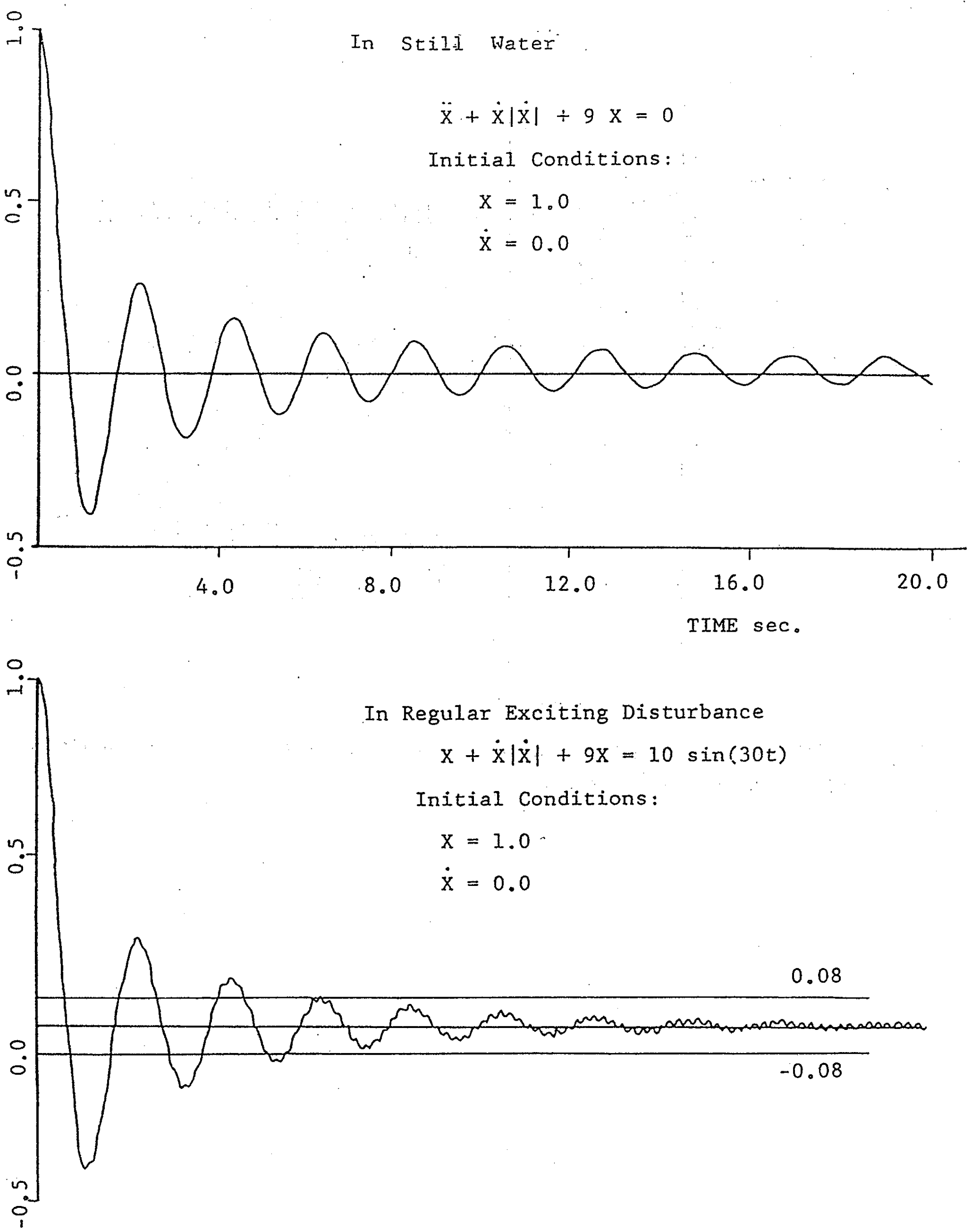

Figure D.1 Free oscillations in still water and in regular exciting disturbance

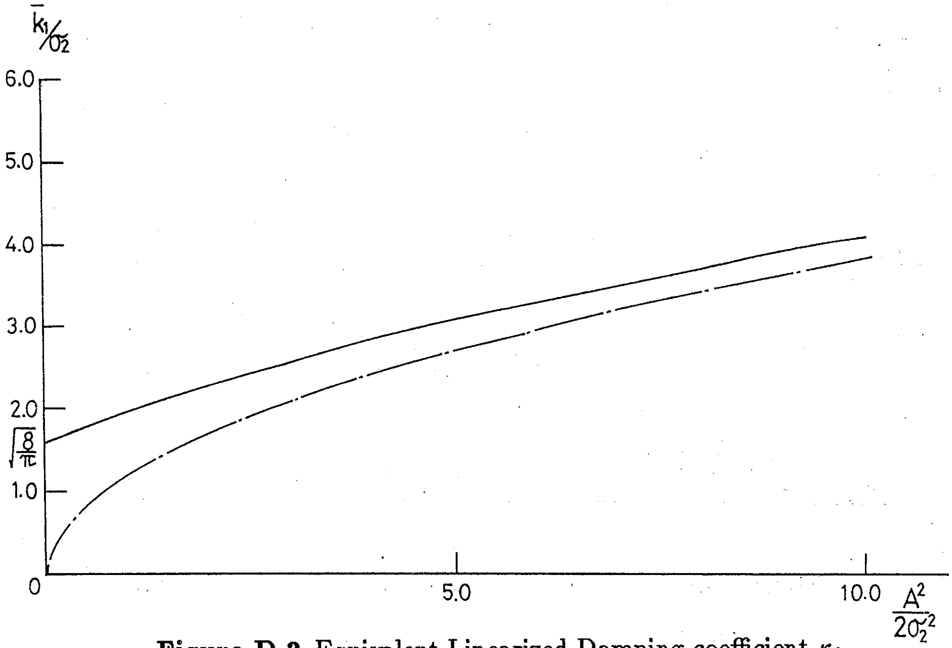

Figure D.2 Equivalent Linearized Damping coefficient κ_1

$(— - —; \frac{8}{3\pi}\sqrt{\frac{A}{\sigma_2}}, ——— ; \frac{\kappa_1}{\sigma_2})$

