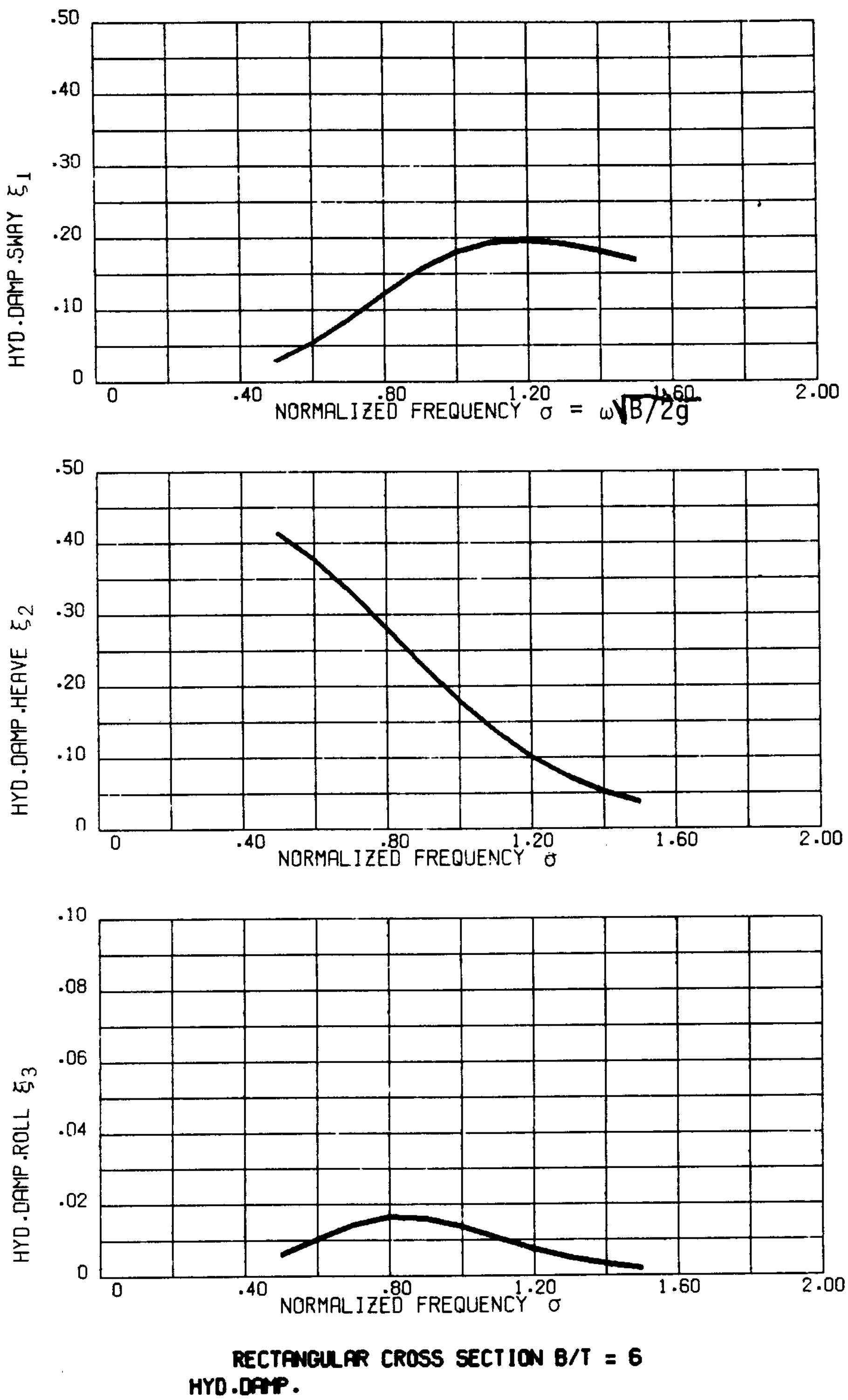


Fig. 3.2.b

Hydrodynamic Damping (rectangular cross section B/T = 6)

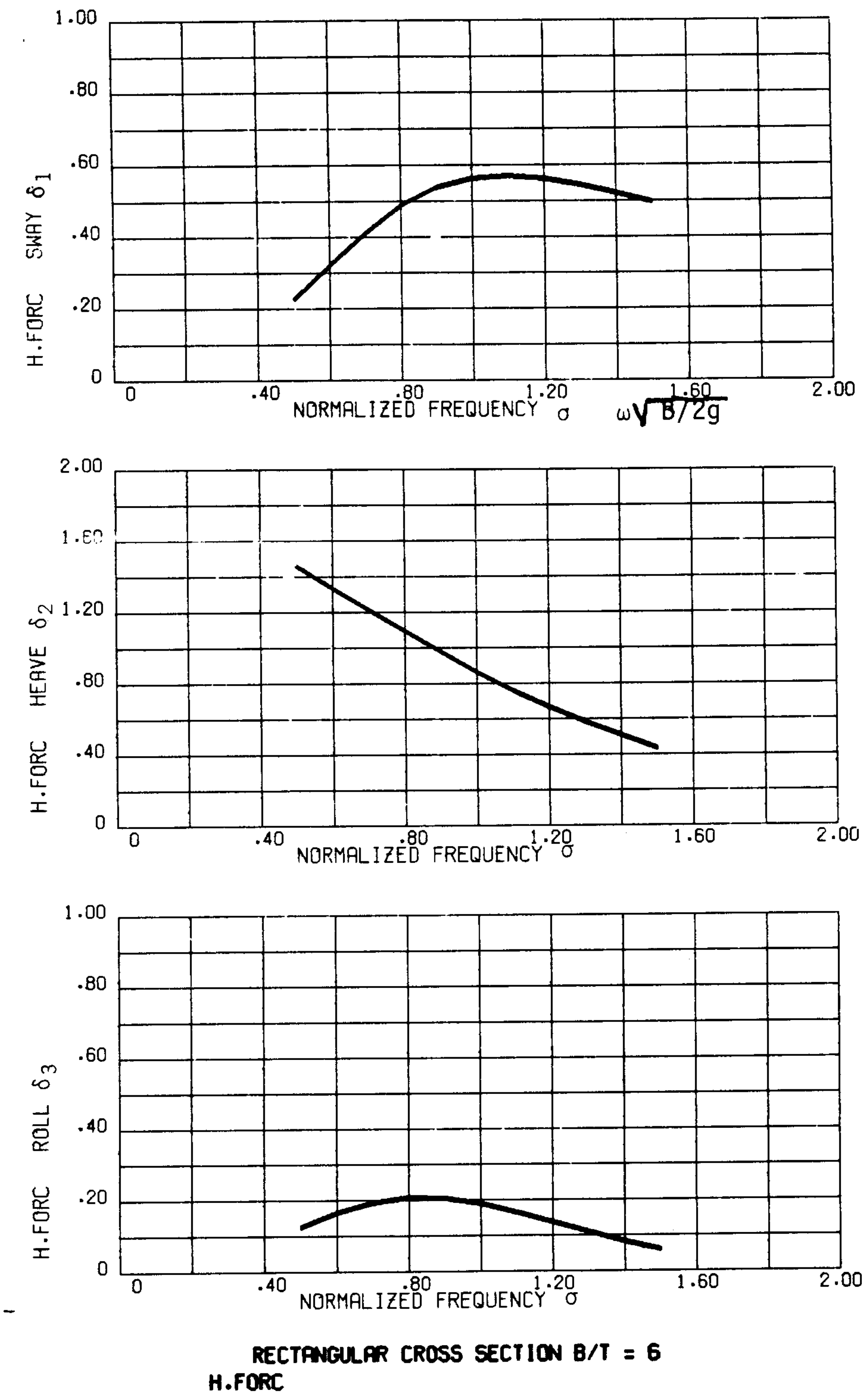


Fig. 3.2.c

Hydrodynamic Exciting Force (rectangular cross section B/T = 6)

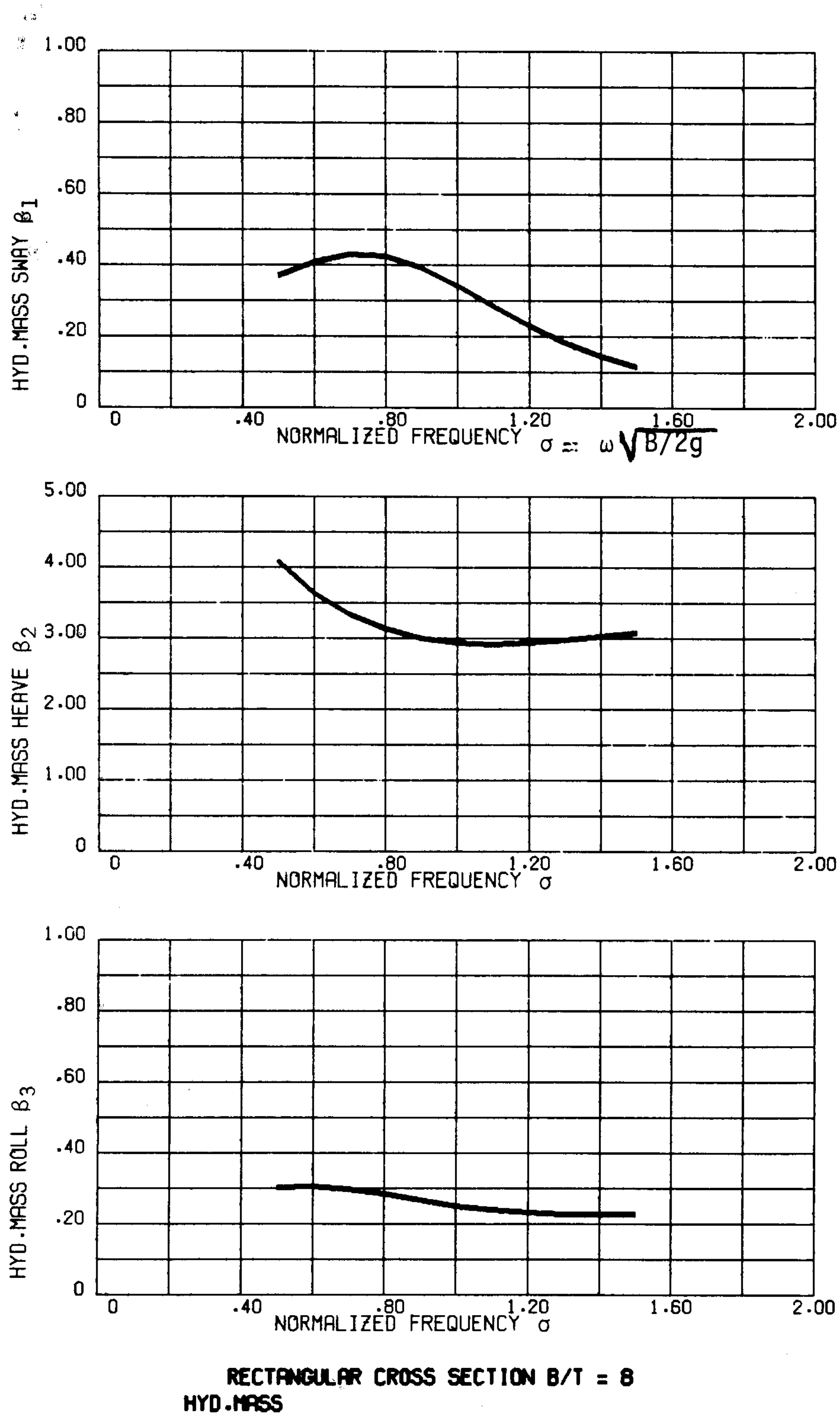


Fig. 3.3.a

Hydrodynamic Mass (rectangular cross section B/T = 8)

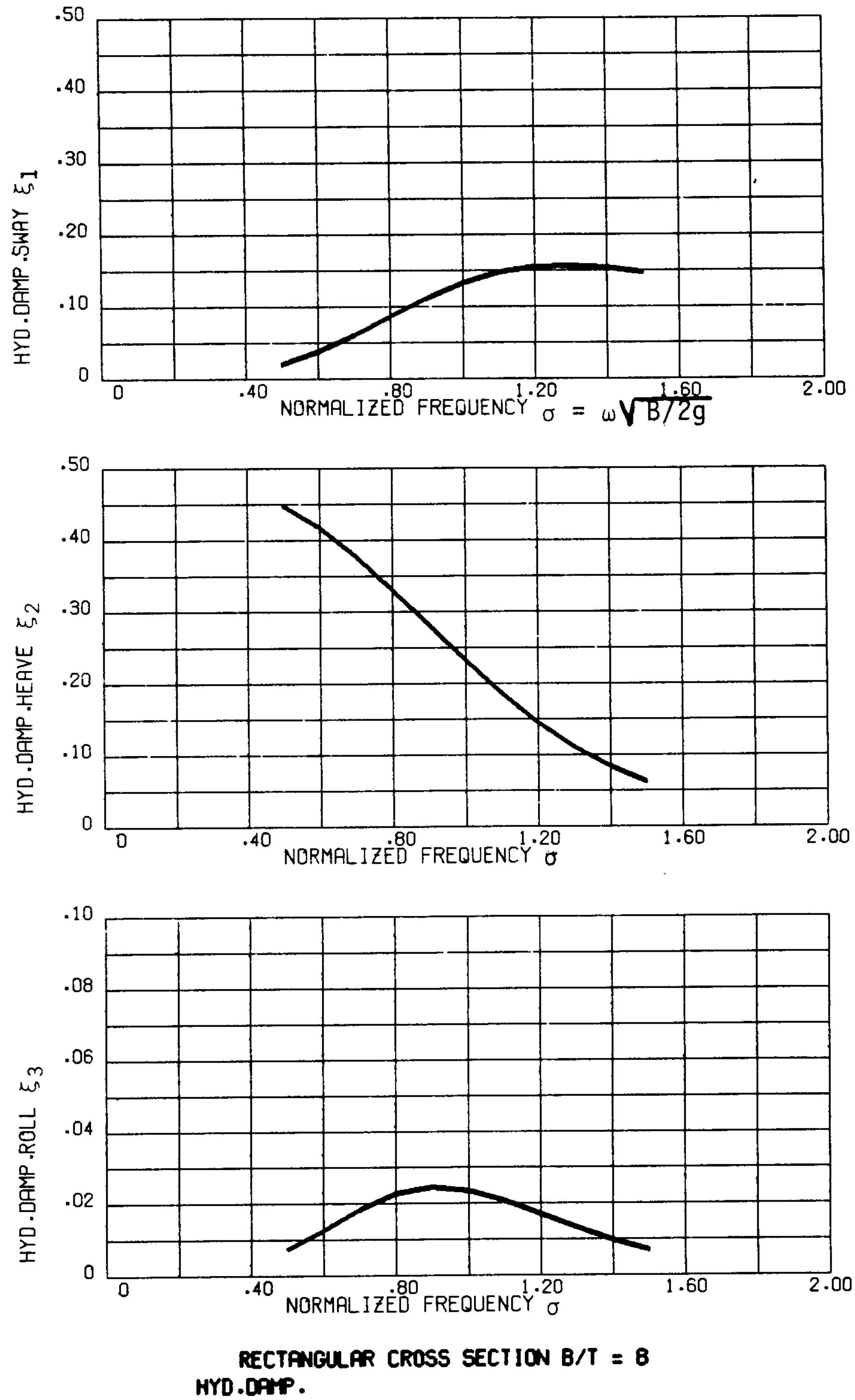


Fig. 3.3.b

Hydrodynamic Damping (rectangular cross section B/T = 8)

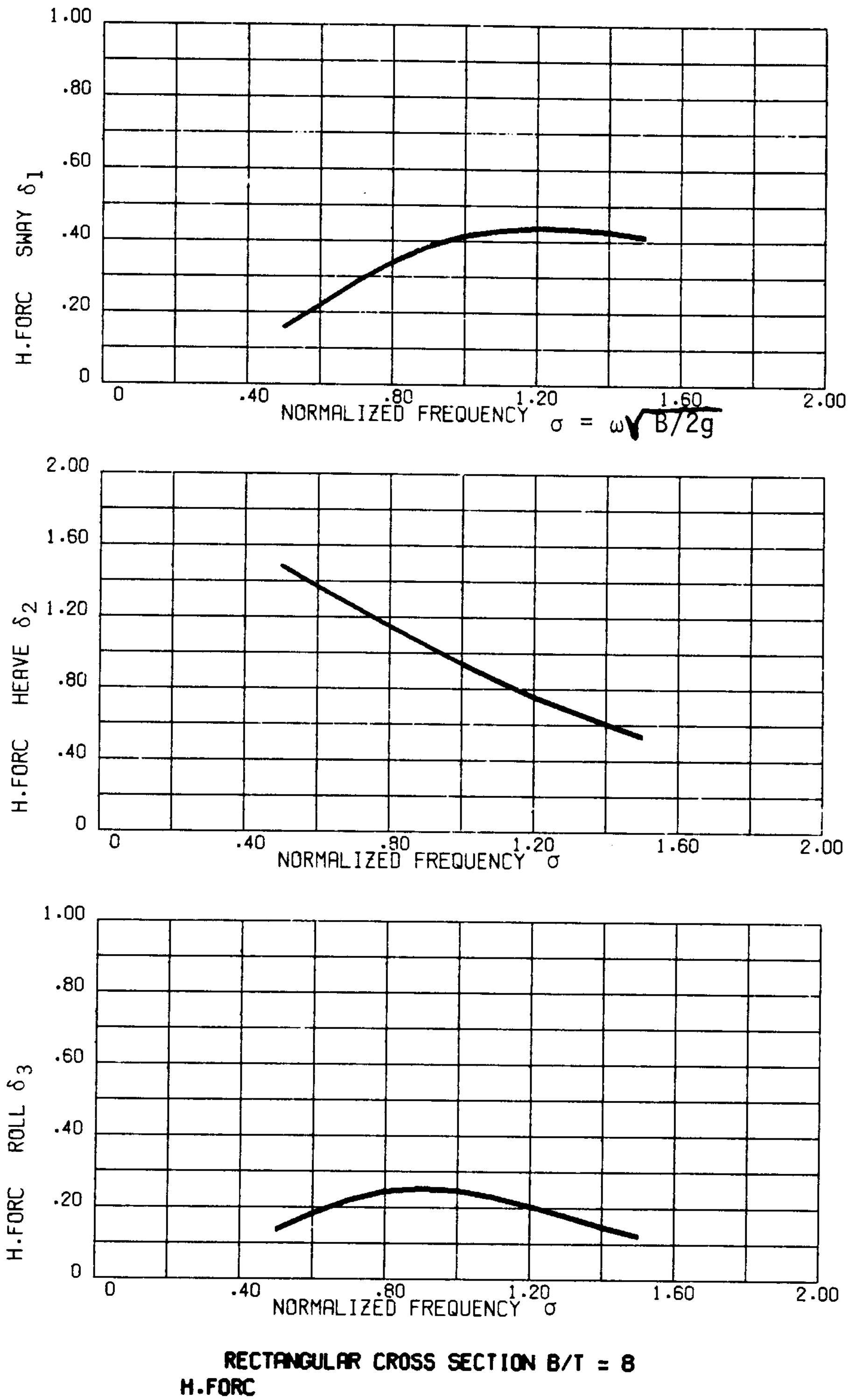
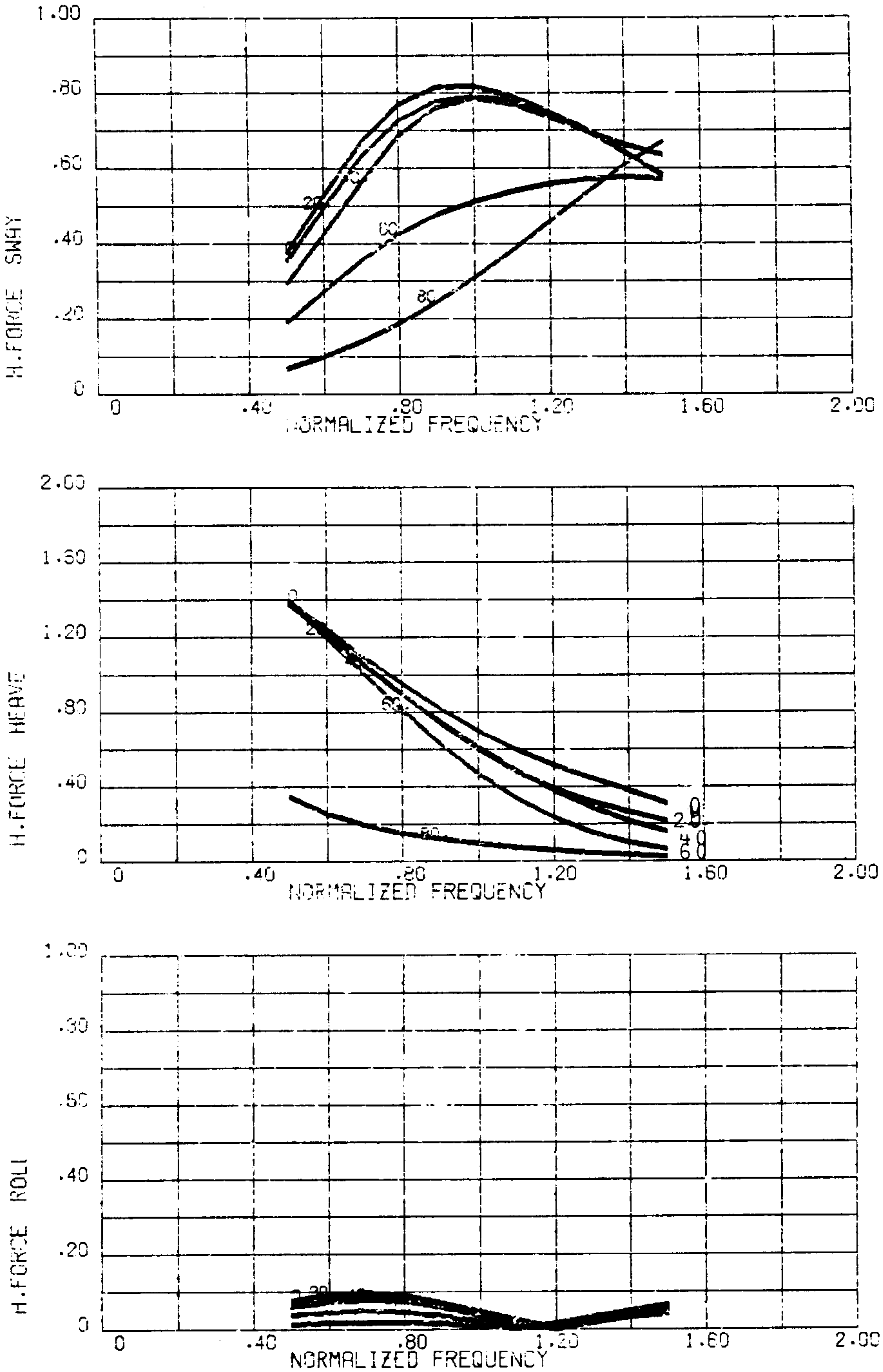


Fig. 3.3.c

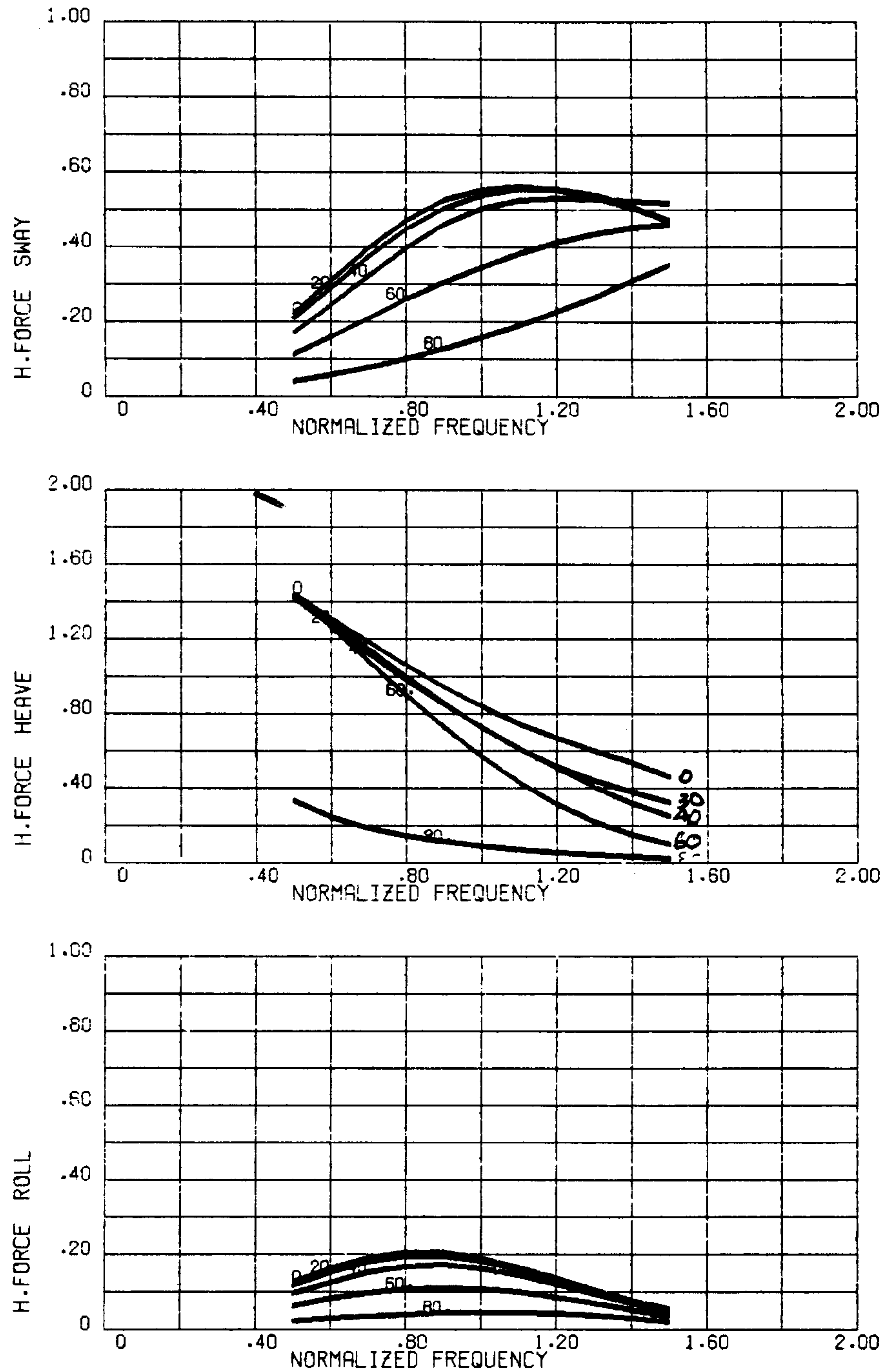
Hydrodynamic Exciting Force (rectangular cross section B/T = 8)



RECTANGULAR CROSS SECTION B/T = 4
H.FORCE

Fig. 3.4.a

Hydrodynamic Exciting Force For Different Wave Directions
(rectangular cross section B/T = 4)
*On graphs wave direction with bridge in degrees



RECTANGULAR CROSS SECTION B/T = 6
H.FORCE

Fig. 3.4.b

Hydrodynamic Exciting Force for Different Wave Directions
(rectangular cross section B/T = 6)
*On graphs wave direction in degrees

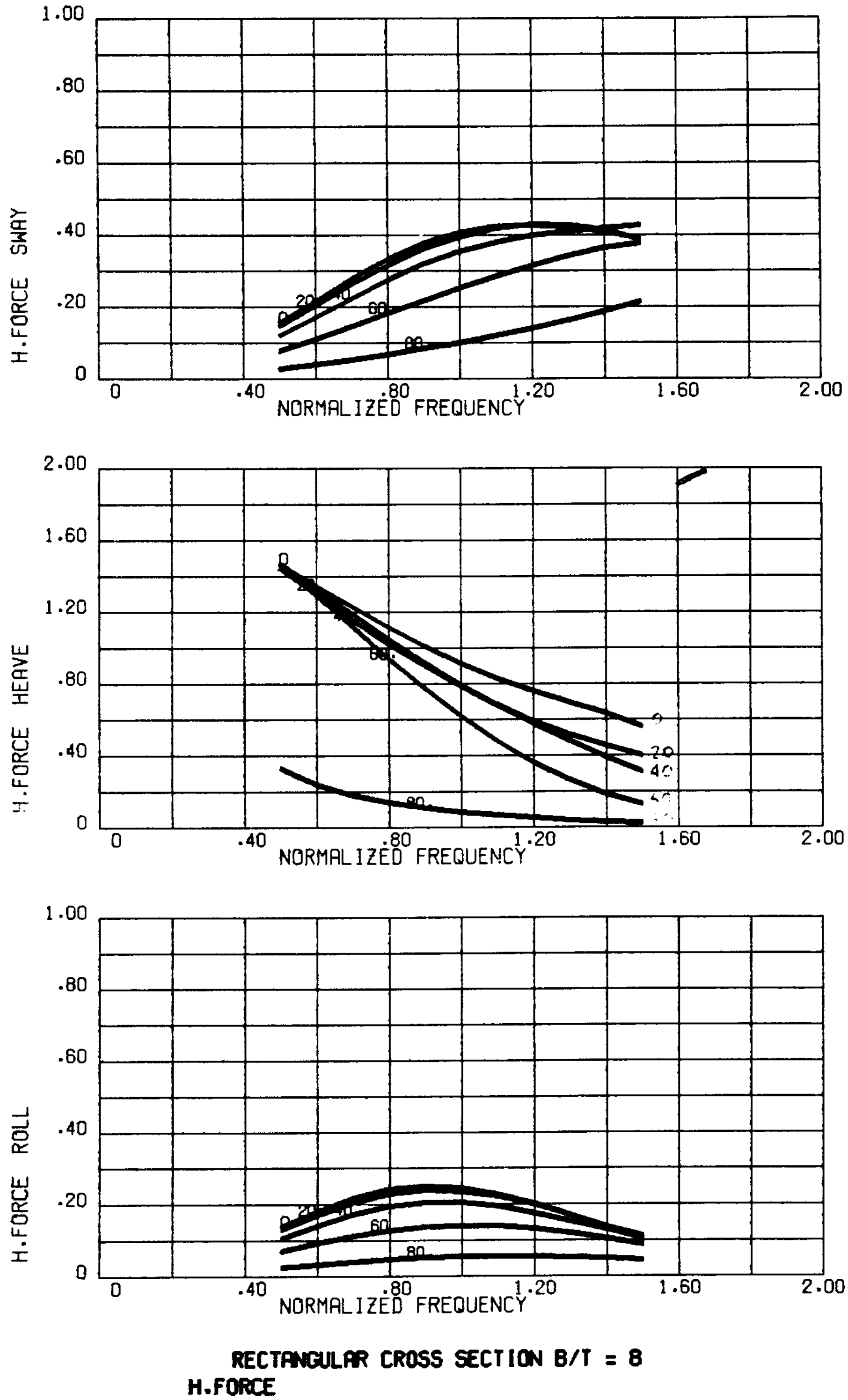


Fig. 3.4.c

Hydrodynamic Exciting Force for Different Wave Directions
(rectangular cross section B/T = 8)
*On curves wave direction in degrees

Table 3.1. Hydrodynamic Coefficients, Tabulated Results of Figures 3.1, 3.2. 3.3.

	$\sigma = \omega\sqrt{B/2g}$	MASS (β)			DAMPING (ξ)			FORCE (δ)		
		SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL
B/T=4	.50	.742	1.923	.261	.049	.353	.002	.391	1.410	.076
	.60	.806	1.722	.258	.092	.307	.003	.554	1.270	.092
	.70	.778	1.604	.255	.148	.254	.003	.701	1.130	.096
	.80	.650	1.551	.252	.204	.199	.003	.796	.990	.087
	.90	.482	1.546	.251	.245	.149	.001	.832	.854	.068
	1.00	.334	1.575	.251	.264	.107	.001	.824	.727	.045
	1.10	.225	1.621	.253	.264	.074	.000	.794	.614	.022
	1.20	.152	1.672	.254	.251	.051	.000	.754	.516	.002
	1.30	.104	1.720	.255	.230	.034	.000	.708	.433	.017
	1.40	.075	1.758	.255	.207	.024	.000	.661	.360	.031
	1.50	.057	1.784	.255	.184	.017	.001	.615	.291	.042
B/T=6	.50	.491	2.996	.287	.029	.414	.006	.226	1.459	.125
	.60	.541	2.672	.285	.053	.377	.010	.319	1.337	.164
	.70	.559	2.457	.278	.086	.332	.014	.411	1.216	.193
	.80	.529	2.323	.265	.123	.281	.016	.487	1.097	.207
	.90	.458	2.253	.252	.156	.229	.016	.538	.979	.204
	1.00	.369	2.234	.243	.180	.180	.014	.563	.866	.189
	1.10	.284	2.252	.237	.193	.137	.011	.569	.761	.166
	1.20	.213	2.293	.235	.196	.101	.008	.562	.667	.138
	1.30	.159	2.346	.235	.191	.073	.005	.546	.585	.110
	1.40	.119	2.400	.237	.181	.053	.003	.523	.511	.083
	1.50	.090	2.450	.239	.169	.038	.002	.497	.437	.061
B/T=8	.50	.369	4.083	.303	.020	.447	.007	.157	1.484	.138
	.60	.408	3.642	.304	.037	.417	.013	.220	1.370	.182
	.70	.429	3.338	.298	.060	.377	.018	.284	1.260	.219
	.80	.424	3.134	.284	.086	.331	.023	.341	1.152	.244
	.90	.392	3.005	.267	.111	.281	.025	.385	1.046	.252
	1.00	.342	2.937	.251	.132	.232	.024	.414	.942	.247
	1.10	.285	2.917	.239	.147	.186	.021	.431	.845	.230
	1.20	.230	2.933	.232	.155	.145	.017	.437	.756	.206
	1.30	.183	2.972	.228	.157	.111	.013	.436	.677	.177
	1.40	.145	3.025	.227	.154	.083	.010	.428	.605	.148
	1.50	.114	3.081	.228	.148	.062	.007	.413	.533	.122

Table 3.2. Hydrodynamic Exciting Forces (δ) for Different Wave Angles, Tabulated Results of Figure 3.4.

