COAL UNLOADING HARBOUR KAYAMKULAM

Annexures

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Contents

Annexure 2.1

ships observations of combined sea and swell waves near Cochin
data source: KNMI 8.5-11.5 N, 74-77 E, 1961-1980
open sea wave climate
season: annual
input waveheight assumed to be significant waveheight

TABLE OF OCCURRENCE PROBABILITIES (%)

direction	significant waveheight (m)										
	<0.25	0.25–0.75	0.75–1.25	1.25–1.75	1.75–2.25	2.25–2.75	2.75–3.25	3.25–4.25	4.25–5.25	5.25–7.25	7.25	total
0	0.44	2.31	2.37	0.73	0.22	0.04	0.00	0.00	0.00	0.00	0.00	6.11
30	0.59	1.84	1.19	0.38	0.04	0.06	0.00	0.00	0.00	0.00	0.00	4.11
60	0.18	1.42	1.03	0.49	0.14	0.00	0.00	0.02	0.00	0.00	0.00	3.28
90	0.18	1.07	0.81	0.53	0.32	0.08	0.04	0.00	0.00	0.00	0.00	3.03
120	0.12	0.69	0.61	0.32	0.08	0.08	0.00	0.00	0.00	0.00	0.00	1.90
150	0.14	0.91	1.60	0.81	0.40	0.12	0.02	0.02	0.00	0.00	0.00	4.03
180	0.18	1.21	1.70	1.40	0.87	0.38	0.04	0.06	0.00	0.00	0.00	5.85
210	0.14	1.31	1.09	0.85	0.65	0.34	0.08	0.04	0.02	0.02	0.00	4.55
240	0.26	1.70	2.39	2.35	1.66	1.19	0.42	0.40	0.20	0.00	0.00	10.58
270	0.49	3.07	4.49	3.84	4.53	2.22	1.98	1.03	0.40	0.02	0.00	22.09
300	0.81	4.96	5.46	3.42	1.80	1.21	0.79	0.49	0.04	0.00	0.00	18.97
330	1.11	5.34	5.28	2.75	0.61	0.28	0.08	0.04	0.02	0.00	0.00	15.51
total	4.65	25.83	28.01	17.86	11.33	6.03	3.46	2.10	0.69	0.04	0.00	100.00

Annexure 2.2

ships observations of combined sea and swell waves near Cochin

data source: KNMI 8.5-11.5 N, 74-77 E, 1961-1980

open sea wave climate

season: annual

input waveheight assumed to be significant waveheight

TABLE OF OCCURRENCE PROBABILITIES (%)

significant period (s)	significant waveheight (m)											
	<0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25	7.25	total
<5.5	4.65	22.31	15.96	6.59	2.08	0.75	0.28	0.16	0.08	0.00	0.00	52.87
5.5-7.5	0.00	1.84	7.58	6.23	4.45	2.49	1.23	0.38	0.02	0.02	0.00	24.25
7.5-9.5	0.00	0.89	3.26	3.64	3.50	1.88	1.36	1.07	0.20	0.02	0.00	15.82
9.5-11.5	0.00	0.47	0.91	0.95	0.91	0.51	0.32	0.40	0.30	0.00	0.00	4.77
11.5-13.5	0.00	0.24	0.20	0.32	0.34	0.28	0.22	0.06	0.08	0.00	0.00	1.76
13.5-15.5	0.00	0.02	0.03	0.04	0.01	0.04	0.01	0.01	0.00	0.00	0.00	0.16
15.5-17.5	0.00	0.02	0.03	0.04	0.01	0.04	0.01	0.01	0.00	0.00	0.00	0.16
17.5-19.5	0.00	0.02	0.03	0.04	0.01	0.04	0.01	0.01	0.00	0.00	0.00	0.16
19.5-21.5	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.04
>21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	4.65	25.83	28.01	17.86	11.33	6.03	3.46	2.10	0.69	0.04	0.00	100.00

Annexure 2.3

ships observations of combined sea and swell waves near Cochin
data source: KNMI 8.5-11.5 N, 74-77 E, 1961-1980
open sea wave climate
season: annual
input waveheight assumed to be significant waveheight

MEAN SIGNIFICANT WAVE PERIOD (s)

direction	significant waveheight (m)										
	<0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25	7.25
0	4.50	4.97	5.59	6.56	6.68	8.50	-	-	-	-	-
30	4.50	4.70	5.14	5.55	6.50	5.83	-	-	-	-	-
60	4.50	4.61	5.32	5.00	6.21	-	-	4.50	-	-	-
90	4.50	4.92	5.35	5.88	5.88	7.50	8.50	-	-	-	-
120	4.50	5.21	5.90	5.75	7.00	6.00	-	-	-	-	-
150	4.50	5.52	6.61	7.26	7.92	7.50	8.50	8.50	-	-	-
180	4.50	6.71	7.46	8.22	8.03	10.44	8.50	7.83	-	-	-
210	4.50	5.62	6.32	7.21	7.69	7.68	8.50	9.50	10.50	8.50	-
240	4.50	5.07	5.81	6.64	7.58	7.83	8.31	8.60	9.30	-	-
270	4.50	4.91	6.04	6.88	7.53	7.63	7.70	8.74	9.70	6.50	-
300	4.50	4.85	5.52	6.09	6.25	7.47	8.67	8.17	7.50	-	-
330	4.50	4.76	5.40	6.03	7.23	5.93	6.00	7.50	6.50	-	-
total	4.50	5.00	5.80	6.56	7.29	7.70	8.00	8.41	9.32	7.50	-

Annexure 2.4

ships observations of combined sea and swell waves near Cochin
data source: KNMI 8.5-11.5 N, 74-77 E, 1961-1980
open sea wave climate
season: annual
input waveheight assumed to be significant waveheight

TABLE OF EXCEEDANCE PROBABILITIES(%)

direction	significant waveheight (m)										
	0.00	0.25	0.75	1.25	1.75	2.25	2.75	3.25	4.25	5.25	7.25
0	6.11	5.66	3.36	0.99	0.26	0.04	0.00	0.00	0.00	0.00	0.00
30	4.11	3.52	1.68	0.49	0.10	0.06	0.00	0.00	0.00	0.00	0.00
60	3.28	3.09	1.68	0.65	0.16	0.02	0.02	0.02	0.00	0.00	0.00
90	3.03	2.85	1.78	0.97	0.44	0.12	0.04	0.00	0.00	0.00	0.00
120	1.90	1.78	1.09	0.49	0.16	0.08	0.00	0.00	0.00	0.00	0.00
150	4.03	3.88	2.97	1.38	0.57	0.16	0.04	0.02	0.00	0.00	0.00
180	5.85	5.66	4.45	2.75	1.36	0.49	0.10	0.06	0.00	0.00	0.00
210	4.55	4.41	3.09	2.00	1.15	0.51	0.16	0.08	0.04	0.02	0.00
240	10.58	10.32	8.62	6.23	3.88	2.22	1.03	0.61	0.20	0.00	0.00
270	22.09	21.60	18.53	14.04	10.19	5.66	3.44	1.46	0.42	0.02	0.00
300	18.97	18.16	13.21	7.75	4.33	2.53	1.31	0.53	0.04	0.00	0.00
330	15.51	14.40	9.06	3.78	1.03	0.42	0.14	0.06	0.02	0.00	0.00
total	100.00	95.35	69.52	41.50	23.64	12.32	6.29	2.83	0.73	0.04	0.00

Annexure 2.5

data source: OCEAN WAVE STATISTICS by N. Hogben, Ph.D and F.E. Lumb, M.Sc
(area 30)

all seasons

26517 observations; input waveheight assumed to be significant waveheight

TABLE OF OCCURRENCE PROBABILITIES (%)

direction	significant waveheight (m)													
	0.25	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	total
0	0.98	1.64	1.92	0.97	0.30	0.06	0.05	0.01	0.00	0.00	0.00	0.00	0.00	5.93
30	0.89	2.15	3.24	1.85	0.66	0.23	0.08	0.04	0.00	0.00	0.00	0.00	0.00	9.14
60	0.65	1.66	2.87	1.99	0.64	0.12	0.06	0.03	0.00	0.00	0.00	0.00	0.00	8.02
90	0.56	1.20	1.60	0.97	0.43	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	4.88
120	0.35	0.60	0.67	0.39	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.13
150	0.33	0.56	1.12	0.79	0.37	0.14	0.05	0.03	0.02	0.02	0.00	0.00	0.00	3.43
180	0.33	0.81	1.67	1.57	0.65	0.35	0.16	0.03	0.03	0.03	0.00	0.00	0.00	5.63
210	0.43	1.03	2.73	3.04	1.43	0.64	0.21	0.11	0.06	0.03	0.00	0.02	0.00	9.73
240	0.43	1.52	4.77	5.05	3.76	2.18	0.80	0.34	0.12	0.06	0.02	0.00	0.00	19.05
270	0.71	1.78	4.77	5.28	3.23	1.64	0.67	0.24	0.12	0.02	0.01	0.00	0.00	18.47
300	0.67	1.56	2.99	2.10	1.06	0.43	0.14	0.05	0.02	0.00	0.00	0.00	0.00	9.02
330	0.54	1.29	1.62	0.72	0.26	0.08	0.02	0.02	0.01	0.00	0.00	0.00	0.00	4.56
total	6.54	15.80	29.97	24.72	12.87	6.00	2.26	0.91	0.38	0.16	0.03	0.02	0.00	99.99

Annexure 2.6

ships observations of combined sea and swell waves near Cochin
data source: KNMI 8.5-11.5 N, 74-77 E, 1961-1980
open sea wave climate
season: annual
input waveheight assumed to be significant wavwheight

INTERPOLATED MEAN SIGNIFICANT WAVE PERIOD (s)

direction	significant waveheight (m)									
	<0.25	0.75	1.25	1.75	2.25	2.75	3.25	4.25	5.25	7.25
165	4.5	6.6	7.4	7.9	8.5	8.7	8.3	8.2	-	-
180	4.5	7.1	7.8	8.1	9.2	9.5	8.2	7.8	-	-
195	4.5	6.5	7.3	7.8	8.5	8.8	8.6	8.9	9.5	8.5
210	4.5	6.0	6.8	7.5	7.7	8.1	9.0	10.0	9.5	8.5
225	4.5	5.7	6.5	7.3	7.7	8.1	8.7	9.5	9.4	8.5
240	4.5	5.4	6.2	7.1	7.7	8.1	8.5	9.0	9.3	-
255	4.5	5.5	6.3	7.2	7.6	7.9	8.3	9.1	8.7	6.5
270	4.5	5.5	6.5	7.2	7.6	7.7	8.2	9.2	8.1	6.5
285	4.5	5.3	6.1	6.7	7.2	7.9	8.3	8.5	7.8	6.5
300	4.5	5.2	5.8	6.2	6.9	8.1	8.4	7.8	7.5	-
315	4.5	5.1	5.8	6.4	6.7	7.0	7.6	7.4	7.0	-
330	4.5	5.1	5.7	6.6	6.6	6.0	6.8	7.0	6.5	-

Annexure 2.7

Determination of breaker depths for various waveheights and breakerindices

direction	φ_o (deg)	Hos (m)	Lop (m)	h_b (m)	φ_b (deg)	Ks	Kr	H_b (m)	γ
210°N	35	7.25	112.8	9.31	22.15	0.9515	0.9404	6.49	0.70
270°N	-25	7.25	66.0	9.24	-19.77	0.9146	0.9814	6.51	0.70
210°N	35	7.25	112.8	11.62	24.29	0.9306	0.9480	6.40	0.55
270°N	-25	7.25	66.0	11.88	-21.42	0.9145	0.9867	6.54	0.55
210°N	35	6.25	112.8	8.12	20.89	0.9677	0.9364	5.66	0.70
270°N	-25	6.25	66.0	8.05	-18.82	0.9197	0.9785	5.62	0.70
210°N	35	6.25	112.8	10.15	22.99	0.9422	0.9433	5.55	0.55
270°N	-25	6.25	66.0	10.23	-20.45	0.9132	0.9835	5.61	0.55
210°N	35	5.25	140.9	7.19	17.89	1.020	0.9278	4.97	0.70
240°N	5	5.25	135.0	7.56	2.79	1.004	0.9987	5.26	0.70
270°N	-25	5.25	102.4	7.07	-14.95	0.9733	0.9685	4.95	0.70
300°N	-55	5.25	87.8	5.93	-29.70	0.9764	0.8126	4.17	0.70
330°N	-85	5.25	66.0	2.51	-27.84	1.075	0.3140	1.77	0.70
210°N	35	5.25	140.9	8.81	19.62	0.9874	0.9325	4.83	0.55
240°N	5	5.25	135.0	9.32	3.05	0.9733	0.9988	5.10	0.55
270°N	-25	5.25	102.4	8.81	-16.41	0.9469	0.9720	4.83	0.55
300°N	-55	5.25	87.8	7.46	-33.03	0.9481	0.8272	4.12	0.55
330°N	-85	5.25	66.0	3.14	-31.12	1.033	0.3191	1.73	0.55
210°N	35	4.75	172.1	6.71	15.79	1.070	0.9227	4.69	0.70
240°N	5	4.75	135.0	7.00	2.69	1.037	0.9986	4.92	0.70
270°N	-25	4.75	146.9	6.76	-12.48	1.038	0.9635	4.75	0.70
300°N	-55	4.75	87.8	5.44	-28.54	0.9885	0.8081	3.79	0.70
330°N	-85	4.75	66.0	2.31	-26.74	1.092	0.3124	1.62	0.70

direction	φ_o (deg)	Hos (m)	Lop (m)	h_b (m)	φ_b (deg)	Ks	Kr	H_b (m)	γ
210°N	35	4.75	172.1	8.26	17.40	1.031	0.9265	4.54	0.55
240°N	5	4.75	135.0	8.51	2.93	0.9862	0.9988	4.68	0.55
270°N	-25	4.75	146.9	8.37	-13.75	1.0015	0.9659	4.60	0.55
300°N	-55	4.75	87.8	6.76	-31.57	0.9594	0.8205	3.74	0.55
330°N	-85	4.75	66.0	2.87	-29.79	1.049	0.3169	1.58	0.55
180°N	65	4.25	95.0	4.37	27.62	1.038	0.6906	3.05	0.70
210°N	35	4.25	156.1	6.01	15.70	1.072	0.9224	4.20	0.70
240°N	5	4.25	126.5	6.20	2.63	1.027	0.9986	4.36	0.70
270°N	-25	4.25	132.1	6.08	-12.48	1.038	0.9635	4.25	0.70
300°N	-55	4.25	95.0	4.94	-26.26	1.017	0.7997	3.46	0.70
330°N	-85	4.25	76.5	2.14	-23.90	1.142	0.3088	1.50	0.70
180°N	65	4.25	95.0	5.42	30.64	1.0015	0.7009	2.98	0.55
210°N	35	4.25	156.1	7.34	17.23	1.034	0.9261	4.07	0.55
240°N	5	4.25	126.5	7.72	2.89	0.9909	0.9987	4.21	0.55
270°N	-25	4.25	132.1	7.46	-13.70	1.003	0.9658	4.12	0.55
300°N	-55	4.25	95.0	6.18	-29.19	0.9815	0.8106	3.38	0.55
330°N	-85	4.25	76.5	2.64	-26.54	1.095	0.3121	1.45	0.55
180°N	65	3.75	95.0	3.90	26.10	1.060	0.6860	2.73	0.70
210°N	35	3.75	140.9	5.30	15.50	1.078	0.9220	3.73	0.70
240°N	5	3.75	115.5	5.49	2.60	1.033	0.9986	3.87	0.70
270°N	-25	3.75	118.2	5.38	-12.42	1.040	0.9633	3.76	0.70
300°N	-55	3.75	105.0	4.46	-23.84	1.053	0.7919	3.13	0.70
330°N	-85	3.75	87.8	1.98	-21.41	1.197	0.3060	1.37	0.70
180°N	65	3.75	95.0	4.85	29.04	1.020	0.6953	2.66	0.55
210°N	35	3.75	140.9	6.55	17.14	1.036	0.9259	3.60	0.55
240°N	5	3.75	115.5	6.81	2.85	0.9960	0.9987	3.73	0.55
270°N	-25	3.75	118.2	6.62	-13.64	1.004	0.9657	3.64	0.55
300°N	-55	3.75	105.0	5.51	-26.38	1.015	0.8002	3.05	0.55
330°N	-85	3.75	87.8	2.41	-23.69	1.1465	0.3085	1.33	0.55

direction	φ_o (deg)	Hos (m)	Lop (m)	h_b (m)	φ_b (deg)	Ks	Kr	H_b (m)	γ
180°N	65	3.25	105.0	3.47	23.46	1.105	0.6787	2.44	0.70
210°N	35	3.25	126.5	4.62	15.31	1.084	0.9216	3.25	0.70
240°N	5	3.25	112.8	4.85	2.48	1.051	0.9986	3.41	0.70
270°N	-25	3.25	105.0	4.67	-12.30	1.044	0.9631	3.27	0.70
300°N	-55	3.25	110.2	3.97	-22.00	1.086	0.7865	2.78	0.70
330°N	-85	3.25	72.2	1.70	-21.89	1.185	0.3065	1.18	0.70
180°N	65	3.25	105.0	4.31	26.10	1.060	0.6860	2.36	0.55
210°N	35	3.25	126.5	5.69	16.89	1.042	0.9253	3.13	0.55
240°N	5	3.25	112.8	5.98	2.72	1.013	0.9987	3.29	0.55
270°N	-25	3.25	105.0	5.78	-13.54	1.007	0.9655	3.16	0.55
300°N	-55	3.25	110.2	4.90	-24.38	1.044	0.7936	2.69	0.55
330°N	-85	3.25	72.2	2.09	-24.33	1.134	0.3093	1.14	0.55

Annexure 2.8.a

Wave transformation at 10 m waterdepth (h=10 m)

direction	φ_o (deg)	Hos (m)	T (s)	Lop (m)	Sop	h/Lop	φ(deg)	Kr	Ks	Hs/h graphs	Hs (m)
195°N	50	7.25	8.5	112.8	0.0643	0.089	31.3	0.867	0.943	0.450	3.90
225°N	20	7.25	8.5	112.8	0.0643	0.089	13.4	0.983	0.943	0.450	4.42
255°N	–10	7.25	6.5	66.0	0.1098	0.152	– 8.2	0.997	0.913	±0.40	3.99
285°N	–40	7.25	6.5	66.0	0.1098	0.152	–31.9	0.950	0.913	±0.40	3.80
195°N	50	5.25	9.5	140.9	0.0373	0.071	28.3	0.854	0.970	0.453	3.87
225°N	20	5.25	9.4	138.0	0.0380	0.072	12.3	0.981	0.968	0.456	4.47
255°N	–10	5.25	8.7	118.2	0.0444	0.085	– 6.6	0.996	0.948	0.435	4.33
285°N	–40	5.25	7.8	95.0	0.0553	0.105	–27.7	0.930	0.929	0.418	3.89
315°N	–70	5.25	7.0	76.5	0.0686	0.131	–47.3	0.710	0.917	–	3.42
330°N	–85	5.25	6.5	66.0	0.0795	0.152	–55.0	0.390	0.913	–	1.87
165°N	80	4.25	8.2	105.0	0.0405	0.095	43.2	0.488	0.937	0.403	1.96
195°N	50	4.25	8.9	123.7	0.0344	0.081	30.0	0.861	0.953	0.410	3.53
225°N	20	4.25	9.5	140.9	0.0302	0.071	12.2	0.981	0.970	0.421	4.13
255°N	–10	4.25	9.1	129.3	0.0329	0.077	– 6.4	0.995	0.959	0.415	4.12
285°N	–40	4.25	8.5	112.8	0.0377	0.089	–25.8	0.923	0.943	0.406	3.75
315°N	–70	4.25	7.4	85.5	0.0497	0.117	–44.9	0.695	0.922	–	2.72
330°N	–85	4.25	7.0	76.5	0.0556	0.131	–51.2	0.373	0.917	–	1.45
165°N	80	3.25	8.3	107.6	0.0302	0.093	42.8	0.486	0.939	–	1.48
195°N	50	3.25	8.6	115.5	0.0281	0.087	31.0	0.866	0.946	–	2.66
225°N	20	3.25	8.7	118.2	0.0275	0.085	13.2	0.982	0.948	–	3.03
255°N	–10	3.25	8.3	107.6	0.0302	0.093	– 6.9	0.996	0.939	–	3.04
285°N	–40	3.25	8.3	107.6	0.0302	0.093	–26.3	0.924	0.939	–	2.82
315°N	–70	3.25	7.6	90.2	0.0360	0.111	–43.9	0.689	0.925	–	2.07
330°N	–85	3.25	6.8	72.2	0.0450	0.139	–52.7	0.379	0.915	–	1.13
165°N	80	2.75	8.7	118.2	0.0233	0.085	40.9	0.479	0.948	–	1.25
195°N	50	2.75	8.8	120.9	0.0227	0.083	30.3	0.863	0.951	–	2.26
225°N	20	2.75	8.1	102.4	0.0269	0.098	13.9	0.984	0.934	–	2.53
255°N	–10	2.75	7.9	97.4	0.0282	0.103	– 7.2	0.996	0.931	–	2.55
285°N	–40	2.75	7.9	97.4	0.0282	0.103	–27.4	0.929	0.931	–	2.38
315°N	–70	2.75	7.0	76.5	0.0359	0.131	–47.3	0.710	0.917	–	1.79
330°N	–85	2.75	6.0	56.2	0.0489	0.178	–59.1	0.412	0.914	–	1.04
165°N	80	2.25	8.5	112.8	0.0199	0.089	41.9	0.483	0.943	–	1.02
195°N	50	2.25	8.5	112.8	0.0199	0.089	31.3	0.867	0.943	–	1.84
225°N	20	2.25	7.7	92.6	0.0243	0.108	14.5	0.985	0.927	–	2.05
255°N	–10	2.25	7.6	90.2	0.0249	0.111	– 7.4	0.996	0.925	–	2.07
285°N	–40	2.25	7.2	80.9	0.0278	0.124	–29.6	0.938	0.919	–	1.94
315°N	–70	2.25	6.7	70.1	0.0321	0.143	–49.2	0.724	0.914	–	1.49
330°N	–85	2.25	6.6	68.0	0.0331	0.147	–54.1	0.386	0.914	–	0.79
165°N	80	1.75	7.9	97.4	0.0180	0.103	44.9	0.495	0.931	–	0.81
195°N	50	1.75	7.8	95.0	0.0184	0.105	33.6	0.878	0.929	–	1.43
225°N	20	1.75	7.3	83.2	0.0210	0.120	15.0	0.986	0.920	–	1.59
255°N	–10	1.75	7.2	80.9	0.0216	0.124	– 7.7	0.997	0.919	–	1.60
285°N	–40	1.75	6.7	70.1	0.0250	0.143	–31.2	0.946	0.914	–	1.51
315°N	–70	1.75	6.4	64.0	0.0273	0.156	–51.1	0.738	0.913	–	1.18
330°N	–85	1.75	6.6	68.0	0.0257	0.147	–54.1	0.386	0.914	–	0.62

direction	φ_0 (deg)	Hos (m)	T (s)	Lop (m)	Sop	h/Lop	φ(deg)	Kr	Ks	Hs/h graphs	Hs (m)
165°N	80	1.25	7.4	85.5	0.0146	0.117	47.8	0.508	0.922	–	0.59
195°N	50	1.25	7.3	83.2	0.0150	0.120	35.5	0.889	0.920	–	1.02
225°N	20	1.25	6.5	66.0	0.0189	0.152	16.3	0.990	0.913	–	1.13
255°N	–10	1.25	6.3	62.0	0.0202	0.161	– 8.4	0.998	0.913	–	1.14
285°N	–40	1.25	6.1	58.1	0.0215	0.172	–33.2	0.957	0.914	–	1.09
315°N	–70	1.25	5.8	52.5	0.0238	0.190	–55.5	0.777	0.916	–	0.89
330°N	–85	1.25	5.7	50.7	0.0247	0.197	–61.8	0.429	0.918	–	0.49
165°N	80	0.75	6.6	68.0	0.0110	0.147	53.2	0.538	0.914	–	0.37
195°N	50	0.75	6.5	66.0	0.0114	0.152	39.0	0.909	0.913	–	0.62
225°N	20	0.75	5.7	50.7	0.0148	0.197	17.6	0.993	0.918	–	0.68
255°N	–10	0.75	5.5	47.2	0.0159	0.212	– 9.0	0.999	0.921	–	0.69
285°N	–40	0.75	5.3	43.9	0.0171	0.228	–36.1	0.974	0.926	–	0.68
315°N	–70	0.75	5.1	40.6	0.0185	0.246	–60.9	0.839	0.931	–	0.59
330°N	–85	0.75	5.1	40.6	0.0185	0.246	–67.9	0.482	0.931	–	0.34
165°N	80	0.25	4.5	31.6	0.0079	0.316	72.3	0.756	0.954	–	0.18
195°N	50	0.25	4.5	31.6	0.0079	0.316	47.8	0.978	0.954	–	0.23
225°N	20	0.25	4.5	31.6	0.0079	0.316	19.3	0.998	0.954	–	0.24
255°N	–10	0.25	4.5	31.6	0.0079	0.316	– 9.7	1.000	0.954	–	0.24
285°N	–40	0.25	4.5	31.6	0.0079	0.316	–38.5	0.989	0.954	–	0.24
315°N	–70	0.25	4.5	31.6	0.0079	0.316	–65.4	0.906	0.954	–	0.22
330°N	–85	0.25	4.5	31.6	0.0079	0.316	–74.5	0.571	0.954	–	0.14