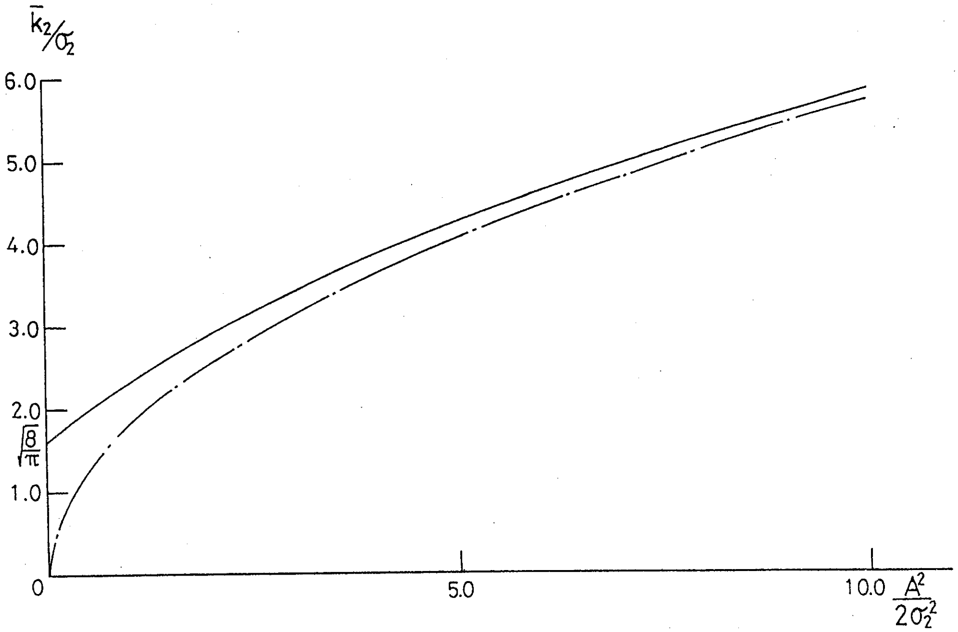

Figure D.3 Equivalent Linearized Damping coefficient κ_2

$(— - —; \frac{4}{\pi}\sqrt{\frac{A}{\sigma_2}}, ——— ; \frac{\kappa_2}{\sigma_2})$

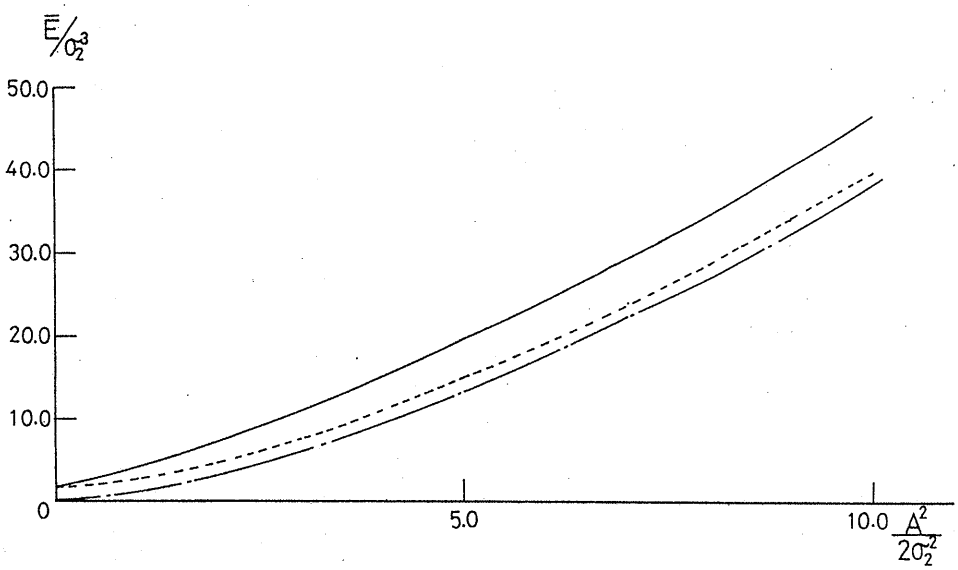

Figure D.4 Energy dissipation due to nonlinear damping $\dot{X}|\dot{X}|$ (— - - —; $\frac{8}{3\pi}\frac{A}{\sigma_2}^3$, ———; $\overline{E}$)

Table 3.1 Principal dimensions

ITEMS	ACTUAL	MODEL
Length(m)	30.0	2.10
Breadth(m)	20.0	1.40
Displacement(t)	527.5 in sea water	0.168 in water
Draft(m)	5.5	0.385
KG(m)	6.8	0.33
κ_{yy}	43.7%L	44.0%L
GM_l(m)	4.8	0.269
Scale ratio	1.0	$\frac{1}{14.3}$
Mooring system	Chain catenary	Linear spring

Table 3.2 Experimental results of free damping oscillation tests

Spring Coefficient(kg/m)	1.683×2	5.09×2
Natural Period(sec.)	21.0	10.6
Virtual Mass(kg·sec^2/m)	37.6	28.97
Equivalent damping force(kgsec/m)	4.6	8.325

