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Evaluation of Negombo Offshore Breakwater Scheme

IHE DELFT

International Institute for Infrastructural, Hydraulic and Environmental Engineering

The Netherlands

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AN EVALUATION OF NEGOMBO OFFSHORE BREAKWATER SCHEME

PREFACE

This brief report deals with both the pre and post implementation of the Negombo offshore breakwater scheme in west coast of Sri Lanka and is published with the collaboration of Ministry of Public works (Rijkswaterstaat), Netherlands and Lanka Hydraulic Institute, Sri Lanka, as a partial fulfilment of a MSc study carried out at International institute for Infrastructural, Hydraulic and Environmental engineering(IHE), Delft, Netherlands.

1. INTRODUCTION

Sri Lanka, which has a total coastline of 1,600 km, has most of its infrastructure, living space and economic activities concentrated along the coastalzone of the western part which is subject to an extremely high development pressure mainly to the presence of tourist beaches and industries. Negombo is one such location. The Negombo Coast Protection Scheme is one of the earliest projects to be implemented after proper investigation coupled with a post-monitoring programme.

The main objectives of this report are to present the circumstances which lead to decide on a offshore breakwater scheme as a shore protection, availability of field data, design and lay out considerations in the absence of specific design procedures and actual performance against the predicted.

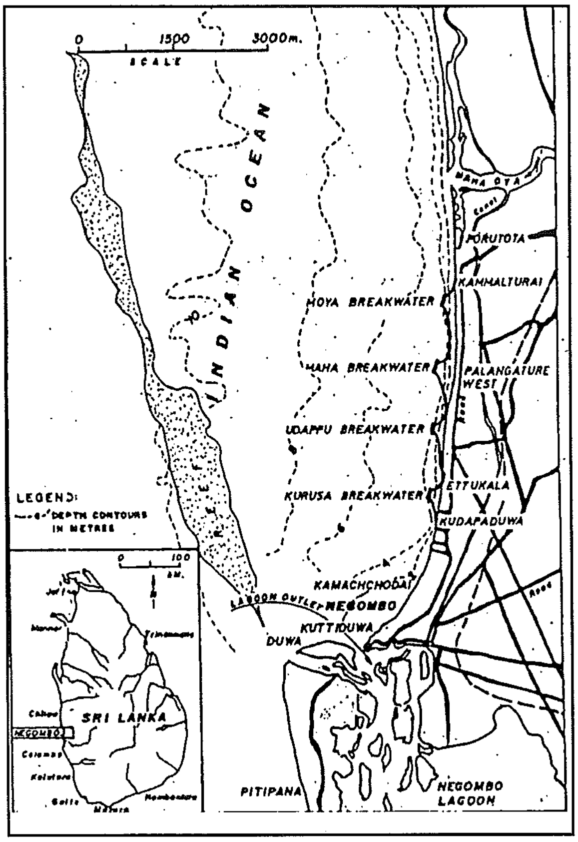


Figure 1: Location of project area and plan of Negombo scheme.

2. BACKGROUND

The Negombo coastal reach from Morawala to Maha Oya Estuary, which is located just 30 km north of Colombo (see Fig. 1) on the west coast of Sri Lanka, is a very famous tourist attraction as well as a highly utilized stretch by the fishing industry. This stretch has been subject to continuous erosion. The annual retreat of the coastline has been estimated to be 2.0 to 2.5m, resulting in an annual sediment loss of 70,000 m^3 to 100,000 m^3 from this coastal reach. The cumulative sediment losses (in m^3/year) as against the cumulative distance of the project area before the implementation of any restoration scheme (Ref /2/), is shown in Fig. 2.