Annexure 2.8.b

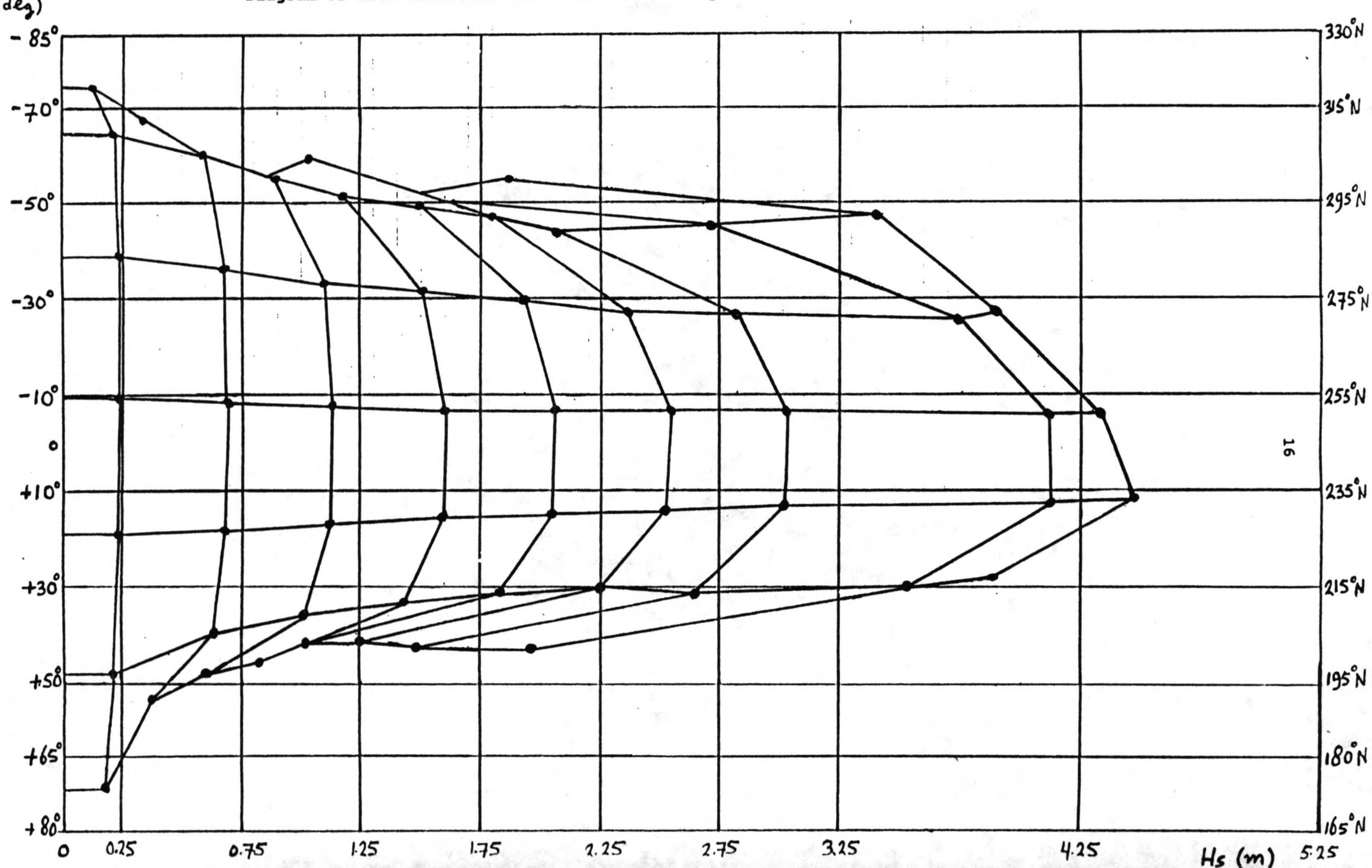
Wave transformation at 6 m waterdepth (h=6 m)

direction	φ_o (deg)	Hos (m)	T (s)	Lop (m)	Sop	h/Lop	φ(deg)	Kr	Ks	Hs/h graphs	Hs (m)
195°N	50	7.25	8.5	112.8	0.0643	0.053	24.7	0.841	1.013	0.520	2.62
225°N	20	7.25	8.5	112.8	0.0643	0.053	10.7	0.978	1.013	0.520	3.05
255°N	-10	7.25	6.5	66.0	0.1098	0.091	- 6.8	0.996	0.941	0.460	2.75
285°N	-40	7.25	6.5	66.0	0.1098	0.091	-26.1	0.923	0.941	0.460	2.55
195°N	50	5.25	9.5	140.9	0.0373	0.043	22.3	0.834	1.051	0.529	2.65
225°N	20	5.25	9.4	138.0	0.0380	0.043	9.8	0.976	1.051	0.532	3.12
255°N	-10	5.25	8.7	118.2	0.0444	0.051	- 5.3	0.995	1.020	0.529	3.16
285°N	-40	5.25	7.8	95.0	0.0553	0.063	-22.2	0.910	0.986	0.510	2.78
315°N	-70	5.25	7.0	76.5	0.0686	0.078	-37.1	0.655	0.958	0.480	1.89
330°N	-85	5.25	6.5	66.0	0.0795	0.091	-42.9	0.345	0.941	0.460	0.95
165°N	80	4.25	8.2	105.0	0.0405	0.057	33.6	0.457	1.001	0.501	1.37
195°N	50	4.25	8.9	123.7	0.0344	0.049	23.8	0.838	1.027	0.508	2.55
225°N	20	4.25	9.5	140.9	0.0302	0.043	9.8	0.976	1.051	0.511	2.99
255°N	-10	4.25	9.1	129.3	0.0329	0.046	- 5.1	0.994	1.038	0.509	3.04
285°N	-40	4.25	8.5	112.8	0.0377	0.053	-20.1	0.903	1.013	0.503	2.73
315°N	-70	4.25	7.4	85.5	0.0497	0.070	-35.3	0.647	0.971	0.489	1.90
330°N	-85	4.25	7.0	76.5	0.0556	0.078	-39.8	0.337	0.958	0.476	0.96
165°N	80	3.25	8.3	107.6	0.0302	0.056	33.3	0.456	1.004	0.471	1.29
195°N	50	3.25	8.6	115.5	0.0281	0.052	24.4	0.840	1.017	0.467	2.35
225°N	20	3.25	8.7	118.2	0.0275	0.051	10.6	0.978	1.020	0.468	2.75
255°N	-10	3.25	8.3	107.6	0.0302	0.056	- 5.6	0.989	1.004	0.471	2.79
285°N	-40	3.25	8.3	107.6	0.0302	0.056	-21.0	0.906	1.004	0.471	2.56
315°N	-70	3.25	7.6	90.2	0.0360	0.067	-34.5	0.644	0.977	0.464	1.79
330°N	-85	3.25	6.8	72.2	0.0450	0.083	-41.0	0.340	0.951	0.445	0.91
165°N	80	2.75	8.7	118.2	0.0233	0.051	31.8	0.452	1.020	0.438	1.19
195°N	50	2.75	8.8	120.9	0.0227	0.050	24.0	0.839	1.023	0.439	2.21
225°N	20	2.75	8.1	102.4	0.0269	0.059	11.3	0.979	0.996	0.435	2.56
255°N	-10	2.75	7.9	97.4	0.0282	0.062	- 5.8	0.995	0.989	-	2.71
285°N	-40	2.75	7.9	97.4	0.0282	0.062	-22.0	0.909	0.989	-	2.47
315°N	-70	2.75	7.0	76.5	0.0359	0.078	-37.1	0.655	0.958	-	1.73
330°N	-85	2.75	6.0	56.2	0.0489	0.107	-46.4	0.356	0.928	-	0.91
165°N	80	2.25	8.5	112.8	0.0199	0.053	32.4	0.454	1.013	-	1.03
195°N	50	2.25	8.5	112.8	0.0199	0.053	24.7	0.841	1.013	-	1.92
225°N	20	2.25	7.7	92.6	0.0243	0.065	11.7	0.980	0.982	-	2.17
255°N	-10	2.25	7.6	90.2	0.0249	0.067	- 6.0	0.995	0.977	-	2.19
285°N	-40	2.25	7.2	80.9	0.0278	0.074	-23.8	0.915	0.964	-	1.98
315°N	-70	2.25	6.7	70.1	0.0321	0.086	-38.9	0.663	0.947	-	1.41
330°N	-85	2.25	6.6	68.0	0.0331	0.088	-42.2	0.343	0.945	-	0.73
165°N	80	1.75	7.9	97.4	0.0180	0.062	35.1	0.461	0.989	-	0.80
195°N	50	1.75	7.8	95.0	0.0184	0.063	26.7	0.848	0.986	-	1.46
225°N	20	1.75	7.3	83.2	0.0210	0.072	12.3	0.981	0.968	-	1.67
255°N	-10	1.75	7.2	80.9	0.0216	0.074	- 6.3	0.995	0.964	-	1.68
285°N	-40	1.75	6.7	70.1	0.0250	0.086	-25.5	0.921	0.947	-	1.53
315°N	-70	1.75	6.4	64.0	0.0273	0.094	-40.6	0.671	0.938	-	1.10
330°N	-85	1.75	6.6	68.0	0.0257	0.088	-42.2	0.343	0.945	-	0.57

direction	φ_o (deg)	Hos (m)	T (s)	Lop (m)	Sop	h/Lop	φ(deg)	Kr	Ks	Hs/h graphs	Hs (m)
165°N	80	1.25	7.4	85.5	0.0146	0.070	37.2	0.467	0.971	-	0.57
195°N	50	1.25	7.3	83.2	0.0150	0.072	28.4	0.855	0.968	-	1.03
225°N	20	1.25	6.5	66.0	0.0189	0.091	13.5	0.983	0.941	-	1.16
255°N	-10	1.25	6.3	62.0	0.0202	0.097	- 7.0	0.992	0.935	-	1.16
285°N	-40	1.25	6.1	58.1	0.0215	0.103	-27.4	0.929	0.931	-	1.08
315°N	-70	1.25	5.8	52.5	0.0238	0.114	-44.4	0.692	0.924	-	0.80
330°N	-85	1.25	5.7	50.7	0.0247	0.118	-48.7	0.363	0.921	-	0.42
165°N	80	0.75	6.6	68.0	0.0110	0.088	41.6	0.482	0.945	-	0.34
195°N	50	0.75	6.5	66.0	0.0114	0.091	31.6	0.869	0.941	-	0.61
225°N	20	0.75	5.7	50.7	0.0148	0.118	14.9	0.986	0.921	-	0.68
255°N	-10	0.75	5.5	47.2	0.0159	0.127	- 7.7	0.997	0.918	-	0.69
285°N	-40	0.75	5.3	43.9	0.0171	0.137	-30.7	0.944	0.916	-	0.65
315°N	-70	0.75	5.1	40.6	0.0185	0.148	-50.0	0.729	0.914	-	0.50
330°N	-85	0.75	5.1	40.6	0.0185	0.148	-54.3	0.386	0.914	-	0.26
165°N	80	0.25	4.5	31.6	0.0079	0.190	59.7	0.587	0.916	-	0.13
195°N	50	0.25	4.5	31.6	0.0079	0.190	42.2	0.931	0.916	-	0.21
225°N	20	0.25	4.5	31.6	0.0079	0.190	17.4	0.992	0.916	-	0.23
255°N	-10	0.25	4.5	31.6	0.0079	0.190	- 8.8	0.998	0.916	-	0.23
285°N	-40	0.25	4.5	31.6	0.0079	0.190	-34.3	0.963	0.916	-	0.23
315°N	-70	0.25	4.5	31.6	0.0079	0.190	-55.5	0.777	0.916	-	0.18
330°N	-85	0.25	4.5	31.6	0.0079	0.190	-60.9	0.423	0.916	-	0.10

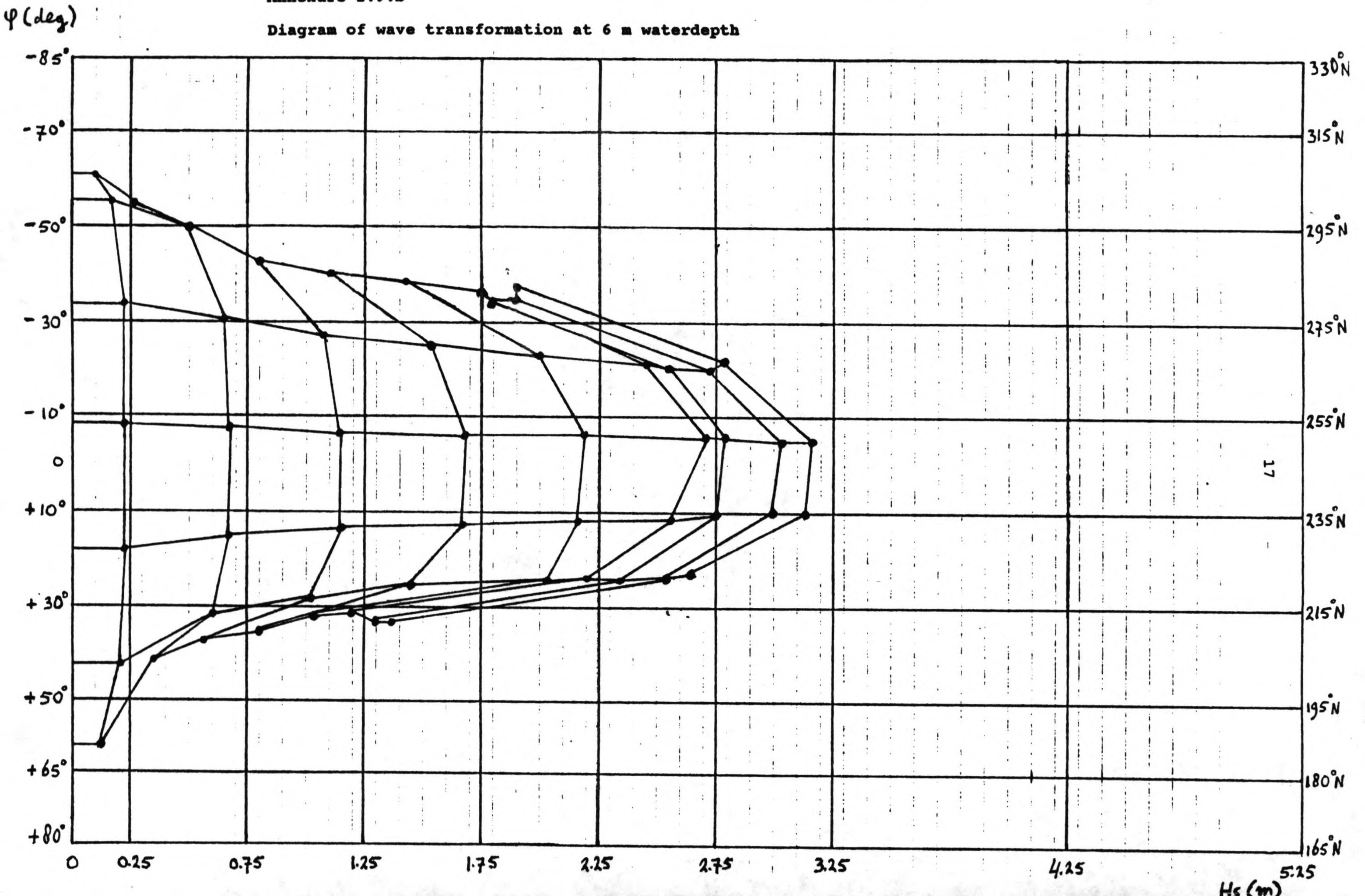
Annexure 2.9.a

Diagram of wave transformation at 10 m waterdepth



Annexure 2.9.b

Diagram of wave transformation at 6 m waterdepth



Annexure 2.10.a

transformation of wave climate at 10 m waterdepth
season: annual
input waveheight assumed to be significant waveheight

TABLE OF OCCURRENCE PROBABILITIES (%)

direction	significant waveheight (m)									
	<0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	total
180-215	0.44	3.17	2.14	1.43	0.20	0.03	0.02	-	-	7.43
215-235	0.14	1.22	1.58	1.31	0.85	0.34	0.08	0.12	0.03	5.67
235-255	0.18	1.65	2.24	2.26	1.81	1.06	0.49	0.61	0.12	10.42
255-275	0.34	2.64	3.80	4.01	3.20	2.06	0.89	0.90	-	17.84
275-295	0.62	4.50	5.73	3.04	1.40	0.50	0.19	0.25	-	16.23
295-330	3.57	15.14	0.81	0.18	0.05	-	-	-	-	19.75
total	5.29	28.32	16.30	12.23	7.51	3.99	1.67	1.88	0.15	77.34

Annexure 2.10.b

transformation of wave climate at 6 m waterdepth

season: annual

input waveheight assumed to be significant waveheight

TABLE OF OCCURRENCE PROBABILITIES (%)

direction	significant waveheight (m)							
	<0.25	0.25–0.75	0.75–1.25	1.25–1.75	1.75–2.25	2.25–2.75	2.75–3.25	total
180–215	0.96	2.43	1.19	0.03	–	–	–	4.61
215–235	0.24	1.64	2.07	2.10	0.88	0.40	0.04	7.37
235–255	0.29	1.89	2.62	2.65	2.43	2.32	1.19	13.39
255–275	0.58	3.20	4.78	4.40	3.83	3.90	0.52	21.21
275–295	1.24	12.33	5.76	1.75	0.41	0.01	–	21.50
295–330	4.94	4.33	–	–	–	–	–	9.27
total	8.25	25.82	16.42	10.93	7.55	6.63	1.75	77.35

Annexure 2.11.a

transformation of wave climate at 10 m waterdepth

season: annual

input waveheight assumed to be significant waveheight

TABLE OF EXCEEDANCE PROBABILITIES (%)

direction	significant waveheight (m)										
	0.00	0.25	0.75	1.25	1.75	2.25	2.75	3.25	4.25	5.25	7.25
180-215	7.43	6.99	3.82	1.68	0.25	0.05	0.02	0.00	0.00	0.00	0.00
215-235	5.67	5.53	4.31	2.73	1.42	0.57	0.23	0.15	0.03	0.00	0.00
235-255	10.42	10.24	8.59	6.35	4.09	2.28	1.22	0.73	0.12	0.00	0.00
255-275	17.84	17.50	14.86	11.06	7.05	3.85	1.79	0.90	0.00	0.00	0.00
275-295	16.23	15.61	11.11	5.38	2.34	0.94	0.44	0.25	0.00	0.00	0.00
295-330	19.75	16.18	1.04	0.23	0.05	0.00	0.00	0.00	0.00	0.00	0.00
total	77.34	72.05	43.73	27.43	15.20	7.69	3.70	2.03	0.15	0.00	0.00