Table 3.3 Statistical values of irregular waves

WAVE	STATISTICAL			SPECTRAL			DURATION
COND. No.	*Variance* (m^2)	$H_{1/3}$ (m)	T_{zcr} (sec)	m_0 (m^2)	$4\sqrt{m_0}$ (m)	T_{01} (sec)	TIME (hour)
1	0.2527 (0.00124)	1.954 (0.1366)	7.888 (2.086)	0.2396 (0.00172)	1.958 (0.1369)	8.038 (2.126)	2.84 (0.75)
2	0.2311 (0.00113)	1.869 (0.1307)	6.562 (1.735)	0.238 (0.00116)	1.952 (0.1365)	6.628 (1.753)	2.84 (0.75)
3	0.2502 (0.00122)	1.957 (0.1368)	5.477 (1.448)	0.2568 (0.00126)	2.027 (0.1417)	5.606 (1.482)	2.84 (0.75)
4	0.3047 (0.00149)	2.219 (0.1552)	5.006 (1.324)	0.3104 (0.00152)	2.229 (0.1559)	5.045 (1.334)	5.67 (1.5)

( ) in Model Scale

Table 3.4 Numerical tables of the quadratic transfer function of slowly varying drift force where $\hat{\omega} = \omega\sqrt{D/g}$ and D is the diameter of a column

$$\Re\{G_2^f(\omega_i, -\omega_j)\}$$

$\hat{\omega}_i$	$\hat{\omega}_j$														
	0.2199	.2687	.3176	.3665	.4154	.4543	.5131	.5620	.6109	.6597	.7086	.7575	.8064	.8553	.9041
.2199	-.000293	-.000633	-.002154	-.00465	-.00988	-.01737	-.024	-.0246	-.0154	.00238	.02738	.049	.0464	.0211	-.0362
.2687	-.000633	-.000266	-.000565	-.001045	-.00224	-.00426	-.00636	-.00625	-.00214	.00357	.01016	.0178	.01684	.00456	-.01048
.3176	-.002154	-.000565	-.000509	-.000801	-.001504	-.00278	-.00416	-.00471	-.00441	-.00237	.0065	.01941	.01547	-.003691	-.01318
.3665	-.00465	-.001045	-.000801	-.00167	-.002967	-.004986	-.00702	-.00742	-.00578	-.00279	.00626	.021	.01995	.00399	.00101
.4154	-.00988	-.00224	-.001504	-.002967	-.00475	-.007324	-.0098	-.01046	-.00928	-.00646	.0045	.02227	.0212	.00558	.0107
.4643	-.01737	-.00426	-.00278	-.004986	-.007324	-.0105	-.01341	-.0144	-.0138	-.01102	.00184	.02086	.01793	.00356	.01918
.5131	-.024	-.00636	-.00416	-.00702	-.0098	-.01341	-.01667	-.01826	-.01878	-.0165	-.00328	.013	.00625	-.00375	.02668
.562	-.0246	-.00625	-.00471	-.00742	-.01046	-.0144	-.01826	-.02142	-.02442	-.0239	-.01319	-.00455	-.01516	-.01295	.03931
.6109	-.0154	-.00214	-.00441	-.00578	-.00928	-.0138	-.01878	-.02442	-.0305	-.03184	-.0257	-.0288	-.4171	-.01964	.05657
.6597	.00238	.00357	-.00237	-.00279	-.00646	-.01102	-.01649	-.0239	-.03184	-.03461	-.03711	-.0594	-.07921	-.0408	.0504
.7086	.02738	.01016	.0065	.00626	.0045	.00184	-.00328	-.01319	-.0257	-.03711	-.06273	-.1191	-.1559	-.111	-.0111
.7575	.049	.0178	.01941	.021	.02227	.02086	.013	-.00455	-.0288	-.0594	-.1191	-.20833	-.2479	-.1881	-.07609
.8064	.0464	.01684	.01547	.01995	.0212	.01793	.00625	-.01516	-.04171	-.07921	-.1559	-.2479	-.26064	-.181	-.08084
.8553	.0211	.00456	-.003691	.00399	.00558	.00356	-.00375	-.01295	-.01964	-.0408	-.111	-.1881	-.181	-.12043	-.0795
.9041	-.0362	-.01048	-.01318	.00101	.0107	.1918	.02668	.03931	.05657	.0504	-.0111	-.07609	-.08084	-.0795	-.1059