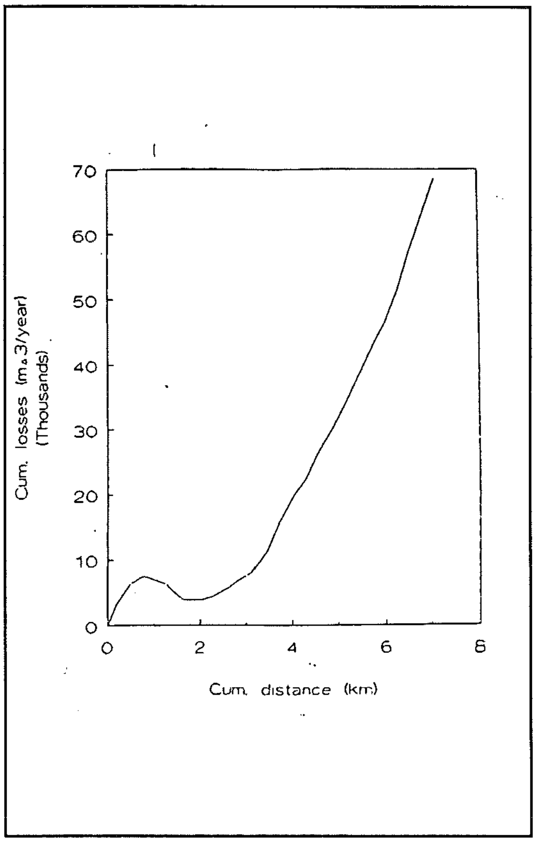


Figure 2: Cumulative losses Vs cumulative distance

The Master Plan for Coast Erosion Management, prepared in 1986, has identified this area

- of morphological complexity and
- subject to multiple development pressure,

and hence being in need of complex solutions.

It had been decided that any restoration scheme for this area should satisfy two major requirements, viz.

- The beaches shall be fully or partially restored by the artificial supply of sand to cover up losses from the system;

- Any restoration structures should not restrict or obstruct the availability of beaches essential for tourism and local fishing.

The restoration concept adopted for this area was beach nourishment stabilised by four offshore breakwaters.

3. FIELD DATA AVAILABLE

3.1 Pre-construction

1. Bathymetric and Shoreline Survey (1986) together with cross shore profiles;

2. Wave and current measurements off Negombo for a period of 8 months covering both the SW and NE Monsoons;

3. Sea bed sediment sampling.

3.2 Post-construction

1. Bathymetric and shoreline surveys together with cross shore profiles (done in December 1989, April 1990, January 1991 and January 1992);

2. Sea bed sediment sampling.

3. Diffraction Study on directional wave measurements on the Southwest coast, in which, statistics pertaining to most western stretches could be considered as applicable to the Negombo stretch.

In addition to the above information, a comprehensive wave measurement programme (using a waverider buoy) has been carried out off Colombo from 1980 to 1994. This information could be considered as representative of Negombo also, due to reasons mentioned elsewhere in this report.

4. SITE CONDITIONS

4.1 Wave Conditions

Sri Lanka experiences two monsoons during a year (the South West Monsoon and the North East Monsoon) and hence the sea waves also undergo seasonal fluctuations during the year, viz. the South West monsoonal wind waves (May-September) and the North East Monsoonal wind waves (December-February). The South West Monsoon generates waves much higher than during the North East Monsoon. In addition to that, through out the year, southerly perennial swell waves exists.

During the period April to October, due to the superposition of perennial southerly swell generated by the trade winds near the equator on the wind waves generated by the SW monsoon winds, very often results in a double peaked spectra both with respect to frequency and direction.

This phenomena happens during the NE monsoon also, but double peak spectra cannot be observed clearly due to the existence of small wave heights and dominance of swell situation.

The directional wave climate of Colombo could be considered as applicable to the Negombo area since the coastal stretch between Colombo and Negombo is almost straight, with a bearing of 351° from the north. For 60% of the time, the significant wave height off Colombo (derived from a refraction study of Galle directional wave measurements - Ref /1/ & Appendix A-1) lies between 1.40m and 2.25m, while for 45% of the time waves come from the direction 235°-245°. During the NE Monsoon, 45 percent of time H_s lies between 0.30m and 0.70m, while 64 percent of time waves coming from the direction of 215-225°. The low wave heights and the direction more inclined towards the south during the NE Monsoon could be attributed to the fact that during this period, swell waves are dominant. The corresponding average wave periods for the two seasons are 6.0 s and 14.0 s respectively.

4.2 Tides and Currents

Tides are predominantly semi-diurnal and the tidal range varies between 0.45m and 0.60m during spring tide and between 0.1m and 0.25m during the neap tide. These variations occur almost at the same time along the coastal stretch under consideration.

Ocean currents circulating around the country depend on monsoonal changes, and during the SW Monsoon they are in a northerly direction while currents in a southerly direction are experienced during the NE Monsoon (Ref / 8 /). While the magnitude of the currents may be as high as 1.0 m/s occasionally, most of the time it is in the range of 0.15 m/s.

4.3 Beach Profile

The coastal profile up to 2m water depth MSL is very steep, averaging 1:12. Thereafter, the steepness decreases to approximately 1:110. The beach sand has a mean grain diameter (d_{50}) of 1.3 mm and at water depths below 2m the sea bed material is considerably finer. This may explain why the beach slope is very steep when compared to the deeper area. No significant variation of slopes in the beach profile due to monsoonal changes has been noticed. The closure depth is assumed to be at the 3.0m depth contour.