Annexure 2.11.b

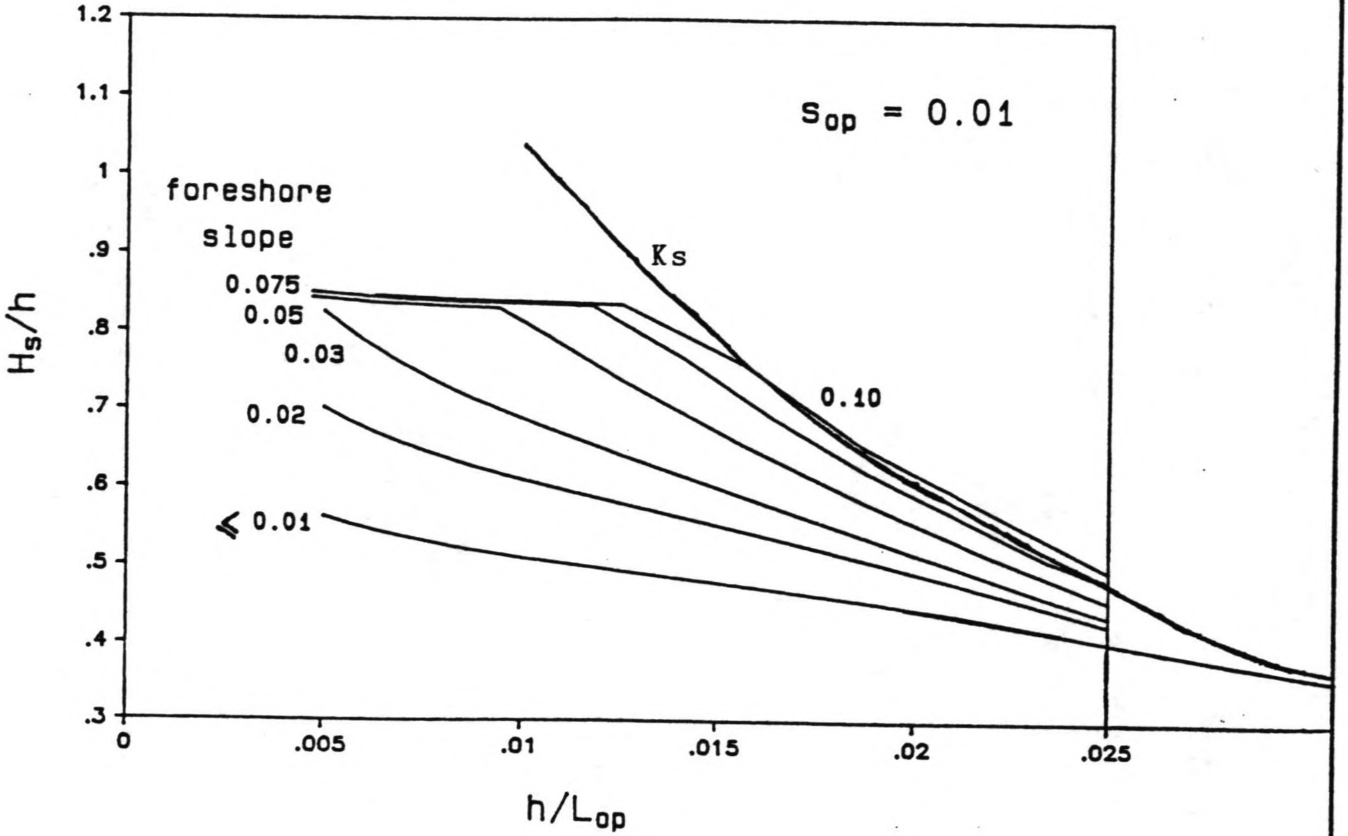
transformation of wave climate at 6 m waterdepth

season: annual

input waveheight assumed to be significant waveheight

TABLE OF EXCEEDANCE PROBABILITIES (%)

direction	significant waveheight (m)								
	0.00	0.25	0.75	1.25	1.75	2.25	2.75	3.25	4.25
180–215	4.61	3.65	1.22	0.03	0.00	0.00	0.00	0.00	0.00
215–235	7.37	7.13	5.49	3.42	1.32	0.44	0.04	0.00	0.00
235–255	13.39	13.10	11.21	8.59	5.94	3.51	1.19	0.00	0.00
255–275	21.21	20.63	17.43	12.65	8.25	4.42	0.52	0.00	0.00
275–295	21.50	20.26	7.93	2.17	0.42	0.01	0.00	0.00	0.00
295–330	9.27	4.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	77.35	69.10	43.28	26.86	15.93	8.38	1.75	0.00	0.00



Description of parameters

$s_{op} = H_{os}/L_{op}$

$L_{op} = gT_p^2/2\pi$

s_{op} = deep water wave steepness

L_{op} = deep water wave length

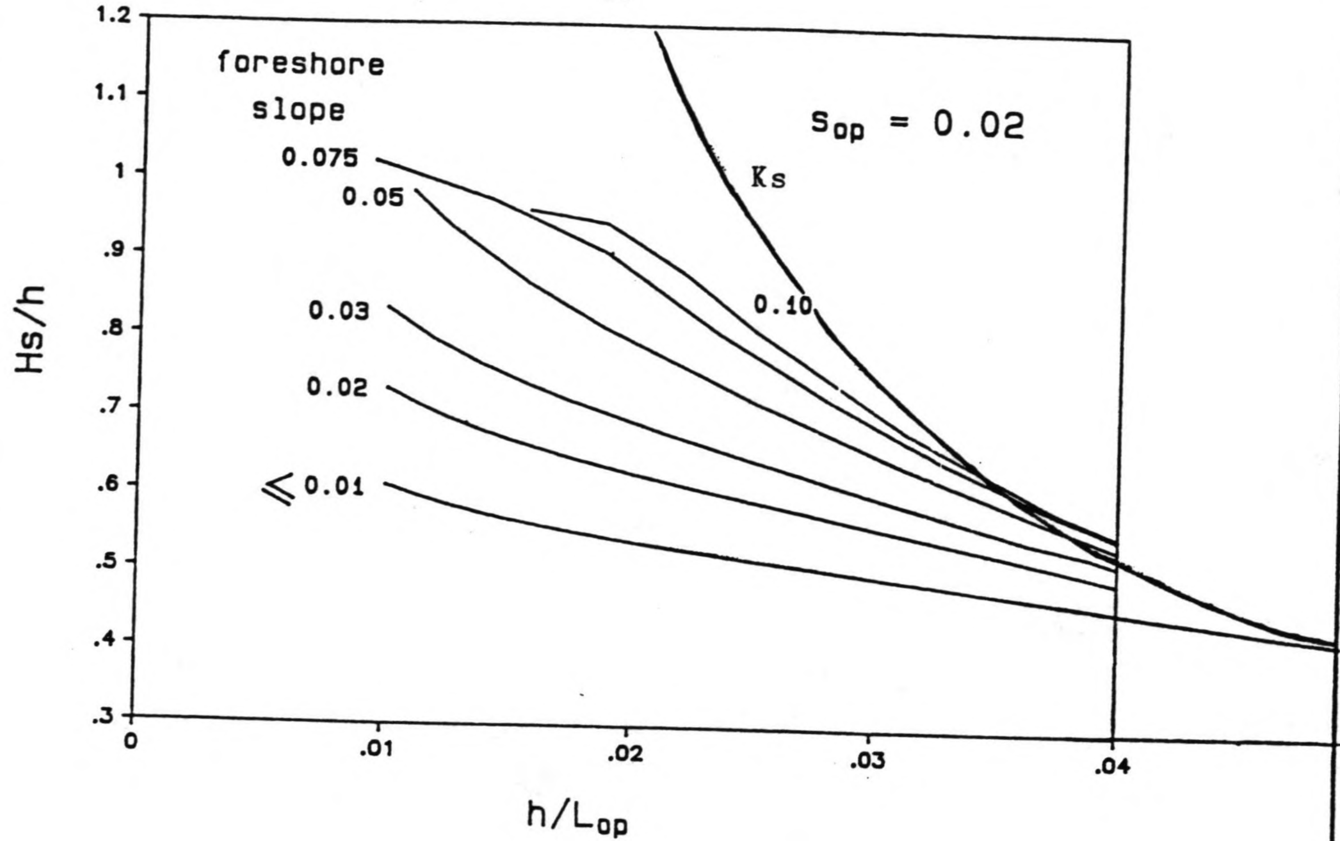
H_{os} = significant wave height on deep water

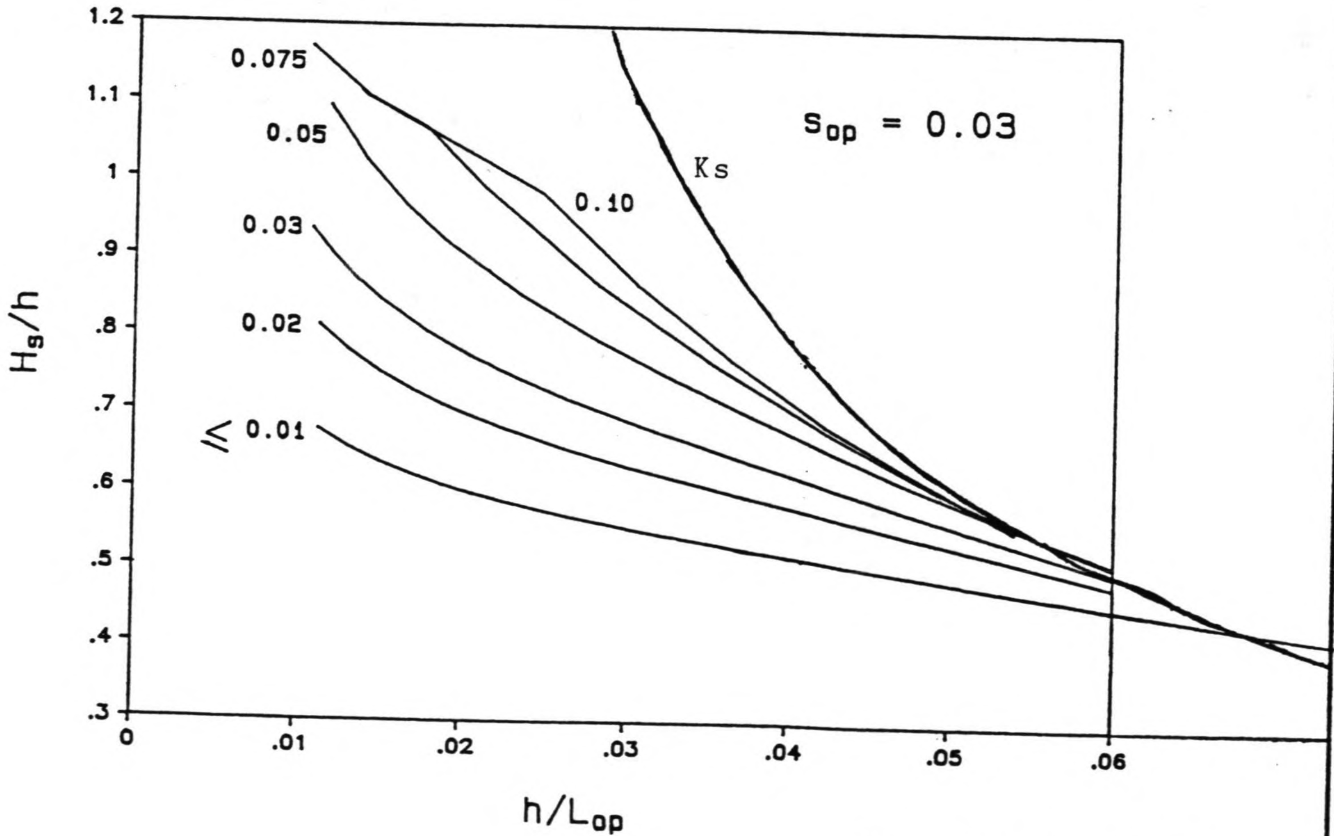
H_s = local maximum significant wave height

T_p = peak period

h = local water depth

MAXIMUM SIGNIFICANT WAVE HEIGHT ON SLOPE FOR DEEP WATER WAVE STEEPNESS s_{op}=0.01	**Annexure 2.12**
DELFT HYDRAULICS	FIG. 1