$$\Im\{G_2^f(\omega_i, -\omega_j)\}$$

$\hat{\omega}_i$	$\hat{\omega}_j$														
	0.2199	.2687	.3176	.3665	.4154	.4543	.5131	.5620	.6109	.6597	.7086	.7575	.8064	.8553	.9041
.2199	.0	-.01886	-.00080	-.03595	-.05041	-.05470	-.0444	-.02034	.00966	.03532	.04695	.0322	-.00137	-.04963	-.0915
.2687	.01886	.0	.00782	-.0112	-.02149	-.0274	-.0244	-.00965	.01334	.03638	.05063	.04024	.00129	-.05029	-.07833
.3176	.00080	-.00782	.00	-.00771	-.00946	-.01153	-.01430	-.01685	-.01596	-.00576	.01377	.02379	.01342	-.01031	-.04245
.3665	.03595	.0112	.00771	.00	-.00656	-.01214	-.01468	-.01261	-.00572	.00718	.02416	.02634	.00751	-.01437	-.03581
.4154	.05041	.02149	.00946	.00656	.00	-.00626	-.01014	-.01083	-.00801	.00104	.01575	.01727	.00365	-.00250	-.01466
.4643	.05470	.02740	.01153	.01214	.00626	.00	-.00497	-.00845	-.01006	-.00552	.00525	.00477	-.00229	.01013	.0075
.5131	.0444	.0244	.0143	.01468	.01014	.00497	.00	-.00523	-.01011	-.00980	-.00492	-.00964	-.01034	.01973	.02361
.562	-.02034	.00965	.01685	.01261	.01083	.00845	.00523	.00	-.00648	-.0104	-.01454	-.02629	-.02103	.02381	.03055
.6109	-.00966	-.01334	.01596	.00572	.00801	.01006	.01011	.00648	.00	-.00807	-.02354	-.04198	-.02724	.03224	.04023
.6597	-.03532	-.03638	.00576	-.00718	-.00104	.00552	.00980	.0104	.00807	.00	-.02226	-.03937	-.00892	.06155	.06197
.7086	-.04695	-.05063	-.01377	-.02416	-.01575	-.00525	.00492	.01454	.02354	.0226	.00	-.00971	.02979	.08913	.06230
.7575	-.03220	-.04024	-.02379	-.02634	-.01727	-.00477	.00964	.02629	.04198	.03937	.00971	.00	.02936	.0500	-.00436
.8064	.00137	-.00129	-.01342	-.00751	-.00365	.00229	.01031	.02103	.02724	.00892	-.02979	-.02936	.00	-.00417	-.0589
.8553	.04963	.05029	.01031	.01437	.00250	-.01013	-.01973	-.02381	-.03224	-.06155	-.08913	-.0500	.00417	.00	-.0399
.9041	.09150	.07833	.04245	.03581	.01466	-.0075	-.02361	-.03055	-.04023	-.06197	-.06230	.00436	.0589	.0399	.00

Table 3.5 Comparisons with hydrodynamic coefficients in still water and in slow drift oscillations

Wave cond.	$\widetilde{M_1 + m_{11}}/M_1 + m_{11}$	$\widetilde{N^e_{11}}/N^e_{11}$
2	1.0	1.39
3	0.89	1.67
4	0.87	1.65

Table 4.1 Principal dimensions of 2-D structures

Items	Case No.		
	No.1	No.2	No.3
Structure type	Circular	Circular	Rectangular
Beam or Diameter	20m	20m	20m
Draft (d)	10m	10m	10m
Total Mass ($M_1 + m_{11}$)	3.21×10^5 kg/m	3.21×10^5 kg/m	3.21×10^5 kg/m
Undamped natural freq. (ω_0)	0.06 rad/sec	0.06 rad/sec	0.06 rad/sec
Relative damping coef. (κ)	3.0×10^{-5}	0.1	0.1