4.4 Sediment Transport

Even though there is a change in the sediment transport direction during the monsoonal variations, the net annual transport is in the direction of north, and the annual loss from the system had been 70,000 to 100,000 m^3 before the implementation of any restoration scheme.

4.5 Design, Layout and Execution

As a first step, the available literature on beach response to breakwaters had been reviewed, based on prototype experience and model test results (Ref /10/). Based on the knowledge gathered from literature review and physical modelling results, layout and structural design had been carried out. The most important finding was that a tombolo is formed in most cases when ratio of length of the breakwater to the perpendicular distance to the coast (from the breakwater) is greater than one, provided that the breakwater is located just outside the breaker zone. It has also found that amount of accumulation increases when the distance from shore to the breakwater increases. But when the distance is more than twice the width of the breaker zone, the accumulation starts to decrease.

But this indicates only the initial changes in the transport conditions and no co-relation is mentioned about the amount of accumulation and tombolo formation. However, from literature review, it was found that when the tombolos are formed, more than 50% of the drift will get accumulated.

The minimum distance from the coastline to the breakwater to avoid erosion of existing coastline will depend on the near shore direction of propagating waves and on the location of the upstream breakwater head.

All the 3D tests were carried out in an undistorted scale model of 1:50 with a prototype wave height of 1.6m and an incident angle of 235^0.

The final layout was composed of four offshore breakwaters located approximately 140m from the coastline at 3.0m depth. The length of the breakwaters varies from 168m to 182m, and the distance between the breakwaters (centre to centre) varies from 906m to 1,026m. The breakwaters are oriented 6 to 9 degrees from the bearing of the coastline. It had been decided to turn the breakwater clockwise around its upstream head so that the downstream head come closer to the land. This was expected to reduce the effect of diffraction and leeside erosion next to the breakwater. Due to the abundance of granite rock in the area, the breakwaters were designed as rubble mound structures. Construction commenced in January 1988 and was completed in February 1989. The beach had been nourished with 400,000 m^3 of sand (40% more than the quantity calculated, to account for losses) with a mean grain diameter, d_{50}, of 0.8 mm. Sand was placed in four lots between the breakwaters on the beach.

5. POST CONSTRUCTION

5.1 From 1989 to 1992:

At the end of the very first year (December 1989) after completion of the project tombolos had developed behind the breakwaters. Although at the end of the first year after construction, i.e. in 1989, the formation of tombolos has resulted, some recession in the January, 1987 shoreline (see Dwg No. 1: shoreline before construction), and some stabilization of the beach, was observed during the next few years. Since the net sediment transport is in the direction of north, during the first year after construction, development of the beach on the south of the first breakwater had been noticed, while erosion had occurred on the north of the fourth breakwater, as expected. But it would appear that the rate of erosion north of the fourth breakwater is reducing (see Dwg. 1 & Fig. 3) Hence, the deduction could be made that the stretch is approaching a state of equilibrium.

A comparison has been made of the variation of the total sand volume in each bay (in m^3) between breakwaters with the duration, and the results are illustrated in Fig. 3.