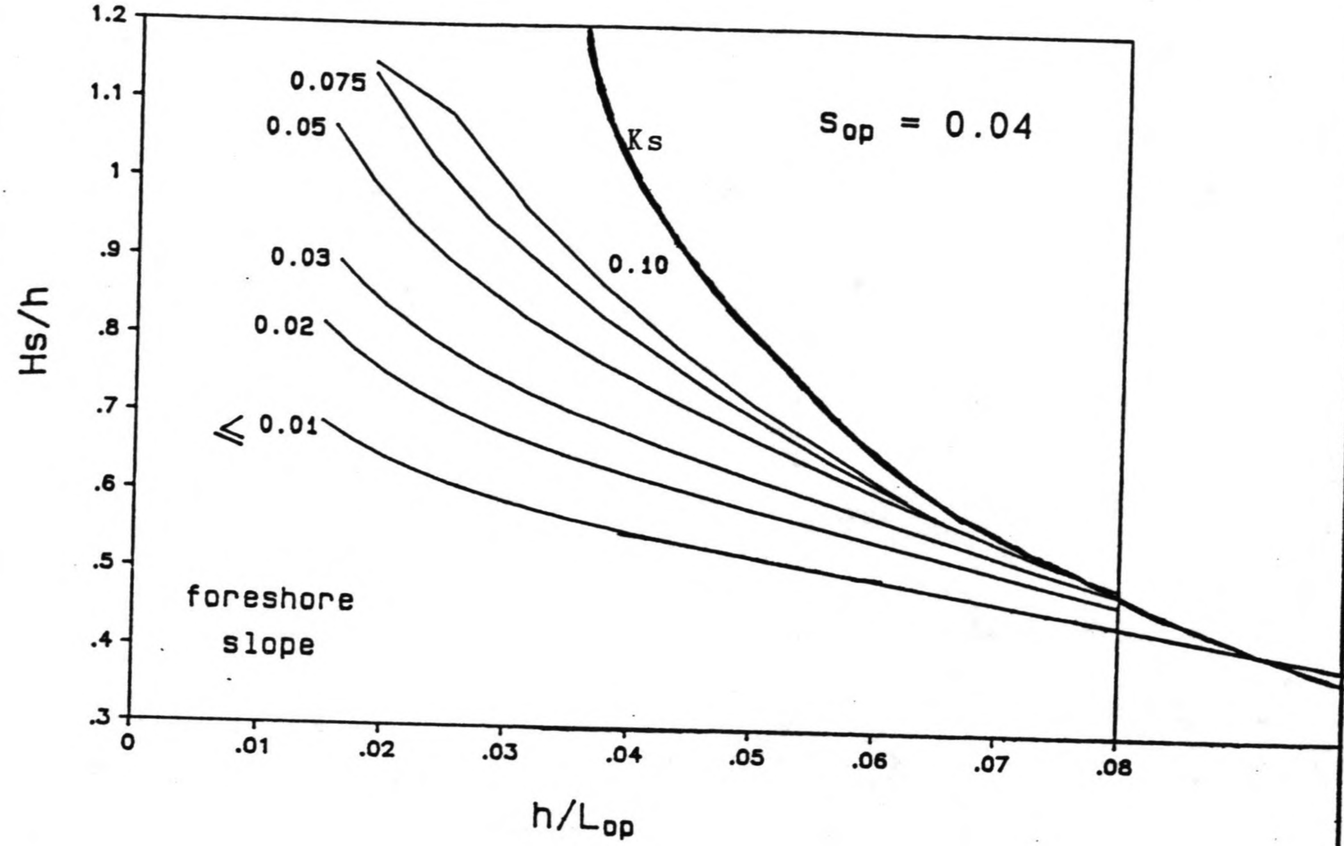


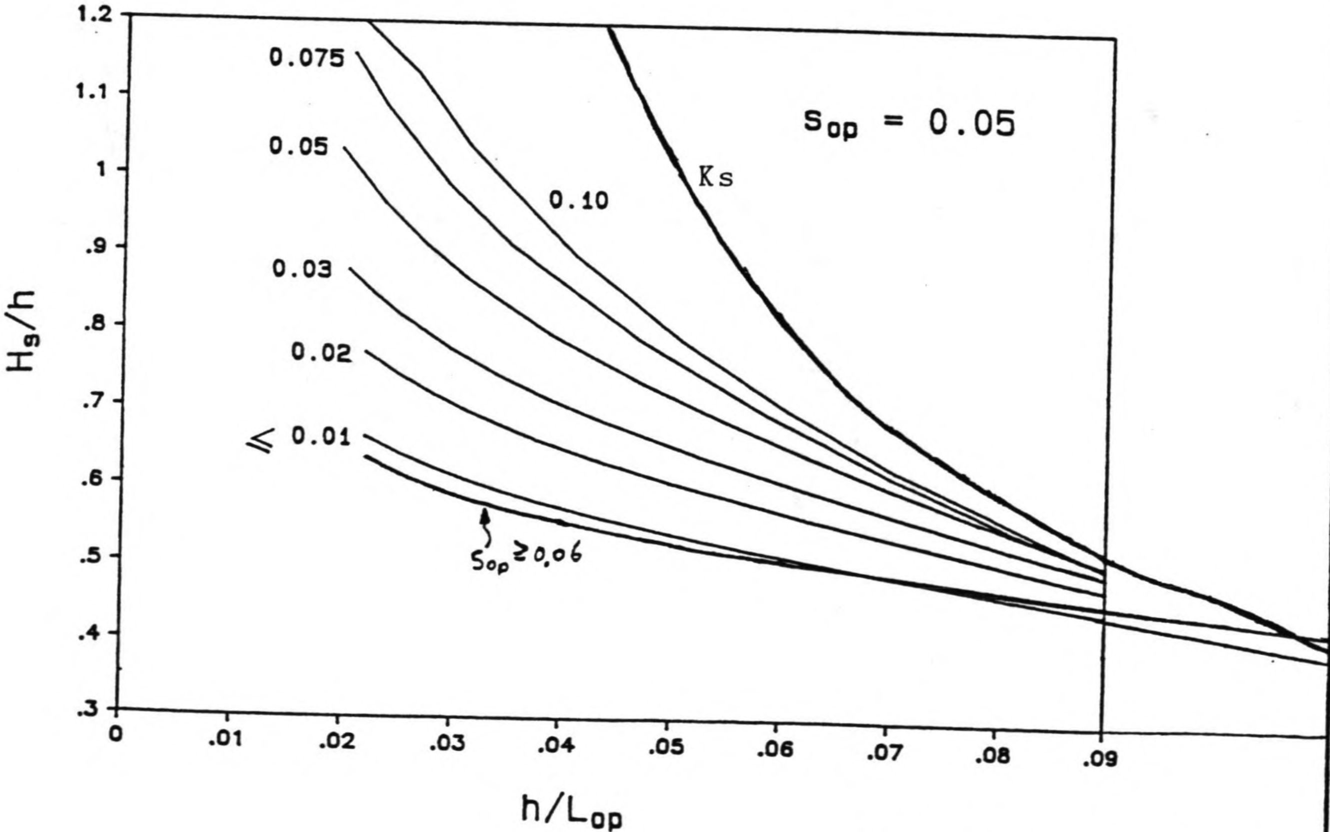
For legend, see Fig. 1

MAXIMUM SIGNIFICANT WAVE HEIGHT ON SLOPE
FOR WAVE STEEPNESSES s_{op}=0.02 AND 0.03

DELFT HYDRAULICS

FIG. 2



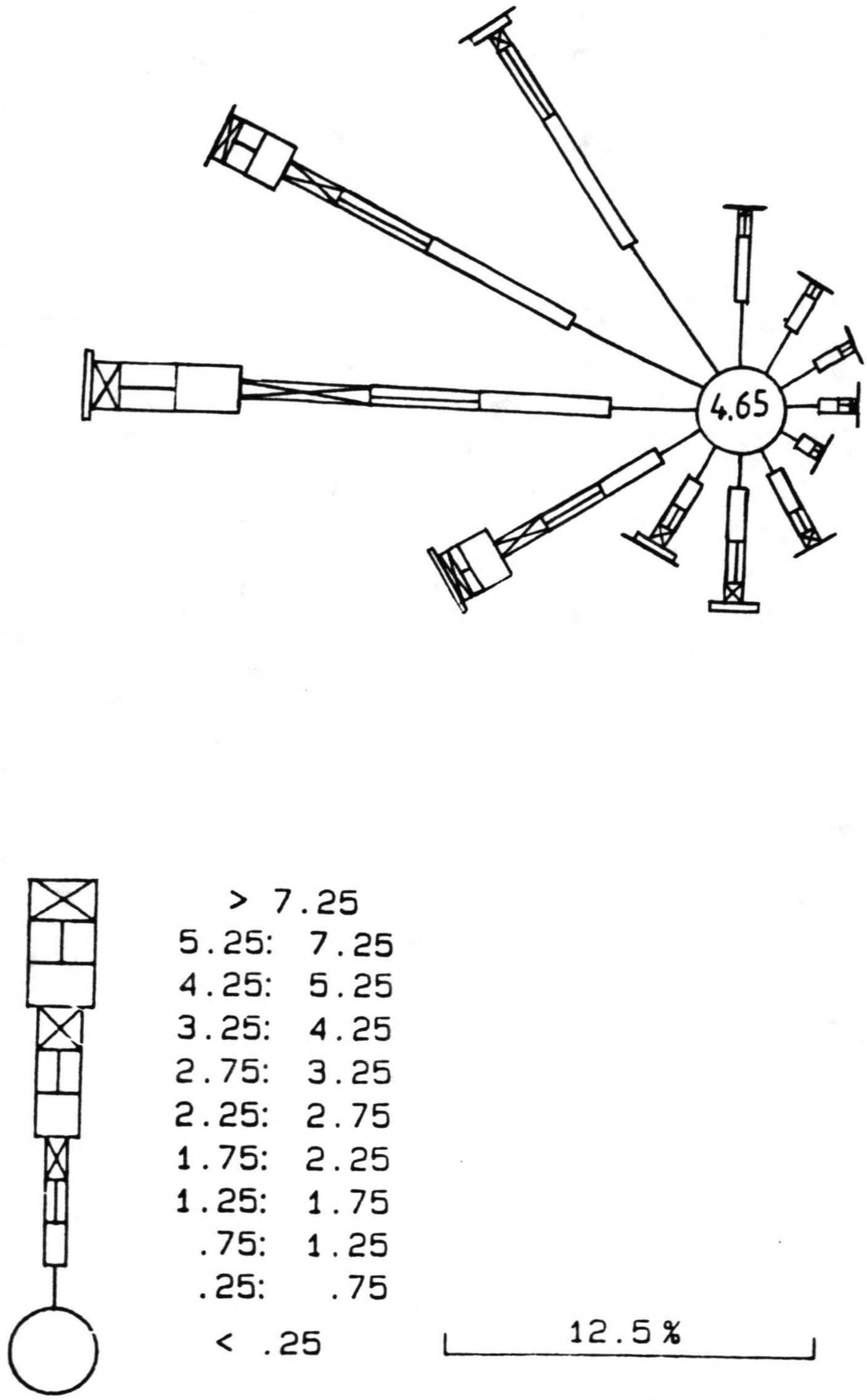


For legend, see Fig. 1

MAXIMUM SIGNIFICANT WAVE HEIGHT ON SLOPE FOR WAVE STEEPNESSES s_{op}=0.04 AND 0.05

DELFT HYDRAULICS

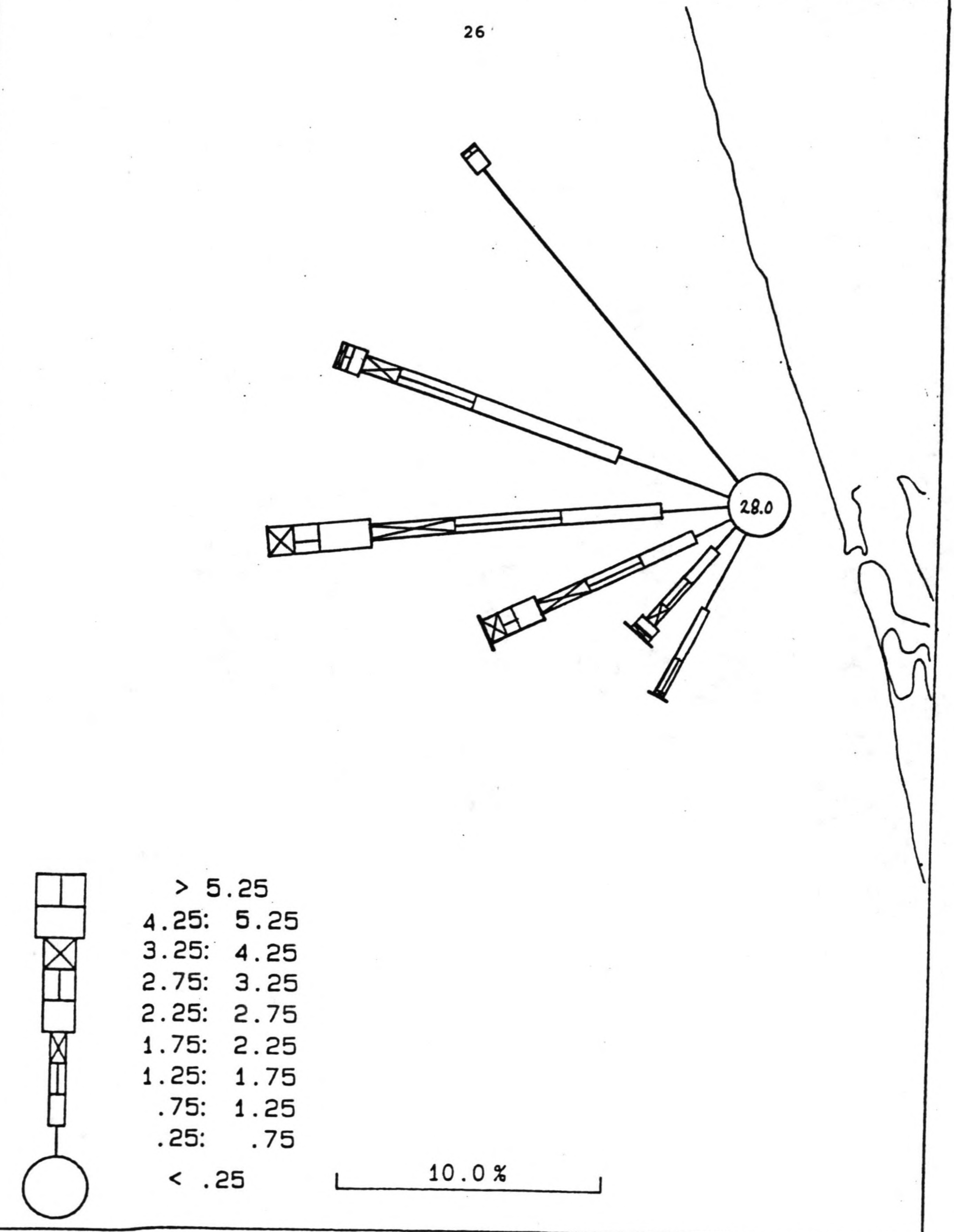
FIG. 3



Wave height rose on
open sea near Cochin

ALL YEAR

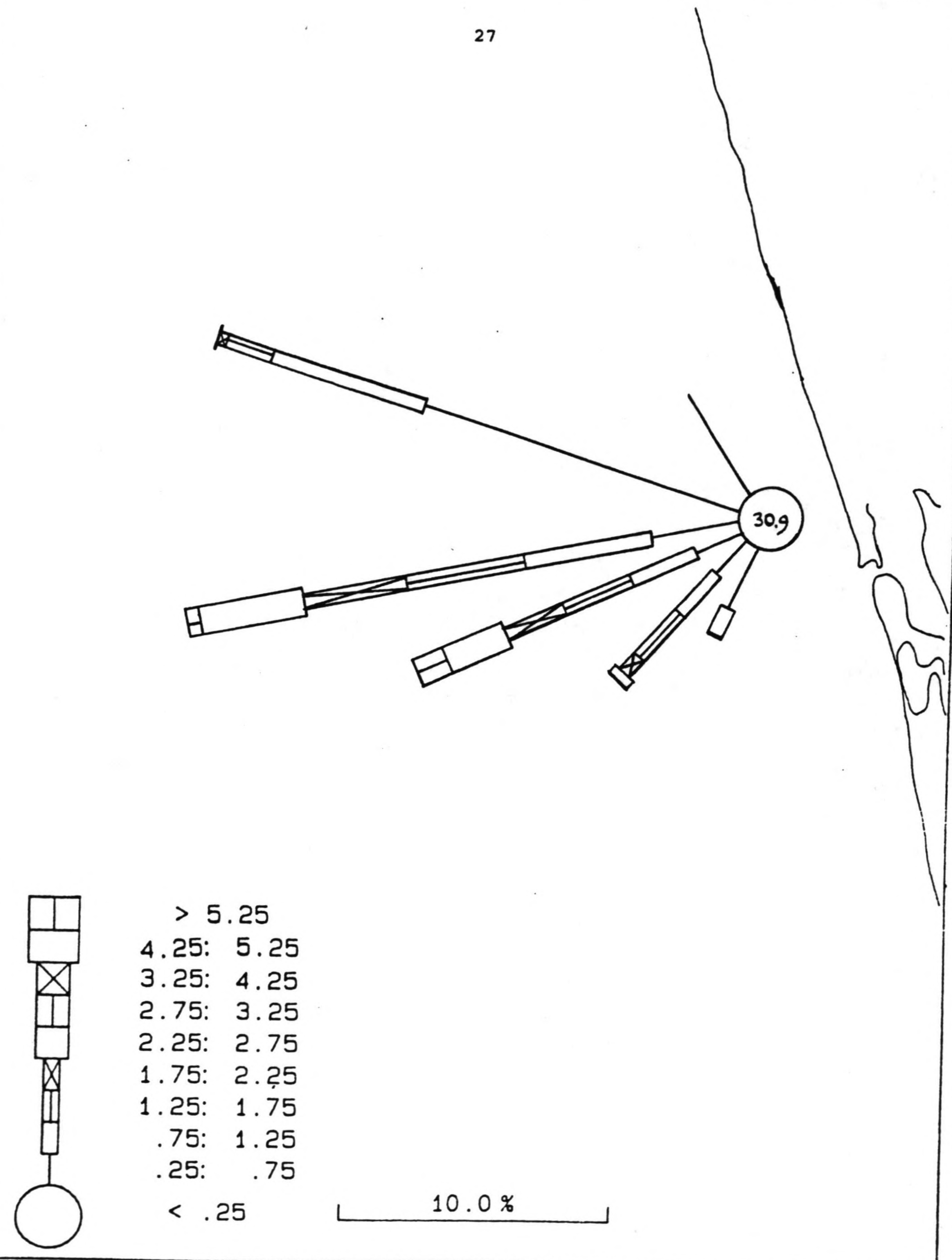
Annexure 2.13



Wave height rose at
10 m depth

ALL YEAR

Annexure 2.14.a



Wave height rose at
6 m depth

ALL YEAR

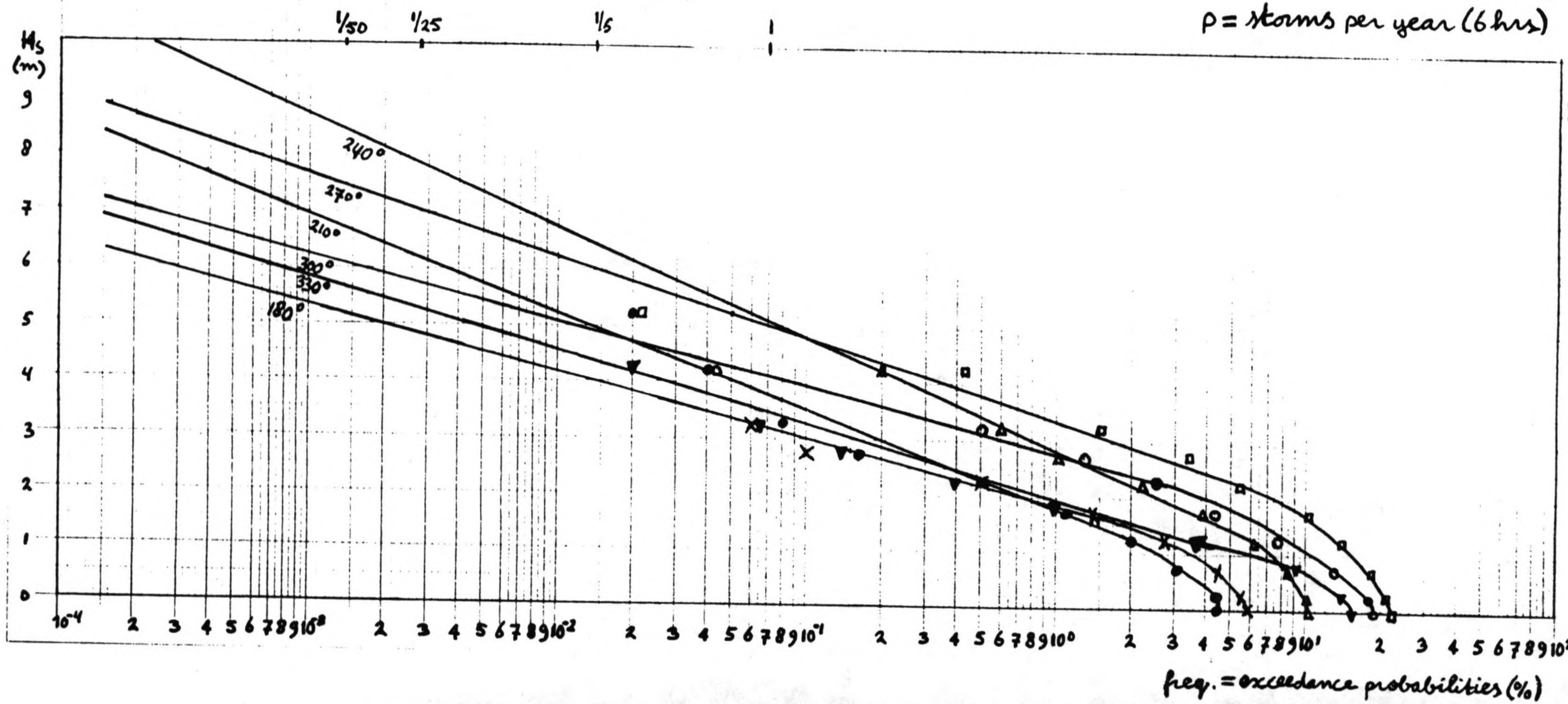
Annexure 2.14.b

Annexure 2.15

Exceedance curves for Hs; open sea wave climate (deep water)

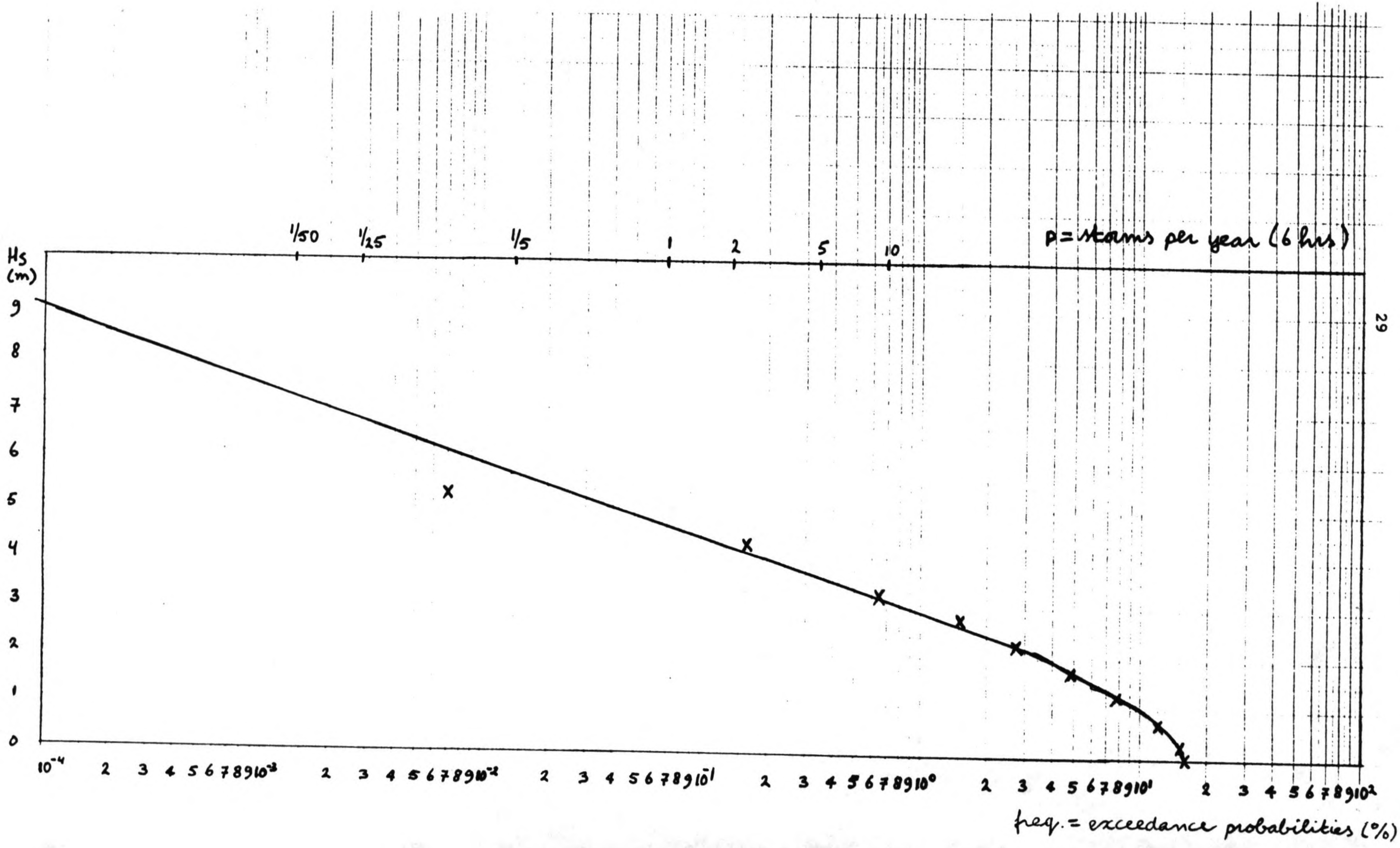
deep water wave direction	frequency of occurrence	symbol
180° N	5,85 %	×
210°	4.55 %	●
240°	10.58 %	△
270°	22.09 %	□
300°	18.97 %	○
330°	15.51 %	▼

$$\frac{p*6}{365*24}*100\% = \text{freq.}$$



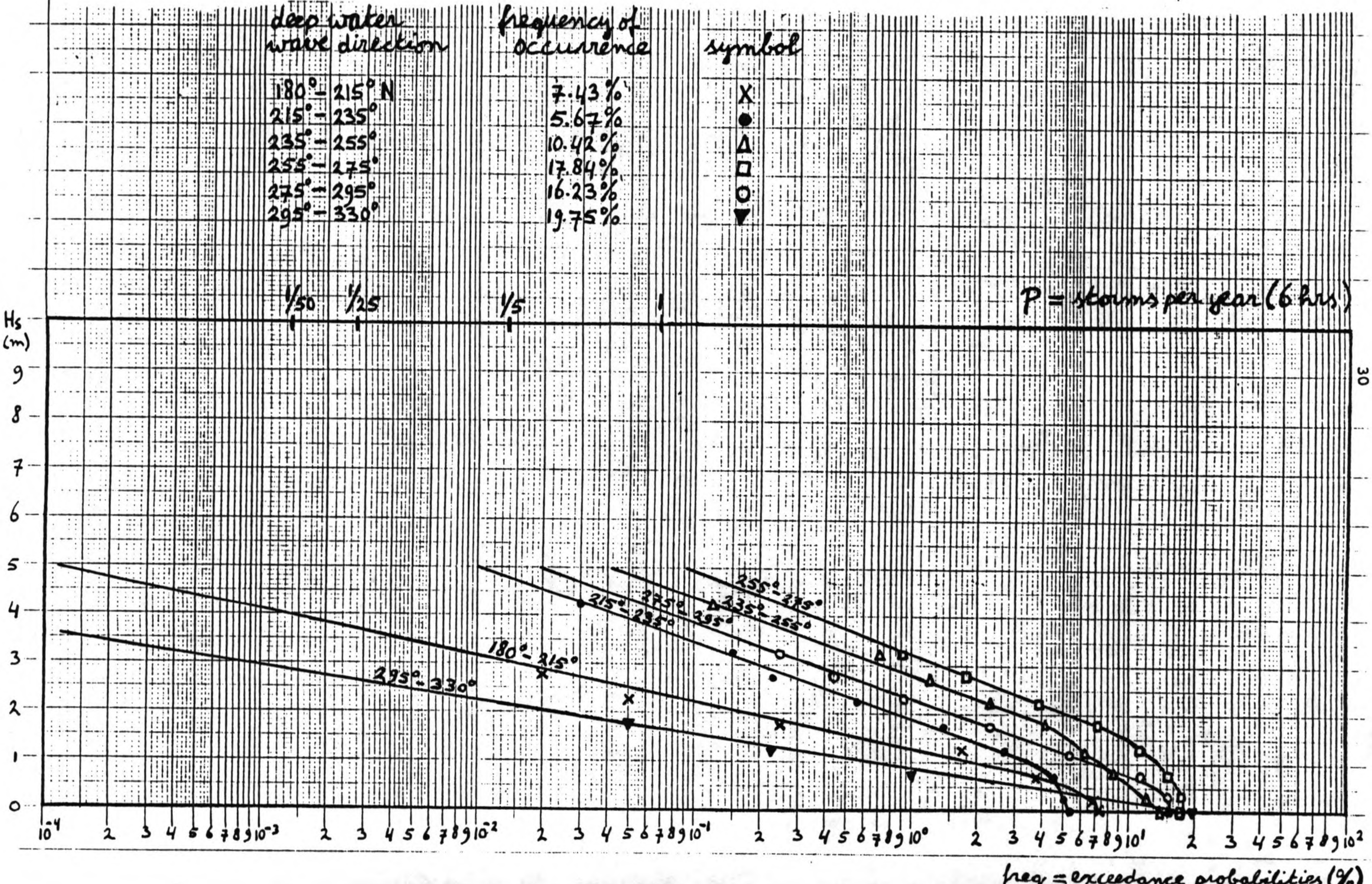
Annexure 2.16

Resulting exceedance curve for Hs; open sea wave climate (deep water)