	σ	H.FORC. THETA= 0			H.FORC. THETA=20.			H.FORC. THETA=40.			H.FORC. THETA=60.			H.FORC THETA=80.		
		SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL
B/T=4	.50	.375	1.394	.076	.352	1.383	.071	.293	1.375	.059	.191	1.393	.038	.067	.346	.013
	.60	.527	1.244	.092	.495	1.222	.086	.424	1.210	.072	.273	1.203	.046	.100	.256	.017
	.70	.668	1.096	.097	.629	1.059	.091	.563	1.049	.078	.355	1.006	.049	.140	.196	.018
	.80	.767	.954	.089	.726	.897	.083	.684	.898	.074	.425	.813	.045	.188	.152	.018
	.90	.814	.821	.071	.777	.742	.066	.761	.751	.058	.477	.633	.034	.246	.120	.015
	1.00	.817	.701	.048	.791	.601	.044	.786	.614	.036	.513	.473	.021	.311	.095	.008
	1.10	.792	.600	.024	.779	.482	.021	.771	.488	.014	.540	.339	.006	.383	.075	.002
	1.20	.749	.516	.002	.748	.389	.001	.736	.379	.008	.560	.233	.011	.460	.060	.016
	1.30	.697	.445	.017	.703	.319	.020	.697	.289	.025	.572	.155	.026	.538	.047	.032
	1.40	.640	.379	.032	.645	.264	.034	.663	.218	.040	.577	.100	.040	.610	.038	.049
	1.50	.586	.312	.041	.577	.215	.044	.636	.160	.052	.573	.064	.051	.671	.027	.066
B/T=6	.50	.220	1.445	.124	.207	1.433	.117	.171	1.421	.098	.112	1.443	.063	.039	.334	.022
	.60	.309	1.312	.162	.291	1.289	.152	.244	1.268	.126	.159	1.266	.082	.057	.246	.029
	.70	.397	1.183	.190	.374	1.144	.179	.322	1.121	.152	.210	1.082	.098	.077	.187	.036
	.80	.471	1.060	.205	.447	.999	.194	.398	.982	.168	.259	.900	.108	.101	.144	.041
	.90	.524	.944	.205	.502	.858	.194	.460	.851	.172	.305	.728	.111	.128	.113	.045
	1.00	.553	.839	.190	.537	.726	.182	.503	.729	.163	.346	.570	.108	.158	.089	.046
	1.10	.562	.746	.166	.554	.609	.160	.525	.613	.144	.382	.431	.099	.190	.070	.046
	1.20	.553	.668	.137	.554	.514	.133	.531	.505	.120	.412	.315	.086	.227	.055	.043
	1.30	.533	.600	.108	.539	.439	.103	.528	.406	.094	.436	.221	.070	.266	.044	.037
	1.40	.504	.535	.077	.509	.380	.074	.523	.320	.069	.452	.150	.053	.309	.034	.030
	1.50	.472	.463	.055	.467	.325	.048	.517	.247	.046	.459	.100	.036	.352	.027	.021
B/T=8	.50	.154	1.470	.137	.145	1.458	.129	.119	1.444	.106	.078	1.466	.069	.027	.328	.024
	.60	.215	1.347	.181	.203	1.323	.170	.169	1.297	.141	.111	1.297	.092	.039	.240	.032
	.70	.277	1.228	.217	.262	1.188	.205	.222	1.156	.172	.146	1.118	.112	.053	.181	.040
	.80	.333	1.115	.242	.316	1.052	.229	.274	1.022	.194	.182	.942	.128	.068	.139	.047
	.90	.377	1.010	.251	.362	.920	.239	.319	.899	.206	.218	.774	.138	.084	.109	.052
	1.00	.407	.915	.246	.396	.795	.236	.356	.784	.206	.252	.619	.141	.101	.086	.055
	1.10	.424	.831	.228	.419	.683	.222	.381	.677	.195	.286	.482	.139	.120	.068	.056
	1.20	.428	.759	.202	.430	.590	.199	.399	.574	.176	.316	.363	.132	.141	.053	.056
	1.30	.422	.696	.170	.428	.516	.169	.410	.478	.153	.343	.264	.120	.163	.042	.053
	1.40	.409	.633	.138	.414	.456	.135	.420	.389	.129	.364	.186	.105	.188	.032	.050
	1.50	.390	.563	.112	.388	.401	.103	.428	.310	.105	.377	.128	.087	.214	.025	.045

WIND DIRECTION = 0 DEG (B/T) = 4.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\bar{\delta}(\omega)/\delta(\omega,0)$	.50	.787	.948	.782	.887	.991	.884	.923	.994	.920	.941	.994	.938	.952	.995	.949	.960	.996	.957
	.60	.796	.933	.785	.894	.982	.886	.927	.986	.921	.944	.988	.939	.954	.989	.950	.961	.990	.958
	.70	.810	.914	.793	.905	.968	.892	.935	.975	.926	.950	.978	.943	.958	.980	.954	.964	.982	.960
	.80	.831	.888	.799	.920	.948	.898	.946	.958	.928	.958	.962	.944	.965	.966	.953	.969	.968	.959
	.90	.854	.855	.790	.936	.921	.890	.958	.934	.924	.967	.941	.940	.972	.946	.950	.975	.950	.957
	1.00	.878	.812	.758	.951	.885	.866	.971	.903	.905	.978	.913	.926	.981	.920	.939	.983	.926	.947
	1.10	.901	.758	.663	.964	.840	.796	.981	.864	.853	.987	.878	.885	.989	.888	.905	.991	.897	.919
	1.20	.928	.701	.587	.978	.792	.631	.991	.825	.664	.996	.844	.691	.998	.858	.715	.998	.869	.738
	1.30	.958	.647	.529	.991	.749	.714	1.000	.790	.818	1.000	.815	.883	1.000	.833	.925	1.000	.847	.952
	1.40	.992	.604	.516	1.000	.718	.706	1.000	.765	.813	1.000	.795	.880	1.000	.816	.923	1.000	.833	.951
	1.50	1.000	.576	.512	1.000	.696	.704	1.000	.750	.812	1.000	.784	.879	.999	.808	.922	.997	.827	.950
$\bar{\delta}(\omega)$	.50	.295	1.322	.059	.333	1.382	.067	.346	1.385	.070	.353	1.386	.071	.357	1.387	.072	.360	1.388	.073
	.60	.419	1.161	.072	.471	1.221	.081	.489	1.227	.085	.497	1.229	.086	.503	1.230	.087	.506	1.232	.088
	.70	.541	1.002	.077	.604	1.060	.087	.625	1.068	.090	.634	1.072	.092	.640	1.074	.092	.644	1.076	.093
	.80	.637	.847	.071	.706	.904	.080	.726	.914	.083	.735	.918	.084	.740	.921	.085	.743	.924	.085
	.90	.695	.702	.056	.762	.756	.063	.780	.767	.066	.787	.773	.067	.791	.776	.067	.794	.780	.068
	1.00	.717	.569	.036	.777	.620	.042	.793	.633	.043	.799	.640	.044	.801	.645	.045	.803	.649	.045
	1.10	.714	.455	.016	.784	.504	.019	.777	.519	.020	.782	.527	.021	.784	.533	.022	.785	.538	.022
	1.20	.695	.361	.001	.732	.409	.001	.742	.426	.001	.746	.435	.001	.747	.443	.001	.748	.448	.001
	1.30	.668	.288	.009	.691	.333	.012	.697	.352	.014	.697	.363	.015	.697	.371	.016	.697	.377	.016
	1.40	.635	.229	.016	.640	.271	.023	.640	.290	.026	.640	.301	.028	.640	.309	.030	.640	.316	.030
	1.50	.586	.180	.021	.586	.217	.029	.586	.234	.033	.586	.245	.036	.585	.252	.038	.584	.258	.039

WIND DIRECTION = 20 DEG (B/T) = 4.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\bar{\delta}(\omega)/\delta(\omega,0)$	.50	.745	.899	.740	.835	.968	.831	.869	.986	.865	.887	.991	.883	.898	.992	.894	.905	.993	.901
	.60	.753	.883	.743	.843	.955	.833	.876	.975	.867	.893	.981	.885	.904	.983	.896	.911	.984	.903
	.70	.768	.864	.750	.856	.938	.841	.888	.960	.874	.905	.967	.892	.915	.970	.903	.921	.971	.910
	.80	.788	.839	.757	.873	.916	.846	.905	.939	.879	.921	.947	.897	.930	.951	.907	.936	.952	.914
	.90	.811	.808	.749	.893	.886	.838	.922	.910	.872	.937	.920	.890	.946	.924	.901	.951	.926	.908
	1.00	.836	.767	.718	.912	.846	.810	.939	.873	.846	.953	.884	.865	.961	.889	.877	.966	.891	.885
	1.10	.861	.716	.625	.931	.797	.728	.954	.825	.770	.966	.838	.794	.973	.844	.809	.977	.846	.819
	1.20	.890	.662	.567	.951	.745	.608	.969	.775	.620	.979	.790	.624	.985	.797	.623	.989	.800	.619
	1.30	.923	.611	.499	.973	.697	.620	.986	.730	.674	.993	.748	.706	.997	.755	.731	1.000	.759	.752
	1.40	.961	.571	.485	.997	.659	.609	1.000	.694	.664	1.000	.712	.698	1.000	.722	.723	1.000	.728	.744
	1.50	.995	.544	.482	1.000	.634	.607	1.000	.672	.662	1.000	.691	.696	1.000	.703	.721	1.000	.709	.742
$\bar{\delta}(\omega)$	.50	.279	1.253	.056	.313	1.349	.063	.326	1.374	.066	.333	1.381	.067	.337	1.383	.068	.339	1.384	.068
	.60	.397	1.099	.068	.444	1.188	.077	.462	1.213	.080	.471	1.220	.081	.476	1.223	.082	.480	1.224	.083
	.70	.513	.947	.073	.571	1.029	.082	.593	1.052	.085	.604	1.060	.087	.611	1.063	.088	.616	1.064	.088
	.80	.604	.801	.067	.670	.874	.075	.694	.895	.078	.706	.904	.080	.714	.907	.081	.718	.908	.081
	.90	.661	.663	.053	.727	.727	.060	.750	.747	.062	.763	.755	.063	.770	.759	.064	.774	.760	.064
	1.00	.683	.538	.034	.746	.593	.039	.767	.612	.041	.778	.620	.042	.785	.623	.042	.789	.625	.042
	1.10	.682	.430	.015	.737	.478	.017	.755	.495	.018	.765	.503	.019	.771	.507	.019	.774	.508	.020
	1.20	.667	.341	.001	.712	.384	.001	.726	.400	.001	.733	.408	.001	.738	.411	.001	.741	.413	.001
	1.30	.644	.272	.008	.678	.310	.011	.687	.325	.011	.692	.332	.012	.695	.336	.012	.697	.338	.013
	1.40	.615	.216	.016	.638	.250	.020	.640	.263	.021	.640	.270	.022	.640	.274	.023	.640	.276	.024
	1.50	.583	.170	.020	.586	.198	.025	.586	.210	.027	.586	.216	.029	.586	.219	.030	.586	.221	.030

Table 4.5.a. Hydrodynamic Force Coefficients, $\bar{\delta}$ including directional effect. N for Directional Spectrum-$S_w(f,\theta)=S_w(f)\ \cos^N(\theta-\theta_0)$. B/T= 4

Table 4.5.a continued

WIND DIRECTION = 40 DEG (B/T) = 4.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
	.50	.634	.778	.629	.690	.872	.684	.714	.918	.709	.728	.945	.723	.738	.962	.732	.744	.972	.738
	.60	.642	.762	.632	.699	.854	.688	.725	.900	.712	.740	.927	.726	.750	.944	.735	.758	.955	.742
	.70	.655	.743	.639	.715	.832	.695	.743	.877	.721	.760	.903	.736	.771	.920	.747	.780	.931	.754
	.80	.674	.720	.645	.738	.804	.703	.769	.847	.730	.788	.873	.747	.801	.889	.758	.811	.900	.766
	.90	.698	.691	.638	.765	.769	.694	.798	.809	.719	.817	.833	.734	.831	.849	.745	.842	.860	.752
$\overline{\delta}(\omega)/\delta(\omega,0)$	1.00	.724	.654	.609	.794	.725	.659	.827	.761	.680	.846	.783	.693	.860	.797	.701	.870	.808	.707
	1.10	.753	.608	.523	.825	.670	.554	.856	.700	.563	.874	.717	.567	.886	.730	.570	.894	.739	.571
	1.20	.787	.560	.508	.861	.611	.542	.890	.634	.538	.905	.646	.528	.914	.655	.519	.921	.663	.512
	1.30	.826	.515	.412	.902	.556	.403	.929	.571	.375	.941	.579	.350	.948	.584	.327	.953	.589	.307
	1.40	.870	.479	.399	.950	.510	.386	.976	.518	.357	.986	.522	.331	.991	.524	.308	.994	.526	.287
	1.50	.912	.455	.395	.997	.480	.382	1.000	.483	.352	1.000	.483	.326	1.000	.483	.303	1.000	.483	.282
	.50	.238	1.085	.048	.259	1.215	.052	.268	1.280	.054	.273	1.318	.055	.277	1.341	.056	.279	1.355	.058
	.60	.338	.948	.058	.368	1.062	.063	.382	1.119	.066	.390	1.153	.067	.395	1.174	.068	.399	1.188	.068
	.70	.437	.815	.062	.478	.912	.067	.496	.961	.070	.508	.990	.071	.515	1.009	.072	.521	1.021	.073
	.80	.517	.687	.057	.566	.767	.063	.590	.808	.065	.604	.833	.066	.614	.848	.067	.622	.859	.068
	.90	.568	.567	.045	.623	.631	.049	.649	.664	.051	.665	.684	.052	.677	.697	.053	.685	.706	.053
	1.00	.592	.458	.029	.649	.508	.032	.675	.533	.033	.691	.549	.033	.702	.559	.034	.711	.566	.034
$\overline{\delta}(\omega)$	1.10	.596	.365	.013	.653	.402	.013	.678	.420	.014	.692	.430	.014	.701	.438	.014	.708	.443	.014
	1.20	.589	.289	.001	.645	.315	.001	.667	.327	.001	.678	.334	.001	.685	.338	.001	.690	.342	.001
	1.30	.575	.229	.007	.629	.247	.007	.648	.254	.006	.656	.257	.006	.661	.260	.006	.664	.262	.005
	1.40	.557	.182	.013	.608	.193	.012	.625	.196	.011	.631	.198	.011	.634	.199	.010	.636	.199	.009
	1.50	.535	.142	.016	.584	.150	.016	.586	.151	.014	.586	.151	.013	.586	.151	.012	.586	.151	.012

WIND DIRECTION = 60 DEG (B/T) = 4.

		N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
	.50	.485	.624	.481	.486	.681	.481	.488	.719	.482	.490	.748	.483	.492	.772	.485	.493	.792	.486
	.60	.492	.607	.484	.496	.659	.485	.499	.694	.487	.502	.721	.488	.504	.744	.489	.506	.763	.491
	.70	.504	.589	.489	.513	.635	.492	.518	.666	.494	.521	.691	.496	.524	.712	.497	.526	.729	.498
	.80	.523	.567	.495	.538	.607	.501	.546	.634	.504	.551	.655	.506	.555	.673	.508	.557	.688	.509
	.90	.546	.541	.489	.569	.573	.492	.581	.595	.494	.589	.613	.495	.593	.628	.495	.596	.640	.495
$\overline{\delta}(\omega)/\delta(\omega,0)$	1.00	.573	.509	.462	.604	.531	.456	.621	.548	.452	.632	.561	.451	.638	.572	.449	.641	.582	.449
	1.10	.603	.469	.382	.645	.480	.347	.668	.489	.327	.681	.498	.315	.690	.505	.306	.694	.511	.299
	1.20	.640	.427	.418	.694	.426	.440	.724	.427	.457	.742	.430	.470	.753	.433	.480	.759	.435	.487
	1.30	.683	.387	.279	.753	.373	.193	.791	.367	.144	.814	.365	.114	.827	.364	.094	.836	.363	.081
	1.40	.732	.355	.266	.821	.329	.174	.869	.316	.122	.898	.309	.089	.915	.305	.069	.926	.301	.055
	1.50	.781	.333	.262	.891	.299	.169	.950	.281	.116	.985	.270	.083	1.000	.263	.062	1.000	.257	.049
	.50	.182	.869	.037	.182	.949	.037	.183	1.002	.037	.184	1.043	.037	.184	1.076	.037	.185	1.103	.037
	.60	.259	.756	.045	.262	.820	.045	.263	.863	.045	.264	.897	.045	.266	.925	.045	.266	.949	.045
	.70	.337	.646	.047	.342	.696	.048	.346	.730	.048	.348	.757	.048	.350	.780	.048	.351	.799	.048
	.80	.401	.541	.044	.412	.579	.045	.419	.605	.045	.423	.625	.045	.425	.642	.045	.427	.657	.045
	.90	.445	.444	.035	.463	.470	.035	.473	.488	.035	.479	.503	.035	.483	.515	.035	.485	.526	.035
$\overline{\delta}(\omega)$	1.00	.468	.357	.022	.494	.372	.022	.508	.384	.022	.516	.393	.022	.521	.401	.022	.524	.408	.022
	1.10	.478	.281	.009	.511	.288	.008	.529	.294	.008	.540	.299	.008	.546	.303	.007	.550	.307	.007
	1.20	.479	.220	.001	.520	.220	.001	.542	.220	.001	.556	.222	.001	.564	.223	.001	.569	.225	.001
	1.30	.476	.172	.005	.525	.166	.003	.551	.163	.002	.567	.162	.002	.577	.162	.002	.582	.161	.001
	1.40	.469	.134	.009	.525	.125	.006	.556	.120	.004	.575	.117	.003	.586	.115	.002	.592	.114	.002
	1.50	.458	.104	.011	.522	.093	.007	.557	.088	.005	.577	.084	.003	.586	.082	.003	.586	.080	.002

Table 4.5.a continued

WIND DIRECTION = 0 DEG (B/T) = 4.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.853	.983	.849	.908	.993	.905	.933	.994	.930	.947	.995	.944	.956	.995	.954	.962	.996	.960
	.60	.861	.972	.851	.914	.985	.907	.937	.987	.931	.950	.989	.945	.958	.990	.954	.964	.991	.961
	.70	.873	.955	.859	.923	.972	.913	.944	.976	.936	.955	.979	.949	.961	.981	.957	.966	.982	.963
	.80	.891	.933	.864	.936	.954	.916	.953	.960	.937	.962	.964	.949	.967	.967	.956	.971	.970	.962
	.90	.910	.903	.856	.950	.929	.910	.964	.938	.933	.970	.944	.946	.974	.948	.954	.976	.952	.960
	1.00	.928	.864	.828	.963	.896	.889	.975	.909	.917	.979	.917	.933	.982	.923	.943	.984	.928	.951
	1.10	.944	.814	.747	.975	.854	.829	.985	.872	.871	.988	.883	.896	.990	.893	.913	.991	.901	.925
	1.20	.962	.761	.611	.986	.811	.648	.994	.835	.678	.997	.851	.703	.998	.864	.726	.999	.874	.746
	1.30	.980	.713	.637	.997	.773	.773	1.000	.804	.854	1.000	.824	.906	1.000	.840	.940	1.000	.854	.962
	1.40	1.000	.675	.627	1.000	.744	.766	1.000	.781	.850	1.000	.806	.904	1.000	.825	.938	1.000	.841	.961
	1.50	1.000	.650	.624	1.000	.727	.764	1.000	.769	.849	1.000	.797	.903	.998	.818	.938	.996	.835	.961
$\bar{\delta}(\omega)$	.50	.320	1.371	.065	.341	1.384	.069	.350	1.386	.071	.355	1.387	.072	.359	1.387	.072	.361	1.388	.073
	.60	.454	1.209	.078	.482	1.225	.083	.494	1.228	.086	.500	1.230	.087	.505	1.231	.088	.508	1.232	.088
	.70	.583	1.047	.083	.617	1.065	.089	.630	1.070	.091	.638	1.073	.092	.642	1.075	.093	.645	1.077	.093
	.80	.684	.890	.077	.718	.910	.081	.731	.916	.083	.738	.920	.084	.742	.923	.085	.744	.925	.086
	.90	.741	.741	.061	.773	.763	.065	.785	.770	.066	.790	.775	.067	.792	.778	.068	.795	.781	.068
	1.00	.758	.606	.040	.787	.628	.043	.796	.637	.044	.800	.642	.045	.802	.647	.045	.804	.651	.046
	1.10	.748	.488	.018	.772	.513	.020	.780	.523	.021	.783	.530	.021	.784	.536	.022	.785	.540	.022
	1.20	.720	.393	.001	.739	.419	.001	.745	.431	.001	.747	.439	.001	.748	.446	.001	.748	.451	.001
	1.30	.683	.317	.011	.695	.344	.013	.697	.358	.015	.697	.367	.015	.697	.374	.016	.697	.380	.016
	1.40	.640	.256	.020	.640	.282	.025	.640	.296	.027	.640	.306	.029	.640	.313	.030	.640	.319	.031
	1.50	.586	.203	.026	.586	.227	.031	.586	.240	.035	.586	.249	.037	.585	.255	.038	.584	.261	.039

WIND DIRECTION = 20 DEG (B/T) = 4.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.804	.945	.799	.855	.979	.851	.879	.989	.875	.893	.992	.889	.902	.993	.898	.908	.993	.904
	.60	.812	.932	.802	.862	.968	.853	.886	.979	.877	.899	.982	.891	.908	.983	.900	.913	.984	.906
	.70	.825	.914	.809	.875	.952	.861	.898	.964	.884	.911	.969	.898	.919	.970	.907	.924	.971	.912
	.80	.844	.890	.815	.892	.930	.865	.914	.944	.889	.926	.949	.902	.934	.951	.911	.938	.952	.916
	.90	.865	.859	.807	.910	.901	.858	.931	.916	.882	.942	.923	.896	.949	.925	.905	.953	.926	.911
	1.00	.887	.819	.778	.928	.863	.831	.947	.880	.857	.957	.887	.872	.963	.890	.881	.967	.891	.887
	1.10	.909	.769	.691	.944	.814	.752	.961	.833	.783	.970	.842	.802	.975	.846	.814	.979	.847	.823
	1.20	.932	.715	.595	.962	.763	.615	.975	.784	.622	.982	.794	.624	.987	.799	.621	.990	.801	.617
	1.30	.959	.666	.575	.981	.716	.651	.990	.739	.691	.995	.751	.719	.998	.757	.741	1.000	.760	.761
	1.40	.989	.627	.563	1.000	.679	.641	1.000	.705	.682	1.000	.718	.711	1.000	.726	.734	1.000	.729	.754
	1.50	1.000	.601	.560	1.000	.656	.638	1.000	.683	.680	1.000	.698	.709	1.000	.706	.732	1.000	.711	.752
$\bar{\delta}(\omega)$	.50	.301	1.318	.061	.321	1.365	.065	.330	1.379	.067	.335	1.383	.068	.338	1.384	.068	.340	1.384	.069
	.60	.428	1.159	.074	.455	1.204	.078	.467	1.218	.081	.474	1.222	.082	.478	1.223	.083	.481	1.224	.083
	.70	.551	1.001	.078	.584	1.043	.083	.600	1.057	.086	.608	1.062	.087	.614	1.063	.088	.617	1.064	.089
	.80	.647	.849	.073	.684	.887	.077	.701	.901	.079	.710	.906	.080	.716	.908	.081	.720	.908	.082
	.90	.704	.705	.057	.741	.740	.061	.758	.752	.063	.767	.758	.064	.772	.760	.064	.776	.760	.065
	1.00	.725	.574	.037	.758	.605	.040	.773	.617	.041	.782	.622	.042	.787	.624	.042	.790	.625	.043
	1.10	.720	.461	.017	.748	.488	.018	.761	.500	.019	.768	.505	.019	.773	.507	.020	.775	.508	.020
	1.20	.698	.369	.001	.720	.394	.001	.730	.405	.001	.736	.410	.001	.739	.412	.001	.742	.413	.001
	1.30	.668	.296	.010	.683	.319	.011	.690	.329	.012	.693	.334	.012	.696	.337	.013	.697	.338	.013
	1.40	.633	.238	.018	.640	.258	.021	.640	.267	.022	.640	.272	.023	.640	.275	.023	.640	.276	.024
	1.50	.586	.188	.023	.586	.205	.026	.586	.213	.028	.586	.218	.029	.586	.220	.030	.586	.222	.031

Table 4.5.a continued

WIND DIRECTION = 40 DEG (B/T) = 4.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.669	.834	.664	.704	.898	.698	.722	.933	.716	.734	.955	.728	.741	.968	.735	.747	.976	.741
	.60	.677	.817	.667	.714	.880	.702	.734	.915	.720	.746	.936	.731	.754	.950	.739	.761	.959	.744
	.70	.692	.796	.674	.731	.857	.710	.752	.892	.730	.766	.913	.742	.776	.926	.751	.784	.935	.757
	.80	.714	.770	.681	.756	.828	.719	.779	.861	.739	.795	.882	.753	.806	.895	.762	.815	.905	.770
	.90	.739	.738	.673	.784	.792	.708	.808	.823	.727	.825	.842	.740	.837	.855	.749	.846	.865	.756
	1.00	.767	.697	.640	.813	.745	.671	.837	.773	.687	.853	.791	.697	.865	.803	.704	.874	.812	.709
	1.10	.798	.646	.544	.843	.687	.560	.866	.709	.566	.880	.724	.569	.890	.735	.570	.898	.743	.572
	1.20	.834	.592	.534	.878	.624	.542	.898	.641	.533	.910	.651	.523	.918	.659	.515	.924	.666	.510
	1.30	.875	.542	.415	.919	.565	.389	.936	.575	.362	.945	.581	.338	.951	.586	.317	.955	.591	.298
	1.40	.923	.500	.400	.966	.516	.371	.982	.520	.343	.988	.523	.319	.992	.525	.297	.995	.527	.277
	1.50	.968	.473	.396	1.000	.482	.367	1.000	.483	.339	1.000	.483	.314	1.000	.483	.292	1.000	.483	.272
$\bar{\delta}(\omega)$	.50	.251	1.163	.050	.264	1.252	.053	.271	1.301	.054	.275	1.331	.055	.278	1.349	.056	.280	1.361	.056
	.60	.357	1.016	.061	.376	1.095	.065	.387	1.138	.066	.393	1.165	.067	.398	1.182	.068	.401	1.193	.068
	.70	.462	.873	.065	.488	.940	.069	.503	.977	.071	.512	1.000	.072	.518	1.015	.073	.523	1.025	.073
	.80	.547	.735	.061	.580	.790	.064	.598	.822	.066	.609	.841	.067	.618	.854	.068	.625	.863	.068
	.90	.602	.606	.048	.638	.650	.050	.658	.675	.052	.671	.691	.053	.681	.702	.053	.689	.710	.054
	1.00	.627	.488	.031	.664	.523	.032	.684	.542	.033	.697	.554	.033	.707	.563	.034	.714	.569	.034
	1.10	.632	.388	.013	.668	.412	.013	.686	.426	.014	.697	.434	.014	.705	.441	.014	.711	.446	.014
	1.20	.624	.306	.001	.658	.322	.001	.673	.331	.001	.682	.336	.001	.688	.340	.001	.692	.344	.001
	1.30	.610	.241	.007	.640	.251	.007	.653	.256	.006	.659	.259	.006	.663	.261	.005	.666	.263	.005
	1.40	.590	.190	.013	.618	.195	.012	.628	.197	.011	.633	.198	.010	.635	.199	.010	.637	.200	.009
	1.50	.567	.148	.016	.586	.150	.015	.586	.151	.014	.586	.151	.013	.586	.151	.012	.586	.151	.011

WIND DIRECTION = 60 DEG (B/T) = 4.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.486	.656	.481	.487	.701	.481	.489	.734	.482	.491	.760	.484	.493	.782	.485	.494	.801	.486
	.60	.495	.636	.485	.498	.678	.486	.501	.708	.487	.503	.733	.489	.505	.754	.490	.506	.771	.491
	.70	.509	.615	.491	.515	.652	.493	.520	.679	.495	.523	.702	.497	.525	.721	.498	.527	.737	.499
	.80	.532	.589	.499	.542	.621	.503	.549	.645	.505	.553	.665	.507	.556	.681	.509	.558	.695	.509
	.90	.559	.559	.491	.576	.585	.493	.585	.604	.494	.591	.621	.495	.595	.634	.495	.597	.646	.495
	1.00	.591	.522	.458	.614	.540	.454	.627	.555	.451	.635	.567	.450	.640	.577	.449	.642	.586	.448
	1.10	.628	.475	.362	.658	.485	.336	.675	.494	.321	.686	.502	.310	.692	.508	.302	.696	.514	.297
	1.20	.672	.426	.431	.711	.426	.449	.734	.429	.464	.748	.432	.476	.756	.434	.484	.761	.436	.490
	1.30	.724	.379	.229	.774	.370	.165	.804	.366	.127	.821	.364	.103	.832	.363	.087	.838	.362	.077
	1.40	.784	.340	.212	.848	.322	.145	.885	.312	.104	.908	.307	.078	.921	.303	.061	.929	.299	.050
	1.50	.846	.313	.208	.924	.288	.139	.970	.275	.098	.997	.266	.072	1.000	.260	.055	1.000	.255	.044
$\bar{\delta}(\omega)$	.50	.182	.914	.037	.183	.978	.037	.183	1.024	.037	.184	1.060	.037	.185	1.090	.037	.185	1.116	.037
	.60	.261	.792	.045	.262	.843	.045	.264	.881	.045	.265	.912	.045	.266	.937	.045	.267	.960	.045
	.70	.340	.674	.048	.344	.714	.048	.347	.745	.048	.349	.769	.048	.351	.790	.048	.352	.808	.048
	.80	.408	.562	.044	.416	.592	.045	.421	.615	.045	.424	.634	.045	.426	.650	.045	.428	.663	.045
	.90	.455	.459	.035	.469	.480	.035	.476	.496	.035	.481	.509	.035	.484	.521	.035	.486	.530	.035
	1.00	.483	.366	.022	.501	.378	.022	.512	.389	.022	.519	.397	.022	.523	.405	.022	.525	.411	.022
	1.10	.497	.285	.009	.521	.291	.008	.535	.296	.008	.543	.301	.007	.548	.305	.007	.551	.308	.007
	1.20	.503	.220	.001	.533	.220	.001	.550	.221	.001	.560	.223	.001	.567	.224	.001	.570	.225	.001
	1.30	.505	.169	.004	.540	.164	.003	.560	.163	.002	.573	.162	.002	.580	.162	.001	.584	.161	.001
	1.40	.502	.129	.007	.543	.122	.005	.567	.118	.003	.581	.116	.002	.590	.115	.002	.594	.113	.002
	1.50	.495	.098	.009	.542	.090	.006	.568	.086	.004	.584	.083	.003	.586	.081	.002	.586	.080	.002

Table 4.5.b B/T=6

WIND DIRECTION = 0 DEG (B/T) = 6.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.787	.944	.788	.887	.989	.888	.923	.993	.924	.942	.994	.942	.953	.995	.954	.960	.995	.961
	.60	.792	.930	.785	.891	.980	.886	.926	.985	.922	.943	.987	.940	.954	.989	.952	.961	.990	.959
	.70	.800	.910	.795	.897	.965	.894	.930	.973	.928	.946	.977	.945	.956	.980	.955	.963	.982	.962
	.80	.817	.883	.804	.910	.945	.901	.940	.957	.933	.954	.962	.949	.962	.966	.959	.968	.969	.965
	.90	.836	.851	.813	.924	.920	.907	.950	.935	.937	.962	.942	.952	.969	.947	.960	.974	.952	.966
	1.00	.858	.812	.828	.940	.887	.918	.963	.906	.946	.973	.916	.960	.978	.923	.968	.981	.929	.973
	1.10	.882	.765	.839	.956	.848	.925	.975	.872	.951	.983	.886	.964	.987	.895	.971	.990	.903	.976
	1.20	.910	.713	.851	.973	.805	.932	.989	.836	.957	.995	.854	.969	.997	.867	.975	.999	.878	.980
	1.30	.939	.661	.862	.989	.763	.937	1.000	.802	.960	1.000	.825	.971	1.000	.842	.977	1.000	.856	.981
	1.40	.972	.617	.869	1.000	.730	.937	1.000	.777	.957	1.000	.805	.967	1.000	.825	.972	1.000	.841	.976
	1.50	1.000	.586	.818	1.000	.707	.882	1.000	.760	.904	1.000	.793	.916	1.000	.816	.924	1.000	.834	.931
$\bar{\delta}(\omega)$	.50	.173	1.364	.098	.195	1.430	.110	.203	1.435	.115	.207	1.436	.117	.210	1.437	.118	.211	1.438	.119
	.60	.245	1.221	.127	.275	1.286	.144	.286	1.292	.149	.292	1.295	.152	.295	1.297	.154	.297	1.299	.155
	.70	.318	1.076	.151	.356	1.142	.170	.369	1.151	.176	.376	1.156	.180	.380	1.159	.181	.382	1.161	.183
	.80	.385	.936	.165	.428	1.002	.185	.443	1.014	.191	.449	1.020	.195	.453	1.024	.197	.456	1.027	.198
	.90	.438	.804	.167	.484	.868	.186	.498	.882	.192	.504	.889	.195	.508	.894	.197	.510	.898	.198
	1.00	.475	.681	.157	.520	.744	.174	.532	.760	.180	.538	.769	.182	.541	.775	.184	.543	.779	.185
	1.10	.496	.570	.139	.537	.633	.153	.548	.651	.158	.553	.661	.160	.555	.668	.161	.556	.674	.162
	1.20	.503	.476	.117	.538	.538	.128	.547	.559	.131	.550	.571	.133	.552	.579	.134	.552	.586	.134
	1.30	.501	.397	.091	.527	.458	.099	.533	.481	.102	.533	.495	.103	.533	.505	.104	.533	.513	.104
	1.40	.490	.330	.067	.504	.390	.072	.504	.416	.074	.504	.431	.074	.504	.442	.075	.504	.450	.075
	1.50	.472	.271	.045	.472	.327	.049	.472	.352	.050	.472	.367	.050	.472	.378	.051	.472	.386	.051

WIND DIRECTION = 20 DEG (B/T) = 6.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.745	.894	.744	.835	.964	.835	.869	.983	.869	.887	.989	.887	.898	.991	.898	.905	.991	.905
	.60	.749	.880	.743	.839	.953	.834	.873	.973	.868	.891	.979	.886	.901	.981	.896	.908	.982	.904
	.70	.758	.860	.753	.847	.935	.842	.880	.957	.876	.897	.965	.893	.907	.968	.904	.914	.969	.911
	.80	.774	.834	.762	.861	.912	.851	.893	.936	.884	.910	.945	.901	.920	.948	.911	.926	.950	.918
	.90	.793	.804	.771	.878	.883	.858	.908	.909	.890	.924	.919	.907	.933	.923	.917	.939	.925	.923
	1.00	.815	.766	.785	.897	.847	.871	.926	.875	.902	.940	.886	.918	.949	.891	.928	.954	.893	.934
	1.10	.839	.721	.797	.917	.804	.880	.943	.834	.910	.956	.847	.925	.964	.853	.934	.969	.855	.940
	1.20	.868	.672	.810	.940	.757	.890	.963	.789	.918	.974	.803	.932	.981	.811	.941	.985	.814	.946
	1.30	.898	.623	.821	.962	.710	.898	.981	.744	.924	.990	.761	.937	.995	.769	.945	.999	.773	.950
	1.40	.932	.582	.828	.987	.672	.901	1.000	.708	.925	1.000	.726	.937	1.000	.736	.943	1.000	.742	.948
	1.50	.964	.552	.780	1.000	.645	.848	1.000	.683	.870	1.000	.703	.881	1.000	.714	.886	1.000	.720	.889
$\bar{\delta}(\omega)$	.50	.164	1.292	.092	.184	1.393	.104	.191	1.421	.108	.195	1.429	.110	.197	1.432	.111	.199	1.432	.112
	.60	.232	1.154	.120	.259	1.250	.135	.270	1.277	.141	.275	1.285	.143	.278	1.288	.145	.281	1.289	.146
	.70	.301	1.017	.143	.336	1.106	.160	.349	1.132	.166	.356	1.141	.170	.360	1.145	.172	.363	1.146	.173
	.80	.364	.884	.156	.406	.967	.174	.421	.992	.181	.429	1.001	.185	.433	1.005	.187	.436	1.007	.188
	.90	.415	.759	.158	.460	.834	.176	.476	.858	.182	.484	.868	.186	.489	.872	.188	.492	.873	.189
	1.00	.451	.643	.149	.496	.711	.165	.512	.734	.171	.520	.744	.174	.525	.748	.176	.528	.750	.177
	1.10	.472	.538	.132	.515	.600	.146	.530	.622	.151	.537	.632	.154	.542	.636	.155	.545	.638	.156
	1.20	.480	.449	.111	.520	.506	.122	.532	.527	.126	.539	.537	.128	.542	.541	.129	.545	.543	.130
	1.30	.479	.374	.087	.513	.426	.095	.523	.446	.098	.528	.456	.099	.531	.462	.100	.532	.464	.101
	1.40	.470	.311	.064	.497	.359	.069	.504	.379	.071	.504	.389	.072	.504	.394	.073	.504	.397	.073
	1.50	.455	.256	.043	.472	.298	.047	.472	.316	.048	.472	.325	.048	.472	.331	.049	.472	.334	.049

Table 4.5.b continued

WIND DIRECTION = 40 DEG (B/T) = 6.