Table 4.2 Quadratic transfer function for circular cylinder in beam sea where
$\hat{\omega} = \omega\sqrt{d/g}$ and d is the draft

Numerical Calculation of $\Re\{\frac{G_2^{f*}(\omega_i,-\omega_j)}{2\rho g}\}$

$\hat{\omega}_i$	$\hat{\omega}_j$							
	1.25	1.18	1.12	1.06	0.95	0.89	0.84	0.65
1.25	0.308	0.285	0.259	0.25	0.24	0.24	0.233	0.256
1.18	0.285	0.314	0.308	0.292	0.277	0.246	0.234	0.254
1.12	0.239	0.308	0.338	0.34	0.324	0.267	0.234	0.247
1.06	0.25	0.292	0.34	0.368	0.367	0.301	0.245	0.243
0.95	0.25	0.277	0.324	0.367	0.383	0.329	0.257	0.241
0.89	0.24	0.246	0.267	0.301	0.329	0.303	0.227	0.195
0.84	0.233	0.234	0.234	0.245	0.257	0.277	0.147	0.105
0.65	0.256	0.234	0.247	0.243	0.241	0.195	0.105	0.051

Numerical Calculation of $\Im\{\frac{G_2^{f*}(\omega_i,-\omega_j)}{2\rho g}\}$

$\hat{\omega}_i$	$\hat{\omega}_j$							
	1.25	1.18	1.12	1.06	0.95	0.89	0.84	0.65
1.25	0.0	0.043	0.059	0.061	0.059	0.069	0.112	0.16
1.18	-0.043	0.0	0.030	0.038	0.032	0.028	0.066	0.112
1.12	-0.059	-0.030	0.0	0.015	0.013	0.004	0.041	0.087
1.06	-0.061	-0.038	-0.015	0.0	0.0	-0.006	0.033	0.082
0.95	-0.059	-0.032	-0.013	0.0	0.0	-0.004	0.04	0.094
0.89	-0.069	-0.028	-0.004	0.006	0.004	0.0	0.056	0.129
0.84	-0.11	-0.066	-0.041	-0.033	-0.04	-0.056	0.0	0.09
0.65	-0.16	-0.112	-0.087	-0.082	-0.094	-0.129	-0.09	0.0

Table 4.3 Quadratic transfer function for rectangular cylinder in beam sea
where $\hat{\omega} = \omega\sqrt{d/g}$ and d is the draft

Numerical Calculation of $\Re\{\frac{G_2^{f*}(\omega_i,-\omega_j)}{2\rho g}\}$

$\hat{\omega}_i$	$\hat{\omega}_j$							
	1.25	1.18	1.12	0.89	0.84	0.79	0.76	0.69
1.25	0.363	0.317	0.272	0.270	0.286	0.302	0.330	0.406
1.18	0.317	0.336	0.305	0.260	0.269	0.264	0.261	0.321
1.12	0.272	0.305	0.315	0.245	0.255	0.248	0.228	0.258
0.89	0.270	0.260	0.245	0.326	0.339	0.313	0.236	0.172
0.84	0.286	0.269	0.355	0.339	0.384	0.380	0.300	0.208
0.79	0.302	0.264	0.248	0.313	0.380	0.405	0.337	0.234
0.76	0.330	0.261	0.228	0.236	0.300	0.337	0.280	0.175
0.69	0.406	0.321	0.258	0.172	0.208	0.234	0.175	0.059