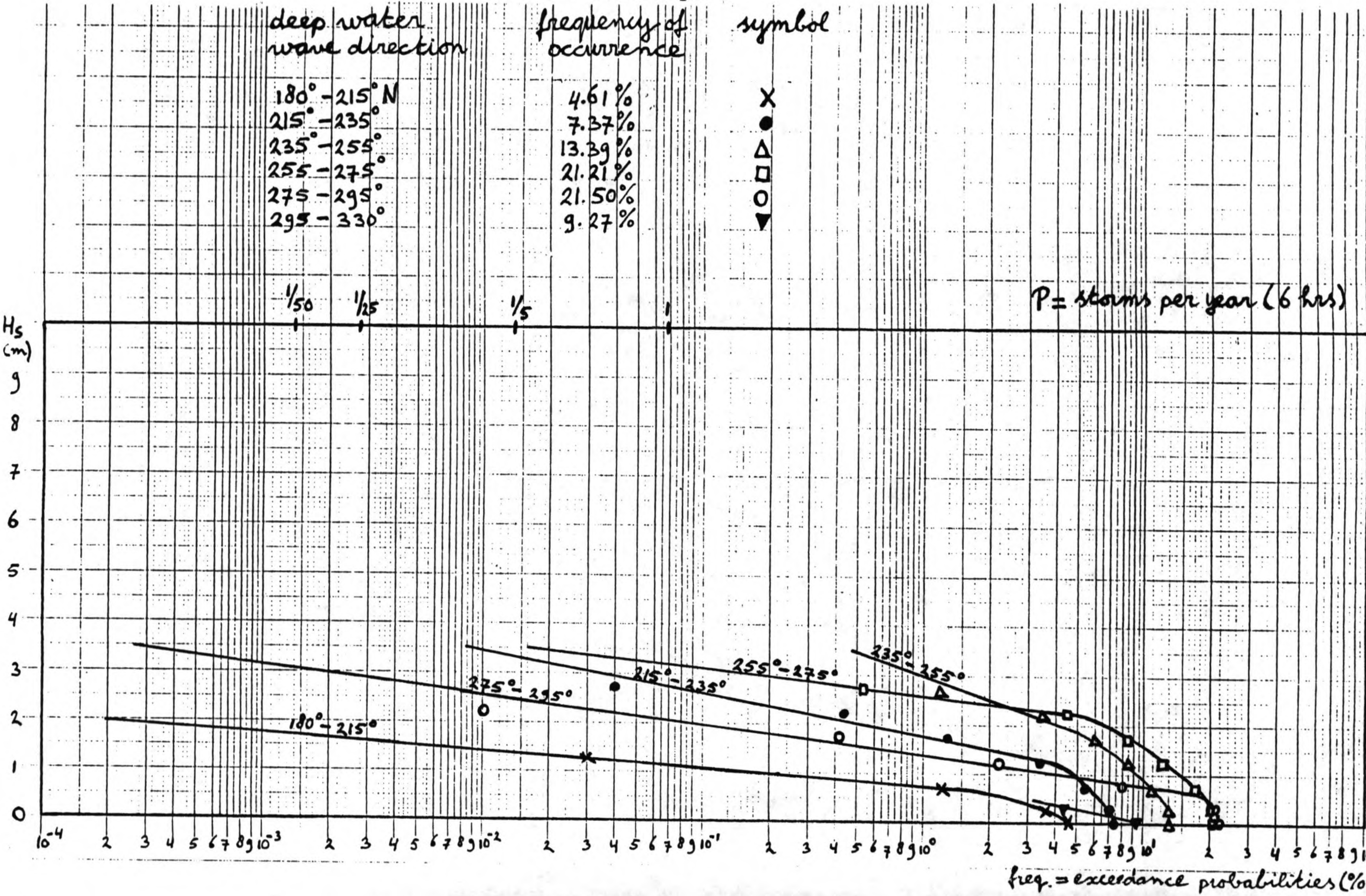
Annexure 2.17.a

Exceedance curves for Hs; 10 m waterdepth



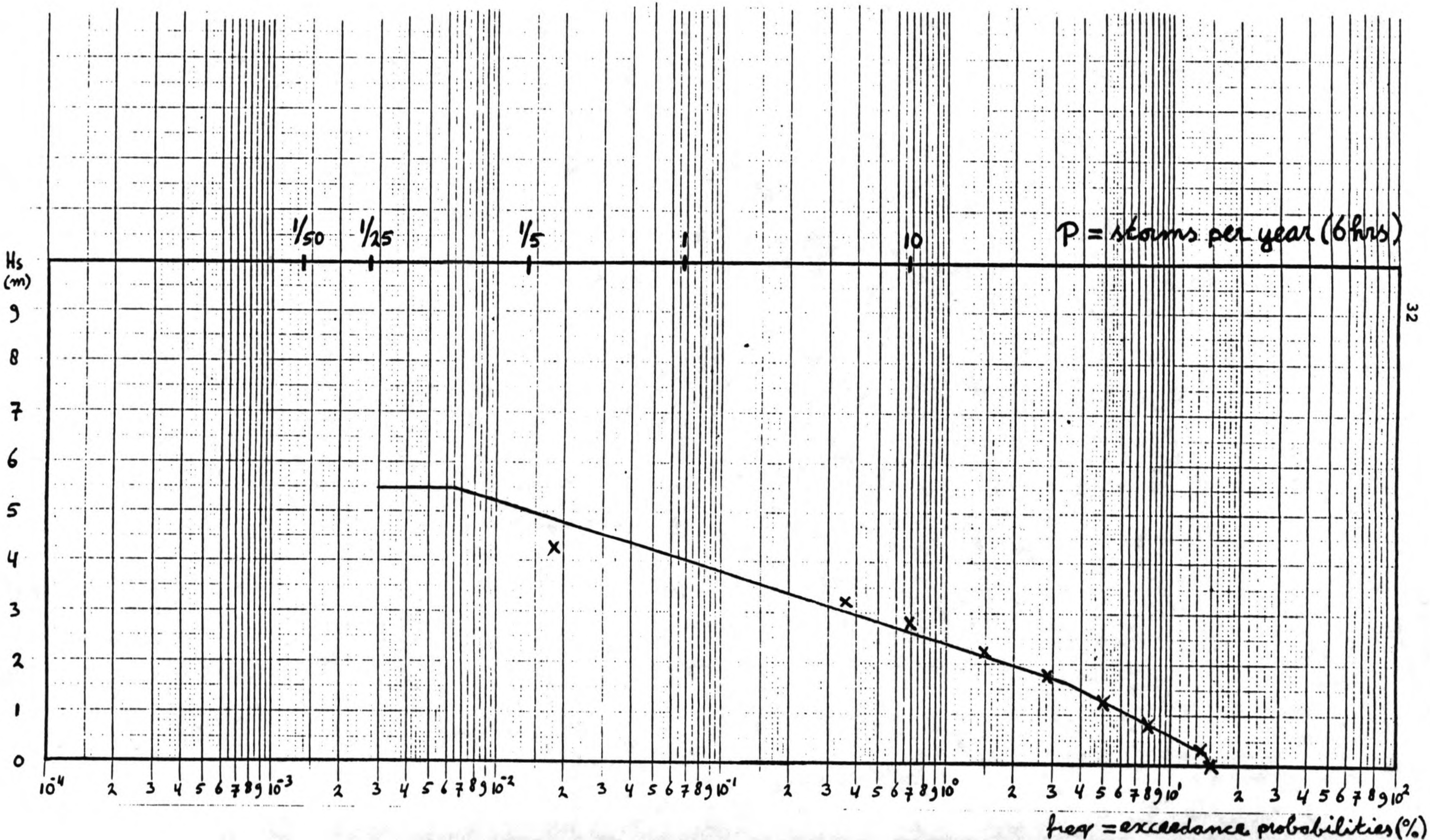
Annexure 2.17 b

Exceedance curves for Hs; 6 m waterdepth



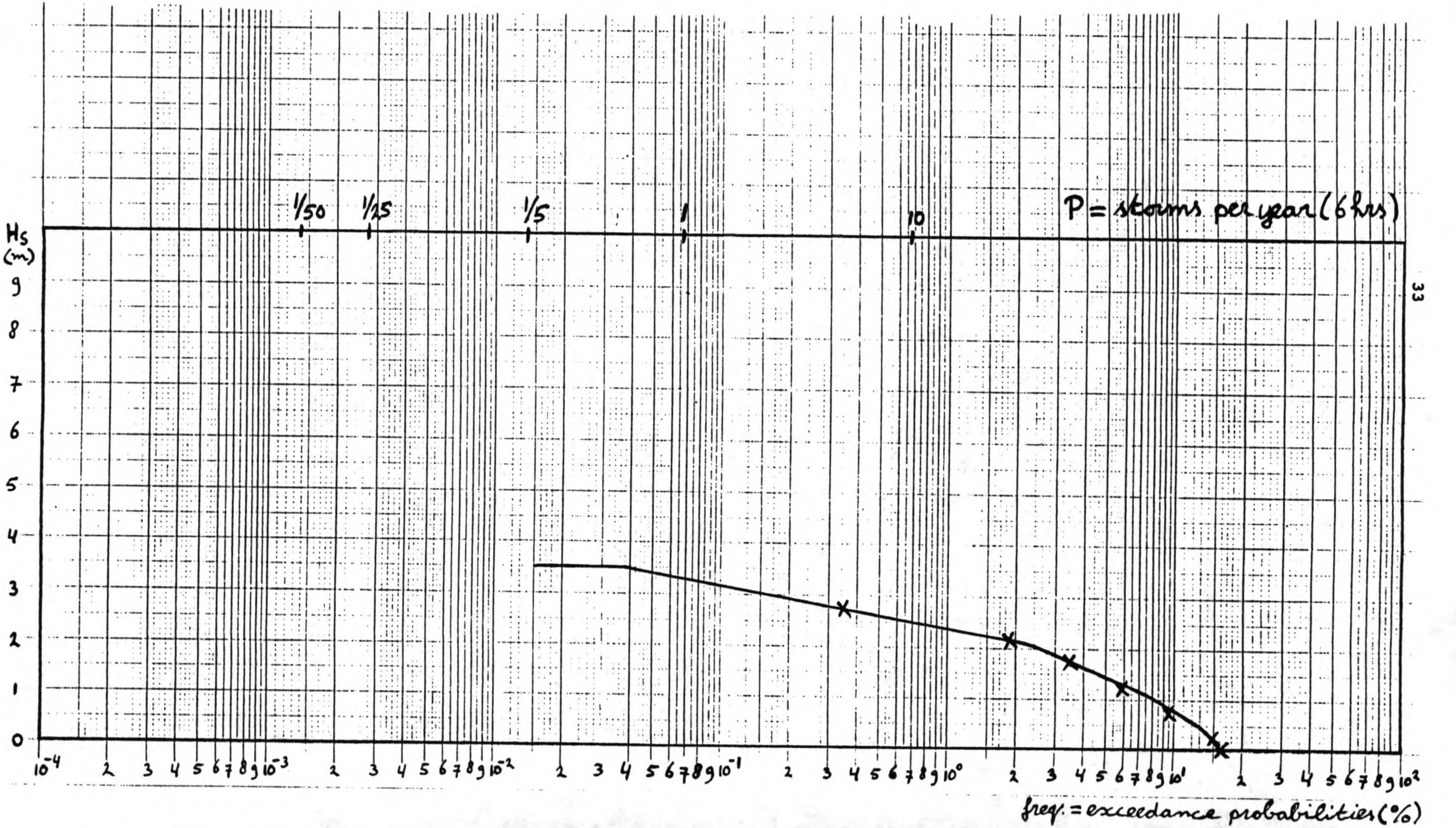
Annexure 2.18.a

Resulting exceedance curve for Hs; 10 m waterdepth



Annexure 2.18.b

Resulting exceedance curve for Hs; 6 m waterdepth



Annexure 2.19

Longshore sediment transport calculations

The CERC-formula is used to calculate the longshore sediment transport. The problem is how to find the representative values of waveheights (Hos), which can be used for this calculation.

Description of parameters in this annexure:

- Lop is the deep water wave length (in m)
- Hos is the deep water significant waveheight (in m)
- Hb is the breaker waveheight (in m)
- hb is the breaker depth (in m)
- Co is the deep water wave celerity (in m/s)
- Cb is the wave celerity at the breakerline (in m/s)
- φo is the deep water angle of wave approach (in deg)
- φb is the angle of wave approach at the breakerline (in deg)
- γ is the breaker index
- Ks is the shoaling coefficient
- Kr is the refraction coefficient
- Sx is the longshore sediment transport rate (in m^3/year)
- P is the occurrence probability per year (in %)
- \+ is sediment transport from S to N
- \- is sediment transport from N to S
- g is the acceleration of gravity (in m/s^2)

In the CERC-formula, the sediment transport is a function of (Hb^2)*Cb ; the value of wave celerity (Cb) is a function of √hb (Cb=√(g*hb)), and the waterdepth at the breakerline (hb) is a function of the breaker waveheight (hb=Hb/γ).
So, it is reasonable to assume the longshore sediment transport at the breakerzone is a function of H^2.5 .
A representative value of the waveheight (Hos) for each direction can be taken as the 2.5^{th} root of the sum of all waveheights raised to the 2.5^{th} power, multiplied by the percentage of observation of each waveheight.

So, for different directions the representative waveheights can be calculated, using annexure 2.1 (see table 1):

table 1 Representative waveheights for different directions

P=occurrence probabilities (%)

$Hos^{2.5}$		180°	210°	240°	270°	300°	330°
$0.25^{2.5}$	*	0.18	0.14	0.26	0.49	0.81	1.11
$0.50^{2.5}$	*	1.21	1.31	1.70	3.07	4.96	5.34
$1.00^{2.5}$	*	1.70	1.09	2.39	4.49	5.46	5.28
$1.50^{2.5}$	*	1.40	0.85	2.35	3.84	3.42	2.75
$2.00^{2.5}$	*	0.87	0.65	1.66	4.53	1.80	0.61
$2.50^{2.5}$	*	0.38	0.34	1.19	2.22	1.21	0.28
$3.00^{2.5}$	*	0.04	0.08	0.42	1.98	0.79	0.08
$3.75^{2.5}$	*	0.06	0.04	0.40	1.03	0.49	0.04
$4.75^{2.5}$	*	0.00	0.02	0.20	0.40	0.04	0.02
$6.25^{2.5}$	*	0.00	0.02	0.00	0.02	0.00	0.00
$\Sigma\ Hos^{2.5}*P$	=	16.71	15.98	57.60	143.73	65.55	23.37
Hos	=	1.52	1.65	1.97	2.12	1.64	1.18

These values of waveheights are used in the longshore sediment transport calculations.
The mean significant wave period (T) is about 6 s, so :

$$Lop = \frac{g*T^2}{2*\pi} = 56.2 \text{ m} \quad \text{and} \quad Co = \frac{Lop}{T} = 9.4 \text{ m/s}$$

The breaker waveheight/breaker depth ratio (=breaker index) is assumed to be 0.7.
For the different directions φo is known, so φb can be calculated by trial and error (choose hb, calculate Hb, control Hb/hb < or > γ, choose new hb, etc.).
When φb is known, the sediment transport rates (in m^3/year) for various directions can be calculated using the CERC-formula:

$$Sx=0.02*Hos^2*Co*\cos(\varphi o)*\sin(\varphi b)*(365*24*3600)*P$$

The results are presented in table 2:

table 2 Longshore sediment transport rate

direction from N	φo	Hos (m)	hb (m)	φb	Ks	Kr	Hb (m)	γ	P (%)	Sx(*10^6 m^3/y)
180°	+65°	1.52	1.65	+22.0°	1.134	0.675	1.16	0.70	5.85	+0.127
210°	+35°	1.65	2.30	+16.2°	1.060	0.924	1.62	0.70	4.55	+0.168
240°	+ 5°	1.97	2.85	+ 2.7°	1.020	0.999	2.01	0.71	10.58	+0.114
270°	-25°	2.12	3.00	-13.3°	1.013	0.965	2.07	0.69	22.09	-1.227
300°	-55°	1.64	2.00	-22.0°	1.086	0.787	1.40	0.70	18.97	-0.650
330°	-85°	1.18	0.70	-15.9°	1.371	0.301	0.49	0.70	15.51	-0.031
				gross sediment transport rate:						2.317

The gross sediment transport rate is 2.317*10^6 m^3/year , the net sediment transport rate is about 1.50*10^6 m^3/year from N to S.
This annual net transport rate is very high and can be explained by the high values of occurrence probabilities for the directions 270° N to 330° N (causing transport from N to S) compared with the occurrence probabilities for the directions 180° N to 240° N (causing transport from S to N).

So, another longshore sediment transport calculation is made, using waveheight data from 'Ocean Wave Statistics' in annexure 2.5.

The representative waveheights for different directions are determined in table 3:

table 3 Representative waveheights for different directions

$Hos^{2.5}$		P=occurrence probabilities (%) 180°	210°	240°	270°	300°	330°
$0.25^{2.5}$	*	0.33	0.43	0.43	0.71	0.67	0.54
$0.50^{2.5}$	*	0.81	1.03	1.52	1.78	1.56	1.29
$1.00^{2.5}$	*	1.67	2.73	4.77	4.77	2.99	1.62
$1.50^{2.5}$	*	1.57	3.04	5.05	5.28	2.10	0.72
$2.00^{2.5}$	*	0.65	1.43	3.76	3.23	1.06	0.26
$2.50^{2.5}$	*	0.35	0.64	2.18	1.64	0.43	0.08
$3.00^{2.5}$	*	0.16	0.21	0.80	0.67	0.14	0.02
$3.50^{2.5}$	*	0.03	0.11	0.34	0.24	0.05	0.02
$4.00^{2.5}$	*	0.03	0.06	0.12	0.12	0.02	0.01
$4.50^{2.5}$	*	0.03	0.03	0.06	0.02	0.00	0.00
$5.00^{2.5}$	*	0.00	0.00	0.02	0.01	0.00	0.00
$\Sigma Hos^{2.5}*P$	=	18.72	36.14	89.58	75.34	23.29	7.20
Hos	=	1.62	1.69	1.86	1.75	1.46	1.20

The mean significant wave period is about 6 s.
The sediment transport rates (in m^3/year) for various directions are presented in table 4:

table 4 Longshore sediment transport rate

direction from N	φo	Hos (m)	hb (m)	φb	Ks	Kr	Hb (m)	γ	P (%)	Sx(*10^6 m^3/y)
180°	+65°	1.62	1.75	+22.8°	1.118	0.677	1.23	0.70	5.63	+0.143
210°	+35°	1.69	2.35	+16.4°	1.055	0.924	1.65	0.70	9.73	+0.380
240°	+ 5°	1.86	2.75	+ 2.6°	1.027	0.999	1.91	0.69	19.05	+0.177
270°	-25°	1.75	2.50	-12.2°	1.046	0.963	1.76	0.70	18.47	-0.642
300°	-55°	1.46	1.80	-20.8°	1.112	0.783	1.27	0.71	9.02	-0.230
330°	-85°	1.20	0.70	-15.9°	1.371	0.301	0.495	0.71	4.56	-0.009
					gross sediment transport rate:					1.581

The net sediment transport rate is about 0.18*10^6 m^3/year from N to S.
This annual net transport rate is much lower compared to the annual net transport rate resulting from table 2: the values of occurrence probabilities for the directions 270° N to 330° N (causing transport from N to S) are lower than the values in table 2 and are nearly equal to the values of occurrrence probabilities for the directions 180° N to 240° N (causing transport from S to N). Although the annual gross sediment transport rate is still high, the annual net transport rate turns out to be rather low.

Annexure 4.1

Dredging quantities and costs for alternative 3 (terminal near shore)

Taking the cost of capital dredging in sand as RS 35 per cu m, the cost of maintenance dredging as RS 45 per cu m.

The total capital dredging quantities and costs for different vessel sizes are summarized in table 1:

table 1 Capital dredging quantities and costs (RS 35 per cu m)

vessel size (dwt)	quantity (million m^3)	cost (million RS)
40,000	11.6	406
50,000	12.8	448
60,000	15.2	532
80,000	18.3	641
100,000	21.8	763
120,000	25.3	886

Estimation of siltation in the harbour:

- estimated net suspended sediment concentration: 50 mg/l (50*10^-3 kg/m^3)
- tides per year: (365*24)/12.4=706
- density of dry sediment particles: 2650 kg/m^3
- density of in-situ sediment: 1200 kg/m^3
- density of sea water: 1025 kg/m^3
- volume of water filled voids in 1 m^3 of sediment (Vv):
  1200=(2650)*(1-Vv)+(1025*Vv) ⇒ Vv=0.89
- dry sediment particles contained in 1 m^3 of sediment:
  (1-0.89)*2650=292 kg
- maximum tidal range: 1.10 m

The maintenance dredging quantities and costs for different vessel sizes are summarized in table 2:

table 2 Maintenance dredging quantities and costs (RS 45 per cu m)

vessel size (dwt)	dredged area A (m^2)	quantity* (kg/year)	volume (m^3/year)	cost (million RS)
40,000	1.81*10^6	7.0*10^7	239.7*10^3	11
50,000	1.93*10^6	7.5*10^7	256.8*10^3	12
60,000	2.14*10^6	8.4*10^7	287.7*10^3	13
80,000	2.43*10^6	9.4*10^7	321.9*10^3	14
100,000	2.71*10^6	10.5*10^7	359.6*10^3	16
120,000	2.97*10^6	11.5*10^7	393.8*10^3	18

* The siltation quantity in the harbour is: Q=A*1.10*(50*10^-3)*706
(in kg/year)

The sediment volume is spread over the harbour bottom in a layer, which is 0.13 m thick. As indicated in section 4.1.2.3, the allowance for siltation is 0.5 m, so the harbour should be dredged about once every four years.

Annexure 4.2

Dredging quantities and costs for alternative 4 (terminal near inlet)

The total capital dredging quantities and costs for different vessel sizes are summarized in table 1:

table 1 Capital dredging quantities and costs (RS 35 per cu m)

vessel size (dwt)	quantity (million m^3)	cost (million RS)
40,000	24.3	850
50,000	26.3	921
60,000	30.1	1054
80,000	35.1	1230
100,000	40.5	1416
120,000	45.5	1594

The maintenance dredging quantities and costs for different vessel sizes are summarized in table 2 (see also annexure 4.1):

table 2 Maintenance dredging quantities and costs (RS 45 per cu m)

vessel size (dwt)	dredged area A (m^2)	quantity (kg/year)	volume (m^3/year)	cost (million RS)
40,000	2.44*10^6	9.5*10^7	325.3*10^3	15
50,000	2.60*10^6	10.1*10^7	345.9*10^3	16
60,000	2.86*10^6	11.1*10^7	380.1*10^3	17
80,000	3.21*10^6	12.5*10^7	428.1*10^3	19
100,000	3.56*10^6	13.8*10^7	472.6*10^3	21
120,000	3.86*10^6	15.0*10^7	513.7*10^3	23

The harbour should be dredged once every four years.

The silt-trap should be dredged once every two years:

quantity: 2.1*10^6 m^3/year
cost: RS 95*10^6

Annexure 4.3

Dredging quantities and costs for alternative 5 (terminal near power plant)

The total capital dredging quantities and costs for different vessel sizes are summarized in table 1:

table 1 Capital dredging quantities and costs (RS 35 per cu m)

vessel size (dwt)	quantity (million m^3)	cost (million RS)
40,000	19.0	665
50,000	20.8	728
60,000	24.0	840
80,000	28.0	980
100,000	32.4	1134
120,000	36.8	1288

The maintenance dredging quantities and costs for different vessel sizes are summarized in table 2 (see also annexure 4.1):

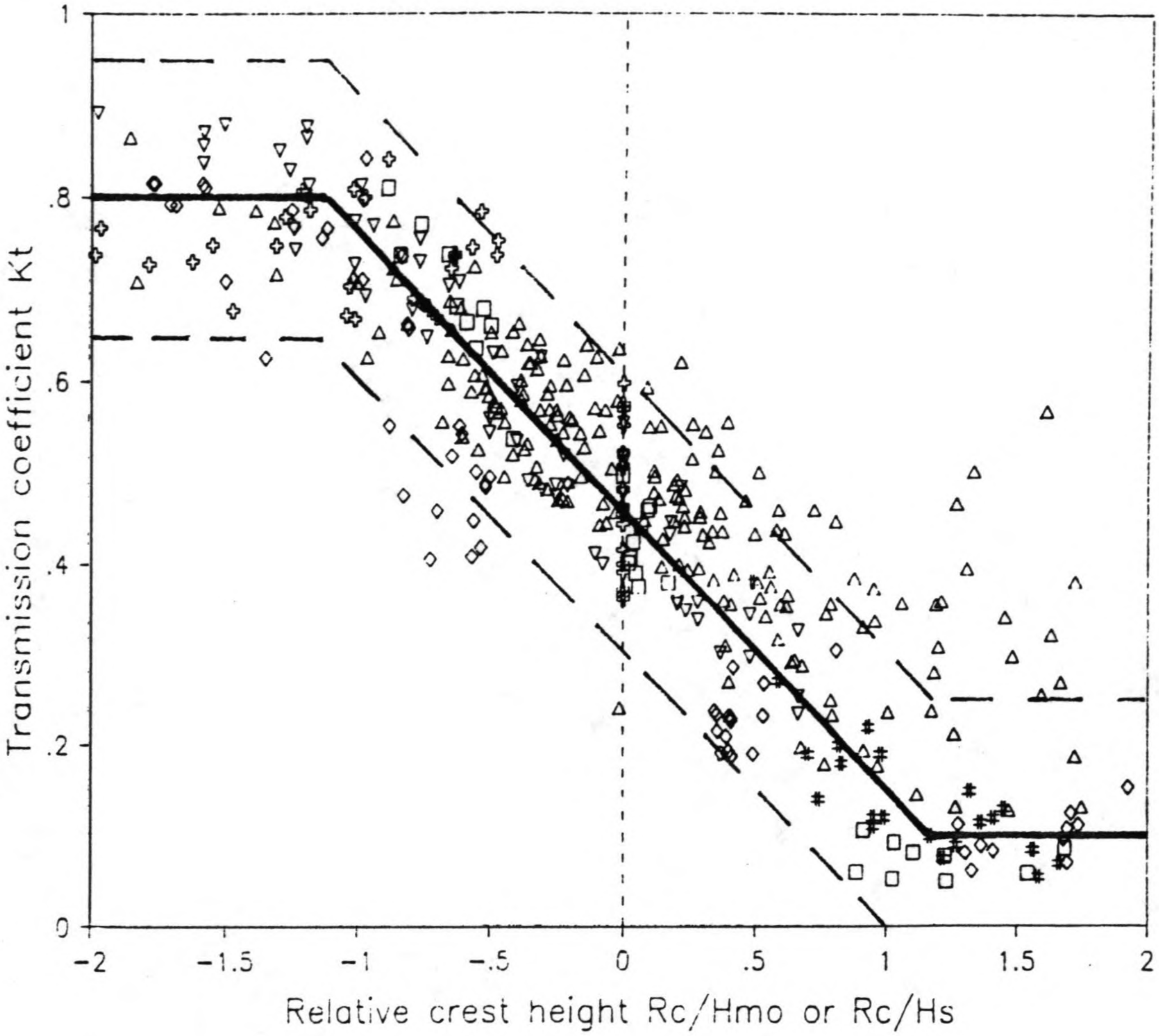
table 2 Maintenance dredging quantities and costs (RS 45 per cu m)

vessel size (dwt)	dredged area A (m^2)	quantity (kg/year)	volume (m^3/year)	cost (million RS)
40,000	2.05*10^6	8.0*10^7	274.0*10^3	12
50,000	2.20*10^6	8.5*10^7	291.1*10^3	13
60,000	2.44*10^6	9.5*10^7	325.3*10^3	15
80,000	2.76*10^6	10.7*10^7	366.4*10^3	16
100,000	3.08*10^6	12.0*10^7	411.0*10^3	18
120,000	3.36*10^6	13.0*10^7	445.2*10^3	20

The harbour should be dredged once every four years.

The silt-trap should be dredged once every two years:

quantity: 2.1*10^6 m^3/year
cost: RS 95*10^6



proposed formula for K_t

90% confidence levels

$-2.0 < R_c/H_s < -1.13$ $\quad K_t = 0.80$

$-1.13 < R_c/H_s < 1.2$ $\quad K_t = 0.46 - 0.3\ R_c/H_s$

$1.2 < R_c/H_s < 2.0$ $\quad K_t = 0.10$

Reliability: $\sigma(K_t) = 0.09$

90% confidence levels: $K_t \pm 0.15$

95% confidence levels: $K_t \pm 0.18$

PROPOSED FORMULA FOR WAVE TRANSMISSION WITH ALL DATA	**Annexure 5.1**
DELFT HYDRAULICS	

Annexure 5.2

Approximate cost of construction per m' length of rubble mound breakwater at 19 m waterdepth

To calculate the repair cost, the (approximate) cost of construction and the (approximate) cost of the cover layer have to be determined first.
This is done for two significant waveheights by determining roughly the dimensions of the breakwater; the average value of costs of the cover layer is used to calculate the repair cost.