		N=1			N=3			N=5			N=7			N=9			N=11		
	σ	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.633	.773	.633	.689	.866	.689	.713	.912	.713	.727	.939	.727	.736	.956	.735	.743	.967	.742
	.60	.638	.758	.633	.695	.849	.688	.720	.896	.712	.734	.923	.726	.744	.940	.735	.750	.951	.742
	.70	.646	.738	.641	.704	.826	.698	.731	.871	.724	.746	.898	.739	.757	.915	.749	.764	.926	.756
	.80	.661	.714	.649	.722	.798	.708	.751	.840	.735	.767	.866	.751	.779	.883	.761	.787	.894	.769
	.90	.679	.686	.658	.743	.764	.719	.774	.804	.746	.792	.828	.763	.804	.844	.774	.813	.855	.782
	1.00	.701	.651	.672	.769	.723	.735	.801	.759	.764	.821	.781	.781	.833	.796	.792	.843	.807	.801
	1.10	.726	.611	.685	.798	.675	.749	.831	.706	.778	.850	.725	.795	.863	.738	.806	.872	.748	.814
	1.20	.755	.567	.698	.831	.621	.764	.865	.646	.793	.884	.661	.810	.897	.672	.821	.906	.680	.828
	1.30	.788	.524	.711	.868	.567	.779	.903	.585	.808	.922	.596	.824	.934	.603	.835	.942	.609	.842
	1.40	.825	.487	.720	.910	.521	.789	.946	.532	.819	.966	.538	.835	.977	.542	.845	.986	.546	.852
	1.50	.861	.460	.679	.952	.487	.743	.990	.493	.768	1.000	.495	.781	1.000	.496	.789	1.000	.498	.794
$\bar{\delta}(\omega)$	.50	.139	1.117	.079	.152	1.251	.085	.157	1.318	.088	.160	1.357	.090	.162	1.382	.091	.163	1.397	.092
	.60	.197	.995	.102	.215	1.114	.111	.222	1.175	.115	.227	1.211	.118	.230	1.233	.119	.232	1.248	.120
	.70	.256	.873	.122	.280	.977	.133	.290	1.031	.138	.296	1.062	.140	.300	1.082	.142	.303	1.095	.144
	.80	.311	.757	.133	.340	.845	.145	.353	.891	.151	.361	.918	.154	.367	.936	.156	.371	.947	.158
	.90	.356	.647	.135	.390	.721	.147	.405	.759	.153	.415	.782	.156	.421	.797	.159	.426	.807	.160
	1.00	.388	.547	.128	.426	.606	.140	.443	.637	.145	.454	.655	.148	.461	.668	.151	.466	.677	.152
	1.10	.408	.456	.114	.448	.503	.124	.467	.527	.129	.478	.541	.132	.485	.551	.134	.490	.558	.135
	1.20	.418	.379	.096	.460	.415	.105	.478	.432	.109	.489	.442	.111	.496	.449	.112	.501	.455	.113
	1.30	.420	.314	.075	.463	.340	.083	.481	.351	.086	.491	.357	.087	.498	.362	.088	.502	.365	.089
	1.40	.416	.260	.055	.459	.279	.061	.477	.285	.063	.487	.288	.064	.493	.290	.065	.497	.292	.066
	1.50	.407	.213	.037	.450	.226	.041	.467	.228	.042	.472	.229	.043	.472	.230	.043	.472	.230	.044

WIND DIRECTION = 60 DEG (B/T) = 6.

		N=1			N=3			N=5			N=7			N=9			N=11		
	σ	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL	SWAY	HEAVE	ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.485	.618	.484	.485	.673	.485	.487	.709	.486	.489	.738	.488	.490	.761	.489	.492	.780	.491
	.60	.489	.603	.484	.491	.653	.485	.494	.688	.486	.496	.715	.488	.498	.737	.490	.499	.756	.491
	.70	.496	.584	.492	.502	.628	.495	.506	.658	.498	.509	.682	.500	.511	.703	.502	.513	.720	.503
	.80	.510	.561	.499	.520	.598	.505	.526	.624	.509	.531	.645	.512	.534	.663	.514	.536	.678	.516
	.90	.527	.536	.508	.543	.565	.517	.553	.586	.523	.559	.603	.527	.564	.618	.530	.567	.631	.532
	1.00	.549	.505	.521	.572	.525	.535	.585	.541	.543	.595	.554	.548	.601	.566	.552	.605	.575	.555
	1.10	.573	.470	.534	.605	.480	.552	.623	.489	.563	.635	.498	.570	.643	.506	.575	.649	.512	.579
	1.20	.603	.431	.548	.645	.430	.571	.669	.432	.585	.685	.436	.594	.696	.439	.600	.704	.442	.605
	1.30	.637	.393	.562	.691	.379	.590	.722	.374	.607	.743	.372	.618	.757	.372	.626	.767	.371	.631
	1.40	.677	.359	.573	.746	.334	.607	.787	.322	.627	.813	.315	.640	.831	.311	.649	.843	.308	.656
	1.50	.718	.335	.542	.805	.301	.573	.855	.283	.592	.888	.273	.605	.909	.266	.615	.923	.261	.622
$\bar{\delta}(\omega)$	.50	.107	.893	.060	.107	.972	.060	.107	1.025	.060	.108	1.066	.060	.108	1.099	.061	.108	1.127	.061
	.60	.151	.791	.078	.152	.857	.079	.152	.902	.079	.153	.937	.079	.154	.967	.079	.154	.992	.080
	.70	.197	.691	.093	.199	.742	.094	.201	.779	.095	.202	.807	.095	.203	.831	.095	.204	.852	.096
	.80	.240	.595	.102	.245	.634	.103	.248	.662	.104	.250	.684	.105	.252	.703	.105	.253	.719	.106
	.90	.276	.506	.104	.285	.533	.106	.290	.553	.107	.293	.570	.108	.295	.584	.109	.297	.596	.109
	1.00	.304	.424	.099	.316	.441	.102	.324	.454	.103	.329	.465	.104	.332	.475	.105	.335	.483	.105
	1.10	.322	.350	.089	.340	.358	.092	.350	.365	.093	.357	.371	.095	.362	.377	.096	.365	.382	.096
	1.20	.334	.288	.075	.357	.287	.078	.370	.289	.080	.379	.291	.081	.385	.293	.082	.389	.295	.083
	1.30	.340	.236	.060	.368	.228	.063	.385	.224	.064	.396	.223	.065	.404	.223	.066	.409	.223	.067
	1.40	.341	.192	.044	.376	.179	.047	.397	.172	.048	.410	.169	.049	.419	.167	.050	.425	.165	.051
	1.50	.339	.155	.030	.380	.140	.031	.404	.131	.033	.419	.126	.033	.429	.123	.034	.436	.121	.034

Table 4.5.b continued

WIND DIRECTION = 0 DEG (B/T) = 6.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.853	.980	.853	.909	.992	.909	.934	.993	.934	.948	.994	.949	.957	.995	.958	.963	.995	.964
	.60	.857	.970	.852	.912	.983	.907	.936	.986	.932	.949	.988	.947	.958	.989	.958	.964	.990	.962
	.70	.865	.953	.860	.917	.970	.914	.939	.975	.938	.952	.978	.951	.960	.981	.959	.965	.982	.965
	.80	.879	.930	.869	.928	.952	.920	.948	.960	.943	.958	.964	.955	.965	.967	.962	.970	.970	.968
	.90	.895	.901	.876	.940	.929	.925	.957	.939	.945	.966	.945	.957	.972	.949	.963	.975	.953	.968
	1.00	.914	.865	.888	.954	.899	.935	.969	.912	.954	.976	.920	.964	.980	.926	.970	.983	.932	.975
	1.10	.933	.822	.897	.968	.863	.941	.980	.880	.959	.986	.891	.968	.989	.899	.974	.991	.907	.978
	1.20	.954	.775	.906	.983	.824	.947	.992	.846	.964	.996	.861	.972	.998	.872	.976	.999	.882	.981
	1.30	.975	.728	.913	.996	.786	.951	1.000	.815	.966	1.000	.834	.974	1.000	.849	.979	1.000	.862	.982
	1.40	.997	.689	.915	1.000	.757	.949	1.000	.792	.963	1.000	.816	.970	1.000	.834	.974	1.000	.848	.978
	1.50	1.000	.662	.861	1.000	.738	.895	1.000	.778	.910	1.000	.805	.920	1.000	.826	.928	.999	.842	.934
$\bar{\delta}(\omega)$	.50	.188	1.417	.106	.200	1.433	.113	.205	1.435	.116	.209	1.437	.118	.211	1.438	.119	.212	1.438	.120
	.60	.265	1.272	.138	.282	1.290	.147	.289	1.294	.151	.293	1.296	.153	.296	1.298	.155	.298	1.299	.156
	.70	.343	1.127	.163	.364	1.148	.174	.373	1.154	.178	.378	1.157	.181	.381	1.160	.182	.383	1.162	.183
	.80	.414	.986	.178	.437	1.009	.189	.446	1.017	.193	.451	1.022	.196	.455	1.025	.197	.457	1.028	.198
	.90	.469	.851	.179	.492	.877	.190	.502	.886	.194	.506	.892	.196	.509	.896	.198	.511	.900	.199
	1.00	.505	.726	.169	.528	.754	.178	.536	.765	.181	.540	.772	.183	.542	.777	.184	.543	.782	.185
	1.10	.524	.613	.149	.544	.644	.156	.551	.656	.159	.554	.664	.161	.556	.671	.162	.557	.677	.162
	1.20	.528	.518	.124	.544	.550	.130	.549	.565	.132	.551	.575	.133	.552	.583	.134	.553	.589	.134
	1.30	.520	.437	.097	.531	.472	.101	.533	.489	.102	.533	.501	.103	.533	.509	.104	.533	.517	.104
	1.40	.503	.369	.070	.504	.405	.073	.504	.424	.074	.504	.438	.075	.504	.446	.075	.504	.454	.075
	1.50	.472	.306	.047	.472	.341	.049	.472	.360	.050	.472	.373	.051	.472	.382	.051	.471	.390	.051

WIND DIRECTION = 20 DEG (B/T) = 6.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.803	.941	.803	.855	.976	.855	.879	.987	.879	.893	.990	.893	.902	.991	.902	.908	.991	.908
	.60	.808	.929	.802	.859	.966	.854	.883	.977	.878	.897	.981	.892	.905	.982	.900	.911	.982	.906
	.70	.816	.910	.811	.868	.949	.862	.890	.962	.886	.903	.967	.899	.911	.968	.908	.917	.969	.914
	.80	.831	.886	.820	.880	.927	.870	.903	.941	.893	.915	.947	.907	.923	.949	.915	.929	.950	.921
	.90	.848	.856	.828	.896	.899	.877	.917	.915	.899	.929	.922	.912	.937	.925	.920	.941	.926	.926
	1.00	.869	.819	.841	.914	.864	.889	.934	.882	.911	.945	.889	.924	.952	.893	.931	.956	.894	.936
	1.10	.891	.775	.852	.933	.822	.898	.951	.841	.918	.961	.850	.930	.967	.854	.937	.971	.856	.942
	1.20	.916	.727	.863	.954	.776	.906	.969	.797	.926	.978	.808	.937	.983	.812	.944	.986	.814	.948
	1.30	.942	.679	.872	.974	.730	.913	.987	.754	.932	.993	.766	.942	.997	.772	.948	1.000	.774	.952
	1.40	.971	.639	.877	.995	.693	.915	1.000	.719	.932	1.000	.732	.940	1.000	.739	.946	1.000	.743	.949
	1.50	.996	.611	.826	1.000	.667	.861	1.000	.694	.876	1.000	.709	.884	1.000	.718	.888	1.000	.722	.890
$\bar{\delta}(\omega)$	.50	.177	1.360	.100	.188	1.411	.106	.193	1.426	.109	.196	1.431	.111	.198	1.432	.112	.200	1.433	.113
	.60	.250	1.218	.130	.266	1.267	.138	.273	1.282	.142	.277	1.287	.144	.280	1.288	.146	.282	1.289	.147
	.70	.324	1.077	.154	.344	1.123	.164	.353	1.138	.168	.358	1.143	.171	.362	1.145	.173	.364	1.146	.174
	.80	.391	.939	.168	.415	.983	.178	.425	.998	.183	.431	1.004	.186	.435	1.006	.188	.437	1.007	.189
	.90	.445	.808	.170	.469	.849	.180	.481	.864	.184	.487	.870	.187	.491	.873	.189	.493	.874	.190
	1.00	.481	.687	.160	.506	.725	.169	.517	.740	.173	.523	.746	.175	.526	.749	.177	.529	.750	.178
	1.10	.501	.578	.141	.524	.613	.149	.534	.628	.152	.540	.634	.154	.543	.637	.156	.546	.638	.156
	1.20	.507	.486	.118	.527	.518	.124	.536	.533	.127	.541	.539	.128	.544	.543	.129	.545	.544	.130
	1.30	.502	.408	.092	.519	.438	.097	.526	.452	.099	.529	.459	.100	.532	.463	.100	.533	.464	.101
	1.40	.489	.342	.068	.502	.371	.070	.504	.384	.072	.504	.392	.072	.504	.396	.073	.504	.398	.073
	1.50	.470	.283	.045	.472	.309	.047	.472	.321	.048	.472	.328	.049	.472	.332	.049	.472	.334	.049

Table 4.5.b continued

WIND DIRECTION = 40 DEG (B/T) = 6.

$\bar{\delta}(\omega) / \delta(\omega,0)$

σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
.50	.668	.829	.668	.703	.892	.703	.721	.927	.720	.732	.949	.731	.740	.962	.739	.745	.971	.744
.60	.673	.813	.667	.709	.876	.702	.728	.911	.720	.739	.933	.731	.747	.946	.739	.753	.955	.744
.70	.682	.791	.677	.720	.852	.713	.740	.886	.732	.752	.907	.744	.761	.921	.752	.767	.929	.758
.80	.699	.764	.686	.738	.822	.723	.760	.855	.744	.774	.875	.756	.783	.889	.765	.791	.898	.772
.90	.719	.733	.696	.761	.787	.735	.784	.817	.755	.799	.837	.769	.809	.850	.778	.817	.859	.785
1.00	.743	.694	.711	.788	.743	.752	.812	.771	.773	.828	.789	.787	.839	.802	.797	.847	.811	.804
1.10	.770	.650	.725	.817	.692	.766	.841	.717	.788	.857	.732	.801	.868	.744	.810	.876	.752	.817
1.20	.802	.600	.739	.851	.636	.781	.876	.655	.803	.891	.667	.816	.902	.676	.825	.909	.684	.831
1.30	.837	.551	.753	.888	.578	.796	.913	.591	.817	.928	.600	.830	.938	.606	.839	.945	.612	.845
1.40	.878	.509	.763	.932	.528	.806	.957	.536	.828	.972	.540	.840	.982	.544	.848	.989	.547	.855
1.50	.918	.479	.720	.975	.491	.758	1.000	.494	.775	1.000	.496	.785	1.000	.497	.792	1.000	.498	.796

$\bar{\delta}(\omega)$

σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
.50	.147	1.197	.083	.155	1.289	.087	.159	1.340	.089	.161	1.371	.091	.163	1.390	.092	.164	1.403	.092
.60	.208	1.066	.108	.219	1.149	.114	.225	1.195	.117	.228	1.224	.118	.231	1.241	.120	.233	1.253	.121
.70	.271	.936	.129	.286	1.008	.135	.294	1.048	.139	.299	1.073	.141	.302	1.089	.143	.305	1.100	.144
.80	.329	.810	.141	.348	.871	.148	.358	.906	.152	.364	.928	.155	.369	.942	.157	.372	.951	.158
.90	.377	.692	.143	.399	.743	.151	.411	.772	.155	.419	.790	.158	.424	.802	.160	.428	.811	.161
1.00	.411	.583	.135	.436	.624	.143	.449	.647	.147	.458	.662	.150	.464	.673	.151	.468	.680	.153
1.10	.433	.485	.120	.459	.517	.127	.473	.535	.131	.482	.546	.133	.488	.555	.135	.492	.561	.136
1.20	.444	.401	.101	.470	.425	.107	.484	.437	.110	.493	.446	.112	.499	.452	.113	.503	.457	.114
1.30	.446	.331	.080	.473	.347	.084	.487	.355	.087	.495	.360	.088	.500	.364	.089	.504	.367	.090
1.40	.443	.273	.059	.470	.282	.062	.482	.287	.064	.490	.289	.065	.495	.291	.065	.498	.293	.066
1.50	.433	.222	.040	.460	.227	.042	.472	.229	.043	.472	.229	.043	.472	.230	.044	.472	.231	.044

WIND DIRECTION = 60 DEG (B/T) = 6.

$\bar{\delta}(\omega) / \delta(\omega,0)$

σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
.50	.485	.649	.485	.486	.692	.485	.488	.724	.487	.490	.750	.489	.491	.771	.490	.493	.789	.492
.60	.490	.631	.484	.492	.672	.486	.495	.702	.487	.497	.726	.489	.498	.747	.490	.500	.765	.492
.70	.499	.608	.494	.504	.644	.496	.507	.671	.499	.510	.693	.501	.512	.712	.503	.514	.728	.504
.80	.516	.582	.502	.523	.612	.507	.529	.635	.510	.533	.654	.513	.535	.671	.515	.537	.685	.517
.90	.536	.552	.513	.548	.576	.520	.556	.595	.525	.561	.611	.529	.565	.625	.531	.568	.637	.533
1.00	.562	.516	.529	.579	.534	.539	.590	.548	.546	.598	.560	.550	.603	.571	.554	.607	.580	.556
1.10	.591	.476	.545	.615	.485	.558	.630	.494	.567	.640	.502	.573	.647	.509	.577	.652	.515	.581
1.20	.627	.430	.562	.658	.431	.579	.678	.434	.590	.691	.437	.597	.701	.441	.603	.707	.444	.607
1.30	.668	.385	.578	.709	.376	.599	.734	.373	.613	.751	.372	.622	.763	.372	.629	.771	.371	.633
1.40	.717	.345	.593	.769	.327	.618	.801	.318	.634	.823	.313	.645	.837	.310	.653	.848	.307	.659
1.50	.769	.316	.580	.833	.291	.583	.873	.278	.599	.899	.269	.611	.917	.263	.619	.929	.259	.625

$\bar{\delta}(\omega)$

σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
.50	.107	.937	.060	.107	1.000	.060	.107	1.047	.060	.108	1.083	.061	.108	1.114	.061	.108	1.140	.061
.60	.151	.828	.078	.152	.881	.079	.153	.921	.079	.153	.953	.079	.154	.980	.079	.154	1.003	.080
.70	.198	.720	.094	.200	.762	.094	.201	.794	.095	.203	.820	.095	.203	.842	.096	.204	.861	.096
.80	.243	.617	.103	.246	.649	.104	.249	.673	.105	.251	.694	.105	.252	.711	.106	.253	.726	.106
.90	.281	.521	.105	.287	.544	.107	.291	.562	.108	.294	.577	.108	.296	.590	.109	.298	.601	.109
1.00	.311	.433	.101	.320	.448	.102	.327	.460	.104	.331	.470	.105	.334	.479	.105	.336	.486	.106
1.10	.332	.355	.090	.345	.362	.093	.354	.368	.094	.359	.374	.095	.363	.380	.096	.366	.384	.096
1.20	.347	.287	.077	.364	.288	.079	.375	.290	.081	.382	.292	.082	.387	.294	.083	.391	.296	.083
1.30	.356	.231	.061	.378	.225	.064	.391	.224	.065	.400	.223	.066	.406	.223	.067	.411	.223	.067
1.40	.361	.185	.046	.388	.175	.048	.404	.170	.049	.415	.168	.050	.422	.166	.050	.427	.164	.051
1.50	.363	.146	.031	.393	.135	.032	.412	.129	.033	.424	.125	.034	.433	.122	.034	.438	.120	.034

Table 4.5.c   B/T = 8

WIND DIRECTION = 0 DEG   (B/T) = 8.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\bar{\delta}(\omega) / \delta(\omega,0)$	.50	.785	.945	.785	.887	.990	.887	.923	.993	.923	.941	.994	.941	.953	.995	.953	.960	.995	.961
	.60	.791	.928	.786	.891	.979	.887	.926	.984	.923	.944	.987	.941	.955	.988	.952	.962	.990	.960
	.70	.799	.907	.794	.897	.964	.893	.930	.972	.928	.947	.976	.945	.957	.979	.956	.964	.981	.963
	.80	.809	.880	.799	.904	.943	.897	.936	.955	.930	.951	.961	.947	.960	.966	.957	.967	.969	.964
	.90	.826	.847	.811	.917	.918	.905	.946	.933	.937	.960	.942	.953	.968	.947	.962	.973	.952	.968
	1.00	.846	.808	.823	.932	.886	.914	.958	.906	.944	.970	.916	.958	.976	.924	.967	.981	.930	.972
	1.10	.869	.764	.840	.948	.849	.927	.970	.874	.954	.980	.888	.968	.986	.897	.975	.989	.906	.980
	1.20	.898	.716	.857	.967	.809	.939	.985	.840	.963	.993	.858	.975	.997	.871	.982	.999	.881	.986
	1.30	.928	.668	.879	.986	.771	.953	.998	.809	.974	1.000	.832	.984	1.000	.848	.989	1.000	.861	.992
	1.40	.959	.626	.896	1.000	.739	.958	1.000	.785	.973	1.000	.812	.980	1.000	.832	.984	1.000	.847	.986
	1.50	.991	.595	.882	1.000	.716	.934	1.000	.769	.946	1.000	.800	.952	1.000	.822	.955	1.000	.840	.958
$\bar{\delta}(\omega)$	.50	.121	1.390	.108	.137	1.455	.121	.142	1.460	.126	.145	1.461	.129	.147	1.462	.131	.148	1.463	.132
	.60	.170	1.250	.142	.192	1.318	.161	.199	1.326	.167	.203	1.329	.170	.205	1.331	.172	.207	1.333	.174
	.70	.221	1.114	.172	.248	1.184	.194	.258	1.194	.201	.262	1.199	.205	.265	1.203	.207	.267	1.205	.209
	.80	.270	.981	.193	.301	1.052	.217	.312	1.065	.225	.317	1.072	.229	.320	1.077	.232	.322	1.080	.233
	.90	.311	.856	.203	.346	.927	.227	.357	.943	.235	.362	.951	.239	.365	.957	.241	.367	.961	.243
	1.00	.344	.740	.202	.379	.810	.225	.390	.829	.232	.395	.838	.236	.397	.845	.238	.399	.851	.239
	1.10	.369	.635	.191	.402	.705	.211	.411	.726	.218	.416	.738	.221	.418	.746	.222	.419	.753	.223
	1.20	.384	.543	.173	.414	.614	.190	.422	.638	.195	.425	.651	.197	.427	.661	.198	.427	.669	.199
	1.30	.391	.465	.149	.416	.536	.162	.421	.563	.166	.422	.579	.167	.422	.590	.168	.422	.599	.169
	1.40	.392	.396	.124	.409	.468	.132	.409	.497	.134	.409	.514	.135	.409	.526	.136	.409	.536	.136
	1.50	.387	.335	.099	.390	.403	.105	.390	.433	.106	.390	.450	.107	.390	.463	.107	.390	.473	.107

WIND DIRECTION = 20 DEG   (B/T) = 8.

	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\bar{\delta}(\omega) / \delta(\omega,0)$	.50	.743	.895	.743	.834	.965	.834	.868	.984	.868	.886	.989	.886	.897	.991	.897	.904	.991	.904
	.60	.749	.878	.744	.840	.951	.835	.873	.972	.869	.891	.978	.886	.902	.980	.897	.909	.981	.904
	.70	.756	.857	.751	.846	.933	.841	.879	.955	.875	.896	.963	.893	.907	.966	.903	.914	.967	.911
	.80	.767	.830	.757	.855	.909	.846	.887	.933	.879	.904	.942	.898	.914	.946	.907	.921	.948	.914
	.90	.783	.799	.768	.869	.880	.856	.901	.906	.888	.917	.917	.905	.926	.921	.915	.933	.923	.922
	1.00	.803	.762	.780	.887	.845	.866	.917	.873	.898	.932	.885	.914	.941	.890	.924	.947	.892	.930
	1.10	.826	.721	.796	.907	.805	.881	.934	.834	.911	.948	.848	.927	.958	.854	.936	.962	.856	.942
	1.20	.853	.675	.814	.930	.761	.898	.955	.792	.924	.968	.807	.939	.975	.815	.947	.979	.818	.953
	1.30	.883	.629	.835	.955	.717	.914	.976	.751	.940	.986	.768	.953	.992	.777	.961	.995	.781	.966
	1.40	.915	.590	.852	.979	.681	.925	.997	.717	.947	1.000	.736	.958	1.000	.746	.964	1.000	.751	.967
	1.50	.948	.560	.841	1.000	.654	.906	1.000	.692	.926	1.000	.712	.934	1.000	.724	.938	1.000	.730	.939
$\bar{\delta}(\omega)$	.50	.114	1.316	.102	.128	1.419	.114	.134	1.446	.119	.136	1.455	.121	.138	1.457	.123	.139	1.457	.124
	.60	.161	1.182	.135	.181	1.281	.151	.188	1.309	.157	.192	1.318	.160	.194	1.321	.162	.195	1.322	.164
	.70	.209	1.052	.163	.234	1.146	.183	.243	1.173	.190	.248	1.183	.194	.251	1.186	.196	.253	1.188	.198
	.80	.255	.926	.183	.285	1.014	.205	.295	1.041	.213	.301	1.051	.217	.304	1.055	.219	.307	1.057	.221
	.90	.295	.807	.193	.328	.889	.215	.340	.915	.223	.346	.926	.227	.349	.931	.230	.352	.933	.231
	1.00	.327	.698	.192	.361	.773	.213	.373	.799	.221	.379	.809	.225	.383	.814	.227	.385	.816	.229
	1.10	.350	.599	.182	.384	.669	.201	.396	.693	.208	.402	.704	.211	.405	.709	.213	.408	.712	.215
	1.20	.365	.512	.164	.398	.577	.181	.409	.601	.187	.414	.613	.190	.417	.618	.191	.419	.621	.193
	1.30	.373	.438	.142	.403	.499	.155	.412	.523	.160	.416	.535	.162	.419	.541	.163	.420	.543	.164
	1.40	.374	.374	.118	.400	.431	.128	.408	.454	.131	.409	.466	.132	.409	.472	.133	.409	.475	.134
	1.50	.370	.315	.094	.390	.368	.102	.390	.390	.104	.390	.401	.105	.390	.407	.105	.390	.411	.105

Table 4.5.c continued

WIND DIRECTION = 40 DEG (B/T) = 8.

Quantity	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.632	.774	.632	.687	.867	.687	.711	.914	.711	.725	.942	.725	.734	.959	.734	.740	.969	.740
	.60	.638	.756	.633	.694	.847	.689	.719	.893	.713	.734	.921	.727	.743	.938	.736	.749	.948	.743
	.70	.644	.735	.639	.702	.823	.696	.728	.867	.722	.743	.894	.736	.753	.911	.746	.760	.921	.753
	.80	.654	.710	.645	.714	.793	.703	.742	.836	.729	.758	.861	.744	.768	.877	.754	.776	.888	.761
	.90	.670	.682	.656	.732	.759	.716	.761	.798	.743	.778	.822	.759	.789	.838	.769	.797	.848	.776
	1.00	.689	.648	.667	.755	.718	.729	.786	.754	.757	.804	.776	.773	.816	.791	.784	.824	.801	.792
	1.10	.711	.610	.683	.781	.673	.748	.814	.705	.777	.833	.724	.794	.845	.737	.805	.853	.746	.813
	1.20	.738	.569	.700	.813	.623	.768	.848	.649	.798	.868	.664	.816	.881	.675	.827	.890	.684	.835
	1.30	.769	.528	.722	.849	.573	.793	.886	.593	.826	.907	.604	.844	.921	.612	.856	.930	.618	.864
	1.40	.802	.493	.740	.889	.529	.816	.929	.542	.851	.951	.549	.870	.966	.554	.882	.976	.559	.891
	1.50	.836	.466	.734	.930	.495	.810	.973	.503	.844	.998	.506	.863	1.000	.508	.874	1.000	.511	.883
$\bar{\delta}(\omega)$	.50	.097	1.137	.087	.106	1.275	.094	.110	1.344	.097	.112	1.384	.099	.113	1.409	.101	.114	1.425	.101
	.60	.137	1.018	.115	.149	1.141	.125	.155	1.203	.129	.158	1.240	.132	.160	1.263	.133	.161	1.278	.134
	.70	.178	.902	.139	.194	1.010	.151	.202	1.065	.157	.206	1.098	.160	.209	1.118	.162	.211	1.132	.163
	.80	.218	.792	.156	.238	.884	.170	.247	.932	.176	.252	.960	.180	.256	.978	.182	.258	.990	.184
	.90	.252	.688	.165	.276	.767	.180	.287	.806	.186	.293	.831	.190	.298	.846	.193	.301	.857	.195
	1.00	.280	.593	.164	.307	.657	.179	.320	.690	.186	.327	.710	.190	.332	.723	.193	.336	.733	.195
	1.10	.301	.507	.156	.331	.559	.170	.345	.586	.177	.353	.601	.181	.358	.612	.184	.362	.620	.185
	1.20	.316	.432	.141	.348	.473	.155	.363	.493	.161	.372	.504	.165	.377	.513	.167	.381	.519	.169
	1.30	.324	.368	.123	.358	.399	.135	.374	.412	.140	.383	.420	.143	.388	.426	.145	.392	.430	.147
	1.40	.328	.312	.102	.363	.335	.113	.380	.343	.117	.389	.348	.120	.395	.351	.122	.399	.354	.123
	1.50	.326	.263	.082	.363	.279	.091	.380	.283	.095	.389	.285	.097	.390	.286	.098	.390	.287	.099

WIND DIRECTION = 60 DEG (B/T) = 8.

Quantity	σ	N=1 SWAY	N=1 HEAVE	N=1 ROLL	N=3 SWAY	N=3 HEAVE	N=3 ROLL	N=5 SWAY	N=5 HEAVE	N=5 ROLL	N=7 SWAY	N=7 HEAVE	N=7 ROLL	N=9 SWAY	N=9 HEAVE	N=9 ROLL	N=11 SWAY	N=11 HEAVE	N=11 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.483	.619	.483	.483	.674	.483	.485	.711	.484	.486	.740	.485	.488	.764	.487	.489	.784	.488
	.60	.488	.600	.484	.491	.650	.485	.493	.684	.487	.495	.711	.489	.497	.733	.490	.499	.752	.492
	.70	.495	.580	.490	.499	.623	.493	.502	.653	.495	.505	.677	.497	.508	.697	.499	.510	.714	.501
	.80	.504	.557	.496	.512	.593	.500	.517	.618	.504	.521	.639	.507	.525	.656	.509	.527	.671	.511
	.90	.518	.531	.505	.531	.559	.513	.539	.579	.519	.545	.596	.523	.549	.610	.526	.552	.623	.529
	1.00	.536	.501	.516	.555	.520	.528	.566	.535	.535	.574	.547	.541	.580	.559	.545	.585	.568	.548
	1.10	.558	.468	.531	.584	.477	.547	.600	.486	.558	.611	.494	.565	.619	.502	.571	.625	.509	.575
	1.20	.585	.432	.548	.620	.430	.571	.641	.432	.585	.656	.436	.594	.667	.439	.602	.675	.443	.608
	1.30	.615	.396	.569	.661	.383	.599	.689	.378	.618	.709	.376	.631	.723	.376	.640	.733	.376	.648
	1.40	.649	.364	.590	.709	.340	.630	.745	.328	.655	.770	.322	.672	.787	.318	.684	.801	.316	.694
	1.50	.686	.340	.590	.762	.306	.637	.807	.289	.665	.837	.279	.685	.859	.272	.699	.874	.267	.710
$\bar{\delta}(\omega)$	.50	.074	.909	.066	.074	.991	.066	.075	1.046	.066	.075	1.088	.066	.075	1.123	.067	.075	1.152	.067
	.60	.105	.809	.088	.105	.875	.088	.106	.921	.088	.106	.957	.088	.107	.987	.089	.107	1.013	.089
	.70	.137	.713	.106	.138	.765	.107	.139	.802	.107	.140	.831	.108	.141	.856	.108	.141	.877	.109
	.80	.168	.621	.120	.170	.661	.121	.172	.689	.122	.174	.712	.123	.175	.731	.123	.176	.749	.124
	.90	.195	.537	.127	.200	.564	.129	.203	.585	.130	.205	.602	.131	.207	.617	.132	.208	.629	.133
	1.00	.218	.459	.127	.226	.476	.130	.230	.489	.132	.234	.501	.133	.236	.511	.134	.238	.520	.135
	1.10	.237	.389	.121	.248	.397	.125	.254	.404	.127	.259	.411	.129	.262	.417	.130	.265	.423	.131
	1.20	.250	.328	.111	.265	.326	.115	.274	.328	.118	.281	.331	.120	.285	.333	.122	.289	.336	.123
	1.30	.260	.275	.097	.279	.266	.102	.291	.263	.105	.299	.262	.107	.305	.262	.109	.310	.262	.110
	1.40	.265	.230	.081	.290	.215	.087	.305	.208	.090	.315	.204	.093	.322	.202	.094	.327	.200	.096
	1.50	.267	.191	.066	.297	.172	.071	.315	.163	.074	.327	.157	.077	.335	.153	.078	.341	.151	.079

Table 4.5.c continued

WIND DIRECTION = 0 DEG (B/T) = 8.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\overline{\delta}(\omega)}{\delta(\omega,0)}$	.50	.852	.981	.852	.908	.992	.908	.933	.993	.933	.948	.994	.948	.957	.995	.957	.963	.995	.964
	.60	.858	.988	.853	.912	.982	.908	.937	.986	.933	.950	.988	.947	.959	.989	.956	.965	.990	.963
	.70	.864	.951	.860	.917	.969	.914	.940	.975	.938	.953	.978	.951	.961	.980	.960	.967	.982	.966
	.80	.873	.927	.864	.923	.951	.917	.944	.959	.940	.956	.964	.953	.964	.967	.961	.969	.970	.967
	.90	.887	.898	.874	.934	.927	.924	.954	.938	.946	.964	.945	.958	.971	.950	.965	.975	.954	.970
	1.00	.904	.863	.884	.947	.898	.932	.965	.912	.952	.973	.920	.963	.979	.927	.970	.982	.933	.974
	1.10	.923	.823	.898	.961	.864	.943	.976	.881	.962	.983	.893	.972	.988	.902	.978	.990	.909	.982
	1.20	.946	.779	.912	.978	.828	.954	.990	.850	.970	.995	.865	.979	.998	.876	.984	.999	.886	.988
	1.30	.969	.735	.930	.994	.793	.966	1.000	.821	.979	1.000	.840	.987	1.000	.854	.991	1.000	.866	.993
	1.40	.992	.699	.939	1.000	.765	.967	1.000	.800	.977	1.000	.822	.982	1.000	.840	.985	1.000	.854	.987
	1.50	1.000	.671	.919	1.000	.746	.942	1.000	.786	.949	1.000	.812	.954	1.000	.832	.957	1.000	.847	.960
$\overline{\delta}(\omega)$	.50	.131	1.443	.117	.140	1.458	.124	.144	1.460	.128	.146	1.462	.130	.147	1.463	.131	.148	1.463	.132
	.60	.184	1.304	.154	.196	1.323	.164	.201	1.327	.169	.204	1.330	.171	.206	1.332	.173	.208	1.334	.174
	.70	.239	1.167	.187	.254	1.190	.198	.260	1.197	.203	.264	1.201	.206	.266	1.204	.208	.268	1.206	.210
	.80	.291	1.034	.209	.307	1.060	.222	.315	1.069	.227	.318	1.074	.231	.321	1.078	.233	.323	1.082	.234
	.90	.334	.907	.219	.352	.937	.232	.360	.947	.237	.363	.954	.240	.366	.959	.242	.368	.963	.244
	1.00	.368	.790	.217	.386	.821	.229	.393	.834	.234	.396	.842	.237	.398	.848	.239	.400	.854	.240
	1.10	.391	.684	.205	.408	.718	.215	.414	.733	.219	.417	.742	.222	.419	.749	.223	.420	.756	.224
	1.20	.405	.591	.184	.419	.628	.193	.424	.645	.196	.426	.656	.198	.427	.665	.199	.428	.673	.200
	1.30	.409	.512	.158	.419	.552	.164	.422	.572	.167	.422	.585	.168	.422	.595	.168	.422	.603	.169
	1.40	.406	.442	.130	.409	.485	.134	.409	.506	.135	.409	.521	.136	.409	.531	.136	.409	.540	.136
	1.50	.390	.378	.103	.390	.420	.105	.390	.442	.106	.390	.457	.107	.390	.468	.107	.390	.477	.108

WIND DIRECTION = 20 DEG (B/T) = 8.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\overline{\delta}(\omega)}{\delta(\omega,0)}$	.50	.802	.942	.802	.854	.977	.854	.878	.988	.878	.892	.991	.892	.901	.991	.901	.907	.992	.907
	.60	.808	.927	.803	.859	.964	.855	.883	.976	.879	.897	.980	.892	.906	.981	.901	.912	.981	.907
	.70	.814	.907	.810	.865	.947	.861	.889	.960	.885	.902	.965	.899	.910	.967	.907	.916	.968	.913
	.80	.824	.882	.815	.874	.924	.866	.897	.939	.889	.910	.945	.902	.918	.947	.911	.923	.948	.917
	.90	.840	.853	.826	.888	.896	.875	.910	.913	.898	.922	.919	.911	.930	.923	.919	.935	.924	.924
	1.00	.858	.816	.836	.905	.862	.885	.926	.880	.907	.937	.888	.919	.944	.891	.927	.949	.893	.932
	1.10	.879	.775	.852	.923	.823	.899	.942	.842	.920	.953	.851	.932	.959	.855	.940	.964	.857	.945
	1.20	.905	.730	.868	.945	.780	.913	.902	.801	.933	.972	.812	.943	.977	.816	.950	.981	.818	.955
	1.30	.931	.686	.887	.968	.738	.930	.982	.761	.947	.989	.773	.957	.994	.779	.963	.997	.782	.968
	1.40	.959	.648	.901	.990	.702	.939	1.000	.728	.954	1.000	.742	.961	1.000	.749	.966	1.000	.752	.969
	1.50	.986	.620	.885	1.000	.676	.918	1.000	.704	.931	1.000	.719	.936	1.000	.727	.939	1.000	.732	.940
$\overline{\delta}(\omega)$	.50	.124	1.385	.110	.132	1.437	.117	.135	1.452	.120	.137	1.456	.122	.139	1.457	.123	.140	1.458	.124
	.60	.174	1.249	.145	.185	1.299	.155	.190	1.314	.159	.193	1.319	.162	.195	1.321	.163	.196	1.322	.164
	.70	.226	1.114	.176	.240	1.163	.187	.246	1.179	.192	.250	1.185	.195	.252	1.187	.197	.254	1.188	.198
	.80	.274	.984	.197	.291	1.031	.210	.299	1.047	.215	.303	1.053	.218	.306	1.056	.220	.307	1.057	.222
	.90	.317	.861	.207	.335	.905	.220	.343	.922	.225	.348	.929	.229	.351	.932	.231	.353	.933	.232
	1.00	.349	.747	.206	.368	.789	.218	.377	.805	.223	.381	.812	.226	.384	.816	.228	.386	.817	.229
	1.10	.373	.644	.194	.391	.684	.205	.399	.700	.210	.404	.707	.213	.407	.711	.214	.409	.712	.215
	1.20	.387	.554	.175	.405	.592	.184	.412	.608	.188	.416	.616	.191	.418	.620	.192	.420	.621	.193
	1.30	.393	.477	.151	.408	.513	.158	.414	.530	.161	.418	.538	.163	.419	.542	.164	.421	.544	.164
	1.40	.392	.410	.124	.405	.445	.130	.409	.461	.132	.409	.469	.133	.409	.474	.133	.409	.476	.134
	1.50	.385	.349	.099	.390	.381	.103	.390	.396	.104	.390	.405	.105	.390	.409	.105	.390	.412	.105

Table 4.5.c continued

WIND DIRECTION = 40 DEG (B/T) = 8.