Numerical Calculation of $\Im\{\frac{G_2^{f*}(\omega_i,-\omega_j)}{2\rho g}\}$

$\hat{\omega}_i$	$\hat{\omega}_j$							
	1.25	1.18	1.12	0.89	0.84	0.79	0.76	0.69
1.25	0.0	0.045	0.059	0.050	0.034	0.031	0.049	0.075
1.18	-0.045	0.0	0.034	0.024	0.002	-0.021	-0.014	0.009
1.12	-0.059	-0.034	0.0	0.009	-0.017	-0.047	-0.048	-0.021
0.89	-0.050	-0.024	-0.009	0.0	-0.026	-0.086	-0.115	-0.067
0.84	-0.034	-0.001	0.017	0.026	0.0	-0.068	-0.111	-0.052
0.79	-0.031	0.021	0.047	0.086	0.068	0.0	-0.053	0.008
0.76	-0.049	0.014	0.048	0.113	0.111	0.053	0.0	0.068
0.69	-0.075	-0.009	0.021	0.067	0.052	-0.008	-0.068	0.0

Table 4.4 Linear transfer function for circular structure in beam sea where
$\hat{\omega} = \omega\sqrt{d/g}$ and d is the draft

$\hat{\omega}_i$	$\Re\{\frac{G_1^f(\omega_i)}{\rho g d^2}\}$	$\Im\{\frac{G_1^f(\omega_i)}{\rho g d^2}\}$
1.25	0.0495	0.0
1.18	0.0543	0.0085
1.12	0.0570	0.0168
0.89	0.0621	0.0432
0.84	0.0631	0.0463
0.79	0.0645	0.0490
0.76	0.0662	0.0498
0.69	0.0705	0.0459

Table 4.5 Eigenvalues

Eigenvalues	Wave condition No.			
No.	1 (m)	2 (m)	3 (m)	4 (m)
1	-0.117	-0.2068	-0.3028	-0.3751
2	0.0455	-0.1391	-0.1749	-0.2494
3	-0.0636	-0.0810	-0.1409	-0.2273
4	0.0253	0.0796	-0.0963	-0.1251
5	-0.0319	-0.0528	0.1137	0.1379
6	0.0127	0.0373	0.0657	0.0978
7	-0.0184	-0.0323	0.0558	0.0853
8	-0.017	-0.0254	-0.0576	-0.0816
9	-0.0142	-0.0249	0.0368	0.0456
10	-0.0105	0.0218	-0.0379	0.0313
11	0.0072	0.0206	-0.0341	-0.0483
12	0.0067	0.0114	0.0214	-0.042
13	0.0061	0.009	0.014	-0.0307
14	0.0042	0.007	0.0117	-0.0279
15	-0.0075	-0.0115	-0.0218	-0.0243
16	-0.0068	-0.0104	-0.0193	0.0188
17	0.0026	0.0043	-0.0166	0.0152
18	-0.0041	-0.0063	0.0069	0.0094
19	-0.0036	-0.0059	-0.0114	-0.016
20	-0.0024	-0.0054	-0.0109	-0.0147
21	-0.0021	-0.0032	-0.0072	0.0058
22	-0.0019	-0.0027	-0.0059	-0.0102
23	0.0016	0.0021	0.0043	-0.0064
24	0.0009	0.0019	0.0028	0.0027

Table 4.6 Comparisons of statistical values between estimations and experimental results

WAVE	Sample		estimated		Parameters of Gamma p.d.f.			
COND. No.	$\|E[X]\|$ (m)	$V[X]$ (m^2)	$\|k_1\|$ (m)	k_2 (m^2)	$\tilde{\theta}_1$ (m)	$\tilde{\theta}_2$ (m)	$\tilde{\nu}_1$	$\tilde{\nu}_2$
1	0.291~0.477	0.162~0.198	0.380	0.1831	0.03	0.061	8.554	9.307
2	0.409~0.57	0.173~0.275	0.746	0.2919	0.0472	0.1132	8.655	10.112
3	0.607~0.844	0.269~0.719	1.220	0.7254	0.0672	0.1627	10.012	11.276
4	1.183~1.327	1.173~1.558	1.675	1.294	0.09	0.215	10.3	11.71