The formulae of Van der Meer are used, assuming no damage (S=2):

$(Hs/\delta*Dn50)*\sqrt{\xi z} = 6.2*(P^{0.18})*(S/\sqrt{N})^{0.2}$ for plunging waves,

$(Hs/\delta*Dn50) = 1.0*(P^{-0.13})*(S/\sqrt{N})^{0.2}*(\xi z^{P})*\sqrt{\cot\alpha}$ for surging waves,

$$\xi z = \frac{\tan\alpha}{\sqrt{(2*\pi*Hs/g*T^2)}}$$

The transition from plunging waves to surging waves is:

$\xi z = (6.2*(P^{0.31})*\sqrt{\tan\alpha})^{1/(P+0.5)}$

The properties of the structure are:

- the mass density of the armour unit (ρa) is 2500 kg/m^3 (concrete cubes)
- the mass density of sea water (ρ) is 1025 kg/m^3
- the relative mass density (δ)is 1.44
- the damage level (S) is 2 (no damage)
- the permeability coefficient (P) is 0.5
- the slope angle (α): cotα is 1.5 (slope 1:1.5)
- the number of waves (N) is 3000
- the average design period (T) is 10 s
- Dn50 is the nominal diameter (in m)

1) Hs = 7.0 m

primary armour layer:
ξz=3.15 (plunging waves)
Dn50=3.06 m
weight: (3.06^3)*2500=71,632 kg, say 72 T
layer thickness: $t=m*k*(W/\rho a*g)^{1/3}$, where

W is weight (in Newton)
m is no. of layers of armour units (m=2)
k is emperical layer coefficient
(1.1 for random placement)

So, t=6.75 m

berm:	size of stone in the berm: W/10=7200 kg width of the berm: $3*k*(W/\rho a*g)^{1/3}$=4.7 m height of the berm: $2*k*(W/\rho a*g)^{1/3}$=3.1 m
crest elevation (overtopping breakwater):	maximum waveheight in protected area: Ht=0.8 m design waveheight (once per year): Hi=4.75 m (see section 4.1.1 and annexure 2.16) using annexure 5.1: Kt=Ht/Hi=0.8/4.75=0.17=0.46-(0.3*Rc/Hs), so Rc=4.6 m crest elevation is: Rc + design water level at 19 m depth=4.6+1.1=5.7 m (see section 2.2.6 and figure 2.2.6)
crest width:	$B=m'*K*(W/\rho a/g)^{1/3}$, where m'=3 (at least) so B=10.0 m
filter layer:	gravel, 1 m thick

volume of the breakwater per m' length: 1300 m^3
volume of the cover layer per m' length: 330 m^3
volume of concrete, assuming 45% voids: 0.55*330≈180 m^3
volume of rock: 1300-330=970 m^3
weight of rock (40% voids): 970*1.6≈1550 T

Initial cost of breakwater per m' length (see section 5.2):

- cost of concrete armour units of 180 m^3 (including transportation and placement):	180*1500= RS 270,000
- cost of rock of 1550 T (average price: RS 275 per T):	1550*275= RS 426,250 say RS 427,000

Armour unit cost per m waveheight: 270,000/7= RS 38,571

2) Hs = 5.0 m

primary armour layer: **ξz=3.72 (plunging waves)**
Dn50=2.37 m
weight: (2.37^3)*2500=33,280 kg, say 34 T
layer thickness: t=5.25 m

- cost of concrete armour units: (5.25/6.75)*270,000= RS 210,000

Armour unit cost per m waveheight: 210,000/5= RS 42,000
Average value of armour unit cost per m waveheight:

(38,571+42,000)/2=40,285 , say RS 40,000

The approximate cost of construction (initial cost) per m' length of rubble mound breakwater for 19 m waterdepth is: RS 40,000*Hs + 427,000.

Annexure 5.3

Repair cost per m' length of rubble mound breakwater at 19 m waterdepth

The dimensions of the cover layer of a breakwater are related to the design waveheight (Hs) corresponding to a 'no damage' criterion.
If the design waveheight is exceeded, displacement of armour units will occur.
For constant intervals ΔHs an amount of damage (w) can be calculated, assuming the damage is equal to: w=2*(S/100)*cost cover layer, where

S is the damage coefficient (formulae of V. d. Meer)

The recurrence interval of waves in the interval ΔHs (=p=storms per year) can be read from annexure 2.16.
The corresponding anticipated annual damage is equal to p*w.

The parameters for computation of the optimum cost of the breakwater are summarized in table 1.

The total anticipated annual damage is equal to Σ p*w.
The capitalized value of the sum depends on the life time of the structure; the present value of the (uniform) annual maintenance payments is determined by multiplying the annual payment by the present worth factor (pwf). As indicated in section 5.3, the pwf is 7.843 (for i=12% and n=25 years).
In table 2 the capitalized repair costs (S) for different design waveheights are given:

table 2 Capitalized repair cost

design waveheight Hs (m)	with repairing partial damage S=7.843*Σp*w (RS)	without repairing partial damage $S=7.843*(p*w)_{collapse}$ (RS)
4.0	495,560	230,192
5.0	82,022	19,670
6.0	14,666	-
7.0	3,569	-
8.0	714	-

This is shown graphically in figure 1.

table 1 Parameters for computation of optimum cost of breakwater

Hs	initial cost (total)	initial cost of cover layer	Hs<H<1.2*Hs			1.2*Hs<H<1.4*Hs			1.4*Hs<H<1.6*Hs			1.6*Hs<H<1.8*Hs collapse			
(m)	(RS)	(RS 40,000*Hs)	S	p	w	S	p	w	S	p	w	S	p	w	Σ p*w
4.0	587,000	160,000	2.92	2.19	9,344	5.45	0.51	17,440	9.33	0.15	29,856	14.88	0.05	587,000	63,185
5.0	627,000	200,000	2.82	0.47	11,280	5.29	0.091	21,160	9.02	0.02	36,080	14.48	0.004	627,000	10,458
6.0	667,000	240,000	2.86	0.098	13,728	5.36	0.017	25,728	9.21	0.002	44,208	-	-	-	1,870
7.0	707,000	280,000	2.83	0.025	15,848	5.30	0.002	29,680	-	-	-	-	-	-	455
8.0	747,000	320,000	2.85	0.005	18,240	-	-	-	-	-	-	-	-	-	91

w=2*(S/100)*cost of cover layer
If breakwater will collapse (S>10), w is equal to the total initial cost

The total cost is given by the sum of the initial cost (I) and the repair cost (S). The total costs for different design waveheights are given in table 3:

table 3 Total cost per m' length

design waveheight Hs (m)	with repairing partial damage I (RS)	S (RS)	total cost (RS)	without repairing partial damage I (RS)	S (RS)	total cost (RS)
4.0	587,000	495,560	1,082,560	587,000	230,192	817,192
5.0	627,000	82,022	709,022	627,000	19,670	646,670
6.0	667,000	14,666	681,666	667,000	-	667,000
7.0	707,000	3,569	710,569	707,000	-	707,000
8.0	747,000	714	747,714	747,000	-	747,000

This is shown graphically in figure 2.

The optimum design wave is found to be 6.0 m, which has a probability of occurrence of 1 in 10 years. However, in view of uncertainities in the quantative values of some assumptions, it is desirable to take a waveheight on higher side. The design waveheight (Hs) is taken as 6.5 m, which has a probability of occurrence of 1 in 20 years (waveheight with magnitude in the range of 6.25 to 6.75 m).

figure 1 Capitalized repair costs versus design waveheight

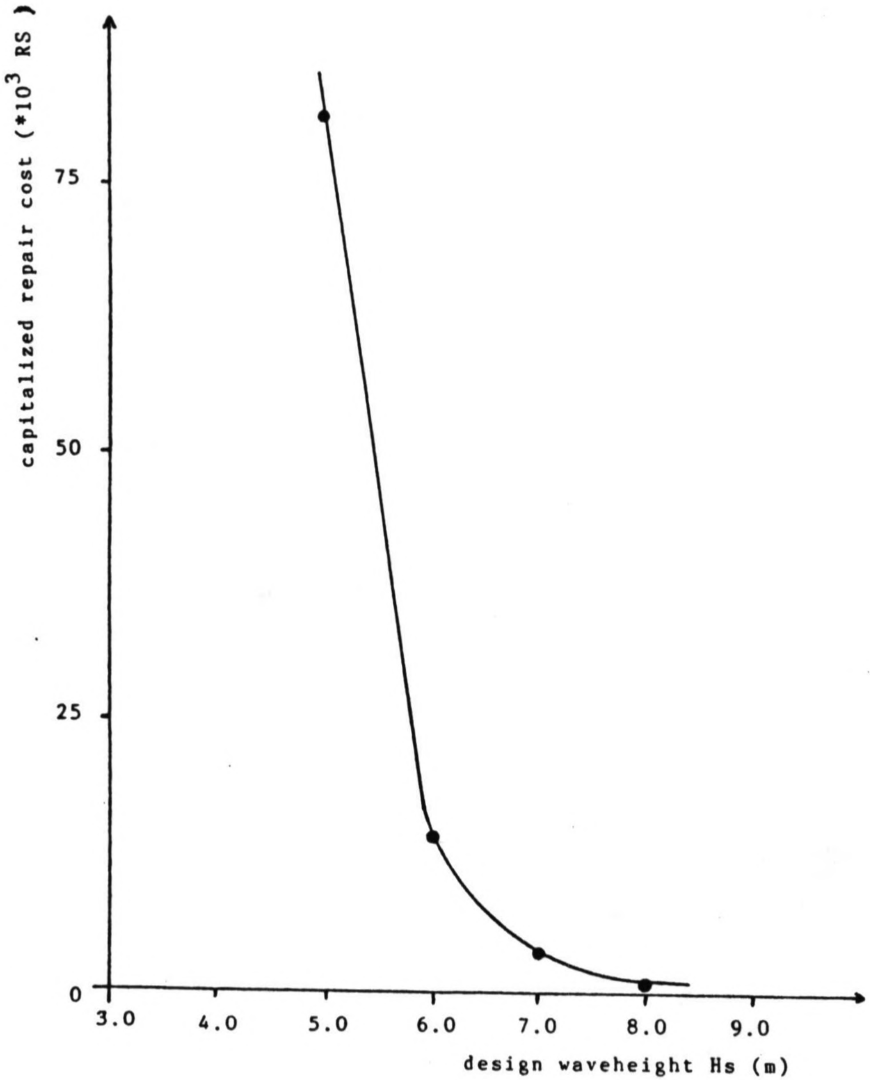
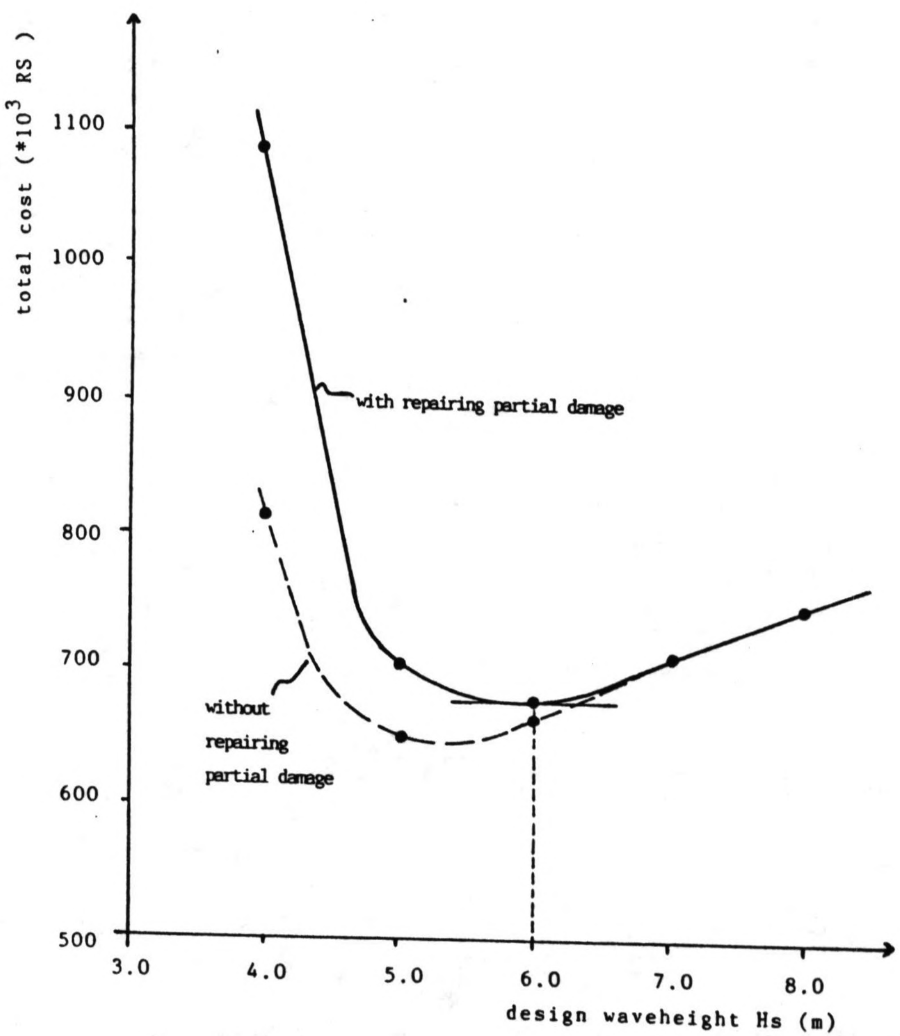


figure 2 Design waveheight versus total cost per m' breakwater length



Annexure 5.4

Design of rubble mound breakwater, bed level at -19 m

The properties of the structure are:

- ρa=2500 kg/m^3 (concrete cubes)
- ρ=1025 kg/m^3
- δ=1.44
- S=5 (tolerable damage)
- P=0.5
- cotα=1.5 (slope 1:1.5)
- N=3000 waves
- T=10 s

The design waveheight (Hs) is 6.5 m.

primary armour layer:
ξz=3.27 (plunging waves)
Dn50=2.41 m
weight: (2.41^3)*2500=34,994 kg, say 35 T
layer thickness: t=2*1.1*(35000/2500)$^{1/3}$=5.3 m

secondary layer:
W/10=3.5 T
t=2.5 m
The secondary layer should withstand the less severe storms during the construction phase. Taking a design storm occuring 10 times per year yields: Hs=3.1 m, Dn50=1.19 m, W=4.2 T. Since this is heavier than 1/10 of the primary armour weight, this value will be used. So t=2.6 m, rock gradation: 5 T to 1 T.

The rock gradation will be so chosen, that all the stone sizes from the quarries will be used.

core:
W/200 to W/6000 = 175 kg to 5 kg, but choose rock gradation of 1 T to 1 kg

filter layer:
1 m thick with stones in the range of 1 kg to 20 kg

crest width:
B=3*1.1*(35000/2500)$^{1/3}$=8 m

berm:
size of stone: W=4.2 T
width: 3*1.1*(4200/2500)$^{1/3}$=4 m
height: 2*1.1*(4200/2500)$^{1/3}$=2.6 m

crest elevation: Kt=Ht/Hi=0.8/4.75=0.17=0.46-(0.3*Rc/Hs), so Rc=4.6 m (annexure 5.1)

crest elevation is:
Rc + design water level at 19 m depth=4.6+1.1=5.7 m (see section 2.2.6 and figure 2.2.6)

A typical breakwater section at 19 m waterdepth is shown in figure 1.

volume of the breakwater per m' length: 1250 m^3
volume of the cover layer per m' length: 265 m^3
volume of concrete, assuming 45% voids: 0.55*265≈145 m^3
volume of rock: 1250-265=985 m^3
weight of rock (40% voids): 985*1.6≈1580 T

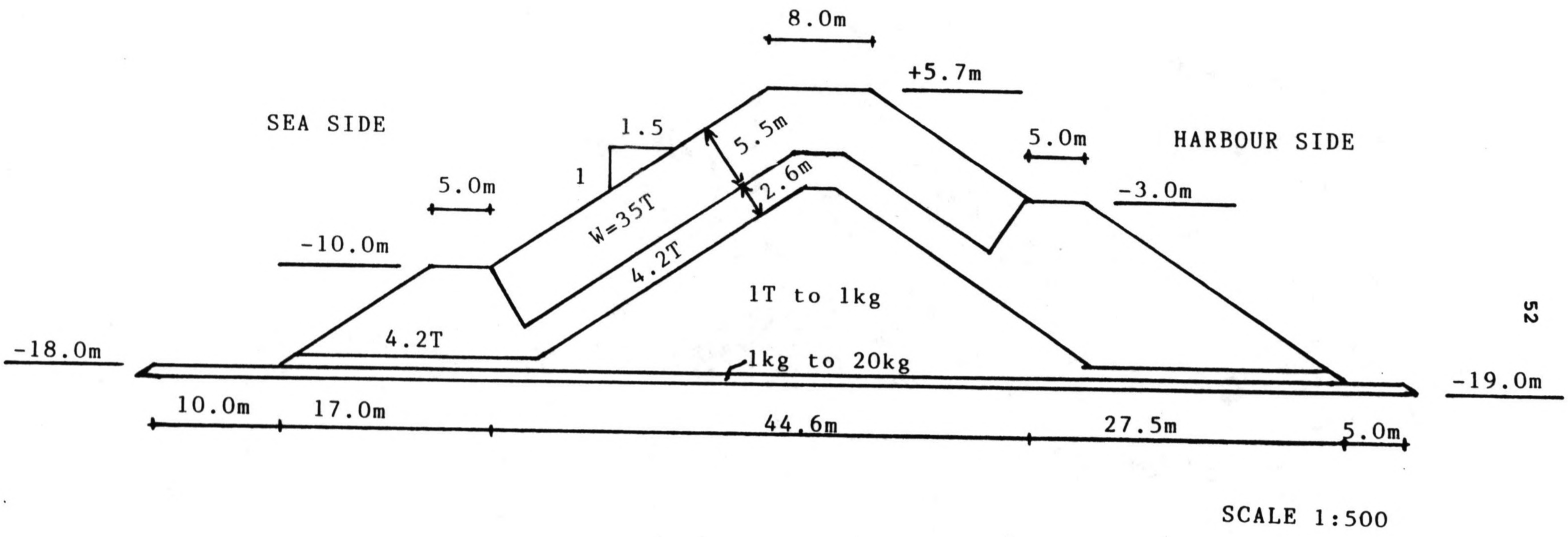
Initial cost of breakwater per m' length:

- cost of concrete armour units of 145 m^3 (including transportation and placement):	145*1500= RS 217,500
- cost of rock of 1580 T (average price: RS 275 per T):	1580*275= RS 434,500
	total= RS 652,000

Capitalized repair cost of breakwater per m' length for waveheight of 6.5 m (see figure 1 in annexure 5.3): RS 7,500.

The total cost of breakwater per m' length is: RS 659,500 , say RS 660,000.

figure 1 Rubble mound breakwater, bed level at -19 m (concrete cubes)



Annexure 5.5

Approximate cost of construction per m' length of rubble mound breakwater at 9 m waterdepth

The approximate cost of construction and the approximate cost of the cover layer are determined for two waveheights.

The properties of the structure are:

- ρa=2500 kg/m^3 (concrete cubes)
- ρ=1025 kg/m^3
- δ=1.44
- S=2 (no damage)
- P=0.5
- cotα=1.5 (slope 1:1.5)
- N=3000 waves
- T=10 s

1) Hs = 5.5 m

primary armour layer:	ξz=3.55 (plunging waves) Dn50=2.55 m weight: (2.55^3)*2500=41453 kg, say 42 T layer thickness: t=5.6 m
berm:	size of stone: W/10=4200 kg width: 3.9 m height: 2.6 m
crest elevation:	maximum waveheight in protected area: Ht=0.8 m design waveheight (once per year): Hi=4.0 m (see section 4.1.1 and annexure 2.18.a) using annexure 5.1: Kt=Ht/Hi=0.8/4.0=0.20=0.46-(0.3*Rc/Hs), so Rc=3.5 m crest elevation is: Rc + design water level at 9 m depth=3.5+1.1=4.6 m (see section 2.2.6 and figure 2.2.6)
crest width:	B=8.45 m
filter layer:	gravel, 1 m thick

volume of the breakwater per m' length: 450 m^3
volume of the cover layer per m' length: 185 m^3
volume of concrete, assuming 45% voids: 0.55*185=102 m^3
volume of rock: 450-185=265 m^3
weight of rock (40% voids): 265*1.6=425 T

Initial cost of breakwater per m' length (see section 5.2):

- cost of concrete armour units of 102 m^3: 102*1500= RS 153,000
- cost of rock of 425 T: 425*275= RS 117,000

Armour unit cost per m waveheight: 153,000/5.5= RS 27,818

2) Hs = 4.0 m

primary armour layer: ξz=4.17 (surging waves)
Dn50=1.97 m
weight: (1.97^3)*2500=19,113 kg, say 20 T
layer thickness: t=4.4 m

- cost of concrete armour units: (4.4/5.6)*153,000= RS 120,000

Armour unit cost per m waveheight: 120,000/4= RS 30,000

Average value of armour unit cost per m waveheight:

(27,818+30,000)/2=28,909 , say RS 29,000

The approximate cost of construction (initial cost) per m' length of rubble mound breakwater for 9 m waterdepth is: RS 29,000*Hs + 117,000.

Annexure 5.6

Repair cost per m' length of rubble mound breakwater at 9 m waterdepth

The repair costs are determined conformably the method used in annexure 5.3; the exceedance curve for Hs at 10 m waterdepth in annexure 2.18.a can be used.

The parameters for computation of the optimum cost of the breakwater are summarized in table 1.

The total anticipated annual damage is equal to Σ p*w.
Using the pwf (see section 5.3), the capitalized repair costs for different design waveheights are as follows (table 2):

table 2 Capitalized repair cost

design waveheight Hs (m)	with repairing partial damage $S=7.843*\Sigma p*w$ (RS)	without repairing partial damage $S=7.843*(p*w)_{collapse}$ (RS)
3.0	1,208,700	751,987
4.0	57,230	-
5.0	7,694	-

This is shown graphically in figure 1.