	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.667	.830	.666	.701	.894	.701	.719	.930	.719	.730	.951	.730	.737	.965	.737	.742	.973	.742
	.60	.673	.810	.668	.709	.873	.703	.727	.909	.721	.739	.930	.732	.746	.944	.740	.752	.952	.745
	.70	.680	.787	.675	.717	.848	.711	.736	.882	.730	.748	.903	.742	.757	.917	.750	.763	.925	.755
	.80	.692	.760	.681	.730	.817	.718	.750	.850	.737	.763	.870	.749	.772	.883	.757	.779	.892	.763
	.90	.708	.728	.693	.749	.781	.731	.771	.812	.752	.784	.831	.764	.794	.844	.773	.801	.852	.779
	1.00	.729	.690	.705	.773	.739	.745	.796	.766	.766	.810	.784	.779	.820	.796	.788	.828	.805	.795
	1.10	.754	.648	.723	.800	.691	.765	.824	.715	.787	.839	.731	.800	.849	.742	.810	.857	.750	.816
	1.20	.785	.602	.742	.833	.638	.786	.859	.657	.808	.875	.670	.822	.886	.680	.831	.893	.687	.838
	1.30	.818	.557	.766	.870	.585	.812	.898	.599	.836	.915	.608	.850	.926	.615	.860	.933	.621	.867
	1.40	.855	.517	.787	.912	.537	.836	.941	.546	.861	.959	.552	.877	.971	.557	.887	.979	.561	.894
	1.50	.893	.486	.781	.955	.500	.830	.987	.505	.854	1.000	.507	.869	1.000	.509	.879	1.000	.512	.886
$\bar{\delta}(\omega)$	.50	.103	1.220	.091	.108	1.314	.096	.111	1.367	.098	.112	1.398	.100	.114	1.418	.101	.114	1.430	.102
	.60	.145	1.091	.121	.152	1.176	.127	.156	1.224	.131	.159	1.253	.133	.160	1.271	.134	.162	1.283	.135
	.70	.188	.967	.146	.199	1.041	.154	.204	1.083	.158	.207	1.109	.161	.210	1.126	.163	.211	1.136	.164
	.80	.230	.847	.165	.243	.911	.174	.250	.947	.178	.254	.970	.181	.257	.985	.183	.259	.994	.185
	.90	.267	.735	.174	.282	.789	.184	.291	.820	.189	.296	.839	.192	.299	.852	.194	.302	.861	.196
	1.00	.297	.632	.173	.314	.676	.183	.324	.701	.188	.330	.717	.192	.334	.729	.194	.337	.737	.196
	1.10	.320	.539	.165	.339	.574	.174	.349	.594	.179	.356	.607	.182	.360	.617	.185	.363	.624	.186
	1.20	.336	.457	.150	.357	.484	.159	.368	.499	.163	.375	.509	.166	.379	.516	.168	.382	.522	.169
	1.30	.345	.387	.130	.367	.407	.138	.379	.417	.142	.386	.423	.145	.391	.428	.146	.394	.432	.147
	1.40	.350	.327	.109	.373	.340	.115	.385	.346	.119	.392	.349	.121	.397	.352	.122	.401	.355	.123
	1.50	.348	.274	.088	.372	.282	.093	.385	.284	.096	.390	.286	.097	.390	.287	.098	.390	.288	.099

WIND DIRECTION = 60 DEG (B/T) = 8.

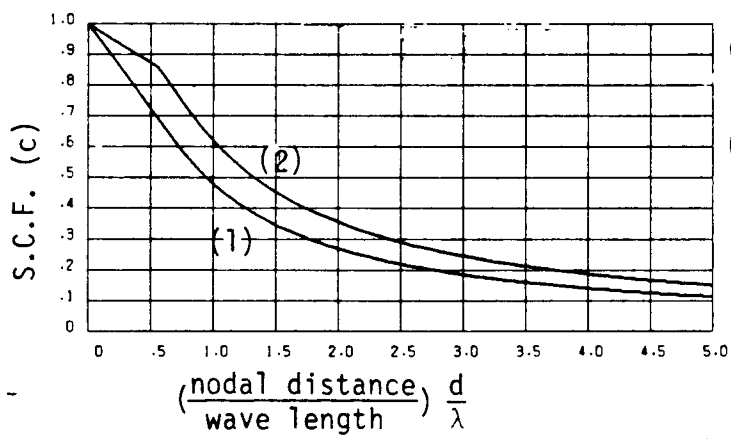
	σ	N=2 SWAY	N=2 HEAVE	N=2 ROLL	N=4 SWAY	N=4 HEAVE	N=4 ROLL	N=6 SWAY	N=6 HEAVE	N=6 ROLL	N=8 SWAY	N=8 HEAVE	N=8 ROLL	N=10 SWAY	N=10 HEAVE	N=10 ROLL	N=12 SWAY	N=12 HEAVE	N=12 ROLL
$\frac{\bar{\delta}(\omega)}{\delta(\omega,0)}$	.50	.483	.650	.483	.484	.694	.483	.485	.727	.485	.487	.752	.486	.489	.774	.487	.490	.793	.489
	.60	.490	.628	.485	.492	.668	.486	.494	.698	.488	.496	.722	.490	.498	.743	.491	.499	.761	.493
	.70	.497	.604	.491	.501	.639	.494	.504	.665	.496	.507	.687	.498	.509	.706	.500	.511	.722	.501
	.80	.509	.577	.498	.515	.606	.502	.519	.629	.505	.523	.648	.508	.526	.664	.510	.528	.678	.512
	.90	.525	.547	.510	.535	.569	.516	.542	.588	.521	.547	.603	.525	.551	.617	.528	.554	.629	.530
	1.00	.547	.512	.523	.561	.528	.532	.571	.541	.538	.577	.553	.543	.583	.564	.547	.587	.573	.549
	1.10	.573	.473	.541	.592	.482	.553	.606	.490	.562	.615	.498	.568	.622	.505	.573	.628	.512	.577
	1.20	.605	.431	.561	.632	.431	.578	.649	.434	.590	.662	.437	.598	.671	.441	.605	.679	.444	.610
	1.30	.642	.388	.586	.677	.379	.609	.700	.377	.625	.716	.376	.636	.728	.376	.644	.738	.376	.651
	1.40	.684	.350	.613	.729	.333	.644	.759	.325	.664	.779	.320	.678	.794	.317	.689	.806	.315	.697
	1.50	.730	.320	.617	.787	.296	.652	.824	.283	.676	.849	.275	.692	.867	.270	.705	.881	.265	.714
$\bar{\delta}(\omega)$	.50	.074	.955	.066	.075	1.020	.066	.075	1.068	.066	.075	1.106	.067	.075	1.138	.067	.075	1.165	.067
	.60	.105	.846	.088	.106	.900	.088	.106	.940	.088	.107	.973	.089	.107	1.000	.089	.107	1.024	.089
	.70	.138	.742	.107	.139	.784	.107	.140	.817	.108	.140	.844	.108	.141	.867	.108	.141	.887	.109
	.80	.169	.643	.121	.171	.676	.122	.173	.701	.122	.174	.722	.123	.175	.740	.124	.176	.756	.124
	.90	.198	.552	.128	.202	.575	.130	.204	.594	.131	.206	.609	.132	.208	.623	.132	.209	.635	.133
	1.00	.223	.468	.129	.228	.483	.131	.232	.495	.132	.235	.506	.134	.237	.516	.134	.239	.524	.135
	1.10	.243	.393	.123	.251	.400	.126	.257	.407	.128	.261	.414	.130	.264	.420	.131	.266	.425	.132
	1.20	.259	.327	.113	.270	.327	.117	.278	.329	.119	.283	.332	.121	.287	.335	.122	.290	.337	.123
	1.30	.271	.270	.100	.286	.264	.104	.295	.262	.106	.302	.262	.108	.307	.262	.109	.311	.262	.111
	1.40	.280	.222	.085	.298	.211	.089	.310	.205	.092	.319	.203	.094	.325	.201	.095	.330	.199	.096
	1.50	.285	.180	.069	.307	.167	.073	.321	.159	.076	.331	.155	.078	.338	.152	.079	.343	.149	.080

IV. Spatial Correlation of Nodal Loads

To deal with the short-crested waves, two methods have been implemented in the program to take into account the spatial correlation of the wave loading.

The first is the S.C.F. method which consist of weighting the nodal loads by a factor to take into account the fact that the wave pressure is not fully correlated between nodal points. The nodes are assumed to be far enough so that the nodal loads are uncorrelated. (Measurements in Hood Canal and Evergreen floating bridges show that after a distance 0.6λ the wave forces can be considered uncorrelated, ref. 9, 18, 20.)

The S.C.F. factor was developed empirically from measurements on the Hood Canal floating bridge and more about it can be found in ref. 28. In fig. 4.1 is shown the variation of S.C.F. with the ratio of nodal distance to wave length. The two curves shown on this figure correspond to linear, curve 1, or quadratic, curve 2, decrease of in-phase loadings from 0 to 0.6λ.



$$(1)\quad c = \frac{0.6}{d/\lambda}\left(1 - \frac{0.2}{d/\lambda}\right) \qquad (4.1)$$

$$(2)\quad c = \frac{0.8}{d/\lambda}\left(1 - \frac{0.225}{d/\lambda}\right) \qquad (4.2)$$

$$\text{for } \frac{d}{\lambda} \geq 0.5$$

Figure 4.1.

"Spatial Correlation Factor vs. ratio of nodal distance to wave length".

The second method is described in ref. 6 and consists in a theoretically developed wave correlation. Briefly it is as follows:

The wave coherence along the bridge is assumed to vary exponentially and for two points at distance Δz assumed to be of the form:

$$\gamma_w (\Delta z/\lambda) = \exp(-\alpha(\Delta z/\lambda)^{\beta}) \tag{4.3}$$

The values of α and β depend on the wave directional spectrum. In Fig. 4.2 are shown curves of the form $y=\exp(-\alpha x^{\beta})$, and in Fig. 4.3 are shown curves for the wave coherence between two points at distance z on the bridge obtained for a directional spectrum of the form:

$$S(f,\theta) = S(f) \cos^{n}(\theta-\theta_o) \tag{4.4}$$

Using least square fitting the values of α and β can be obtained by fitting curves of fig. 4.2 to those of fig. 4.3. (All these have been done using a small program COHER). Results for α and β values are shown in Table 4.1.

The nodal load cross-spectral densities can be written in the form:

$$S_{RiRj}(\omega) = \overline{\delta}(\omega)\ \rho_{ij}(\omega)\ S_w(\omega) \tag{4.5}$$

where $\rho_{ij}(\omega)$ depends on α, β and the nodal distances and can be easily computed using numerical integration (eight point Gauss quadrature method proved to be adequate).

Then the nodal loads are constructed from N series of uncorrelated loads, $X_i(t)$, i = 1,....N, as:

$$R_i(t) = \sum_{j=1}^{N} a_{ij}\ X_j(t) \tag{4.6}$$

In order for the nodal loads to satisfy (4.5) the computation of a_{ij} is reduced to an eigenvalue problem and a_{ij} are obtained as:

$$[a_{ij}] = [Q]\ [\Lambda]^{\frac{1}{2}}\ [Q]^T \qquad (4.7)$$

where $[\Lambda]$ is the eigenvalue matrix of $[\rho_{ij}]$ in respect to a unit matrix and $[Q]$ are the corresponding eigenvectors.

Table 4.1. Results of Program COHER for α and β Coefficients Fitting Eq. 4.3 to Curves of Figure 4.3.

	θ_o	0°	10°	20°	30°	40°	60°	80°
n=2	α β	4.47 1.91	1.70 1.27	1.42 1.23	1.14 1.20	.90 1.13	.53 1.21	.32 1.39
n=4	α β	4.44 2.14	2.36 1.74	1.49 1.44	1.15 1.37	.87 1.35	.44 1.38	.20 1.50
n=6	α β	3.09 2.12	2.33 1.95	1.68 1.78	1.08 1.53	.82 1.51	.38 1.48	.14 1.58
n=8	α β	2.33 2.09	2.09 2.04	1.61 1.92	1.10 1.74	.75 1.62	.34 1.58	.11 1.65
n=10	α β	1.87 2.07	1.77 2.05	1.44 1.98	1.05 1.85	.70 1.70	.31 1.65	.08 1.69
n=12	α β	1.57 2.06	1.52 2.06	1.28 2.00	.97 1.92	.64 1.74	.28 1.70	.07 1.73

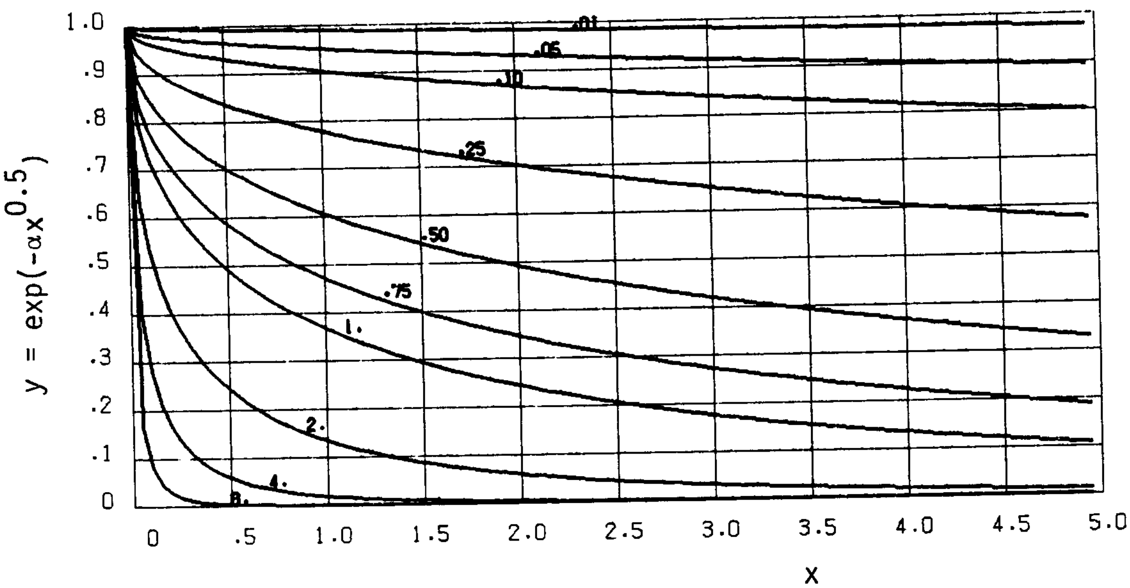


Fig. 4.2.a

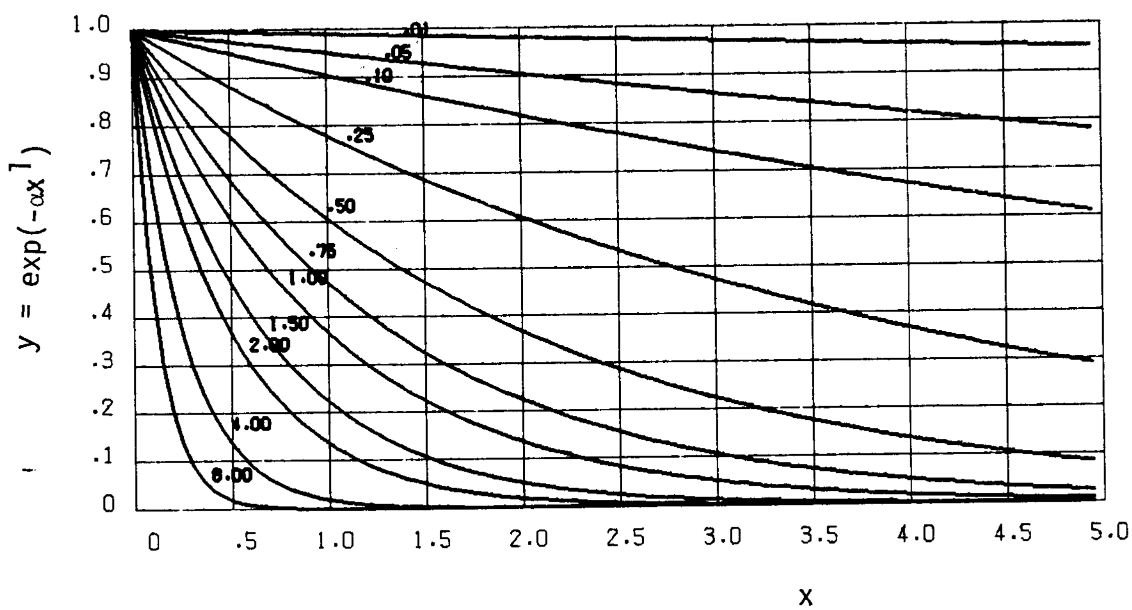


Fig. 4.2.b

Wave Coherence Functions

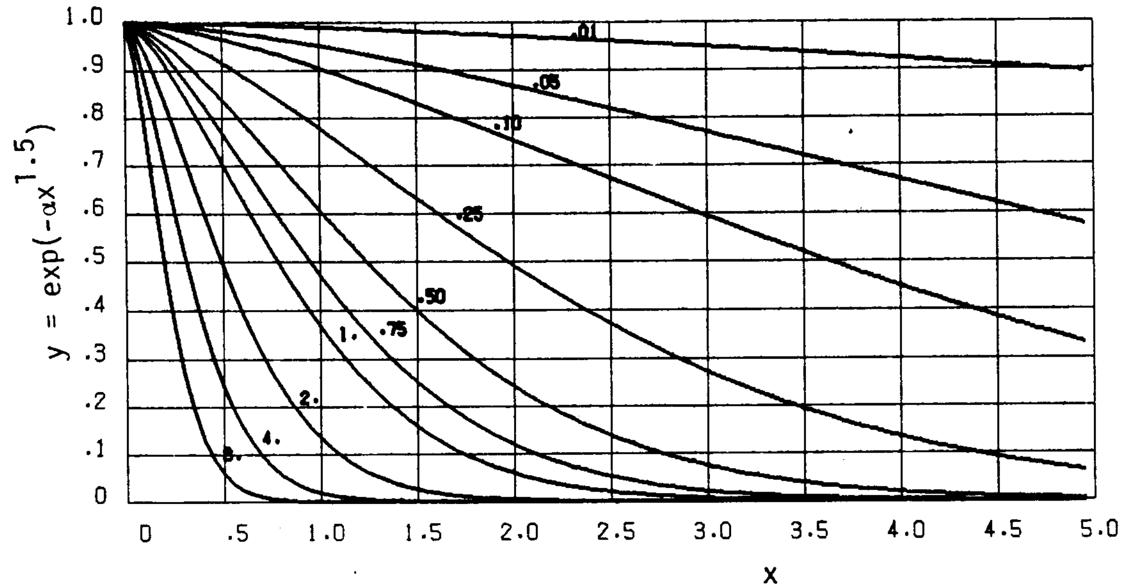


Fig. 4.2.c

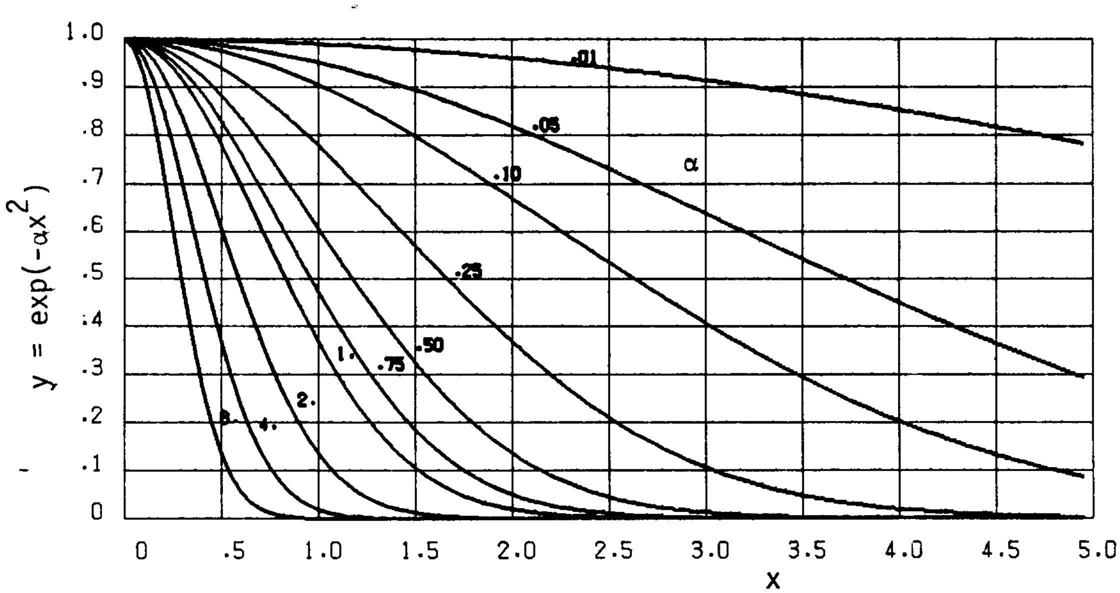


Fig. 4.2.d

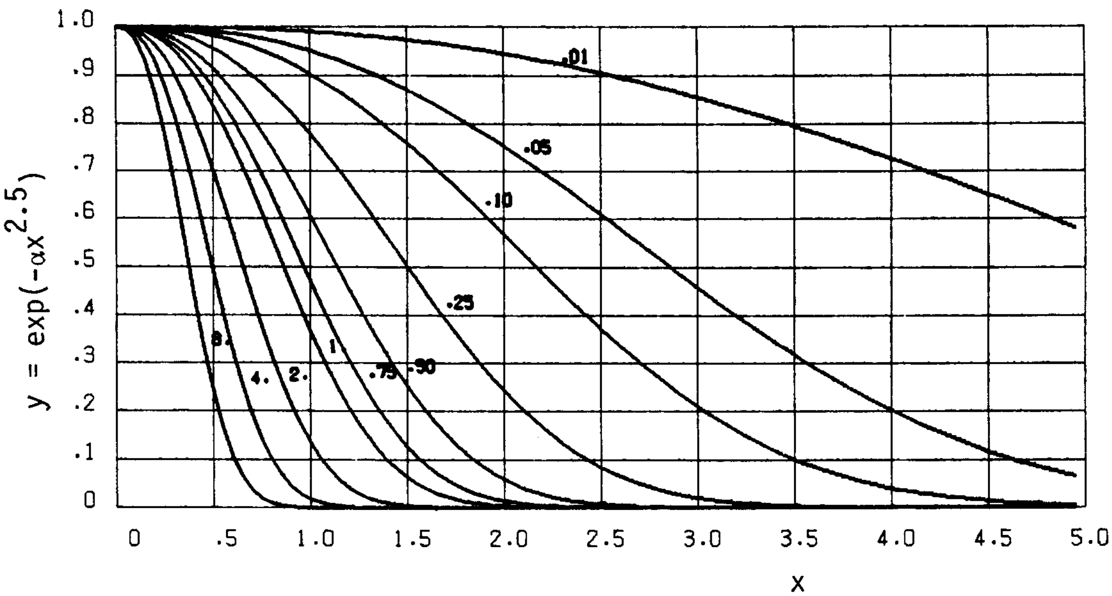


Fig. 4.2.e

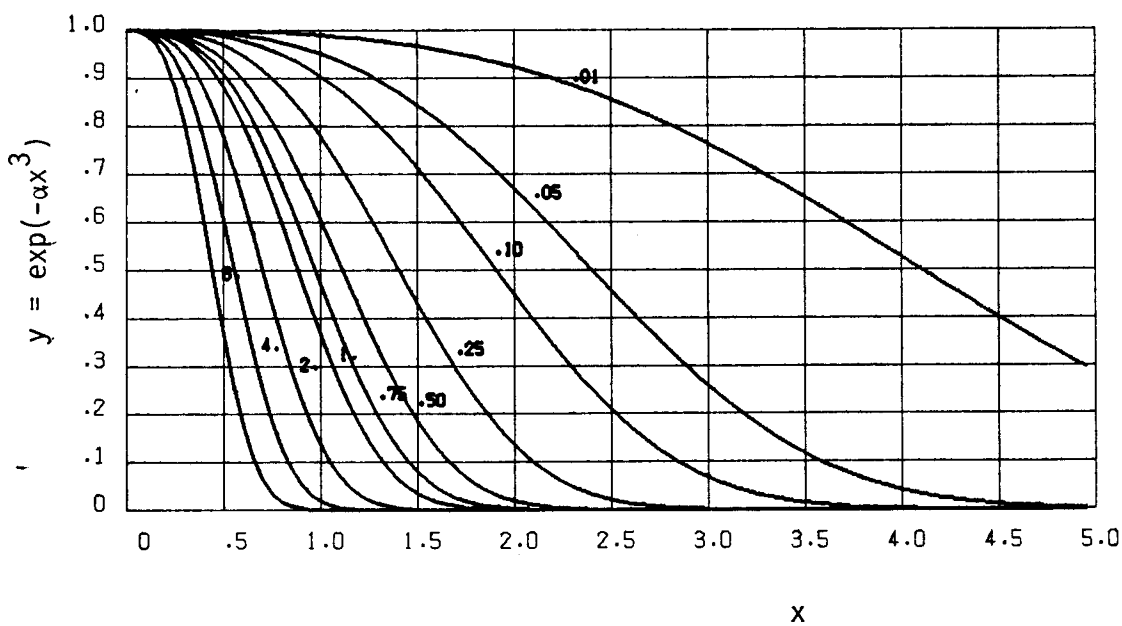


Fig. 4.2.f

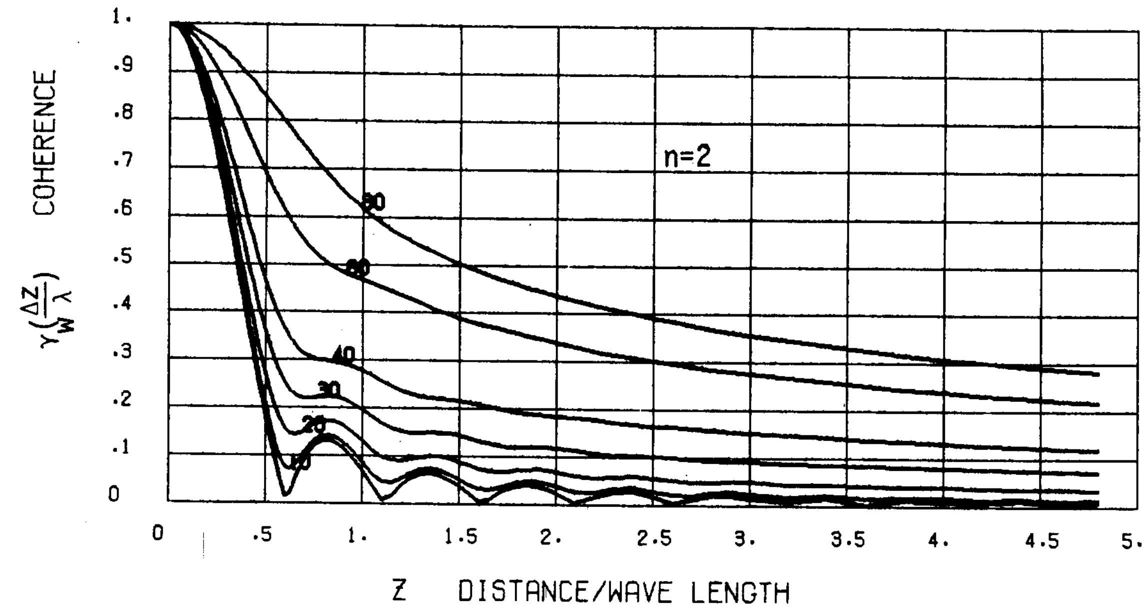


Fig. 4.3.a

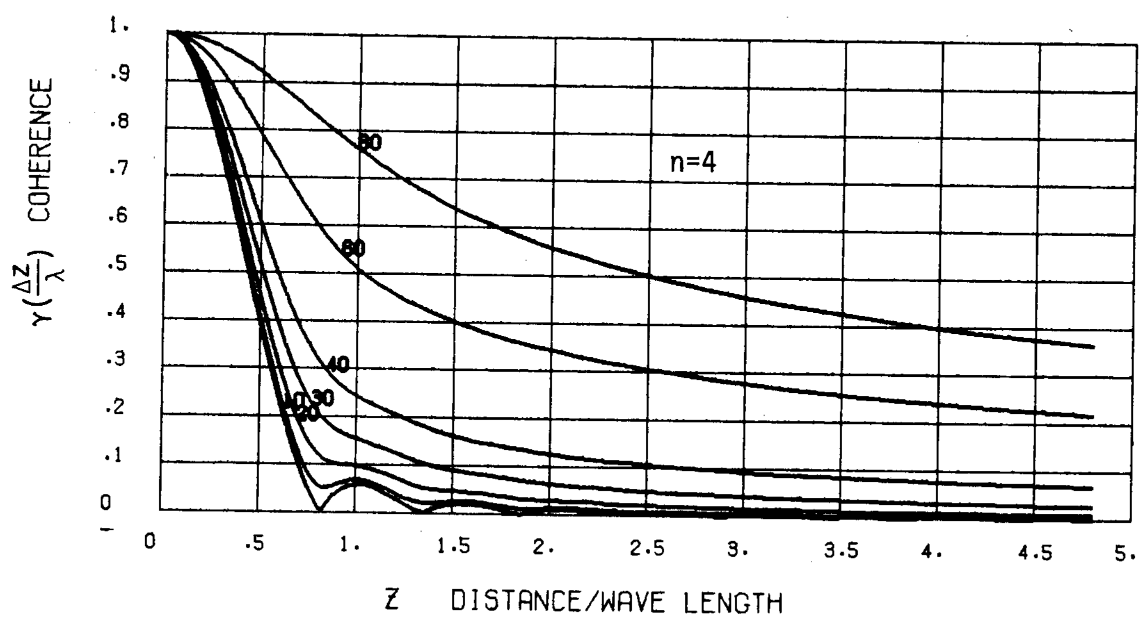


Fig. 4.3.b

Wave Coherence for Directional Spectrum $S(f,\theta) = S(f)\cos^n(\theta-\theta_o)$

Wind Direction on Curves.