The total costs (S+I) for different design waveheights are given in table 3:

table 3 Total cost per m' length

design	with repairing partial damage			without repairing partial damage		
waveheight Hs (m)	I (RS)	S (RS)	total cost (RS)	I (RS)	S (RS)	total cost (RS)
3.0	204,000	1,208,700	1,412,700	204,000	751,987	955,987
4.0	233,000	57,230	290,230	233,000	-	233,000
5.0	262,000	7,694	269,694	262,000	-	262,000
6.0	291,000	-	291,000	291,000	-	291,000

This is shown graphically in figure 2.

table 1 Parameters for computation of optimum cost of breakwater

Hs (m)	initial cost (total) (RS)	initial cost of cover layer (RS 29,000*Hs)	Hs<H<1.2*Hs			1.2*Hs<H<1.4*Hs			1.4*Hs<H<1.6*Hs			Σ p*w
			S	p	w	S	p	w	S	p	w	
3.0	204,000	87,000	3.68	3.50	6,403	10.45	1.97	18,183	21.10	0.47	204,000	154,112
4.0	233,000	116,000	2.92	0.76	6,774	5.45	0.17	12,644	9.33	0.00	-	7,297
5.0	262,000	145,000	2.82	0.12	981	5.29	-	-	-	-	-	981

w=2*(S/100)*cost of cover layer

figure 1 Capitalized repair cost versus design waveheight

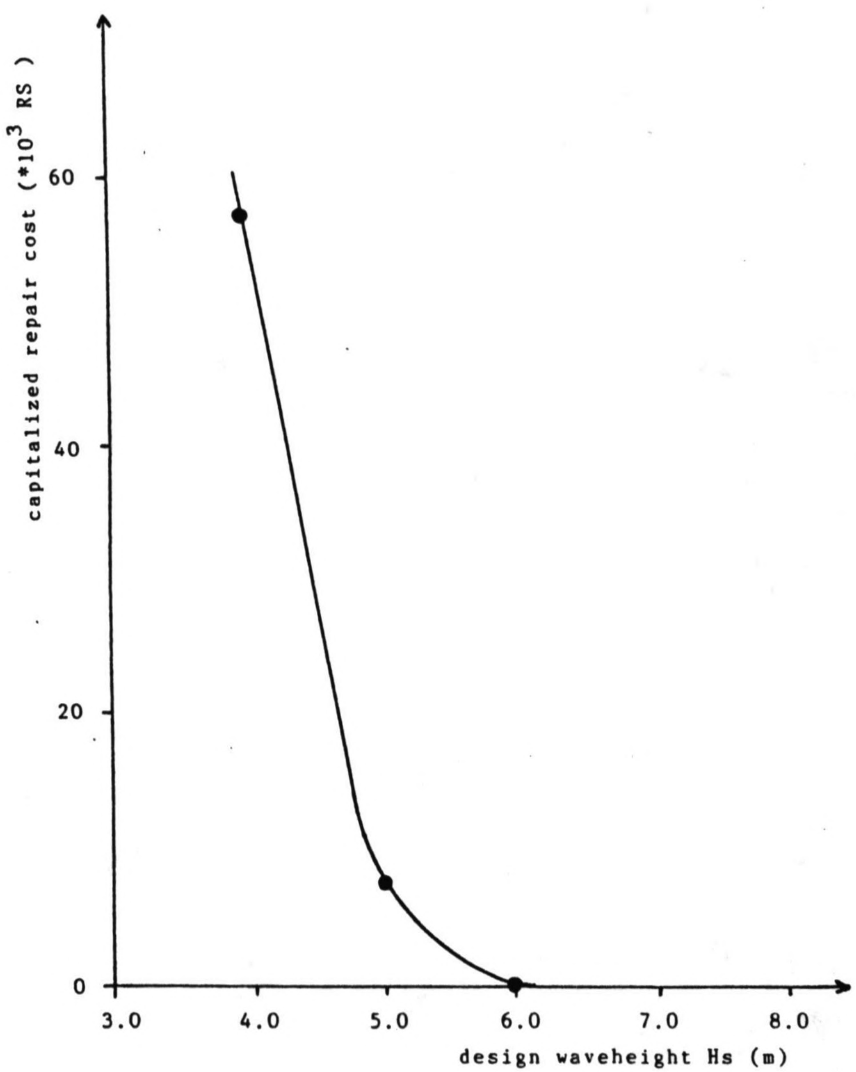
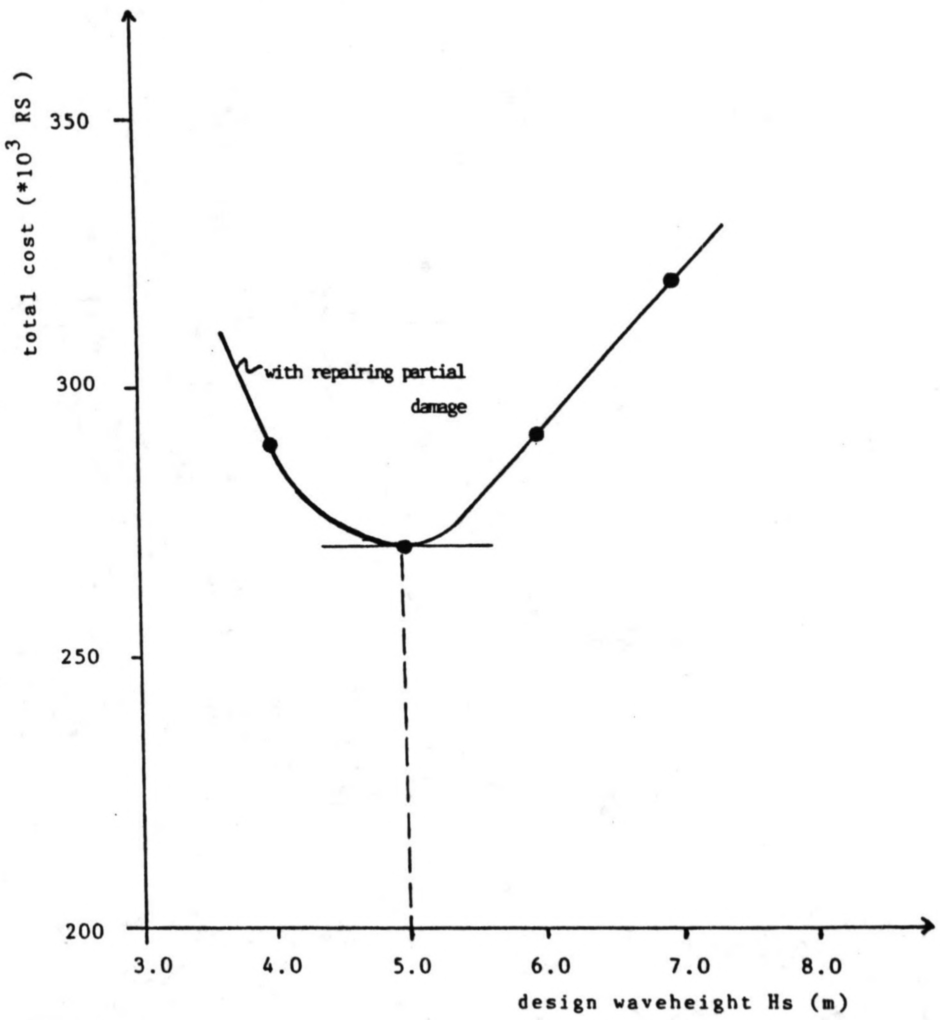


figure 2 Design waveheight versus total cost per m' breakwater length



The optimum design wave is found to be 5.0 m; the design waveheight (Hs) is taken as 5.25 m, which is the maximum expected waveheight at 10 m waterdepth (see tables of occurrence and exceedance probabilities in annexures 2.10.a and 2.11.a). It can be assumed that the optimum design wave at shallow water (10 m waterdepth or less) is the maximum expected waveheight at that depth (the maximum waveheights are limited by the waterdepth).

Annexure 5.7

Design of rubble mound breakwater, bed level at -9 m

The properties of the structure are:

- ρa=2500 kg/m^3 (concrete cubes)
- ρ=1025 kg/m^3
- δ=1.44
- S=5 (tolerable damage)
- P=0.5
- cotα=1.5 (slope 1:1.5)
- N=3000 waves
- T=10 s

The design waveheight (Hs) is 5.25 m.

primary armour layer:	ξz=3.64 (plunging waves) Dn50=2.05 m weight: (2.05^3)*2500=21,538 kg, say 22 T layer thickness: t=4.5 m
secondary layer:	W/10=2.2 T t=2.1 m Taking a design storm occuring 10 times per year yields: Hs=2.7 m, Dn50=1.00 m, W=2.5 T. Since this is heavier than 1/10 of the primary armour weight, this value will be used. So t=2.2 m, rock gradation: 3 T to 1 T.
core:	W/200 to W/6000 = 110 kg to 4 kg, but choose rock gradation of 1 T to 1 kg
filter layer:	1 m thick with stones in the range of 1 kg to 20 kg
crest width:	B=7 m
berm:	size of stone: W=2.5 T width: 3.3 m height: 2.2 m
crest elevation:	Kt=Ht/Hi=0.8/4.0=0.20=0.46-(0.3*Rc/Hs), so Rc=3.5 m (annexure 5.1) crest elevation is: Rc + design water level at 9 m depth=3.5+1.1=4.6 m (see section 2.2.6 and figure 2.2.6)

A typical breakwater section at 9 m waterdepth is shown in figure 1.

volume of the breakwater per m' length: 430 m^3
volume of the cover layer per m' length: 145 m^3
volume of concrete, assuming 45% voids: 0.55*145≈80 m^3
volume of rock: 430-145=285 m^3
weight of rock (40% voids): 285*1.6=456 T

Initial cost of breakwater per m' length:

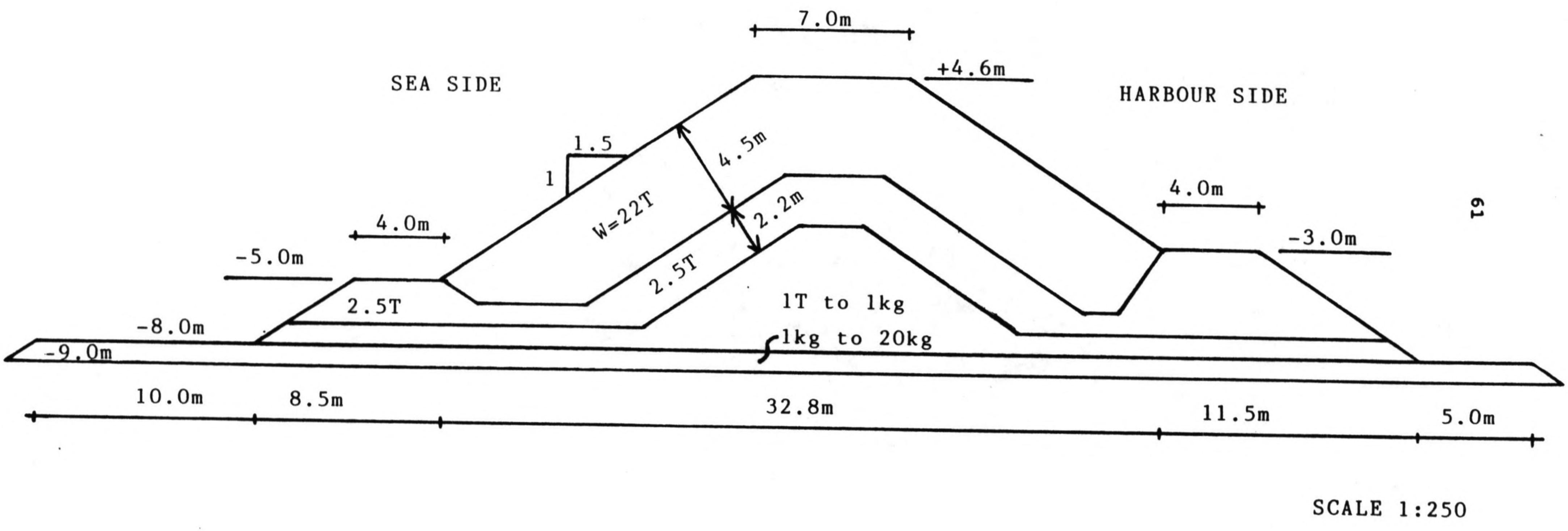
- cost of concrete armour units of 80 m^3 (including transportation and placement): 80*1500= Rs 120,000
- cost of rock of 456 T (average price: RS 275 per T): 456*275= RS 125,400

total= RS 245,400

Capitalized repair cost of breakwater per m' length for waveheight of 5.25 m (see figure 1 in annexure 5.6): RS 4,500.

The total cost of breakwater per m' length is: RS 249,900 , say RS 250,000.

figure 1 Rubble mound breakwater, bed level at -9 m (concrete cubes)



Annexure 5.8

Design of rubble mound breakwater, bed level at -7 m

As indicated in annexure 5.6, it can be assumed that for the optimum design wave at shallow water the maximum expected waveheight can be taken. The total water level rise at the 7 m contour is about 1.20 m, so the maximum local waterdepth is 8.20 m. The maximum expected waveheight at this depth is about 4.25 m.

The properties of the structure are:

- ρa=2500 kg/m^3 (concrete cubes)
- ρ=1025 kg/m^3
- δ=1.44
- S=5 (tolerable damage)
- P=0.5
- cotα=1.5 (slope 1:1.5)
- N=3000 waves
- T=10 s

The design waveheight (Hs) is 4.25 m.

primary armour layer:	ξz=4.04 (plunging waves) Dn50=1.75 m weight: (1.75^3)*2500=13,398 kg, say 14 ton layer thickness: t=3.9 m
secondary layer:	W/10=1.4 T Taking a design storm occuring 10 times per year yields: Hs=2.6 m, Dn50=0.96 m, W=2.2 T (Hs is estimated using annexures 2.18.a and 2.18.b) t=2.1 m, rock gradation: 3 T to 0.1 T.
core:	W/200 to W/6000 = 70 kg to 2.5 kg choose rock gradation: 0.1 T to 1 kg
filter layer:	1 m thick with stones in the range of 1 kg to 20 kg
crest width:	B=7 m
berm:	size of stone: W=2.2 T width: 3.2 m height: 2.1 m
crest elevation:	Kt=Ht/Hi=0.8/3.75=0.21=0.46-(0.3*Rc/Hs), so Rc=3.1 m (annexure 5.1) (Hi is estimated using annexures 2.18.a and 2.18.b) crest elevation is: Rc + design water level at 7 m depth=3.1+1.2=4.3 m (see section 2.2.6 and figure 2.2.6)

A typical breakwater section at 7 m waterdepth is shown in figure 1.

volume of the breakwater per m' length: 350 m^3
volume of the cover layer per m' length: 115 m^3
volume of concrete, assuming 45% voids: 0.55*115≈65 m^3
volume of rock: 350-115=235 m^3
weight of rock (40% voids): 235*1.6=376 T

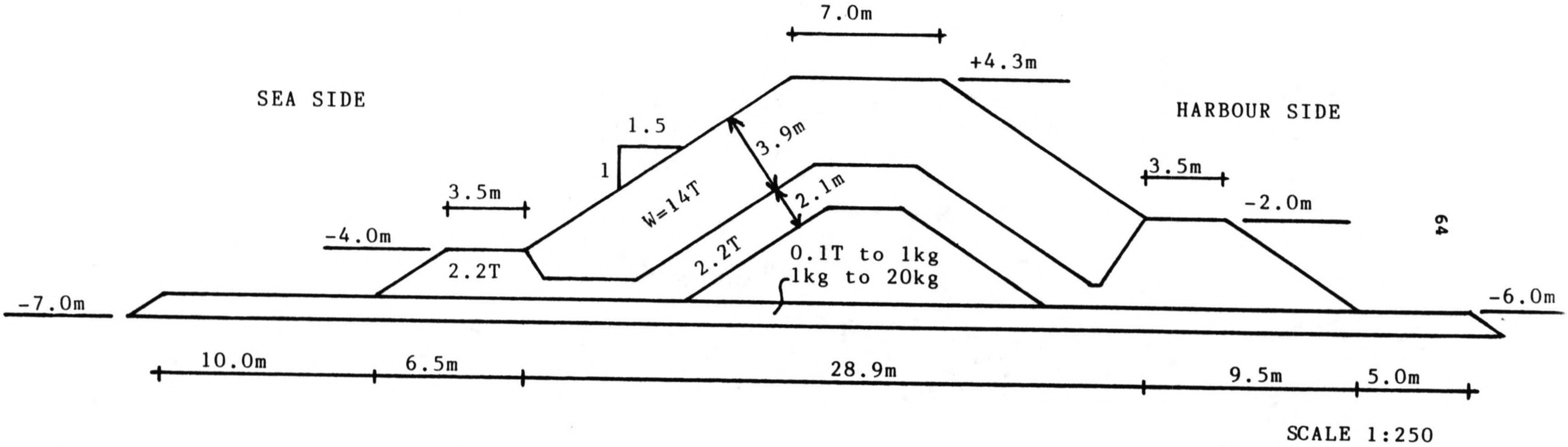
Initial cost of breakwater per m' length:

- cost of concrete armour units of 65 m^3 (including transportation and placement):	65*1500= RS 97,500
- cost of rock of 376 T (average price: RS 275 per T):	376*275= RS 103,400
	total= RS 200,900

Capitalized repair cost of breakwater per m' length (estimated):
RS 2,500

The total cost of breakwater per m' length is: RS 203,400 , say RS 204,000.

figure 1 Rubble mound breakwater, bed level at -7 m (concrete cubes)



Annexure 5.9

Design of rubble mound breakwater, bed level at -7 m

The properties of the structure are:

- **ρa=2650 kg/m^3 (quarry stones)**
- **ρ=1025 kg/m^3**
- **δ=1.59**
- **S=5 (tolerable damage)**
- **P=0.5**
- **cotα=3.0 (slope 1:3.0)**
- **N=3000 waves**
- **T=10 s**

The design waveheight (Hs) is 4.25 m.

primary armour layer:	**ξz=2.02 (plunging waves)** **Dn50=1.12 m** **weight: (1.12^3)*2650=3,723 kg, say 4 T** **layer thickness: t=2.5 m**
secondary layer:	**W/10=0.4 T** **Taking a design storm occuring 10 times per year yields: Hs=2.6 m, Dn50=0.78, W=1.26 T.** **t=1.7 m, rock gradation: 3 T to 0.1 T.**
core:	**W/200 to W/6000 = 20 kg to 1 kg** **choose rock gradation: 0.1 T to 1 kg**
filter layer:	**1 m thick with stones in the range of 1 kg to 20 kg**
crest width:	**B=7 m**
berm:	**size of stone: W=1.26 T** **width: 2.6 m** **height: 1.7 m**
crest elevation:	**Rc + design water level = 4.3 m** **(see annexure 5.8)**

A typical breakwater section at 7 m waterdepth is shown in figure 1.

volume of the breakwater per m' length: 500 m^3
volume of rock: 500 m^3
weight of rock (40% voids): 500*1.6=800 T

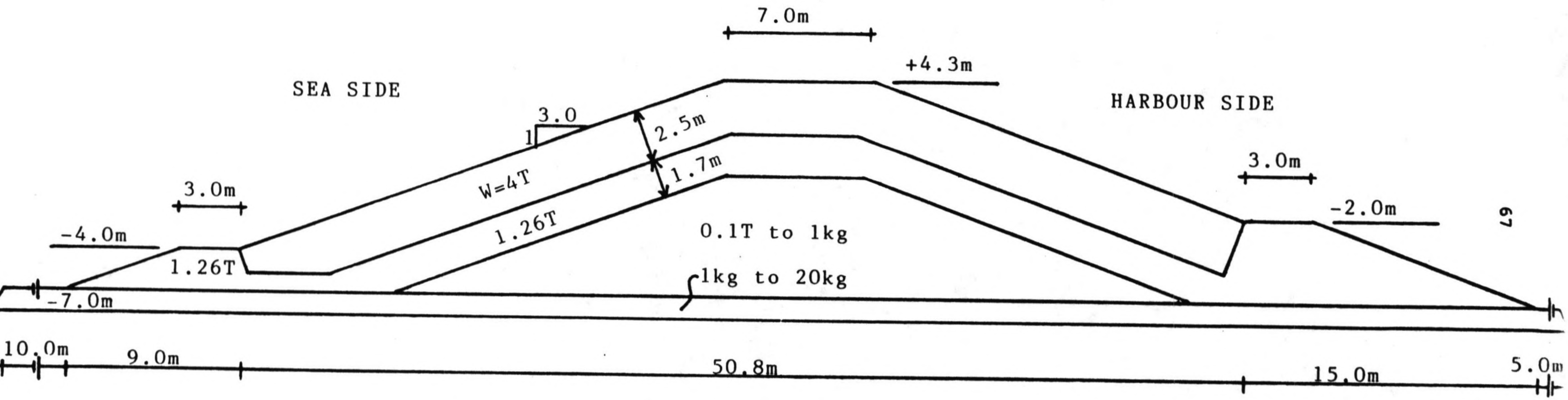
Initial cost of breakwater per m' length:

- cost of rock of 800 T: 800*275= RS 220,000

Capitalized repair cost of breakwater per m' length (estimated):
RS 2,500

The total cost of breakwater per m' length is: RS 222,500 , say 223,000.

figure 1 Rubble mound breakwater, bed level at -7 m (quarry stones)



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Annexure 5.10

Design of rubble mound breakwater, bed level at -5 m

The water level rise at the 5 m contour is about 1.20 m, so the maximum local waterdepth is 6.20 m. The maximum expected waveheight at 6 m waterdepth is about 3.25 m (see tables of occurrence and exceedance probabilities in annexures 2.10.b and 2.11.b).