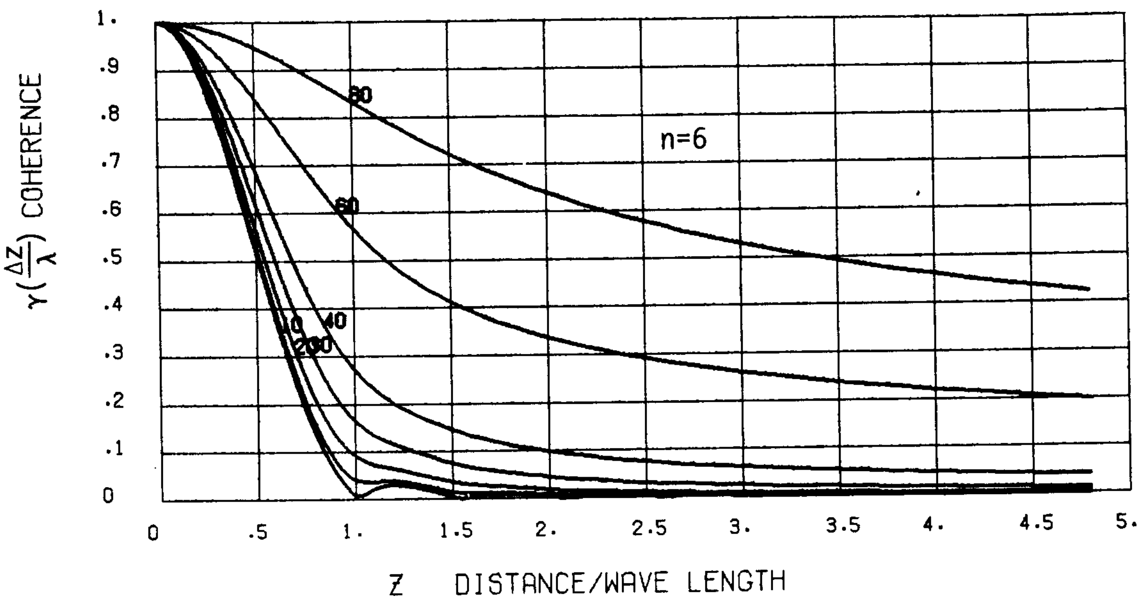


Fig. 4.3.c

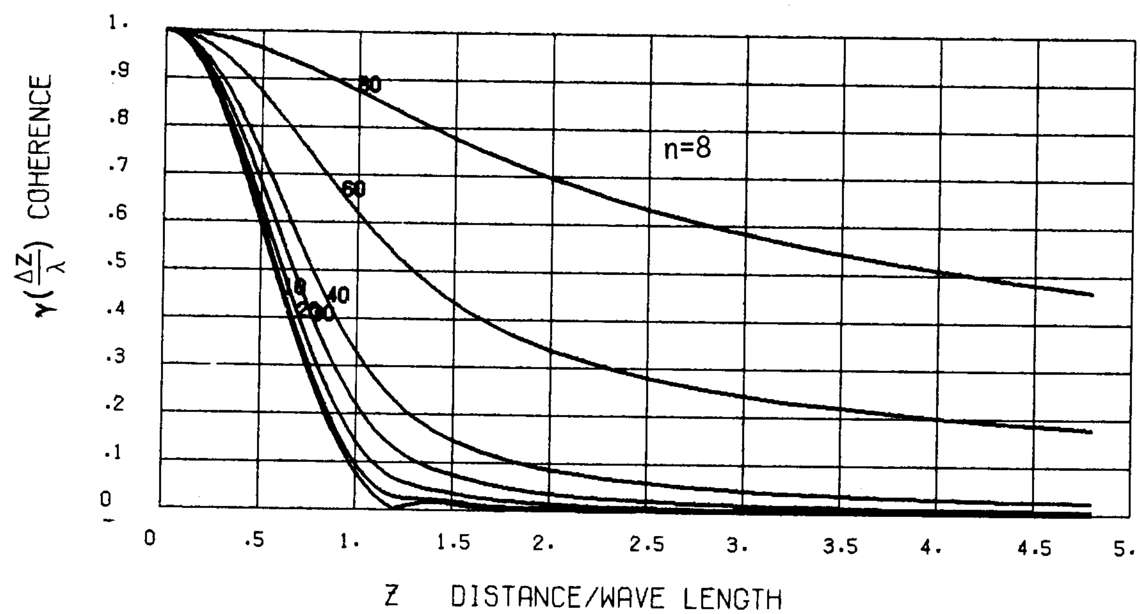


Fig. 4.3.d

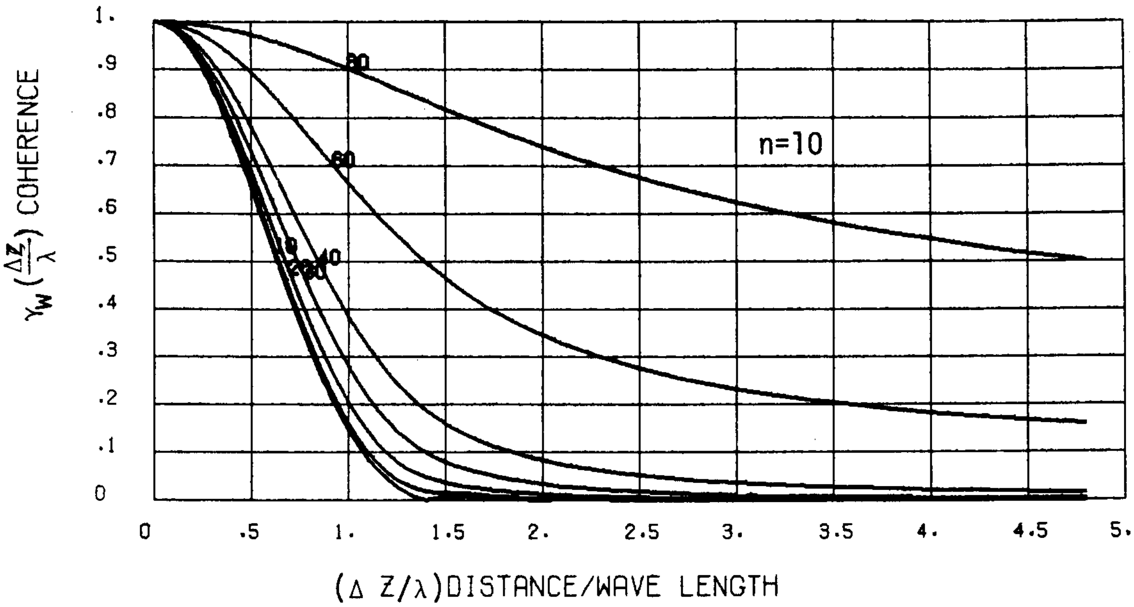


Fig. 4.3.e

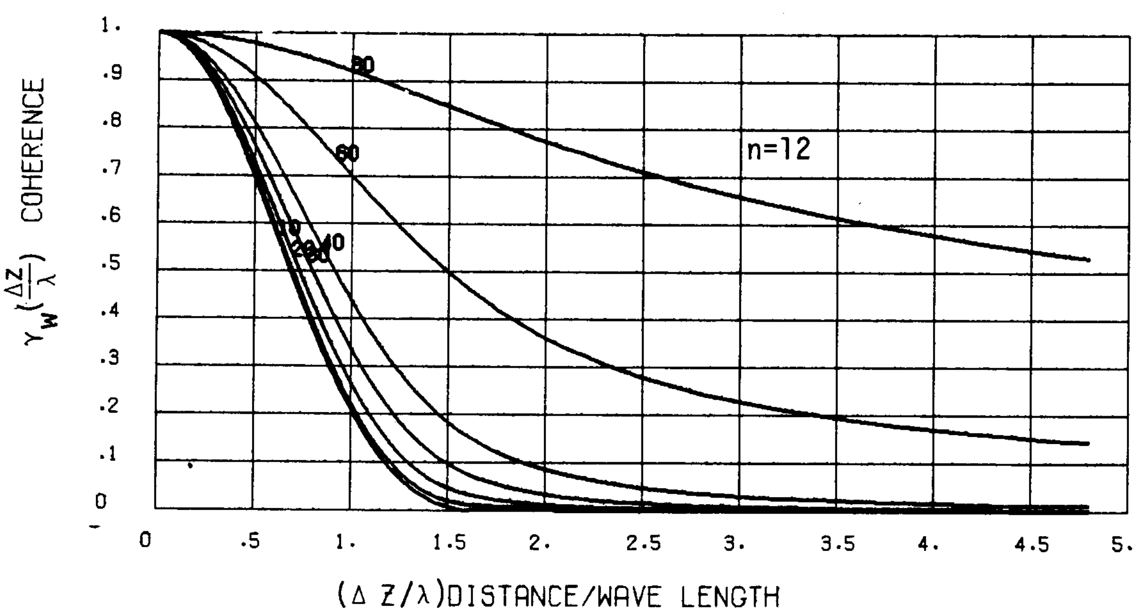


Fig. 4.3.f

V. Monte Carlo Simulation of Random Sea State

In a wave spectrum there are an infinite number of sea states, each one resulting in different loading on the structure.

To estimate the expected response values a Monte Carlo simulation is followed in this program.

For this the structure response is calculated for N sets of different nodal loads resulting from the same wave spectrum.

The mean and standard deviation between these sample response values are calculated, and they approximate the expected response value and its standard deviation provided the sample number N is large enough.

To figure out an appropriate value for N, runs should be made with different N values and from the variation of the results the value of N can be judged. From experience a value for N between 8 and 16 seems adequate. As an example Fig. 5.1, 5.2, and 5.3 show results for N = 8, 16, 24. The small difference between the results for N = 16 and 24, shows that a value for N = 16 is adequate.

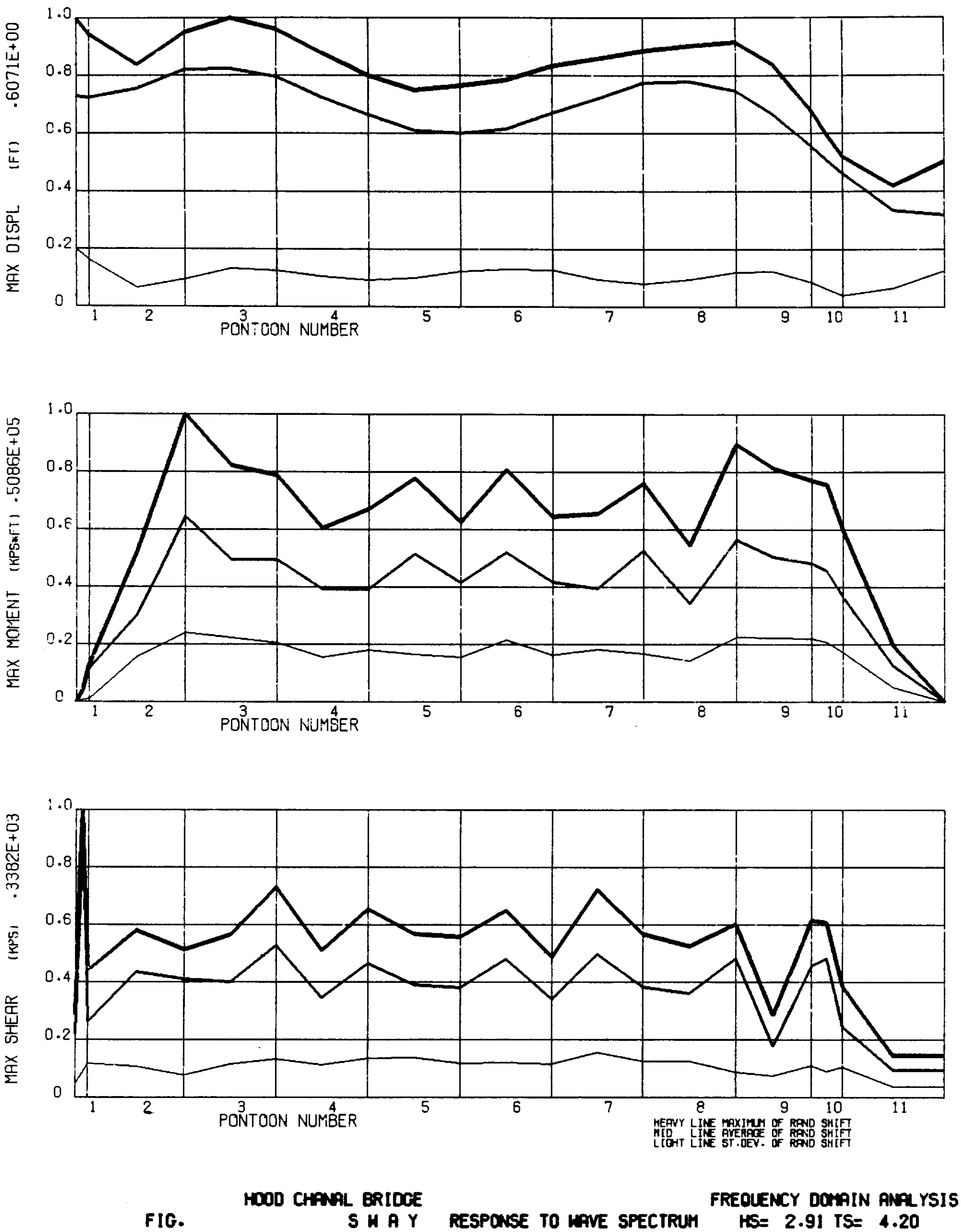
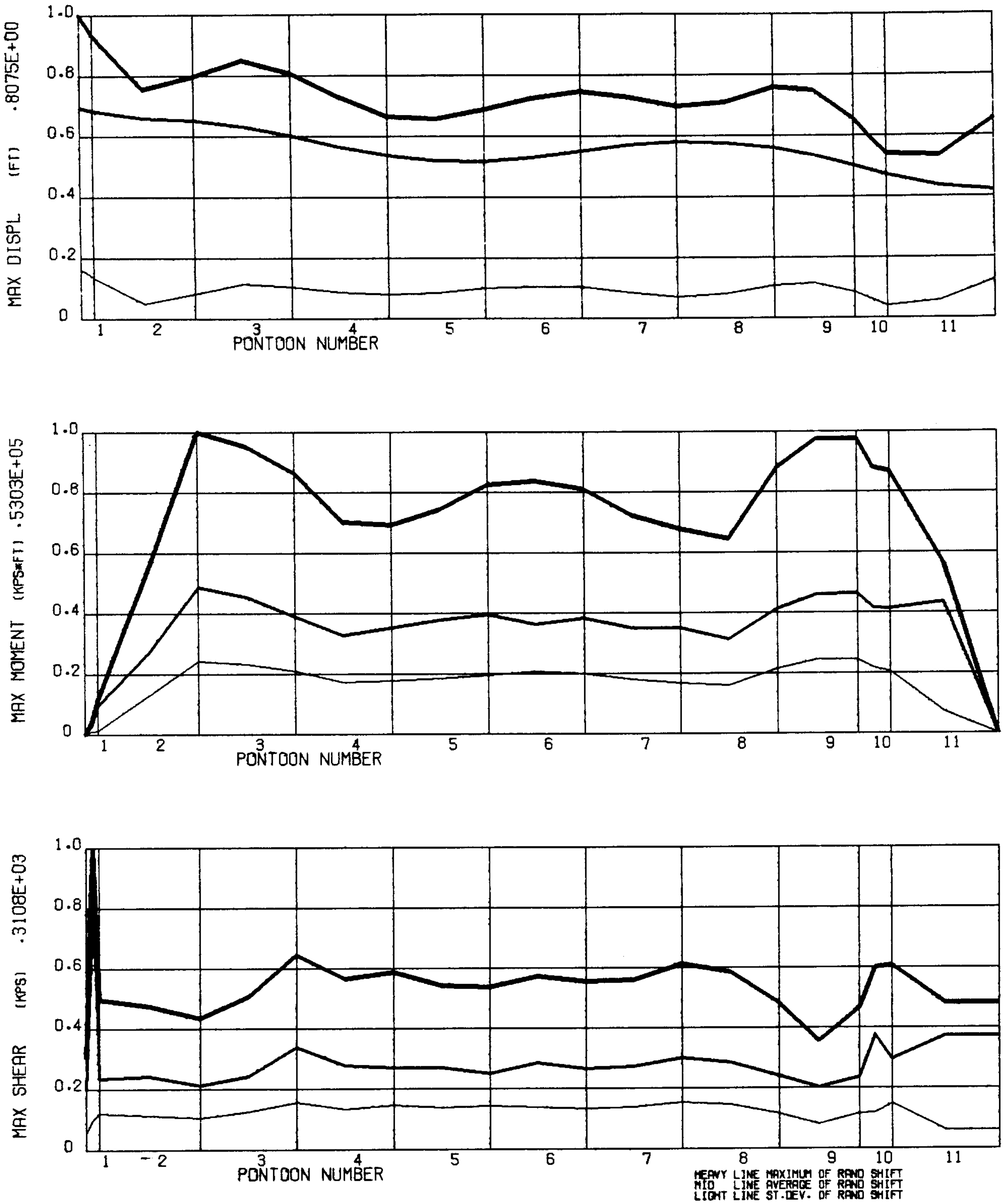


Fig. 5.1

Number of Random Load Samples: 8

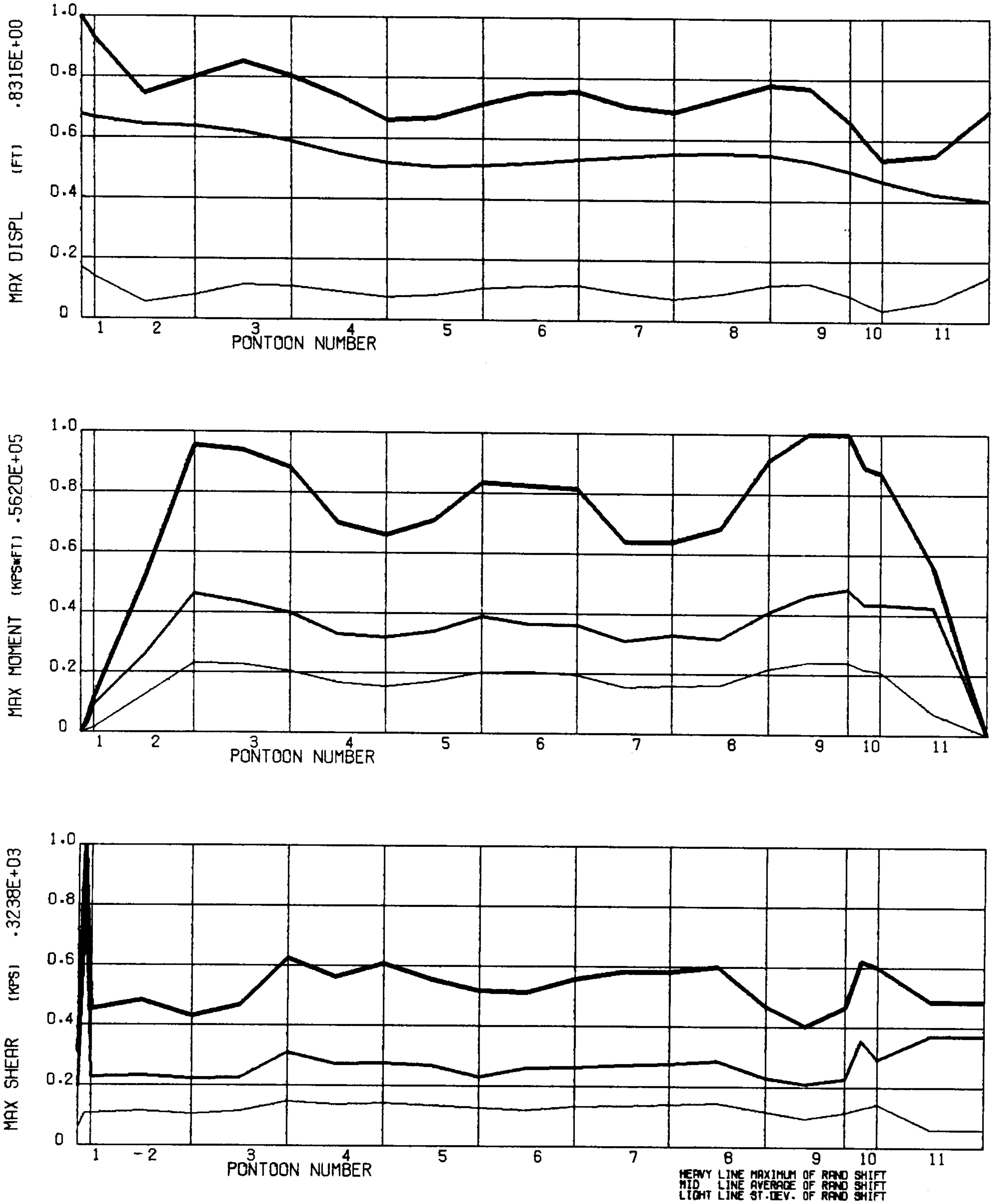


HOOD CHANAL BRIDGE FREQUENCY DOMAIN ANALYSIS

FIG. S W A Y RESPONSE TO WAVE SPECTRUM HS= 2.91 TS= 4.20

Fig. 5.2

Number of Random Load Samples: 16



HOOD CANAL BRIDGE FREQUENCY DOMAIN ANALYSIS

FIG. S W A Y RESPONSE TO WAVE SPECTRUM HS= 2.91 TS= 4.20

Fig. 5.3

Number of Random Load Samples: 24

VI. Frequency Domain Analysis

First the response to short-crested harmonic waves of single frequency ω is calculated assuming the structure oscillates in a steady state with frequency ω. Again two methods are implemented corresponding to the two approaches of 4, above. To take into account the wave spatial correlation (para. 4), the nodal loads are computed as follows (Fig. 6.1.):

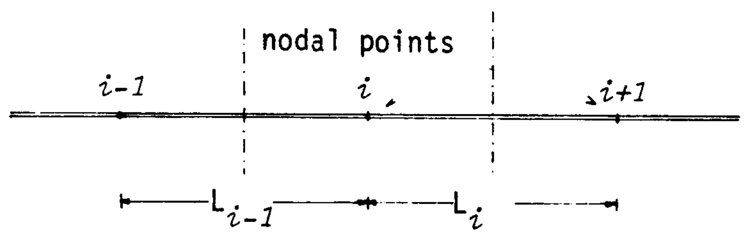


Figure 6.1. Nodal point numbering.

a) $$R_i(t) = \left[\frac{c_{i-1}(\omega,L_{i-1})L_{i-1} + c_i(\omega,L_i)L_i}{2}\right] \bar{\delta}(\omega) \; n(\omega) \; \sin(\omega t+\phi_i) \qquad (6.1)$$

where: $c_i(\omega,L_i)$ is a spatial correlation factor, S.C.F., as described in para. 4.

$\bar{\delta}$ (ω) is the frequency and wave direction dependent hydrodynamic force coefficient, converting wave amplitude to wave force per unit bridge length, and is described in para. 3 and computed in Table 3.2.

$n(\omega)$is the wave amplitude for each frequency component of the wave spectrum.

\- ϕ_i is a random phase angle taking into account that the nodal loads are uncorrelated. This angle can be chosen with a uniform probability between 0 and Φ. A value of Φ equal to $\pi/2$ produces less correlated loads than equal to 2π [6].

b) $$R_i(t) = \bar{\delta}(\omega)\, n(\omega) \sum_{j=1}^{N} a_{ij} \sin(\omega t + \phi_j) \qquad (6.2)$$

Here the nodal loads are constructed from N uncorrelated time series, as described in para. 4, and a_{ij} are obtained from Eq. (4.7) for the wave coherence function assumed to be of the form of Eq. (4.3).

The structure loaded as shown in Figure 6.2, and oscillating in a steady state will have displacements:

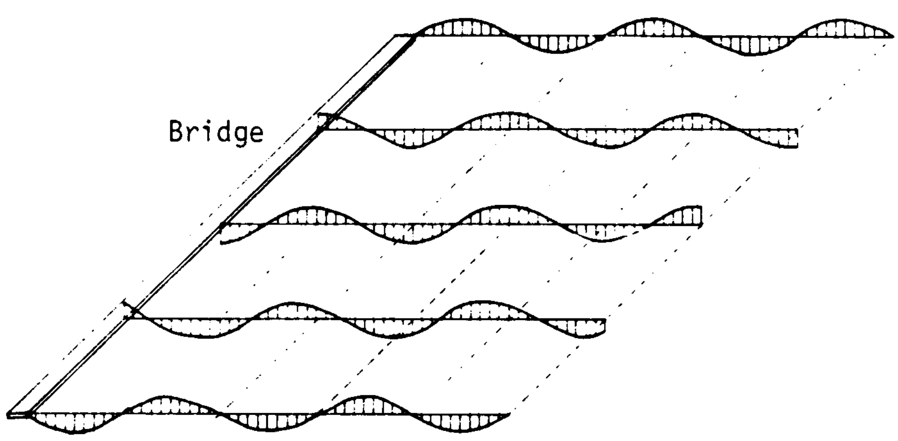


Figure 6.2. Nodal Harmonic Loads

$$r_i(t) = r_i \sin(\omega t + \psi_i) = r_i \sin\omega t \cos\psi_i + r_i \cos\omega t \sin\psi_i =$$
$$= a_i \sin\omega t + b_i \cos\omega t \qquad (6.3.a)$$

and

$$\dot{r}_i(t) = a_i\omega \cos\omega t - b_i\omega \sin\omega t \qquad (6.3.b)$$
$$\ddot{r}_i(t) = -a_i\omega^2 \sin\omega t - b_i\omega^2 \cos\omega t \qquad (6.3.c)$$

and in matrix form:

$$\{r(t)\} = \{a\}\sin\omega t + \{b\} \cos\omega t \qquad (6.4)$$

and for the nodal load:

$$\{R(t)\} = \{A\}\sin\omega t + \{B\} \cos\omega t \qquad (6.5)$$

where $\{a\} = \{a_i\}$, $\{b\} = \{b_i\}$, $\{A\} = \{A_i\}$, $\{B\} = \{B_i\}$

and,

$$A_i = \tfrac{1}{2}\{c_{i-1}(\omega,L_{i-1})L_{i-1} + c_i(\omega,L_i)L_i\}\bar{\delta}(\omega)\ \eta(\omega) \cos \phi_i \qquad (6.6.a)$$
$$B_i = \tfrac{1}{2}\{c_{i-1}(\omega,L_{i-1})L_{i-1} + c_i(\omega,L_i)L_i\}\bar{\delta}(\omega)\ \eta(\omega) \sin \phi_i \qquad (6.6.b)$$

in case of (6.1)

or,

$$A_i = \bar{\delta}(\omega)\ \eta(\omega) \sum_{j=1}^{N} a_{ij}\cos \phi_j \qquad (6.7.a)$$

$$B_i = \bar{\delta}(\omega)\ \eta(\omega) \sum_{j=1}^{N} a_{ij}\sin \phi_j \qquad (6.7.b)$$

in case of (6.2)

Writing the damping in the form: $[c] = 2\ \xi(\omega)\ \omega[m]$ (6.8)

relation (2.1) becomes:

$$\begin{bmatrix} [k] - \omega^2[m] & -2\ \xi\omega^2[m] \\ 2\ \xi\omega^2[m] & [K] - \omega^2[m] \end{bmatrix} \begin{Bmatrix} \{a\} \\ \{b\} \end{Bmatrix} = \begin{Bmatrix} \{A\} \\ \{B\} \end{Bmatrix} \qquad (6.9)$$

Solving (6.9) the sin and cos terms, {a} and {b} for the displacements are obtained and consequently the bending moments and shearing forces. The corresponding maximum values are computed as:

$$\max r_i = \sqrt{a_i^2 + b_i^2} \tag{6.10}$$

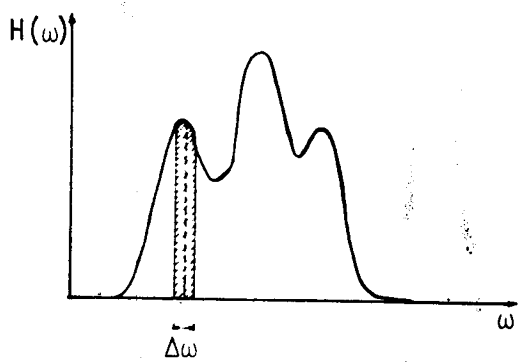


Figure 6.3.a. Response to unit amplitude waves

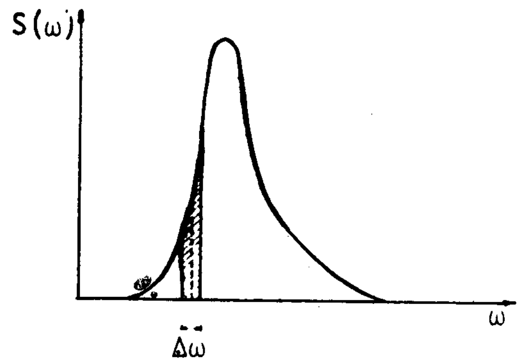


Figure 6.3.b. Wave Spectrum.

The frequency response $H(\omega)$ to unit wave amplitude ($\eta(\omega) = 1$) is evaluated for different wave periods and different sets of random phase angles. Maximum average values and standard deviations between the sets of random shifts are computed and the maximum values along the bridge are plotted for each wave period.

For the response due to a wave spectrum (Fig. 6.3.b), the wave field is constructed by the superposition of certain number of harmonics with amplitude $\eta(\omega) = \sqrt{S(\omega)\Delta\omega}$ and the structural response amplitude is computed as:

$$r = \int_0^\infty H(\omega)\, \eta(\omega)\, d\omega \tag{6.11}$$

Again the response to a wave spectrum is computed for different sets of random phase angles for the wave harmonics, and maximum, average and standard deviations values are computed and plotted along the bridge length. The above procedure is as if we superimpose Figure (6.2) for different wave periods and amplitudes $\eta(\omega)$, with a result shown in Figure (6.4) in which the structure is loaded with different time series having the same energy spectrum, and being either the uncorrelated case (6.1) or the appropriate correlated case (6.2).

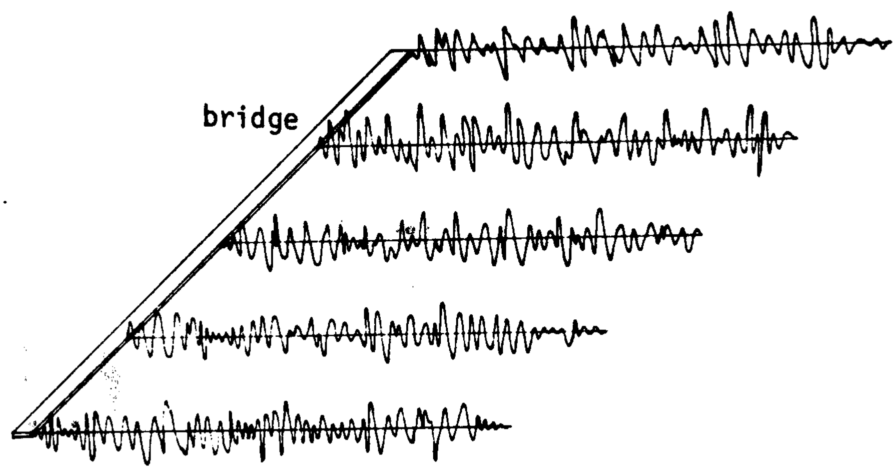


Figure 6.4. Nodal wave loading

VII. Time Domain Analysis

The mode superposition method has been adopted for the time domain analysis, being a more economic solution as the higher mode shapes do not participate in the response. Constant hydrodynamic coefficients S.C.F. and load correlation matrix, are assumed as computed for the peak spectrum frequency. The generalized Jacobi's method [1] is used in the eigenvalue solution. The above method seems more appropriate due to the small number of eigenvalues and to the fact that the condensed stiffness and mass matrices, although not banded, are strongly diagonal which helps in the fast convergence of Jacobi's method.

The wave time series are inputed or constructed from the wave spectrum as described in [4], by superposition of harmonics:

$$w(t) = \sum_{i=1}^{M} \eta_i(\omega_i) \sin(\omega_i t + \psi_i) \qquad (7.1)$$

where: ψ_i are random angles from 0 to 2π and ω_i, $i=1,2....$ M are frequencies in which the wave energy spectrum is split, chosen either at equal spacing or at equal spectra areas between them. $\eta(\omega) = \sqrt{S(\omega)\Delta\omega}$ (Fig. 6.3.b).

To construct different samples of time series the above time series w(t) are shifted at random intervals. If the time series are constructed from the wave spectrum, for each set of random shifts the time series are reconstructed from (7.1) with different phase angles, ψ. For the corresponding cases of (6.1) and (6.2) the nodal loading is constructed as:

$$\text{a)}\ R_i(t) = \{c_{i-1}(\omega_o, L_{i-1})L_{i-1} + c_i(\omega_o, L_i)L_i\}\ \bar{\delta}(\omega_o)\ w(t+T_i) \qquad (7.2)$$

$$\text{b)}\ R_i(t) = \bar{\delta}(\omega_o) \sum_{j=1}^{N} a_{ij}\ w(t+t_j) \qquad (7.3)$$

$$\text{c)}\ R_i(t) = \bar{\delta}(\omega_o) \sum_{j=1}^{N} a_{ij}\ w_j(t) \qquad (7.4)$$

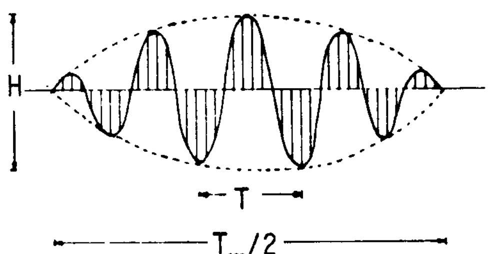
where T_j is the shifting interval range between 0 and T_{SH}, where T_{SH} should be inputed and should be about two to four times the peak wave period. $\bar{\delta}(\omega_o)$ and $c_i(\omega_o, L_i)$ are described in para. 6 and correspond to the peak wave frequency, ω_o. In the third case the time series $w_j(t)$ are constructed using linear filtering methods as is discussed in para. 4.

The decoupled equations of motion are integrated using Wilson's theta method [1], which is unconditionally stable for $\theta \geq 1.4$.

To be able to manipulate the large amount of data in a small central memory, the time integration and all further manipulations are done by writing the time series in blocked form, the optimum size of which is computed by the program to minimize execution time and meet memory limits. Again maximum, average and standard deviations are computed between the sets of randomly shifted time series and plotted along the bridge length. Also, representative time series of the response from each set of randomly shifted series can be plotted for three bridge locations, left bridge end, left quarter span and middle of the bridge.

VIII. Response to boat wake

For the response to boat wakes the wave forces have been modelled as shown in Figure 8.1.



$$\eta(t) = \frac{H}{2}\sin(2\pi\frac{t}{T_m})\sin(2\pi\frac{t}{T}) \qquad (8.1)$$

Figure 8.1. Boat wake ($T_m/T = 9$)

From observed data it seems that a ratio T_m/T of 3 to 15 is appropriate.