The properties of the structure are:

- ρa=2500 kg/m^3 (concrete cubes)
- ρ=1025 kg/m^3
- δ=1.44
- S=5 (tolerable damage)
- P=0.5
- cotα=1.5 (slope 1:1.5)
- N=3000 waves
- T=10 s

The design waveheight (Hs) is 3.25 m.

primary armour layer:	ξz=4.62 (surging waves) Dn50=1.26 m weight: (1.26^3)*2500= 5,001 kg, say 5 T layer thickness: t=2.8 m
secondary layer:	W/10=0.5 T Taking a design storm occuring 10 times per year yields: Hs=2.5 m, Dn50=0.91 m, W=1.9 T. t=2.0 m, rock gradation: 2 T to 0.1 T.
core:	W/200 to W/6000 = 25 kg to 1 kg choose rock gradation: 0.1 T to 1 kg
filter layer:	1 m thick with stones in the range of 1 kg to 20 kg
crest width:	B=7 m
berm:	size of stone: W=1.9 T width: 3.0 m height: 2.0 m
crest elevation:	design waveheight (once per year): Hi=3.25 m (see section 4.1.1 and annexure 2.18.b) Kt=Ht/Hi=0.25=0.46-(0.3*Rc/Hs), so Rc=2.3 m (annexure 5.1) crest elevation is: Rc + design water level at 5 m depth=2.3+1.2=3.5 m (see section 2.2.6 and figure 2.2.6)

A typical breakwater section at 5 m waterdepth is shown in figure 1.

volume of the breakwater per m' length: 200 m^3
volume of the cover layer per m' length: 65 m^3
volume of concrete, assuming 45% voids: 0.55*65≈36 m^3
volume of rock: 200-65=135 m^3
weight of rock (40% voids): 135*1.6≈220 T

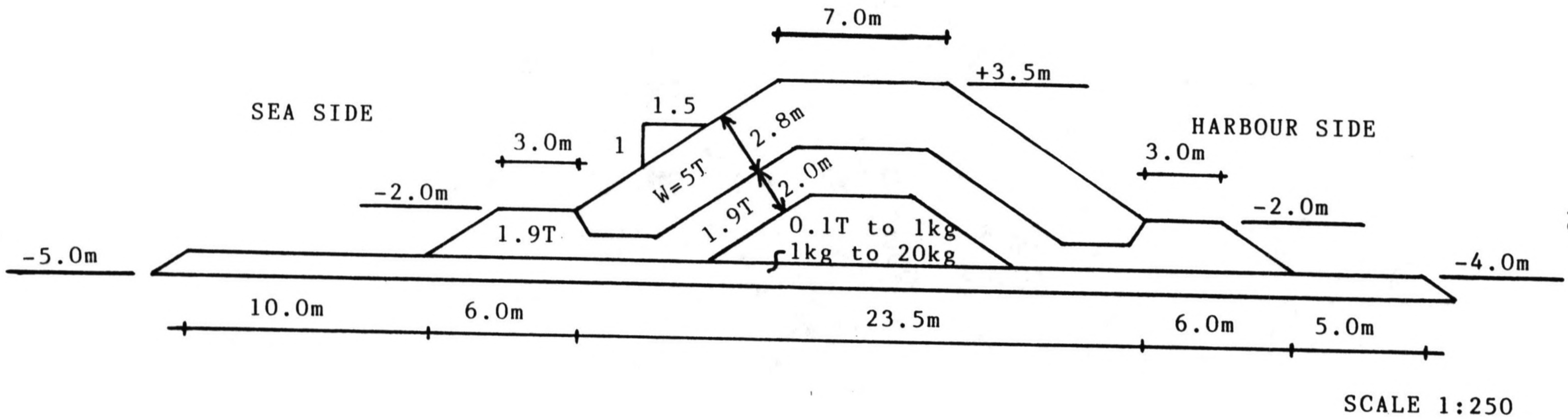
Initial cost of breakwater per m' length:

- cost of concrete armour units of 36 m^3 (including transportation and placement):	36*1500= RS 54,000
- cost of rock of 220 T (average price: RS 275 per T):	220*275= RS 60,500
	total= RS 114,500

Capitalized repair cost of breakwater per m' length (estimated): RS 1,500

The total cost of breakwater per m' length is: RS 116,000.

figure 1 Rubble mound breakwater, bed level at -5 m (concrete cubes)



Annexure 5.11

Design of rubble mound breakwater, bed level at -5 m

The properties of the structure are:

- ρa=2650 kg/m^3 (quarry stones)
- ρ=1025 kg/m^3
- δ=1.59
- S=5 (tolerable damage)
- P=0.5
- cotα=3.0 (slope 1:3.0)
- N=3000 waves
- T=10 s

The design waveheight (Hs) is 3.25 m.

primary armour layer:	ξz=2.31 (plunging waves) Dn50=0.92 m weight: (0.92^3)*2650=2,065 kg, say 2.1 T layer thickness: t=2.0 m
secondary layer:	W/10=0.21 T Taking a design storm occuring 10 times per year yields: Hs=2.5 m, Dn50=0.75 m, W=1.12 T. t=1.65 m, rock gradation: 2 T to 0.1 T.
core:	W/200 to W/6000 = 10 kg to 0.4 kg choose rock gradation: 0.1 T to 1 kg
filter layer:	1m thick with stones in the range of 1 kg to 20 kg
crest width:	B=7 m
berm:	size of stone: W=1.12 T width: 2.5 m height: 1.65 m
crest elevation:	Rc + design water level = 3.5 m (see annexure 5.10)

A typical breakwater section at 5 m waterdepth is shown in figure 1.

volume of the breakwater per m' length: 300 m^3
volume of rock: 300 m^3
weight of rock (40% voids): 300*1.6=480 T

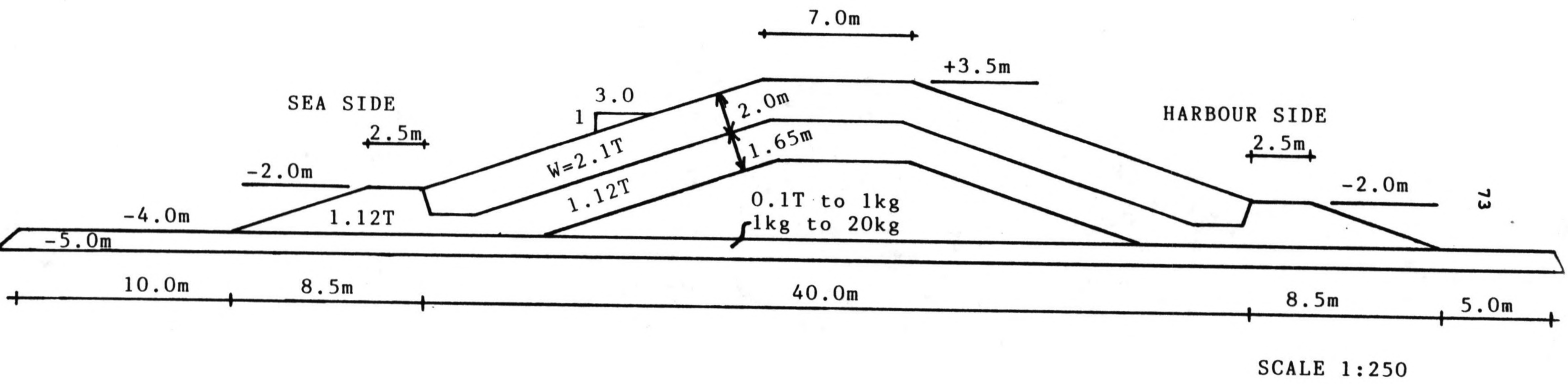
Initial cost of breakwater per m' length:

- cost of rock of 480 T: 480*275= RS 132,000

Capitalized repair cost of breakwater per m' length (estimated):
RS 1,500

The total cost of breakwater per m' length is: RS 133,500 , say RS 134,000.

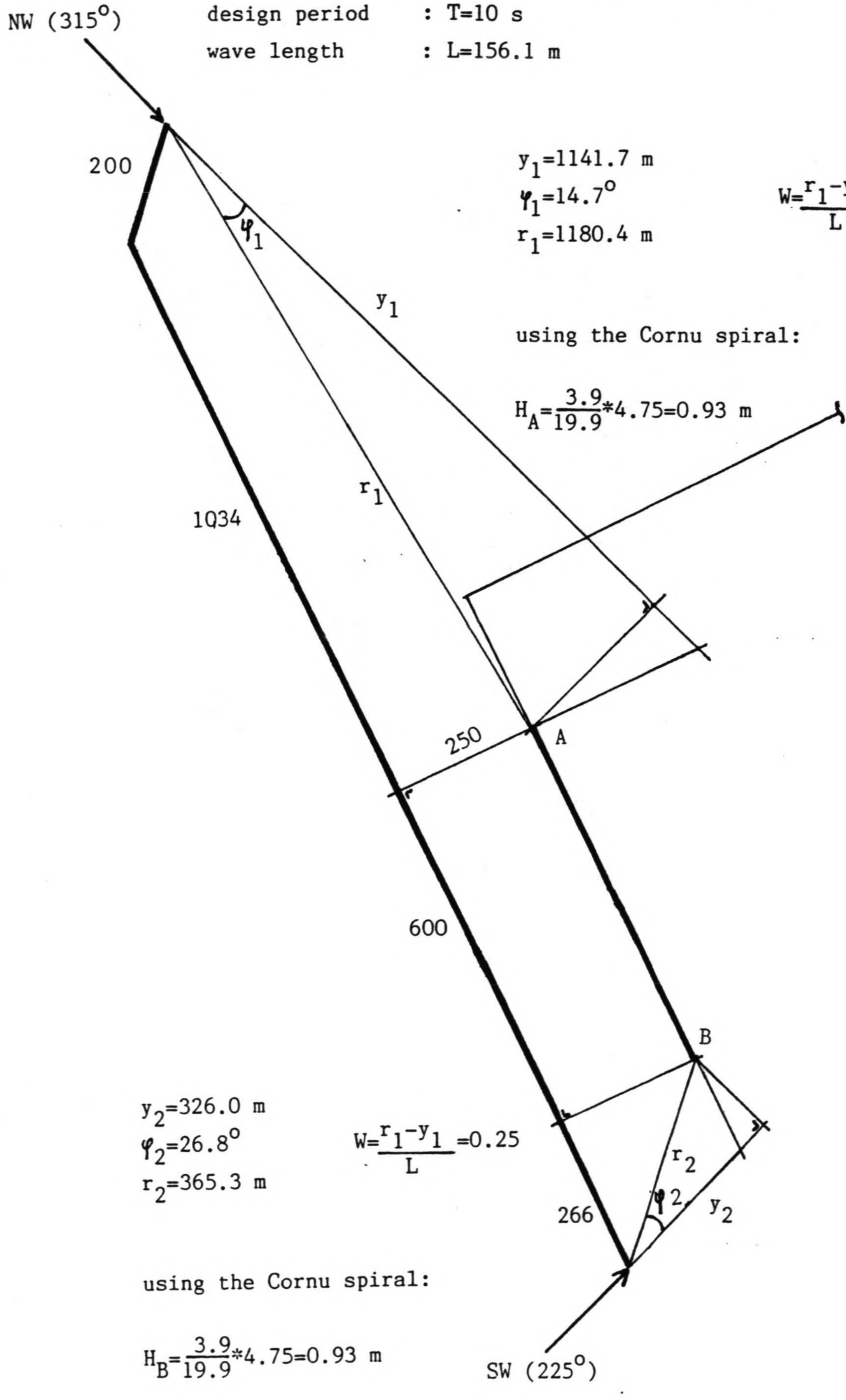
figure 1 Rubble mound breakwater, bed level at -5 m (quarry stones)



Annexure 5.12

Diffraction calculation; waves passing the breakwater at depth contour of 19 m

design waveheight: Hs=4.75 m (once per year)
design period : T=10 s
wave length : L=156.1 m



y_1=1141.7 m
φ_1=14.7°
r_1=1180.4 m

$W=\frac{r_1-y_1}{L}=0.25$

using the Cornu spiral:

$H_A=\frac{3.9}{19.9}*4.75=0.93$ m

y_2=326.0 m
φ_2=26.8°
r_2=365.3 m

$W=\frac{r_1-y_1}{L}=0.25$

using the Cornu spiral:

$H_B=\frac{3.9}{19.9}*4.75=0.93$ m

Annexure 5.13

Accretion at the northern breakwater

The southerly sediment transport is assumed to be 1.06*10^6 m^3/year (see section 2.3.2 and annexure 2.19).
The representative waveheight (Hos) is about 1.65 m; the mean significant wave period (T) is 6 s, so the wave celerity (Co) is 9.4 m/s.

- Using annexure 2.1:

the southerly sediment transport of 1.06*10^6 m^3/year is caused by waves from W to N with occurrence probability of 56.6% per year, which means a sediment transport of (Sx):

$$\frac{1.06*10^6 \text{ m}^3/\text{year}}{0.566*365*24*3600} = 0.06 \text{ m}^3/\text{s} = Sx$$

Using the CERC-formula $Sx=0.02*Hos^2*Co*\cos(\varphi o)*\sin(\varphi b)$, it appears that $\cos(\varphi o)*\sin(\varphi b)=0.116$, so the deep water wave angle (φo) is 14° and the wave angle at the breaker line (φb) is 6.9° (for $\gamma=0.7$).

- Using annexure 2.5:

occurrence probability is 32.1% per year, so Sx=0.11 m^3/s and $\cos(\varphi o)*\sin(\varphi b)=0.205$. Thus $\varphi o=27°$ and $\varphi b=13°$ (for $\gamma=0.7$).

The average angle of wave approach is about 20° (φo), the slope of the accreted beach is assumed to be 1:100, the breaker depth (hb) is about 3.0 m and the total water level rise is about 1.2 m (see figure 1).

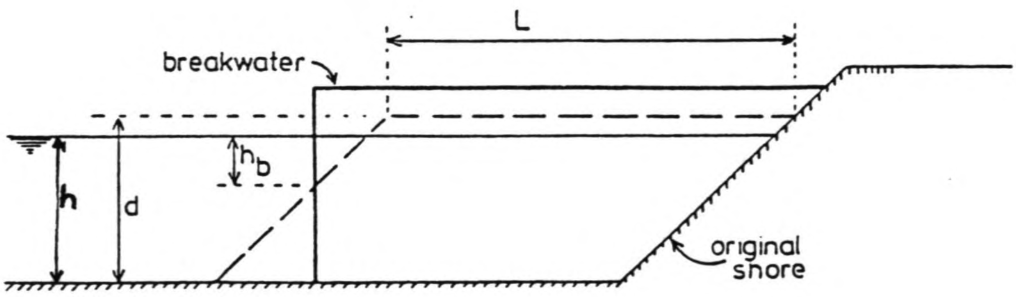
The approximate accretion time for different breakwater lengths (=accretion length=L) is as follows (using the formula in section 5.3):

- h=5 m: d=6.2 m, L=600-(100-1.5)*3=304 m, h/Lo=0.089, φ'=13.4°=0.23 rad
  t=1.8 years

- h=6 m: d=7.2 m, L=1100-(100-1.5)*3=804 m, h/Lo=0.107, φ'=14.4°=0.25 rad
  t=13.8 years

- h=7 m: d=8.2 m, L=1600-(100-1.5)*3=1304 m, h/Lo=0.125, φ'=15.2°=0.27 rad
  t=38.2 years

figure 1 Profile at start of sand passage



Annexure 6.1

Tables for conveyor belt design

TABLE 1 *20° Troughed Belt—Three Equal Rolls Standard Edge Distance = 0.055b + 0.9 Inch*

Belt Width (Inches)	A_t - Cross Section of Load (Ft^2)							Capacity at 100 FPM (Ft^3/Hr)						
	Surcharge Angle							Surcharge Angle						
	0°	5°	10°	15°	20°	25°	30°	0°	5°	10°	15°	20°	25°	30°
18	.089	.108	.128	.147	.167	.188	.209	537	653	769	886	1005	1128	1254
24	.173	.209	.246	.283	.320	.359	.399	1041	1258	1477	1698	1924	2155	2394
30	.284	.343	.402	.462	.522	.585	.649	1708	2060	2414	2772	3137	3511	3897
36	.423	.509	.596	.684	.774	.866	.960	2538	3057	3579	4107	4645	5196	5765
42	.588	.708	.828	.950	1.074	1.201	1.332	3533	4250	4972	5703	6447	7210	7997
48	.781	.940	1.099	1.260	1.424	1.592	1.765	4691	5640	6594	7560	8544	9552	10592
54	1.002	1.204	1.407	1.613	1.822	2.037	2.258	6013	7225	8444	9678	10935	12223	13552
60	1.249	1.501	1.753	2.009	2.270	2.537	2.812	7498	9006	10522	12057	13621	15223	16876
72	1.826	2.192	2.560	2.933	3.312	3.701	4.102	10961	13155	15364	17599	19876	22210	24617
84	2.513	3.014	3.519	4.030	4.551	5.085	5.635	15079	18089	21119	24186	27309	30511	33813
96	3.308	3.967	4.631	5.302	5.986	6.687	7.411	19850	23806	27787	31816	35921	40128	44466

TABLE 2 *35° Troughed Belt—Three Equal Rolls Standard Edge Distance = 0.055b + 0.9 Inch*

Belt Width (Inches)	A_t - Cross Section of Load (Ft^2)							Capacity at 100 FPM (Ft^3/Hr)						
	Surcharge Angle							Surcharge Angle						
	0°	5°	10°	15°	20°	25°	30°	0°	5°	10°	15°	20°	25°	30°
18	.144	.160	.177	.194	.212	.230	.248	864	964	1066	1169	1274	1381	1492
24	.278	.309	.341	.373	.406	.440	.474	1668	1857	2048	2241	2438	2640	2847
30	.455	.506	.557	.609	.662	.716	.772	2733	3039	3346	3658	3975	4300	4636
36	.676	.751	.826	.903	.980	1.060	1.142	4058	4508	4961	5419	5886	6364	6857
42	.940	1.044	1.148	1.254	1.361	1.471	1.585	5644	6266	6891	7524	8169	8830	9511
48	1.248	1.385	1.523	1.662	1.804	1.949	2.099	7491	8312	9138	9974	10825	11698	12598
54	1.599	1.774	1.950	2.128	2.309	2.494	2.686	9598	10646	11700	12768	13855	14969	16118
60	1.994	2.211	2.429	2.651	2.876	3.107	3.345	11966	13269	14580	15906	17257	18642	21058
72	2.913	3.229	3.547	3.869	4.197	4.532	4.879	17484	19378	21285	23215	25182	27196	29275
84	4.007	4.440	4.876	5.317	5.766	6.226	6.701	24043	26641	29256	31902	34597	37360	40210
96	5.274	5.842	6.415	6.994	7.584	8.189	8.812	31645	35058	38490	41966	45506	49134	52876

TABLE 3 *45° Troughed Belt—Three Equal Rolls Standard Edge Distance = 0.055b + 0.9 Inch*

Belt Width (Inches)	A_t - Cross Section of Load (Ft^2)							Capacity at 100 FPM (Ft^3/Hr)						
	Surcharge Angle							Surcharge Angle						
	0°	5°	10°	15°	20°	25°	30°	0°	5°	10°	15°	20°	25°	30°
18	.170	.184	.199	.214	.230	.245	.262	1021	1109	1198	1289	1380	1475	1572
24	.327	.355	.383	.411	.439	.469	.499	1967	2132	2299	2467	2638	2814	2996
30	.536	.580	.625	.670	.716	.763	.812	3218	3484	3752	4023	4299	4581	4873
36	.795	.860	.926	.992	1.060	1.129	1.200	4775	5165	5558	5955	6360	6775	7204
42	1.106	1.195	1.286	1.377	1.470	1.566	1.664	6636	7175	7717	8265	8824	9397	9987
48	1.467	1.585	1.704	1.825	1.948	2.074	2.204	8803	9514	10229	10953	11690	12445	13224
54	1.879	2.030	2.182	2.336	2.492	2.653	2.819	11276	12182	13094	14017	14957	15921	16915
60	2.342	2.529	2.718	2.909	3.104	3.303	3.509	14053	15179	16312	17458	18626	19823	21059
72	3.420	3.693	3.967	4.245	4.528	4.818	5.117	20524	22160	23807	25473	27171	28910	30705
84	4.702	5.076	5.452	5.832	6.220	6.617	7.027	28216	30458	32713	34997	37322	39706	42165
96	6.188	6.678	7.172	7.671	8.180	8.701	9.239	37128	40071	43032	46029	49081	52210	55437

Annexure 6.2

Ship's berthing energy

The berthing energy follows from Saurin's formula:

$E=0.5*m*v^2*C_m*C_e*C_s$, where:

m is the mass of the vessel (in kg)
v is the berthing speed (in m/s)
C_m is the (added) mass factor (hydrodynamic coefficient)
C_e is the eccentricity coefficient
C_s is the deformation coefficient

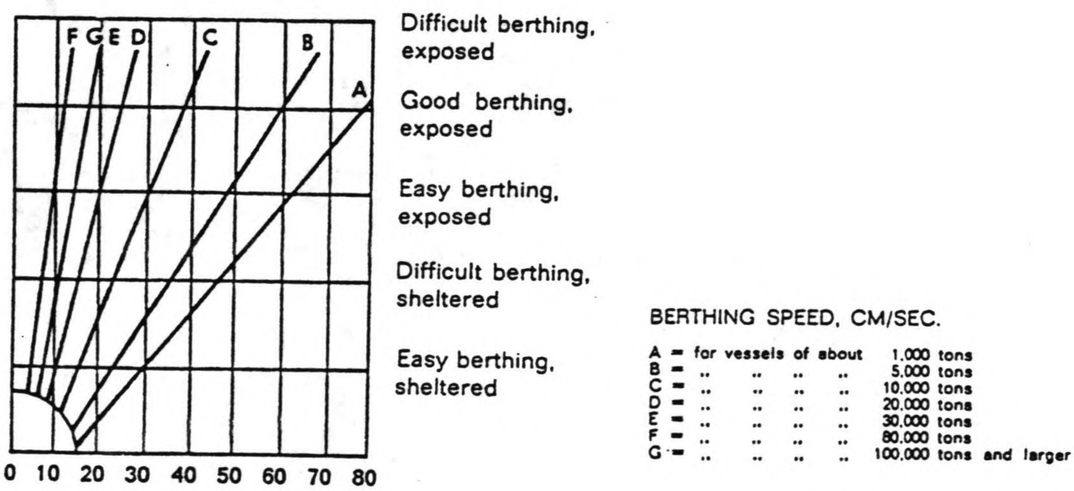
The mass factor can be calculated using Costa's expression:

$C_m=1+2(D/B)$, where:

D is the draft of the vessel
B is the beam of the vessel (see section 4.1.2.1)

The average berthing speed of the vessel (v) is assumed to be 0.15 m/s (see figure 1), the deformation coefficient (C_s) and eccentricity coefficient (C_e) are assumed to be 0.9 and 0.6 respectively.

figure 1 Graph for determining berthing speeds



The berthing energy for various vessel sizes is summarized in table 1:

table 1 Berthing (kinetic) energy

vessel size (dwt)	ship's mass (10^3 kg)	C_m	E (10^3 Nm)
40,000	52,000	1.82	574.9
50,000	65,000	1.80	710.8
60,000	78,000	1.80	852.9
80,000	104,000	1.76	1112.0
100,000	130,000	1.73	1366.3
120,000	156,000	1.74	1649.0

The fender forces depend on the type of fendering system; from energy-deflection curves (marine fendering catalogues) the most suitable type of fendering system can be determined.

Annexure 6.3

Mooring forces due to wind

The resultant wind forces acting on a moored ship are calculated using the following equations:

longitudinal wind force: $F_{xw}=C_{xw}*\gamma_w*A_{xw}*(v_w^2/2*g)$
lateral wind force: $F_{yw}=C_{yw}*\gamma_w*A_{yw}*(v_w^2/2*g)$, where:

C_{xw} is the longitudinal wind force coefficient
C_{yw} is the lateral wind force coefficient
γ_w is the specific weight of air (1.225 kg/m^3)
A_w is the area, exposed to wind forces (in m^2)
v_w is the wind velocity (in m/s)
g is the accèleration of gravity (9.81 m/s^2)

Values for C_{xw} and C_{yw} are indicated in table 1:

table 1 Wind force coefficient

wind direction	C_w max	min	mean
bow (x)	1.04	0.62	0.82
stern (x)	1.02	0.64	0.77
crosswise (y)	1.40	0.80	1.11

The exposed area depends on the load condition: fully loaded or ballasted. Only data of a 150,000 dwt tanker are available (see table 2):

table 2 Exposed area to wind forces

load condition	A_{xw} (m^2)	A_{yw} (m^2)
full	1.2*10^3	2.5*10^3
ballast	1.8*10^3	5.5*10^3

The wind velocity is assumed to be 45 knots, which is a practical value for design (see section 6.3.1).
So, the following wind forces can be calculated ($C_w$min - $C_w$max):

full: F_{xw}= 25 t - 42 t
F_{yw}= 67 t - 117 t
ballast: F_{xw}= 37 t - 63 t
F_{yw}=147 t - 258 t