The loading of the bridge at a time t (t = 0 when the wake is at the left end) is shown in Figure 8.2 and can be represented by the following relations:

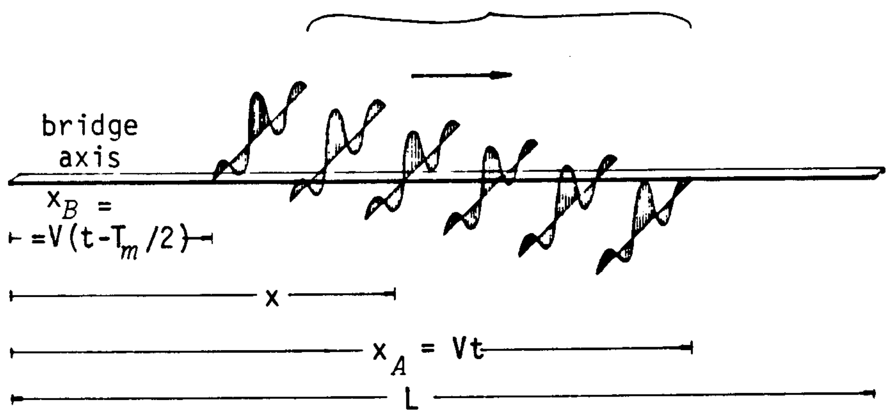


Figure 8.2. Boat wake loading

$$f(x) = \delta(\omega,\theta)(\frac{H}{2})\sin(\frac{2\pi}{T_m}\frac{x_A-x}{V})\sin(\frac{2\pi}{T}\frac{x_A-x}{V}) \quad \text{for } x_B \leq x \leq x_A \qquad (8.2)$$

$f(x) = 0,$ for $x < x_B$ or $x > x_A$ and $x_A = Vt$, $x_B = V(t - \frac{T_m}{2})$

V is the boat speed parallel to the bridge. Assuming linear displacement field for the bridge (Fig. 8.3) we have for node i:

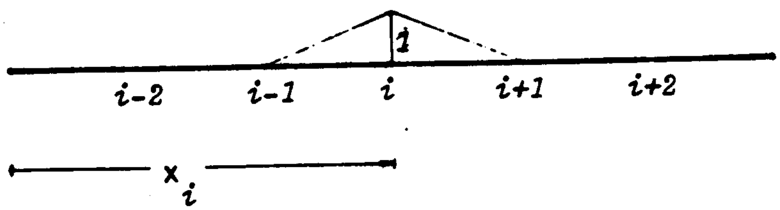


Figure 8.3. Linear displacement field for node i.

$$N_i(x) = \frac{x - x_{i-1}}{x_i - x_{i-1}} \qquad x_{i-1} \leq x \leq x_i$$

$$N_i(x) = \frac{x_{i+1} - x}{x_{i+1} - x_i} \qquad x_i < x \leq x_{i+1} \tag{8.3}$$

$$N_i(x) = 0 \qquad x < x_{i-1}, \quad x > x_{i+1}$$

Applying virtual work, the nodal loads are computed as:

$$R_i(x) = \int_0^L N_i(x)\, f(x) \qquad (L = \text{bridge length}) \tag{8.4}$$

Relation (8.4) can be integrated explicity for the nodal loads.

Another way of computing the boat wake response is by loading the nodal points with a time delay (Δt) between them, where:

$$\Delta t = \frac{\Delta \ell}{V} \qquad (\Delta \ell\text{: nodal distance}) \tag{8.5}$$

The forces would be determined by multiplying (8.1) by $\delta(\omega,\theta)$ and by an appropriate "contribution length", which may or may not be the same as the nodal spacing.

The latter case of computing the nodal loads, can give erroneous results if the nodes are not closely spaced and the "contribution length" properly chosen. Results of boat wake response are shown in Figure 8.4 for a breakwater with flexible connectors.

	1	2	3	4	5	6	7	8

PONTOON PROPERTIES

	1	2	3	4	5	6	7	8
LENGTH (FT)	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03
WIDTH (FT)	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02
I(SWAY) (FT**4)	.5528E+03	.5528E+03	.5528E+03	.5528E+03	.5528E+03	.5528E+03	.5528E+03	.5528E+03
I(HEAVE) (FT**4)	.8230E+02	.8230E+02	.8230E+02	.8230E+02	.8230E+02	.8230E+02	.8230E+02	.8230E+02
J(ROLL) (FT**4)	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03
M(SW,HEA) (KSLAG/FT	.1390E+00	.1390E+00	.1390E+00	.1390E+00	.1390E+00	.1390E+00	.1390E+00	.1390E+00
M(ROLL) (KSL*FT/FT	.8000E+01	.8000E+01	.8000E+01	.8000E+01	.8000E+01	.8000E+01	.8000E+01	.8000E+01
CABL LEFTT (KPS/FT)	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02
CABL MIDL (KPS/FT)	-0	-0	-0	-0	-0	-0	-0	-0
CABL RIGHT (KPS/FT)	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02
SCF FOR T=3.50 (SEC)	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01

CONNECTOR PROPERTIES

LENGTH (FT)	.2000E+01	.2000E+01	.2000E+01	.2000E+01	.2000E+01	.2000E+01	.2000E+01
I(SWAY) (FT**4)	.2000E+03	.2000E+03	.2000E+03	.2000E+03	.2000E+03	.2000E+03	.2000E+03
I(HEAV) (FT**4)	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02	.1000E+02
J(ROLL) (FT**4)	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03	.1000E+03
A(SWAY) (FT**2)	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02
A(HEAV) (FT**2)	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02	.2000E+02

		PONTOON	CONNECTORS
MODUL OF ELAST	(KPS/FT**2	.4175E+06	.1000E+03
POISSONS RATIO		.2200E+00	.4500E+00
SHEAR MODULUS	(KPS/FT**2	.1711E+06	.3448E+02

HYDRODYNAMIC COEFFICIENTS

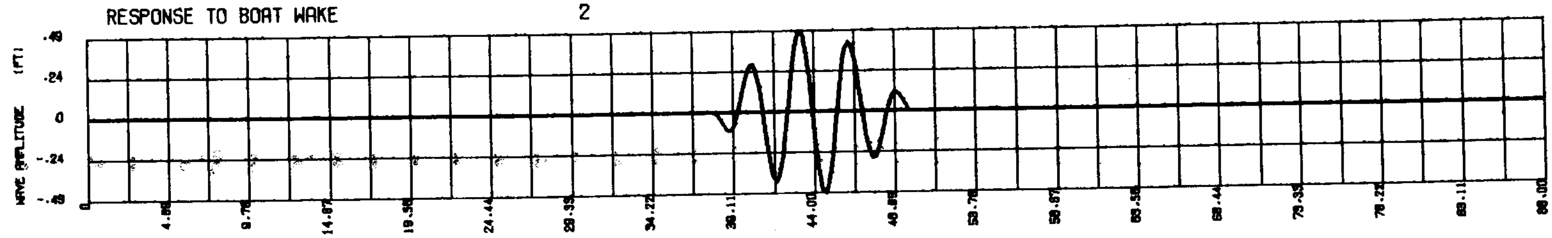
DRAFT = 3.50 (FT) WIDTH = 20.00 (FT)

	SWAY MASS	SWAY DAMP	SWAY FORCE	HEAVE MASS	HEAVE DAMP	HEAVE FORCE	ROLL MASS	ROLL DAMP	ROLL FORCE
T= 1.50	1.10	.17	.31	3.45	.05	.28	1.30	.01	1.00
T= 3.50	1.10	.17	.31	3.45	.05	.28	1.30	.01	1.00
T= 4.20	1.16	.19	.34	3.35	.08	.36	1.24	.03	1.00
T= 6.00	1.46	.16	.34	3.25	.23	.88	1.30	.06	-0
T= 7.90	1.80	.09	.28	3.45	.33	.76	1.30	.06	-0

LOADING DISTANCE HALF PONTOON

NUMBER OF RANDOM SHIFTS 1

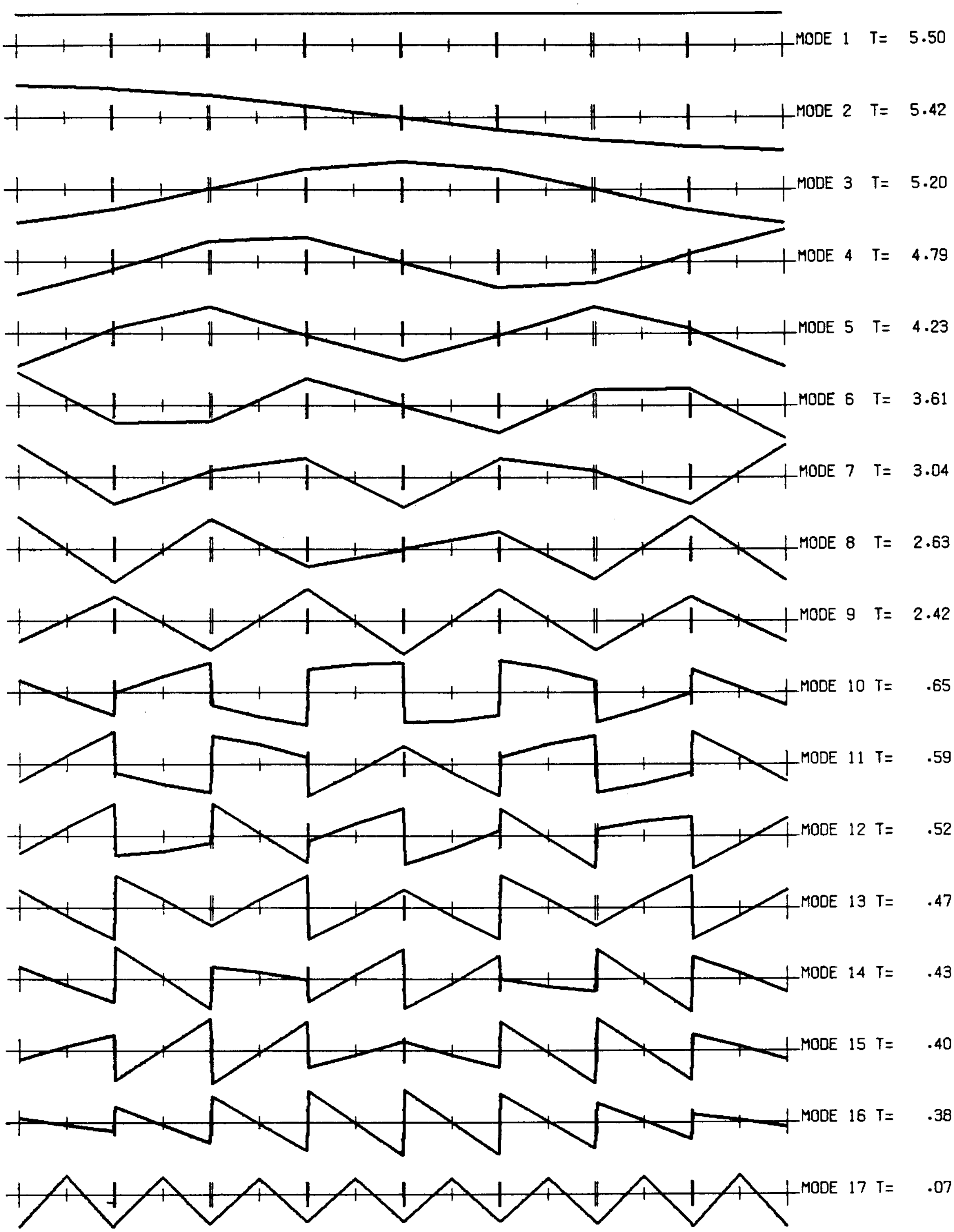
RESPONSE TO BOAT WAKE 2



SIMULATED WAVE TIME SERIES

FIG. FLOATING BREAKWATER BOAT WAKE 15MPH
COMPUTER RUN STRUCTURE AND WAVE CHARACTERISTICS

Figure 8.4



FLOATING BREAKWATER BOAT WAKE 15MPH

FIG. S W A Y MODE SHAPES AND NATURAL PERIODS

Figure 8.4.b

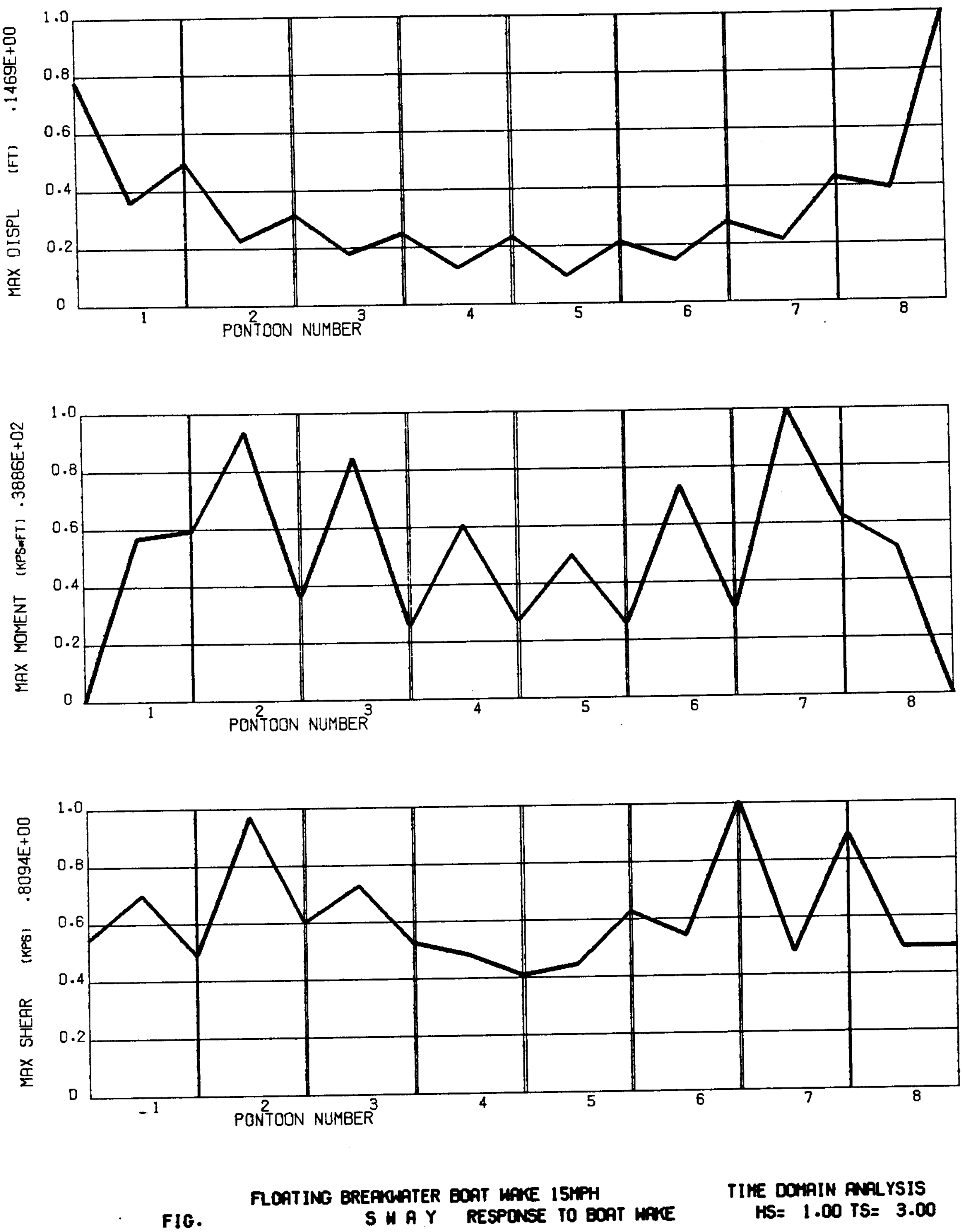

MAX DISPL (FT) .1469E+00
1.0
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8
PONTOON NUMBER
MAX MOMENT (KPS*FT) .3886E+02
1.0
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8
PONTOON NUMBER
MAX SHEAR (KPS) .8094E+00
1.0
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8
PONTOON NUMBER
FLOATING BREAKWATER BOAT WAKE 15MPH
FIG.
S W A Y RESPONSE TO BOAT WAKE
TIME DOMAIN ANALYSIS
HS= 1.00 TS= 3.00

Figure 8.4.c

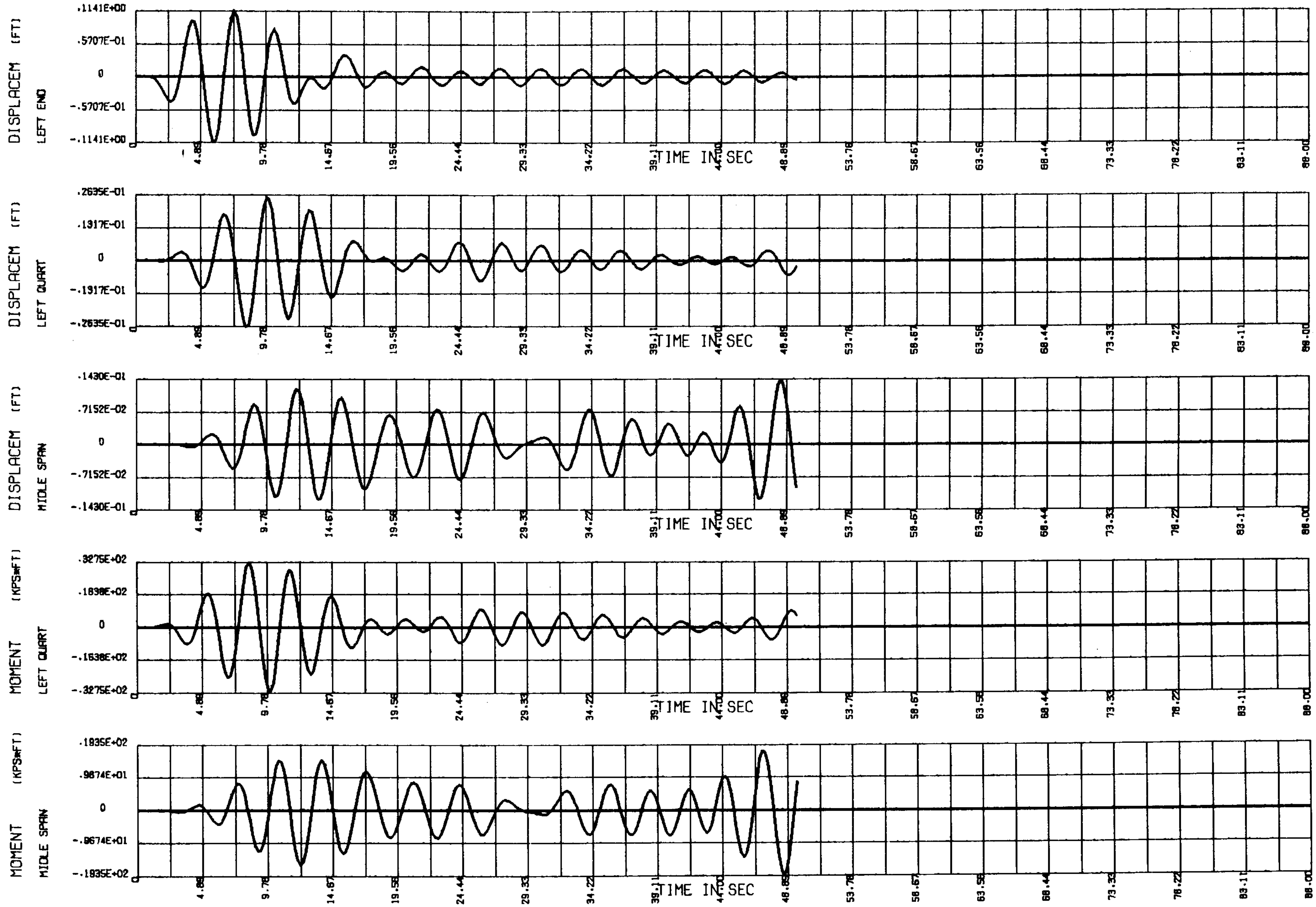


FIG. FLOATINO BREAKWATER BOAT WAKE 15MPH
S W A Y RESPONSE TO WAVE TIME SERIES
TIME DOMAIN ANALYSIS
HS= 1.00 TS= 3.00

Figure 8.4.d

IX. EXAMPLE OF BREAKWATER

The response of a breakwater of length (8 x 75' = 600') with rigid or flexible connectors will be modeled as an example.

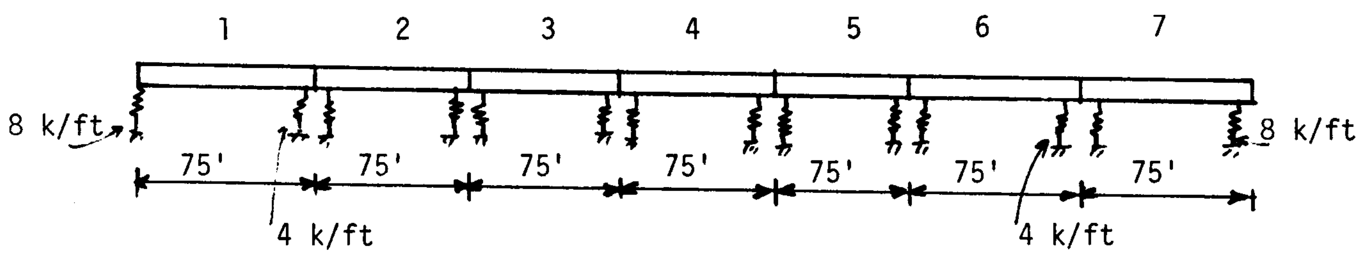


Figure 9.1

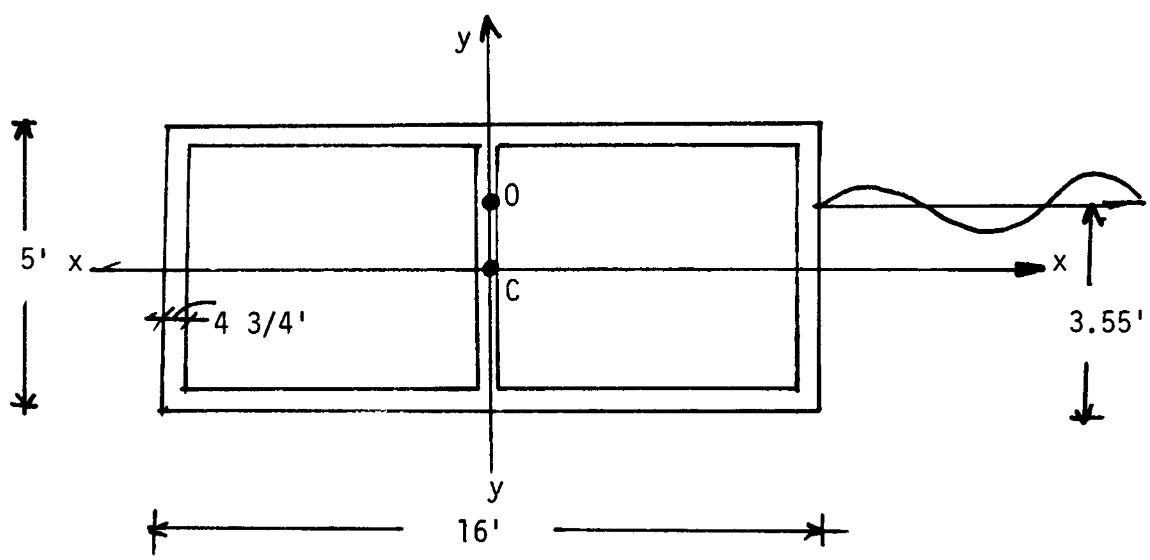


Figure 9.2

Pontoon Cross Section

PONTOON PROPERTIES

Cross section area:

$$A_c = 16 \times 5 - (16-3\times0.396) \times (5-2\times0.396) = \underline{17.67}\ ft^2$$

Moments of inertia:

$$I_{xx} = \frac{16 \times 5^3}{12} - \frac{(16-3\times0.396) \times (5-2\times0.396)^3}{12} = \underline{74.69}\ ft^4$$

$$I_{yy} = \frac{5 \times 16^3}{12} - \frac{(5-2\times0.396) \times (16-2\times0.396)^3}{12} + \frac{(5-2\times0.396) \times 0.396^3}{12} = 473.27\ ft^4$$

$$I_o = I_{xx} + I_{yy} = 74.69 + 473.27 = 547.96\ ft^4$$

$$J = \frac{4 \times (5-0.396)^2\ (16-0.396)^2}{\left[\frac{2\times(16-0.396) + 2\times(5-0.396)}{0.396}\right]} = \underline{202.28}\ ft^4$$

Modulus of Elasticity $E = 417000\ k/ft^2$

Poisson Ratio $\nu = 0.22$

Mass:

$$m_x = m_y = \frac{3.55 \times 16 \times 0.064}{32.2} = 0.113 \quad k\ slug/ft$$

$$m_t = \frac{547.96}{17.67} \times 0.113 = 3.50\ k\ slug\ ft^2/ft$$

(m_t is the mass inertia per unit length)

Hydrodynamic Coefficients for Example Breakwater

B/T = Width/draft = 16/3.55 = 4.5

σ = normalized frequency = $\omega\sqrt{B/2g} = {}^{2\pi}/_{T}\sqrt{16/2(32.2)} = 3.13/T$

$\rho g B/2$ = hydrodynamic force factor in translation = 0.064(16/2) = 0.512

$\rho g(B/2)^2$ = Hydrodynamic force factor in roll = $0.064(16/2)^2$ = 4.096

From Table 3.1 the mass and damping coefficients are found to be:

T		Mass			Damping		
(sec)	σ	sway	heave	roll	sway	heave	roll
2	1.56	1.052	2,87	1.25	0.167	0.017	0.001
3	1.04	1.30	2.76	1.25	0.24	0.111	0.004
4	0.78	1.64	2.76	1.26	0.17	0.23	0.006
5	0.63	1.74	2.92	1.26	0.10	0.31	0.005
6	0.52	1.69	3.15	1.27	0.05	0.36	0.003

The Hydrodynamic Force Coefficients are:

T		Force $\delta(\omega,o)$ - non-dimensional			Force Coefficient, C_F, for FLOAT program		
(sec)	σ	sway	heave	roll	sway	heave	roll
2	1.56	0.56	0.28	0.05	0.29	0.14	0.20
3	1.04	0.75	0.72	0.07	0.38	0.37	0.29
4	0.78	0.70	1.04	0.12	0.36	0.53	0.49
5	0.63	0.54	1.25	0.11	0.28	0.64	0.45
6	0.52	0.38	1.40	0.09	0.19	0.72	0.37

If the directional and short crested effects are to be included in the Hydrodynamic Force Coefficients and an exponentially decayed load correlation instead of in an SCF equation the following values from Table 4.5 would be used*:

T		Force $\overline{\delta}(\omega,o)$*- non-dimensional			Force Coefficient, C_F, for FLOAT program		
(sec)	σ	sway	heave	roll	sway	heave	roll
2	1.56	0.53	0.15	0.03	0.27	0.08	0.12
3	1.04	0.69	0.59	0.06	0.35	0.30	0.25
4	0.78	0.60	0.94	0.10	0.31	0.48	0.41
5	0.63	0.44	1.18	0.10	0.23	0.60	0.41
6	0.52	0.31	1.31	0.08	0.16	0.67	0.33

* this case was not run here but makes a good comparison run.

Flexible Connectors Modeling

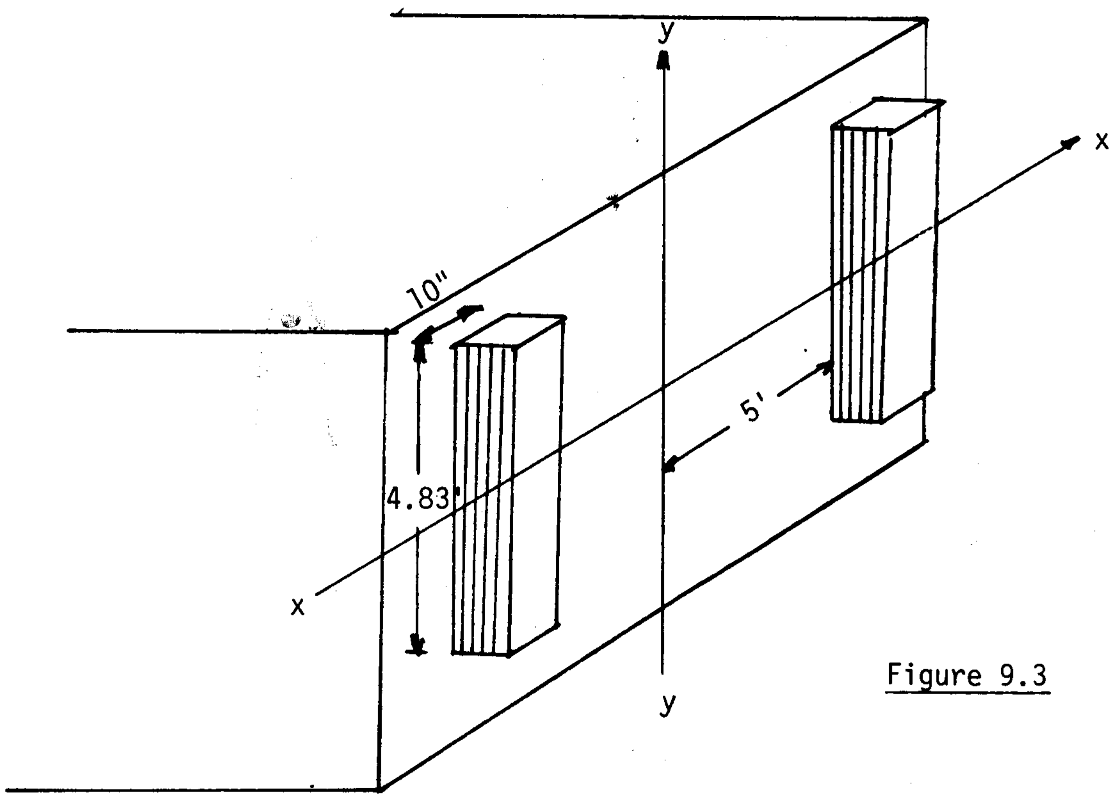


Figure 9.3

Shearing areas: $A_x = A_y = 2x(\frac{5}{6}) \times (\frac{10}{12}) \times 4.83 = 6.7 \text{ ft}^2$

Moments of inertia: $I_{xx} = 2x\ (\frac{10}{12}) \times \frac{4.83^3}{12} = 15.6 \text{ ft}^4$

$$I_{yy} = 2x\ (\frac{10}{12}) \times 4.83 \times (5 + \frac{5}{12})^2 = 936.2 \text{ ft}^4$$

$$J = 2x\ (\frac{10}{12}) \times 4.83 \times (5 + \frac{5}{12})^2 = 236.2 \text{ ft}^4$$

Modulus of elasticity $E = 1000 \text{ k/ft}^2$

Poisson's ratio $\nu = 0.48$

Shearing modulus $G = 510 \text{ k/ft}^2$

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

/JOB
CONST,T200.
/READ USERID
GET,FLOAT.
FLOAT.
PLOTREQ,DEV=GOULD,ROT=NO,PAGE=NO,P1=1,P2=3,P3=5.
/EOR
   FLOATING BREAKWATER - EXAMPLE RUN
    81 1 4 11  2   5    2   12                  24  4.1    8   48
 75.    16.  473.27 74.69202.28.113  3.5   4.         4.
417000.     .22
 1.       236.2       15.6      236.2     6.7      6.7
1000.       .48
 2.   1.052 2.97  1.25  .167  .017  .001  .29   .14   .20
 3.   1.30  2.76  1.25  .24   .111  .004  .38   .37   .29
 4.   1.64  2.76  1.26  .17   .23   .006  .36   .53   .49
 5.   1.74  2.92  1.26  .10   .31   .005  .28   .64   .45
 6.   1.69  3.15  1.27  .05   .36   .003  .19   .72   .37   3.55  16.
1.    5.
1.    5.  3.   3.
.2        100.     5.                     8    8    8    1
/EOR

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

<u>Figure 9.4</u>

Example of Breakwater with Flexible Connectors Every 75 Feet
INPUT DATA

```
1
      FLOATING BREAKWATER - EXAMPLE RUN
0
     NUMBER OF PONTOONS .........     8

     FLAG FOR DIRECTION ........   1       0  SWAY + HEAVE + ROLL
                                           1 SWAY
                                           2 HEAVE
                                           3 ROLL
                                           4 SWAY + HEAVE
     FLAG FOR SAME PONTOONS...... -0       0 SAME
                                           1 DIFFERENT
     FLAG FOR RIGID CONNECTORS...  1       0 RIGID
                                           1 FLEXIBLE
     FLAG FOR SAME CONNECTORS.....-0       0 SAME
                                           1 DIFFERENT
     FLAG FOR RUN MODE ..........  4       0 EIGENVALUE SOLUTION
                                           1 EIGENVALUE + FREQUENC RE SP
                                           2  FREQUENCY RESPONSE
                                           3 EIGENVAL + TIME SERIES
                                           4  ALL THE ABOVE

     FLAG FOR UNITS.............. -0       0 FEET-KPS
                                           1 METERS-KNEWTONS
    FLAG FOR TIME SERIES INPUT...  1       0 SIMULATED FROM SPECTRUM
                                           AT EQUAL FREQUENCY INTERVALS
                                           1 SIMULATED FROM SPECTRUM AT
                                            EQUAL SPECTRA AREAS
                                           2 INPUT TIME   SERIES
                                           3 READED FROM TAPE 11
     FLAG FOR S.C.F.   ..........  1       0  INPUT VALUES
                                           1 LINEAR PREASURE DECREASE
                                           2 QUADRATIC PRESURE DECREASE
                                           3 MORE ACURATE
    FLAG FOR LOAD CORRELATION...  -0       0 UNCORELATED
                                           1 EXPONENT CORRELATION
    FLAG FOR BOAT WAKE ANALYSIS<  -0       0 REGULAR ANALLYSIS
                                           1 BOAT WAKE ANALYSIS
                                           2 BOAT WAKE ANALYSIS
    FLAG FOR WAVE SPECTRUM         2       0 SPECTRUM INPUTED
                                           1 BRETSNEIDER
                                           2 JONSWAP
    FREQUENCIES FOR HYDR COEFF..   5
     MIDLE FREQUENCY FOR HYDR C..  2

     PLOTED MODE SHAPES   ....... 12
     OUTPUT FREQUENCIES.........  17
    MAXIMUM ITERATIONS FOR EIG..   30
    TOLERANCE IN COMPUT EIGEN...    .100E-05

    NUMBER OF FREQUENCIES IN
   -FREQUENCY RESPONCE ........   24
     LOADING PATERN ............   1       0 EVERY NODE
                                           1 IN THE MIDDLE OF PONTOONS
    NUMBER OF RANDOM SHIFTS ....   8
     NUMBER OF FREQUENCIES IN
     WAVE SPECTRUM .............  48
```

Figure 9.5.a

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

```
RANDOM SHIFT REGION 2*PI/(R)   R=                              4.00000
EXPONENT FACTOR FOR LOAD CORRELATION DELAY ALPHA =   8.00000
                                            BETA =     1.00000
WATER SPECIFIC WEIGHT  .....      .06400

NUMBER OF CONNECTORS........      7
NUMBER OF NODAL POINTS......     24
```

1

P O N T O O N   P R O P E R T I E S

PONT NUMB	LENGTH	WIDTH	IXX	IYY	J	MXX,YY
1	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
2	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
3	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
4	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
5	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
6	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
7	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .
8	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00 .

0

```
MODULUS OF ELASTICITY        .41700E+06
POISSONS RATIO                   .22000
SHEAR MODULUS                .17090E+06
```

0

C O N N E C T O R   P R O P E R T I E S

CONN NUMB	LENGTH	KXX	KYY	KZZ	GXX	GYY
1	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
2	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
3	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
4	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
5	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
6	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
7	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01

0

```
MODULUS OF ELASTICITY        .10000E+04
POISSONS RATIO                   .48000
SHEAR MODULUS                .33784E+03
```

Figure 9.5.b

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

```
1 H Y D R O D Y N A M I C   C O E F F I C I E N T S
  ***********************************************

                    MASS       DAMPING  FORCE/WAVE
0      PERIOD      2.00  SEC
     ---------------------
     S W A Y          1.052       .167       .290
     H E A V E        2.970       .017       .140
     R O L L          1.250       .001       .200
0      PERIOD      3.00  SEC
     ---------------------
+                                                  VALUES USED FOR EIGEN. SOLU
     S W A Y          1.300       .240       .380
     H E A V E        2.760       .111       .370
     R O L L          1.250       .004       .290
0      PERIOD      4.00  SEC
     ---------------------
     S W A Y          1.640       .170       .360
     H E A V E        2.760       .230       .530
     R O L L          1.260       .006       .490
0      PERIOD      5.00  SEC
     ---------------------
     S W A Y          1.740       .100       .280
     H E A V E        2.920       .310       .640
     R O L L          1.260       .005       .450
0      PERIOD      6.00  SEC
     ---------------------
     S W A Y          1.690       .050       .190
     H E A V E        3.150       .360       .720
     R O L L          1.270       .003       .370
0
     TIME SERIES ANALYSIS
      TIME INTERVAL IN SECONDS...     .200
      TOTAL TIME IN SECONDS......   100.00
      SHIFT TIME IN SECONDS.......    5.00
      THETA FOR WILSON INTEGR.....   1.40
      PARTICIPATING MODES SWAY         8
      PARTICIPATING MODES HEAVE        8
      PARTICIPATING MODES ROLL         8
      BLOCK LENGTH  .............     181
      NUMBER OF BLOCKS .........        3
0       STD DEV FROM WAVE TIME SERIES    .6607E+00
0       STD DEV FROM WAVE TIME SERIES    .7452E+00
0       STD DEV FROM WAVE TIME SERIES    .7368E+00
0       STD DEV FROM WAVE TIME SERIES    .6785E+00
0       STD DEV FROM WAVE TIME SERIES    .7949E+00
0       STD DEV FROM WAVE TIME SERIES    .7644E+00
0       STD DEV FROM WAVE TIME SERIES    .8578E+00
0       STD DEV FROM WAVE TIME SERIES    .6394E+00
1
```

Figure 9.5.c

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

EIGENVALUE SOLUTION   S W A T

****

MODE	OMEGA	FREQUENCY	PERIOD
1	.852	.13561	7.374
2	.865	.13769	7.263
3	1.115	.17748	5.634
4	2.033	.32353	3.091
5	3.627	.57729	1.732
6	5.757	.91622	1.091
7	8.254	1.31364	.761
8	10.778	1.71541	.583
9	12.672	2.01688	.496
10	27.991	4.45496	.224
11	31.370	4.99276	.200
12	35.569	5.66111	.177
13	39.870	6.34559	.158
14	43.788	6.96915	.143
15	46.929	7.46913	.134
16	48.967	7.79350	.128
17	149.649	23.81775	.042
18	149.679	23.82244	.042
19	151.401	24.09659	.041
20	152.685	24.30098	.041
21	154.193	24.54086	.041
22	155.648	24.77252	.040
23	156.840	24.96219	.040
24	157.616	25.08564	.040

Figure 9.5.d

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

	1	2	3	4	5	6	7	8

PONTOON PROPERTIES

		1	2	3	4	5	6	7	8
LENGTH	(FT)	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02
WIDTH	(FT)	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02
I(SWAY)	(FT**4)	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03
I(HEAVE)	(FT**4)	.7469E+02	.7469E+02	.7469E+02	.7469E+02	.7469E+02	.7469E+02	.7469E+02	.7469E+02
J(ROLL)	(FT**4)	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03
M(SW,HEA)	(KSLAG/FT	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00
M(ROLL)	(KSL*FT/FT	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01
CABL LEFTT	(KPS/FT)	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01
CABL MIDL	(KPS/FT)	-0	-0	-0	-0	-0	-0	-0	-0
CABL RIGHT	(KPS/FT)	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01
SCF FOR T=3.00	(SEC)	.3236E+00	.3236E+00	.3236E+00	.3236E+00	.3236E+00	.3236E+00	.3236E+00	.3236E+00

CONNECTOR PROPERTIES

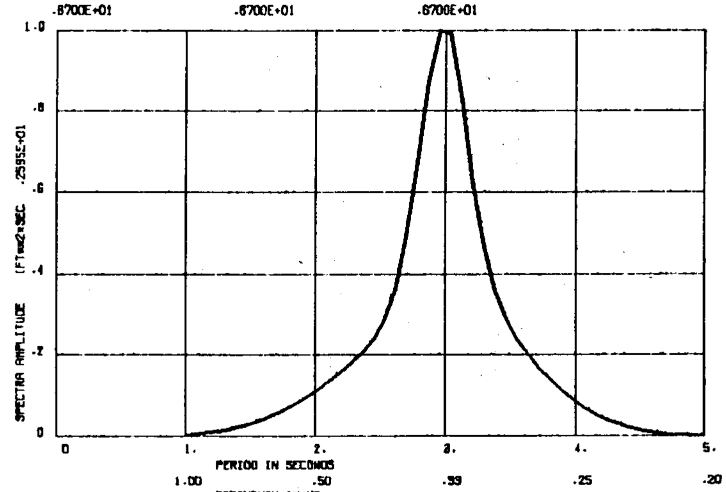
		1–2	2–3	3–4	4–5	5–6	6–7	7–8
LENGTH	(FT)	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01	.1000E+01
I(SWAY)	(FT**4)	.2362E+03	.2362E+03	.2362E+03	.2362E+03	.2362E+03	.2362E+03	.2362E+03
I(HEAV)	(FT**4)	.1580E+02	.1580E+02	.1580E+02	.1580E+02	.1580E+02	.1580E+02	.1580E+02
J(ROLL)	(FT**4)	.2362E+03	.2362E+03	.2362E+03	.2362E+03	.2362E+03	.2362E+03	.2362E+03
A(SWAY)	(FT**2)	.6700E+01	.6700E+01	.6700E+01	.6700E+01	.6700E+01	.6700E+01	.6700E+01
A(HEAV)	(FT**2)	.6700E+01	.6700E+01	.6700E+01	.6700E+01	.6700E+01	.6700E+01	.6700E+01

		PONTOON	CONNECTORS
MODUL OF ELAST	(KPS/FT**2	.4170E+06	.1000E+04
POISSONS RATIO		.2200E+00	.4800E+00
SHEAR MODULUS	(KPS/FT**2	.1709E+06	.3378E+03

HYDRODYNAMIC COEFFICIENTS

DRAFT = 3.55 (FT) WIDTH = 16.00 (FT)

	SWAY MASS	SWAY DAMP	SWAY FORCE	HEAVE MASS	HEAVE DAMP	HEAVE FORCE	ROLL MASS	ROLL DAMP	ROLL FORCE
T= 2.00	1.05	.17	.29	2.97	.02	.14	1.25	.00	.20
T= 3.00	1.30	.24	.38	2.76	.11	.37	1.25	.00	.29
T= 4.00	1.64	.17	.36	2.76	.23	.53	1.28	.01	.49
T= 5.00	1.74	.10	.28	2.92	.31	.64	1.28	.01	.45
T= 6.00	1.89	.05	.19	3.15	.36	.72	1.27	.00	.37



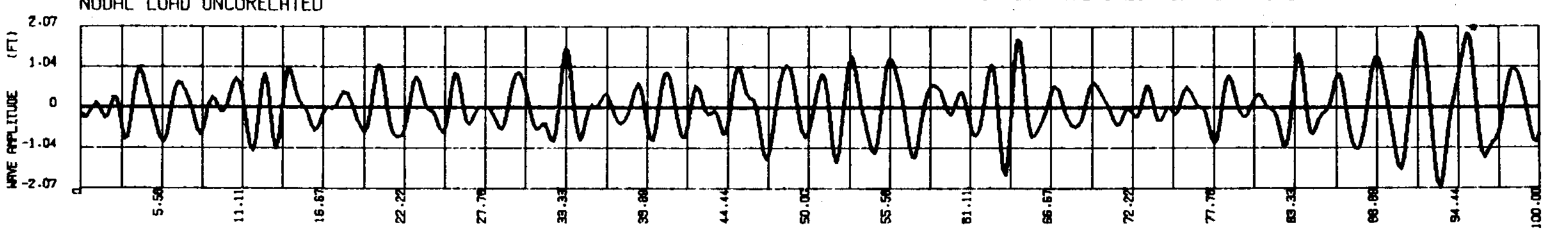
INPUT WAVE SPECTRUM HS= 3.00

LOADING DISTANCE ONE PONTOON

NUMBER OF RANDOM SHIFTS 8

SCF WAVE PERIOD DEPEDEND EQ 1

NODAL LOAD UNCORELATED



SIMULATED WAVE TIME SERIES 48 EQUAL SPECTRA AREAS DT = .20

FLOATING BREAKWATER - EXAMPLE RUN

FIG. **COMPUTER RUN STRUCTURE AND WAVE CHARACTERISTICS**

Figure 9.6.a

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

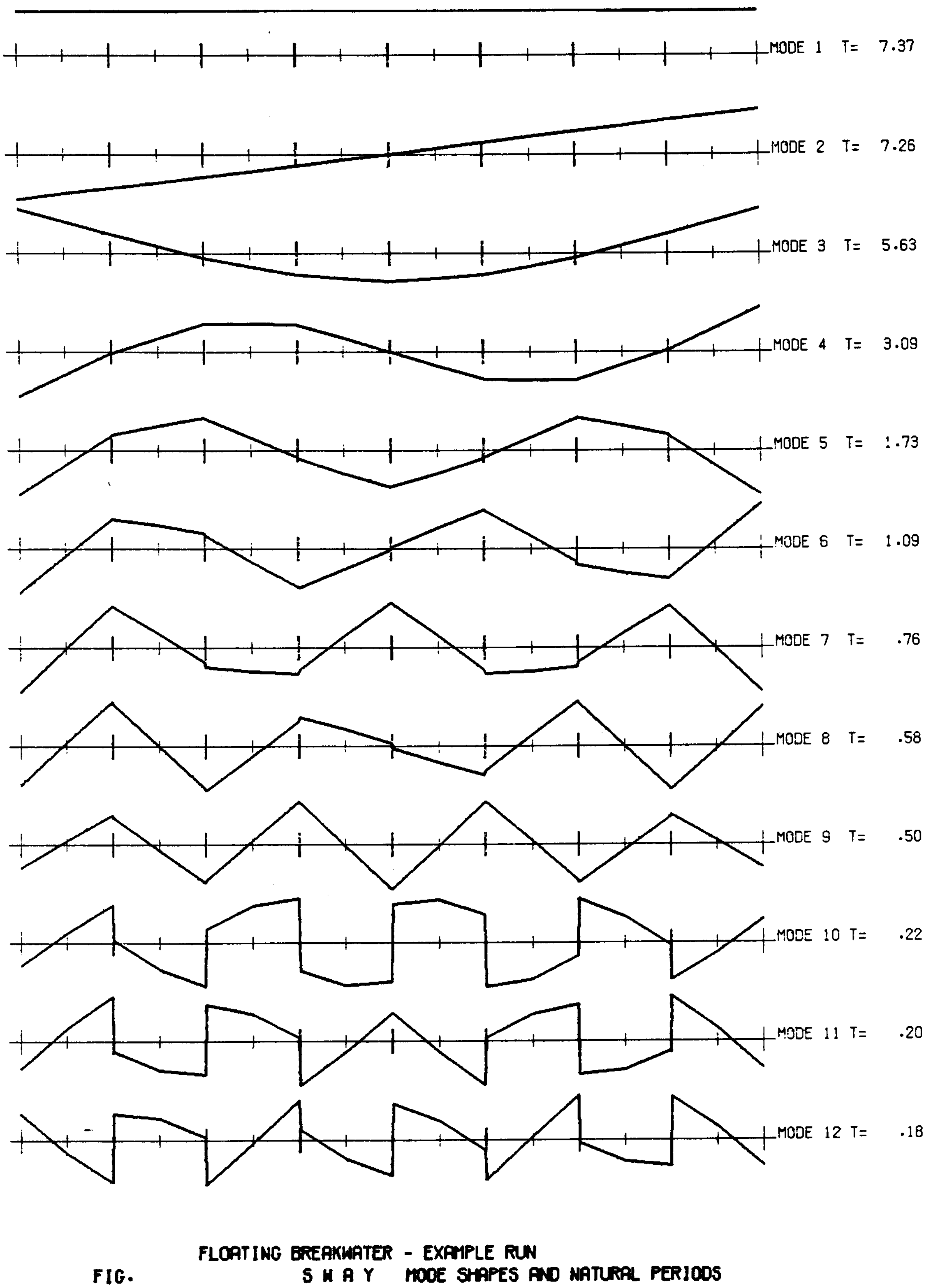


Figure 9.6.b.

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

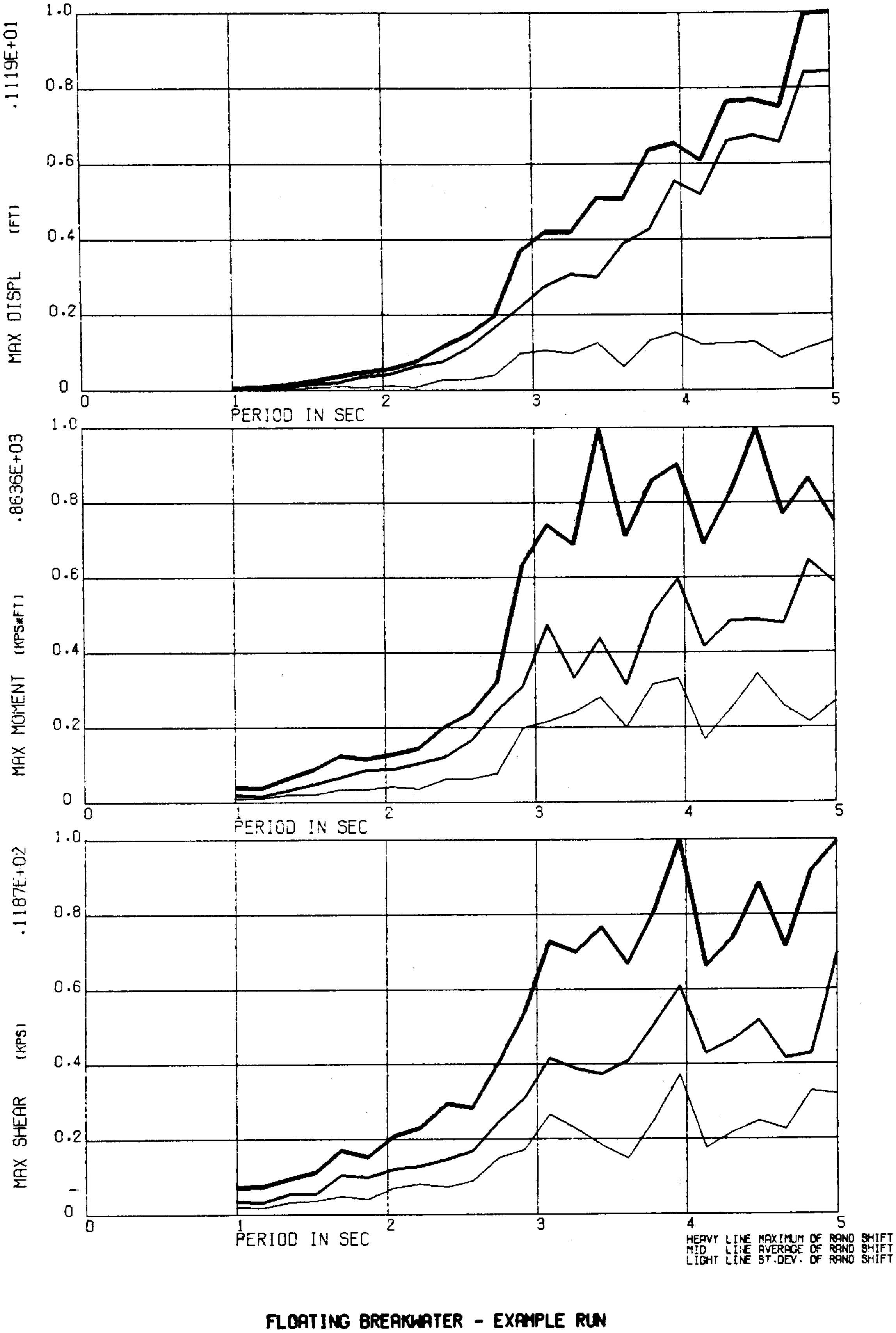


Figure 9.6.c

Example of Breakwater with Flexible Connectors Every 75 Feet

OUTPUT DATA

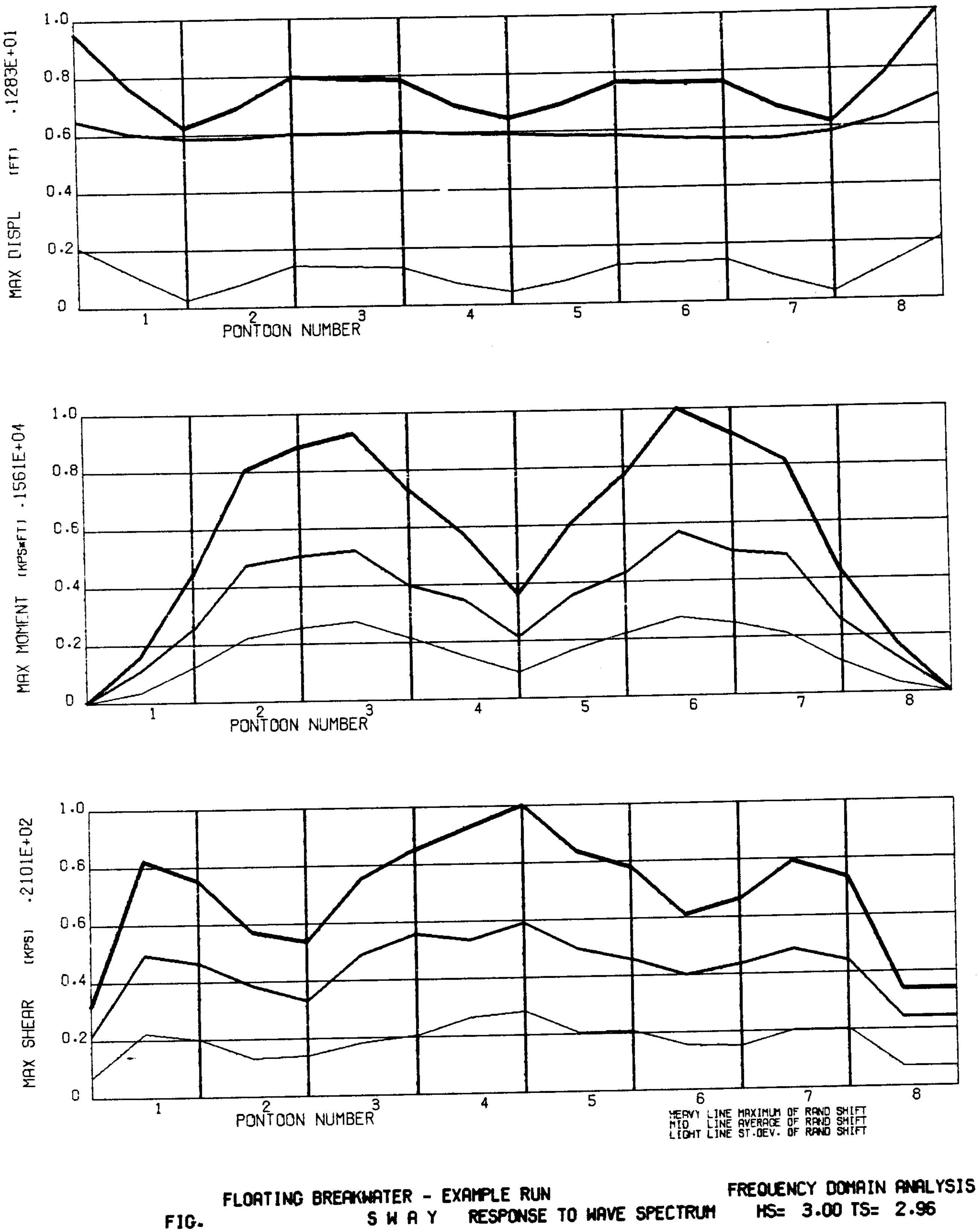


Figure 9.6.d
Example Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

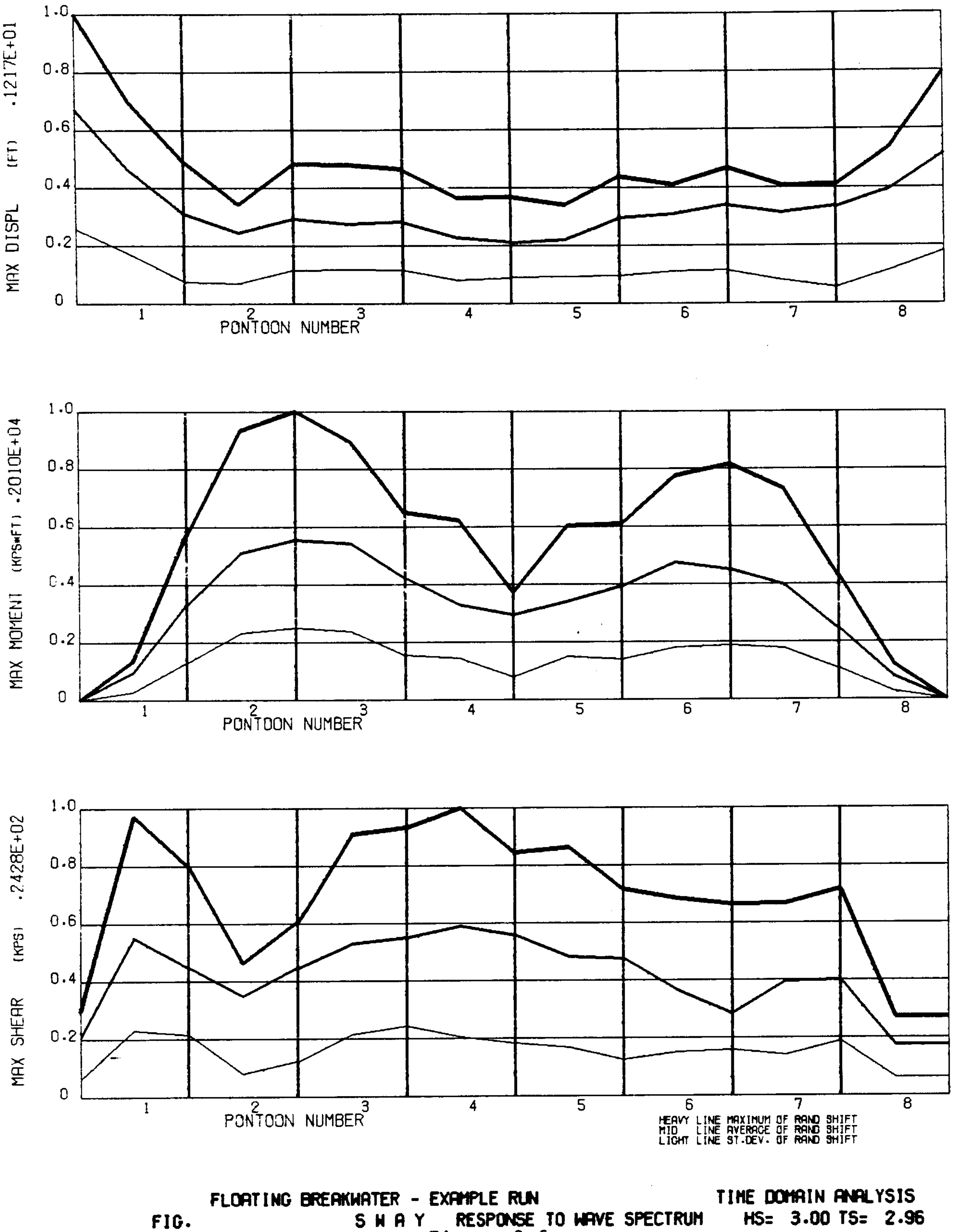


Figure 9.6.e
Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

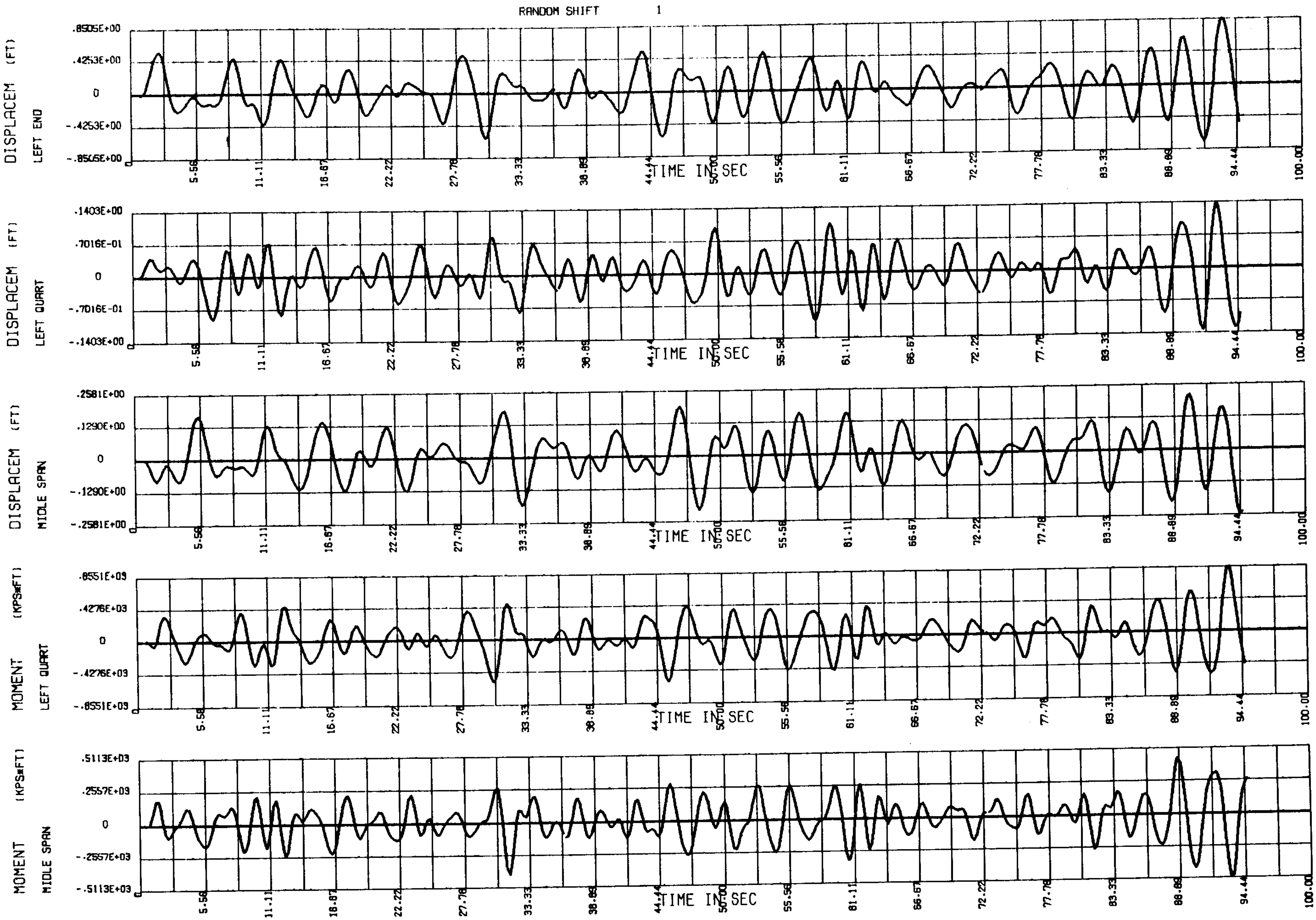


FIG. FLOATING BREAKWATER - EXAMPLE RUN
S W A Y RESPONSE TO WAVE TIME SERIES

TIME DOMAIN ANALYSIS
HS= 3.00 TS= 2.96

Figure 9.6.f

Example of Breakwater with Flexible Connectors Every 75 Feet
OUTPUT DATA

```
FLOATING BREAKWATER

NUMBER OF PONTOONS .........      8

FLAG FOR DIRECTION ........    1      0  SWAY + HEAVE + ROLL
                                      1 SWAY
                                      2 HEAVE
                                      3 ROLL
                                      4 SWAY + HEAVE
FLAG FOR SAME PONTOONS...... -0       0 SAME
                                      1 DIFFERENT
FLAG FOR RIGID CONNECTORS...   1      0 RIGID
                                      1 FLEXIBLE
FLAG FOR SAME CONNECTORS..... 1       0 SAME
                                      1 DIFFERENT
FLAG FOR RUN MODE ..........   1      0 EIGENVALUE SOLUTION
                                      1 EIGENVALUE + FREQUENC RE SP
                                      2  FREQUENCY RESPONSE
                                      3 EIGENVAL + TIME SERIES
                                      4  ALL THE ABOVE

FLAG FOR UNITS.............. -0       0 FEET-KPS
                                      1 METERS-KNEWTONS
FLAG FOR TIME SERIES INPUT...   1     0 SIMULATED FROM SPECTRUM
                                      AT EQUAL FREQUENCY INTERVALS
                                      1 SIMULATED FROM SPECTRUM AT
                                       EQUAL SPECTRA AREAS
                                      2 INPUT TIME   SERIES
                                      3 READED FROM TAPE 11
FLAG FOR S.C.F.   ..........   1      0  INPUT VALUES
                                      1 LINEAR PREASURE DECREASE
                                      2 QUADRATIC PRESURE DECREASE
                                      3 MORE ACURATE
FLAG FOR LOAD CORRELATION...  -0      0 UNCORELATED
                                      1 EXPONENT CORRELATION
FLAG FOR BOAT WAKE ANALYSIS<  -0      0 REGULAR ANALLYSIS
                                      1 BOAT WAKE ANALYSIS
                                      2 BOAT WAKE ANALYSIS
FLAG FOR WAVE SPECTRUM         2      0 SPECTRUM INPUTED
                                      1 BRETSNEIDER
                                      2 JONSWAP

FREQUENCIES FOR HYDR COEFF..   5
 MIDLE FREQUENCY FOR HYDR C..  2

 PLOTED MODE SHAPES   ....... 12
 OUTPUT FREQUENCIES.........  17
MAXIMUM ITERATIONS FOR EIG..   30
TOLERANCE IN COMPUT EIGEN...    .100E-05

NUMBER OF FREQUENCIES IN
FREQUENCY RESPONCE ........   24
 LOADING PATERN ............   1      0 EVERY NODE
                                      1 IN THE MIDDLE OF PONTOONS
NUMBER OF RANDOM SHIFTS ....   8
 NUMBER OF FREQUENCIES IN
 WAVE SPECTRUM .............  48

 RANDOM SHIFT REGION 2*PI/(R)  R=                     4.00000
 EXPONENT FACTOR FOR LOAD CORRELATION DECAY ALPHA =   8.00000

                                                  BETA =     1.00000
 WATER SPECIFIC WEIGHT   .....       .06400

 NUMBER OF CONNECTORS........      7
 NUMBER OF NODAL POINTS......     24
```

Figure 9.7.a

Example of Breakwater with Flexible Connectors Every 150 Feet

OUTPUT DATA

P O N T O O N   P R O P E R T I E S

PONT NUMB	LENGTH	WIDTH	IXX	IYY	J	MXX,YY	MTT	CABLE 1	CABLE 2	CABLE 3	S.C.F.
1	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
2	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
3	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
4	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
5	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
6	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
7	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000
8	.7500E+02	.1600E+02	.4733E+03	.7469E+02	.2023E+03	.1130E+00	.3500E+01	.4000E+01	-0	.4000E+01	1.000

MODULUS OF ELASTICITY	.41700E+06
POISSONS RATIO	.22000
SHEAR MODULUS	.17090E+06

C O N N E C T O R   P R O P E R T I E S

CONN NUMB	LENGTH	KXX	KYY	KTT	GXX	GYY
1	.1000E+00	.1000E+11	.1000E+11	.1000E+11	.1000E+11	.1000E+11
2	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
3	.1000E+00	.1000E+11	.1000E+11	.1000E+11	.1000E+11	.1000E+11
4	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
5	.1000E+00	.1000E+11	.1000E+11	.1000E+11	.1000E+11	.1000E+11
6	.1000E+01	.2362E+03	.1560E+02	.2362E+03	.6700E+01	.6700E+01
7	.1000E+00	.1000E+11	.1000E+11	.1000E+11	.1000E+11	.1000E+11

MODULUS OF ELASTICITY	.10000E+04
POISSONS RATIO	.48000
SHEAR MODULUS	.33784E+03

Figure 9.7.b

Example of Breakwater with Flexible Connectors Every 150 Feet

OUTPUT DATA

H Y D R O D Y N A M I C   C O E F F I C I E N T S
****

	MASS	DAMPING	FORCE/WAVE
PERIOD 2.00 SEC			
S W A Y	1.070	.185	.300
H E A V E	2.960	.022	.110
R O L L	1.250	.002	.120
PERIOD 3.00 SEC			VALUES USED FOR EIGEN. SOLUTION
S W A Y	1.340	.240	.360
H E A V E	2.750	.125	.340
R O L L	1.250	.002	.270
PERIOD 4.00 SEC			
S W A Y	1.650	.180	.330
H E A V E	2.750	.180	.480
R O L L	1.250	.003	.410
PERIOD 5.00 SEC			
S W A Y	1.740	.090	.230
H E A V E	2.960	.320	.640
R O L L	1.260	.003	.300
PERIOD 6.00 SEC			
S W A Y	1.700	.050	.150
H E A V E	3.190	.370	.700
R O L L	1.270	.003	.280

TIME SERIES ANALYSIS

TIME INTERVAL IN SECONDS...	.200
TOTAL TIME IN SECONDS......	100.00
SHIFT TIME IN SECONDS.......	5.00
THETA FOR WILSON INTEGR.....	1.40
PARTICIPATING MODES SWAY	8
PARTICIPATING MODES HEAVE	8
PARTICIPATING MODES ROLL	8
BLOCK LENGTH	181
NUMBER OF BLOCKS	3

STD DEV FROM WAVE TIME SERIES   .6607E+00

Figure 9.7.c

Example of Breakwater with Flexible Connectors Every 150 Feet

OUTPUT DATA

EIGENVALUE SOLUTION   S W A Y

****

MODE	OMEGA	FREQUENCY	PERIOD
1	.836	.13305	7.516
2	.850	.13535	7.388
3	1.246	.19829	5.043
4	2.517	.40059	2.496
5	4.053	.64503	1.550
6	15.058	2.39665	.417
7	20.311	3.23257	.309
8	26.692	4.24822	.235
9	37.614	5.98649	.167
10	42.123	6.70424	.149
11	48.603	7.73555	.129
12	53.582	8.52793	.117
13	103.009	16.39464	.061
14	103.808	16.52178	.061
15	106.949	17.02166	.059
16	109.699	17.45937	.057
17	197.772	31.47676	.032
18	197.843	31.48820	.032
19	199.167	31.69888	.032
20	199.976	31.82754	.031
21	* .694E+07*	.110E+07	.000
22	* .694E+07*	.110E+07	.000
23	* .694E+07*	.110E+07	.000
24	* .695E+07*	.110E+07	.000

Figure 9.7.d

Example of Breakwater with Flexible Connectors Every 150 Feet

OUTPUT DATA

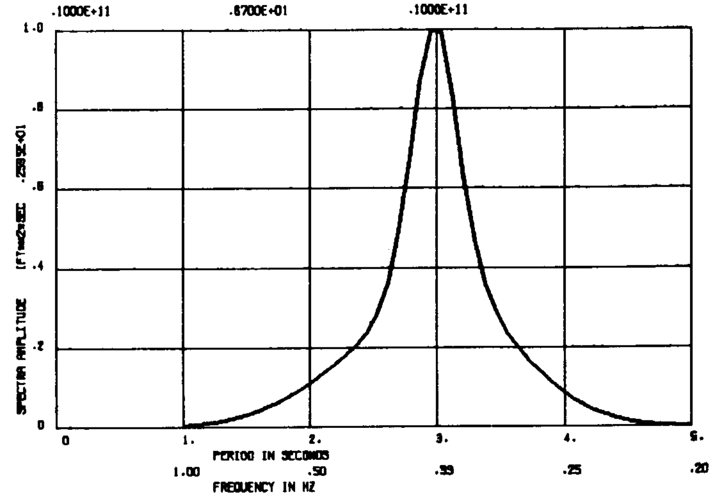
PONTOON PROPERTIES

	1	2	3	4	5	6	7	8
LENGTH (FT)	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02	.7500E+02
WIDTH (FT)	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02	.1600E+02
I(SWAY) (FT**4)	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03	.4733E+03
I(HEAVE) (FT**4)	.7468E+02	.7468E+02	.7468E+02	.7468E+02	.7468E+02	.7468E+02	.7468E+02	.7468E+02
J(ROLL) (FT**4)	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03	.2023E+03
M(SW,HEA) (KSLAG/FT	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00	.1130E+00
M(ROLL) (KSL*FT/FT	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01	.3500E+01
CABL LEFTT (KPS/FT)	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01
CABL MIDL (KPS/FT)	-0	-0	-0	-0	-0	-0	-0	-0
CABL RIGHT (KPS/FT)	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01	.4000E+01
SCF FOR T=3.00 (SEC)	.3238E+00	.3238E+00	.3238E+00	.3238E+00	.3238E+00	.3238E+00	.3238E+00	.3238E+00

CONNECTOR PROPERTIES

LENGTH (FT)	.1000E+00	.1000E+01	.1000E+00	.1000E+01	.1000E+00	.1000E+01	.1000E+00
I(SWAY) (FT**4)	.1000E+11	.2362E+03	.1000E+11	.2362E+03	.1000E+11	.2362E+03	.1000E+11
I(HEAV) (FT**4)	.1000E+11	.1580E+02	.1000E+11	.1580E+02	.1000E+11	.1580E+02	.1000E+11
J(ROLL) (FT**4)	.1000E+11	.2362E+03	.1000E+11	.2362E+03	.1000E+11	.2362E+03	.1000E+11
A(SWAY) (FT**2)	.1000E+11	.6700E+01	.1000E+11	.6700E+01	.1000E+11	.6700E+01	.1000E+11
A(HEAV) (FT**2)	.1000E+11	.6700E+01	.1000E+11	.6700E+01	.1000E+11	.6700E+01	.1000E+11

		PONTOON	CONNECTORS
MODUL OF ELAST	(KPS/FT**2	.4170E+06	.1000E+04
POISSONS RATIO		.2200E+00	.4800E+00
SHEAR MODULUS	(KPS/FT**2	.1709E+06	.3378E+03



INPUT WAVE SPECTRUM HS= 3.00

HYDRODYNAMIC COEFFICIENTS

DRAFT = 3.55 (FT) WIDTH = 16.00 (FT)

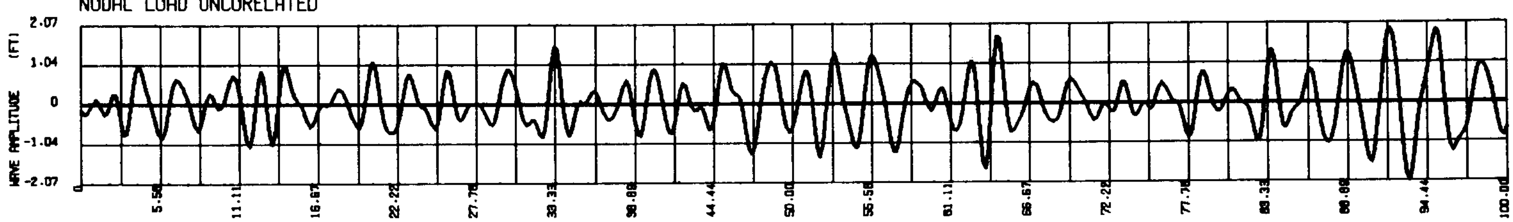
	SWAY MASS	SWAY DAMP	SWAY FORCE	HEAVE MASS	HEAVE DAMP	HEAVE FORCE	ROLL MASS	ROLL DAMP	ROLL FORCE
T= 2.00	1.07	.18	.30	2.98	.02	.11	1.25	.00	.12
T= 3.00	1.34	.24	.36	2.75	.13	.34	1.25	.00	.27
T= 4.00	1.85	.18	.33	2.75	.18	.48	1.25	.00	.41
T= 5.00	1.74	.08	.23	2.98	.32	.84	1.28	.00	.30
T= 6.00	1.70	.05	.15	3.19	.37	.70	1.27	.00	.28

LOADING DISTANCE ONE PONTOON

NUMBER OF RANDOM SHIFTS 8

SCF WAVE PERIOD DEPEDEND EQ 1

NODAL LOAD UNCORELATED



SIMULATED WAVE TIME SERIES 48 EQUAL SPECTRA AREAS

FLOATING BREAKWATER

FIG. COMPUTER RUN STRUCTURE AND WAVE CHARACTERISTICS

Figure 9.8.a

Example of Breakwater with Flexible Connectors Every 150 Feet

OUTPUT DATA

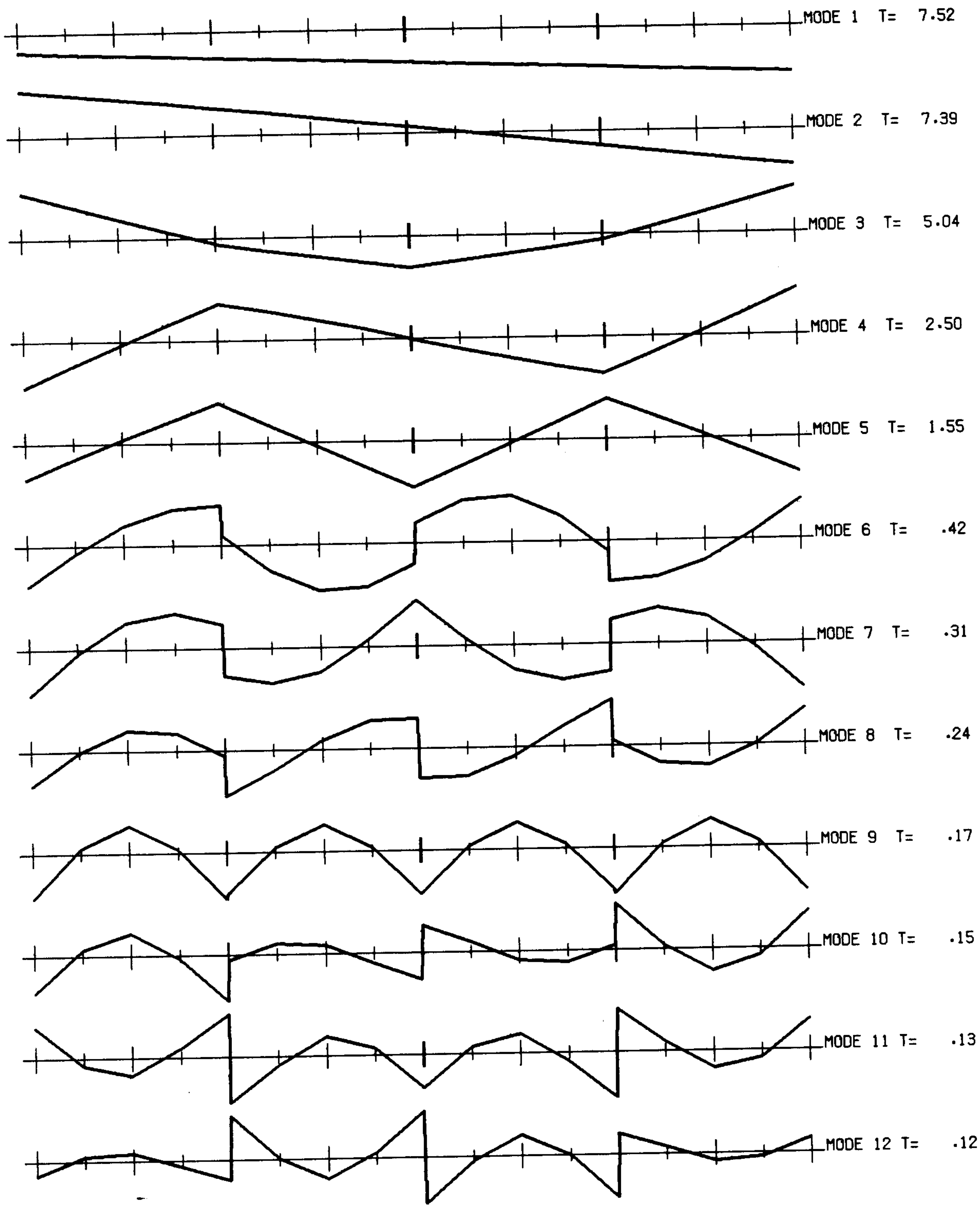


FIG. FLOATING BREAKWATER SWAY MODE SHAPES AND NATURAL PERIODS

Figure 9.8.b

Example of Breakwater with Flexible Connectors Every 150 Feet
OUTPUT DATA

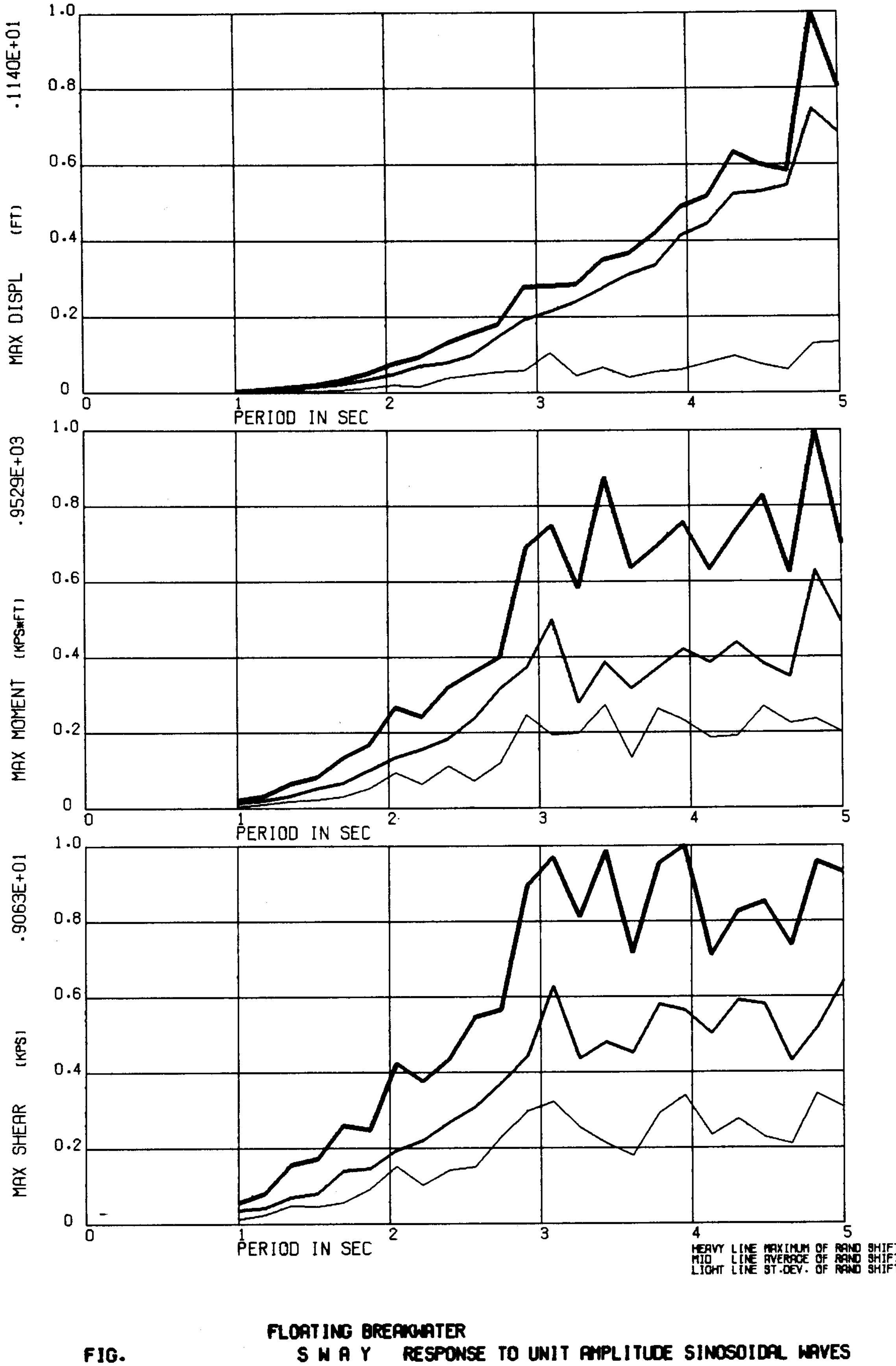


Figure 9.8.c
Example of Breakwater with Flexible Connectors Every 150 Feet
OUTPUT DATA

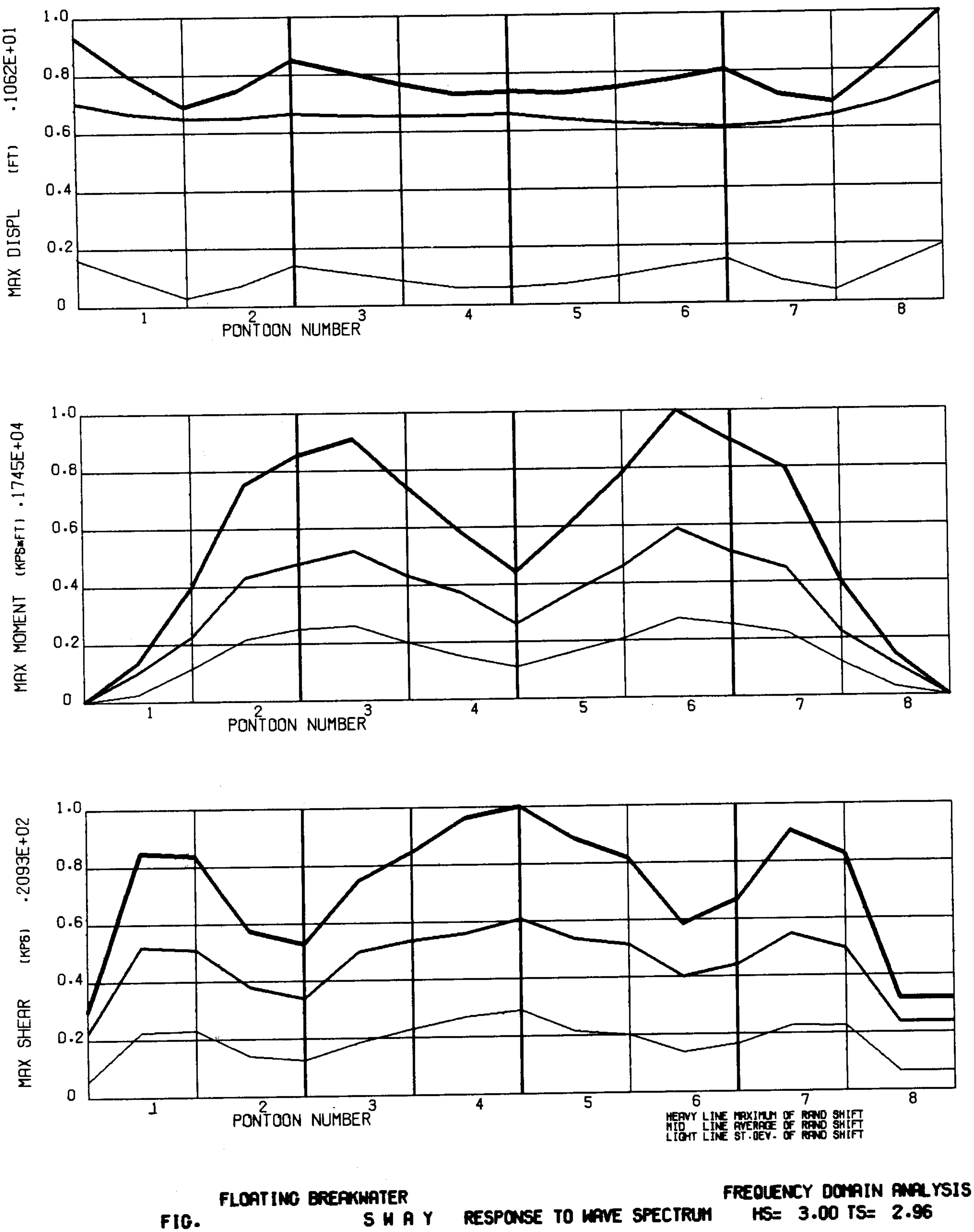


Figure 9.8.d

Example of Breakwater with Flexible Connectors Every 150 Feet

OUTPUT DATA

Appendix A

Program FLOAT

Computer program to compute response of floating bridges and break-waters in short-crested sea states.

Programmed by C. Georgiadis, U.W. 1980

INPUT DATA

Card 1 (8A10)
columns 1-80 Title of the problem.

Card 2 (I5,11I1,I4,4I5,F5.0,I5,F4.0,I1,2I5) General Data

columns	1-5	NP		Number of pontoons.
"	6	IFLO		Flag for desired direction of motion:
			=0	Sway + heave + roll
			=1	Sway
			=2	Heave
			=3	Roll
			=4	Sway + heave
"	7	IFL1		
			=0	All pontoons are the same
			=1	Pontoons are different
"	8	IFL2		
			=0	Rigid connections between pontoons
			=1	Flexible connections between pontoons
"	9	IFL3		
			=0	All connectors are the same.
			=1	Connectors are different
"	10	IFL4		Run mode:
			=0	Eigenvalue solution only
			=1	Eigenvalue solution and frequency response analysis
			=2	Frequency response analysis
			=3	Eigenvalue and time series analysis
			=4	All the above.
"	11	IFL5		Units
			=0	Units in kps and feet
			=1	Units in kN and meters
"	12	IFL6		Wave time series input:
			=0	Wave time series are simulated from wave spectrum at equal frequency intervals
			=1	Wave time series are simulated from wave spectrum at equal spectra areas.
			=2	Wave time series are inputed in cards
			=3	Read time series from a computer file
"	13	IFL7		S.C.F.
			=0	Constant S.C.F.
			=1	Frequency dependent S.C.F. linear pressure

columns	13(cont.)		decrease.
		=2	Frequency dependent quadratic pressure decrease
		=3	Frequency dependent exponentially decayed coherence ($\gamma = EXP(-\alpha(z/\lambda)^{\beta})$)
"	14	IFL8	Correlation between nodal loading:
		=0	Uncorrelated loads
		=1	Exponentially decayed coherence ($\gamma = EXP(-\alpha(z/\lambda)^{\beta})$)
"	15	IFL9	Boat wake response:
		=0	Analysis for regular waves
		=1	Analysis for boat wake. Nodal load computation for very closely spaced nodes. (Not too accurate).
		=2	Analysis for boat wake, more accurate nodal load computation. Nodes not necessarily as close.
	16	IFL10	Flag for wave spectrum input
		=0	Wave spectrum is input from cards
		=1	Pierson-Moskowitz spectrum is constructed by the program.
		=2	JONSWAP spectrum is constructed by the program.
"	17-20	MPI	Number of inputed periods for hydrodynamic coefficients. (The program will linearly interpolate between these values for the periods of the frequency response analysis). Maximum MPI=7.
"	21-25	MPO	Middle period for hydrodynamic coefficients. From the MPI values the program will choose the hydrodynamic coefficients corresponding to MPO period for eigenvalue and time series analysis (default MPO=MPI/2+1.
"	26-30	MREQ	Number of required eigenvectors to be plotted.
"	31-35	MOUT	Number of required eigenvalues to be printed (default all).
"	36-40	ITER	Maximum number of sweeps in the eigenvalue solution by the Generalized Jacobis method (default =30).
"	41-45	TOLE	Exponential factor for convergence tolerance in eigenvalue computation. Should be inputed as negative number (default =-6 and convergence tolerance = 10^{-6}).
"	46-50	MPQ	Number of periods for frequency response calculation (max = 48 and less than $16*NP^2/9$).
	51-54	DRAN	Range of random phase shifts in the frequency domain analysis. The random phase shifts are calculated in the range 0 to 2π/DRAN (default DRAN = 1).
"	55	NLO	Nodal loading pattern:
		=0	Loading every nodal point (half pontoon spacing)
		=1	Loading in the middle of each pontoon
"	56-60	NRS	Number of random loading shifts (max = 48 and less than 2*NP+1, default = 1).
"	61-65	NFS	Number of periods for which the wave spectrum is inputed (not larger than $4*NP^2$).

"	66-70	ALPHA	α factor for exponentially decayed load correlation (default = 8).
"	71-75	BETA	β factor for exponentially decayed load correlation (default = 1).
"	76-80	RANDOM	Any number to be used to start the random number generation, if for another run you want the same random loading shifts, these numbers should be the same.
Card 3	(16F6.0)		Pontoon Properties If all the pontoons are the same, IFL1=0 (column 7, card 2), then supply only one card. Otherwise supply as many as the pontoons (NP).
columns	1-6	L	Length of pontoon
"	7-12	B	Width of pontoon
"	13-18	I_{yy}	Moment of inertia for lateral (sway) motion
"	19-24	I_{xx}	Moment of inertia for vertical (heave) motion
"	25-30	J	Moment of inertia for torsion (roll) motion
"	31-36	m	Translational mass per unit length (sway, heave) (mass units: weight in kps or kN divided by acceleration of gravity in ft/sec^2 or m/sec^2).
"	37-42	m_t	Rotational mass per unit length (roll)(polar inertia divided by acceleration of gravity).
"	43-48		Left pontoon end cable stiffness
"	49-54		Middle pontoon end cable stiffness.
"	55-60		Right pontoon end cable stiffness. For the pontoon ends in case of rigid connectors input half cable stiffness except for bridge ends. In case of supplying one card with pontoon properties input half cable stiffness for the pontoon ends.
"	61-66		S.C.F. (spatial correlation factor) Necessary to be inputed only if IFL7=0 (column 13 of card 2, default=1).
"	67-72		Exponential factor s. In case of large moments of inertia they are computed as $I*10^s$ (where I inputed values for I_{yy}, I_{xx}, J in columns 13-18, 19-24, 25-30).
Card 4	(2F10.0)		Pontoon material properties:
columns	1-10	E	Modulus of elasticity
"	11-20	ν	Poissons ratio (shearing modulus is computed as $G = E/2(1+\nu)$).
Card 5	(6F10.0)		Connector properties: This card must be omitted if rigid connectors IFL2=0 (column 8, card 2). Also input only one card if all connectors are the same IFL3=0 (column 9, card 2), otherwise input (NP-1) cards.
columns	1-10	L_c	Connectors length
"	11-20	I_{cyy}	Moment of inertia for lateral motion
"	21-30	I_{cxx}	Moment of inertia for vertical motion
"	31-40	J_c	Moment of inertia for roll
"	41-50	A_{cxx}	Shear area for sway
"	51-60	A_{cyy}	Shear area for heave

Card 6	(2F10.0)		Connector material properties: This card must be omitted if the connectors are rigid.
columns	1-10	E_c	Modulus of Elasticity
"	11-20	ν_c	Poissons ratio ($G_c = E_c/2(1+\nu_c)$).
Card 7	(12F6.0)		Hydrodynamic coefficients: Input as many cards as the specified number MPI (column 16-20, card 2).
Columns	1-6		Period in seconds
"	7-12		Virtual mass coefficient $\beta^S{}_V$(sway)
"	13-18		Virtual mass coefficient $\beta^H{}_V$(heave)
"	19-24		Virtual mass coefficient $\beta^R{}_V$(roll) $\left(B_V = \frac{\text{structural mass + hydrodynamic mass}}{\text{structural mass}}\right)$
"	25-30		Percent of critical damping $\xi^S{}_V$(sway)
"	31-36		Percent of critical damping $\xi^H{}_V$(heave)
"	37-42		Percent of critical damping $\xi^R{}_V$(roll)
"	43-48		Hydro. force per unit length for unit wave (sway)
"	49-54		Hydro. force per unit length for unit wave (heave)
"	55-60		Hydro. force per unit length for unit wave (roll) (unit wave: $H/2 = 1$)
"	61-66		Draft of cross-section
"	67-72		Width of cross-section (Draft and cross-section width need to be inputed only in the last of the above cards and are used only for label purposes)
Card 8	(16F5.0)		Periods for which the frequency response analysis will be done. Supply as many cards as needed for the periods MPQ (column 46-50, card 2) to be imputed with the above FORMAT. In case of equal period spacing, input only one card with the first (column 1-5) and last (column 6-10) periods. In case of time series inputed in cards or from a computer file (IFL6-2 or 3, column 12, card 2) or boat wake (IFL9 = 1, column 15, card 2) do not supply this card, instead supply card 9.
Card 9	(16F5.0)		This card will be omitted if card 8 is supplied.
columns	1-5	H_s	Significant wave height
"	6-10	T_s	Significant wave period.
"	11-15	T_{ss}	Needed to be inputed only in case of boat wake and represents the period of the modulation wave.
"	16-20	V	Boat speed (ft/sec or m/sec)

Card 10 (16F5.0)	These cards must not be supplied if time series are not simulated from wave spectrum (IFL6-2 or 3 or IFL9=1), otherwise input wave periods in seconds corresponding to the spectra amplitudes which will be inputed next. Supply as many cards as needed to input NFS (column 61-65, card 2) periods with the above FORMAT. Periods should be inputed in ascending order, and to bound the periods of frequency response (card 8) If the maximum period is less than 5, the frequency response plots will be from 0 to 5 seconds, otherwise from 0 to 10 seconds. Maximum value = 10.
Card 11 (16F5.0)	These cards should be omitted if card 10 is omitted, otherwise input wave spectra amplitudes corresponding to the previous inputed periods. The spectra amplitudes correspond to the two-sided spectrum, wave amplitude squared versus frequency in Hz for the corresponding frequencies of the inputed periods. Supply as many cards as needed to input NFS (column 61-65 card 2) values with the above FORMAT.

In case the program constructing the spectrum (IFL10=1 or 2 column 16, card 2), supply only one card with FORMAT (16F5.0) and the following data. (Omit cards 10 and 11).

1-5		Lowest spectra period
6-10		Highest spectra period (The above periods should bound the periods of frequency response, card 8)
11-15	H_s	Significant wave height (default $H_S = 1$).
16-20	T_s	Peak wave period (default $T_S = 3$)
21-25	γ	For JONSWAP spectra (default $\gamma = 3.3$)
26-30	σ_1	For JONSWAP spectra for $f \leq f_S$ (default $\sigma_1 = .07$).
31-35	σ_2	For JONSWAP spectrum for $f > f_S$ (default $\sigma_2 = .09$).

The computed spectrum are assumed to be of the form:

<u>Pierson-Moskowitz</u>

$$S(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp[-(5/4)(f/f_S)^{-4}]$$

<u>JONSWAP:</u>

$$S(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp[(-(5/4)(f/f_S)^{-4}] \times$$

$$\times\ \gamma^{\exp[-(f-f_S)^2/(2\sigma^2 f_S{}^2)]}$$

α values are adjusted to obtain desired H_S.

Card 12	(4F10.0,5I5)		Time series analysis information
column	1-10	DT	Time interval in seconds for simulating time series and computing response (default =1)
"	11-20	TO	Total time of time series in seconds (default=100)
"	21-30	TSH	Time interval inside which the random time shifts will be done
"	31-40	THETA	Value of θ for Wilson's integration method (default =1.4).
"	41-45	MODE(1)	Number of participating mode shapes in sway.
"	46-50	MODE(2)	Number of participating mode shapes in heave
"	51-55	MODE(3)	Number of participating mode shapes in roll. (default all the mode shapes).
"	56-60	NFR	Multiplier for number of frequencies for the wave time series are simulated using NFR*MPQ frequencies. (MPQ has been inputed in columns 46-50 of card 2
"	56-60	NFR	Multiplier for number of frequencies for the wave time series when simulated from spectrum. The time series are simulated using NFR*MPQ frequencies. (MPQ has been inputed in columns 46-50 of card 2, default = 1).
"	61-65	NRSS	Number of response time series from the random shifts to be plotted, less or equal to NRS (column 56-60, card 2), default =1. The plotted time series correspond to the response at the end, quarter span, and half span bridge position.
Card 13	(12F6.0)		Wave time series: These cards need to be inputed only if IFL6 =2 (column 12, card 2). Supply as many cards as needed to input all wave amplitudes at equal time intervals DT defined in previous card 11. In case of reading time series from a computer file (IFL6=3) supply only one card with FORMAT (I5) and the number of time points NT on the TAPE. NT can be larger or smaller than the time steps (TO/DT) used in the program. The computer file should have the local name TAPE11 and the time series should be written as: WRITE(11)(A(J),J=1,NT).

Appendix B

PROGRAM COHER

Programmed by C. Georgiadis, U.W. 1980

Program to compute the wave coherence with the ratio ($\Delta z/\lambda$) where Δz distance between two points on the bridge and λ the wave length. Also fits the results to curves of the form: $y = e^{-\alpha x^{\beta}}$. The program is set for the directional spectra of the form: $S(f,\theta) = S(f)\cos^{n}(\theta-\theta_o)$ but can easily, in a couple of minutes, be modified for other kinds of spectra. The program outputs also nice plots for the wave coherence.

INPUT DATA

Card 1 (3I5)

columns	1-5	(M)	Number of cases. Each case corresponds to different n value for the spectrum. (Max M=20)
	6-10	(NT)	Number of wind directions. (Max NT=10)
	11-15	(ND)	Number of integration points for angle (default 100). The more integration points the smoother the results for high ratios ($\Delta z/\lambda$).

Card 2 (20I2)

Values of n with the above FORMAT.

Card 3 (10F5.0)

Values of wind direction θ_o with the above FORMAT.

Appendix C

Programs HYDR01, HYDR02, HYDR03

Computer Programs to Compute the Hydrodynamic Coefficients for Floating Bridges and Breakwaters

Programmed by C. Georgiadis, U.W. 1980

The programs are based on arguments discussed in Chapter 2. The computer code is the same for all of them. HYDR01 takes into account the sea bottom, HYDR02 and HYDR03 are for deep waters. HYDR03 computes only hydrodynamic exciting forces for different wave directions. HYDR01 and HYDR02 compute all the hydrodynamic quantities for different bridge mode shapes. They are written in FORTRAN IV and the computer code has been optimized in order to be less expensive in the CDC machines. The memory is adjustable with the program needs. The required blank common length is approximately 4*(NE+2)*NE, where NE is the number of boundary elements.

The outputed results are in a format discussed in Article 2.7 in normalized or dimensional form if the basic dimensional quantities are inputed (output values β_H for hydrodynamic added mass, ξ_H for hydrodynamic added, percent of critical damping, $f/[(\frac{H}{2})\rho_w g(\frac{B}{2})]$ for normalized sway and heave force, $m/[(\frac{H}{2})\rho_w g(\frac{B}{2})^2]$ for normalized roll moment). Figures B.1 and B.2 show the region shape for each of the programs as well as the basic dimension nomenclature followed in the input data. On these figures, N_1, N_2, N_3, N_4 represent number of boundary elements of corresponding regions. In the case of Figure B.2, the length of the region AC is adjusted for each frequency according to the input value γ = BC/(wave length). A value γ around 1.0 gives good results. In the case of Figure B.1, the solution should be done in a small bandwidth of frequencies so that AF or BC are not too long compared to the wave length.

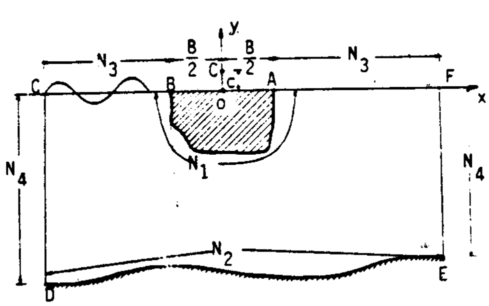


Figure B.1. Fluid Region for HYDR01.

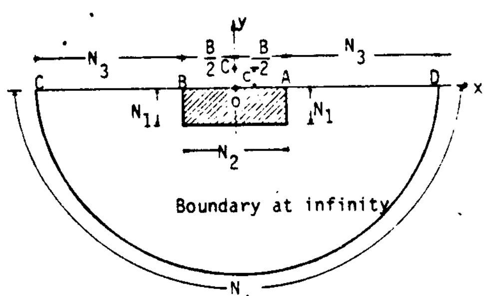


Figure B.2. Fluid Region for HYDR02 and HYDR03.

INPUT DATA

Programs HYDRO2 and HYDRO3

CARD 1	(6A10)			
columns	1-60			Title of the problem
CARD 2	(5I1,8I5, 25X,F10.0)			General data
columns	1	FLAG1		Execution mode
			=-1	The program stops after contruction and plot of the mesh.
			= 0	Normal execution of the Program
"	2	FLAG2		
			= 0	Output results are not smoothed
			= 1	Output results are smoothed
"	3	FLAG3		Blank
"	4	FLAG4		Output units for frequency
			= 0	Normalized frequencies ($\sigma=\omega\sqrt{B/2g}$)
			= 1	Frequencies in Hz
			= 2	Period in seconds
"	5	FLAG5		Maximum values for plots
			= 0	The program finds optimum values.
			= 1	Standard values are used so different plots will be in the same format
"	6-10	N1		Number of elements on vertical side of the cross-section
'	11-15	N2		Number of elements on horizontal side of the cross-section
"	16-20	N3		Number of elements on free surface (for each side of the structure).
"	21-25	N4		Number of elements on the infinite semi-circular boundary.
"	26-30	NF		Number of frequencies for which the hydro-dynamic coefficients are going to be com-puted (max=20)
"	31-35	NH		Order of harmonic in which the bridge os-cillates (not necessary in HYDRO3)
"	41-45	NI		Blank
"	41-45	NT		Number of wave directions for which the exciting forces will be computed (for HYDRO2 max=4, for HYDRO3 max=6)
"	71-80	FMAX		Maximum value for normalized frequency which is going to be used in the plots (default=2.0)
CARD 3	(8F10.0)			Input wave directions with the above FORMAT, total NT values.

CARD 4	(8F10.0)		Structure Properties
columns	1-10	BT	Width to draft ratio for the cross-section
"	11-20	AL	Normalized bridge length (ℓ=2L/B)
"	21-30	B2	Half cross-section width (B/2)
"	31-40	CO	Vertical distance of cross section centroid from free surface, positive above free surface.
"	41-50	AI	Polar moment of inertia of the cross-section
"	51-60	G	Acceleration of gravity
"	61-70	W	Water specific weight
"	71-80	SW	Ratio of free surface length to wave length (default=1)

(The values of B2, CO, AI, G, W, default are equal to 1, so if not inputed normalized results are obtained)

CARD 5 (16F5.0)

Input normalized frequencies for which hydrodynamic coefficients will be computed total (NF) values. If more than 16, input two cards with the above FORMAT. If frequencies are equally spaced, input one card with the first and last values in columns 1-5 and 6-10.

Program HYDRO1

For this program input values are similar to the previous one so: CARD 1, CARD 2, CARD 3, are the same except in CARD2, N1, N2, N3, N4 correspond to numbering in Figure B.1, CARD 4 is as follows:

CARD 4	(6F10.0)		Structure properties
columns	1-10	AL	
"	11-20	B2	
"	21-30	CO	
"	31-40	AI	
"	41-50	G	
"	51-60	W	

Card 5 Same as HYDRO2

Card 6	(I10,2F10.0)	Nodal coordinates
columns	1-10	Node number
"	11-20	x (normalized x = X/(B/2)) coordinate
	21-30	y (normalized y = Y/(B/2)) coordinate

Repeat CARD 6 for nodes of cross-section and for nodes of bottom. If the node numbering is not in sequence, the program linearly interpolates for not-inputed nodes. Necessary to be inputed first and last node for the two above regions. So cross-section nodes start at 1, end at N1+1, bottom nodes start at 1 and end at N2+1 node.

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