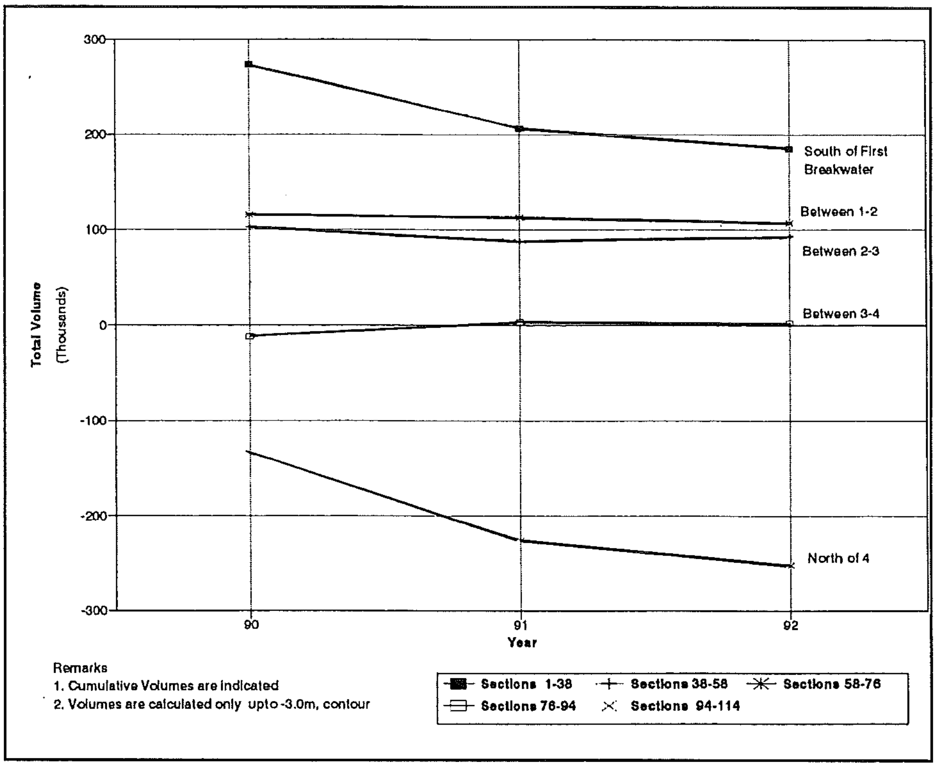


Figure 3: Total sand volume in each bay Vs duration (This graph has to be read in conjunction with Dwg. 1)

In the reach south of the first breakwater, loss of sand from the system could be noticed after 1989 even though the rate of loss is becoming small (see Fig. 3). The loss of sand cannot be completely attributed to longshore drift. A groyne, which was constructed in 1989, between shore profiles 1 and 2 (not shown in the Dwg 1) has triggered some leeside erosion due to the trapping of sand on the updrift side of the groyne. Since volumetric calculations have been done commencing from shore profile No. 1, a part of this trapped sand is not included in the calculations, and hence, any interpretation of results should be made taking this fact into consideration.

The volumetric calculations in the bay between breakwaters 1 - 2, 2 - 3 and 3 - 4 indicate that the quantity of sand remaining in those bays are almost constant with time, indicating a prevalence of a stable situation. The rate of erosion north of the fourth breakwater is also reducing as mentioned earlier.

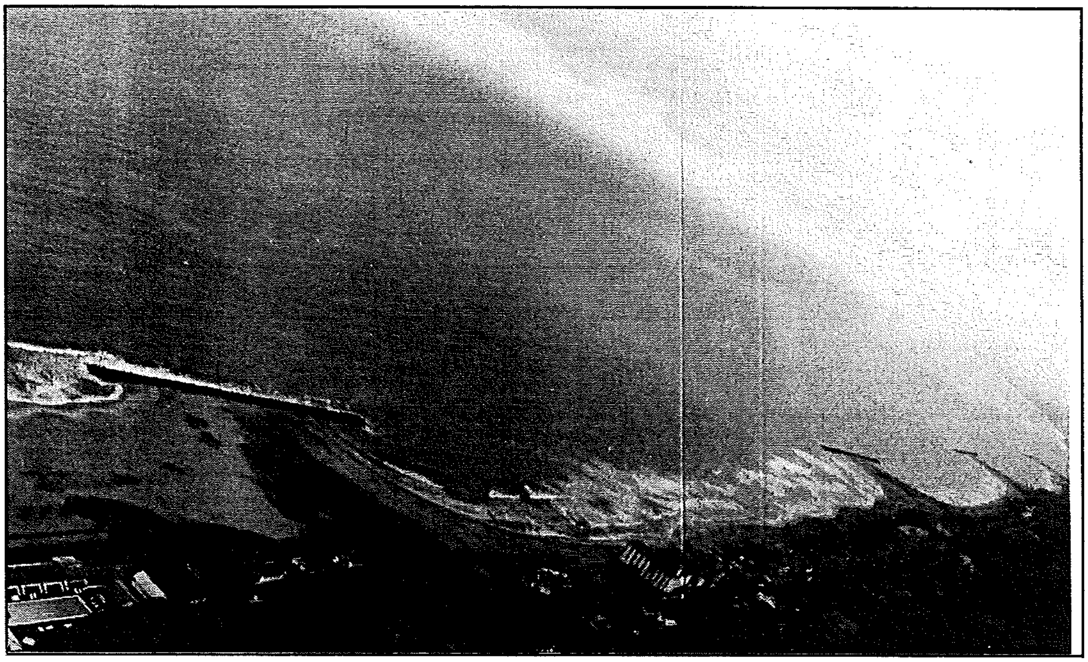
Severe erosion has been experienced in the beach north of Maha Oya soon after the completion of Negombo scheme. But this was mainly due to two reasons:

1. Reduction in sediment supply from updrift side, i.e. south of Maha Oya Estuary due to construction of breakwaters;

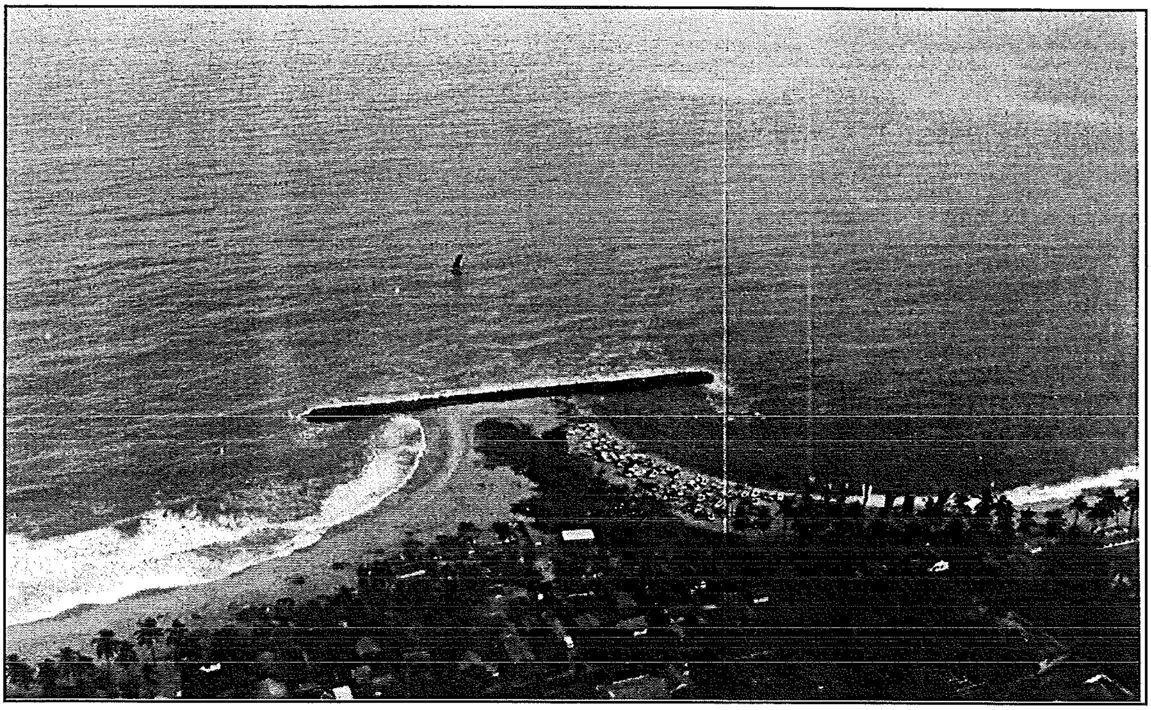
2. Reduction in sediment discharge from Maha Oya River (as a result of extensive mining).

<u>5.2 From 1992 to 1995:</u>

Unfortunately there were no post monitoring surveys carried out during this period. But the aerial photographs taken during October, 1995 depicting the current situation, would give a good comparison between 1992 and 1995.



P-1 : Layout of breakwaters and resulting crenulate shaped bays



P-2 : Formation of tombolo

As illustrated in P-1 and P-2, presence of brownish traces of sand is a good indication of prevalence of sand by-passing. Furthermore, as clearly depicted in P-1, the shore line between first and second breakwaters is well in accordance with the situation prevailed in 1992 (as indicated in Dwg. 1) confirming the stabilization of the system. This has further been proved by the shore parallelness of the wave crests approaching the bay.

P -3 : Most northward breakwater and short groyne
(Note: this picture depicts the mirror image of the actual site lay out)

Since the lee erosion north of the fourth breakwater was severe and it has threatened some existing structures, a short groyne has been constructed approximately at section 106 (Dwg. 1 & P-3). This has created a pocket beach (see P-3) between the breakwater and groyne. This inturn has triggered erosion north of the groyne. However, the development of a pocket beach as well as lee side erosion resulted from groyne construction could not any more be active as pocket beach profile has reached almost the tip of the groyne indicating the by-passing of sand over the groyne.

6. CONCLUDING REMARKS

On the whole, this breakwater scheme could be considered a success as the effect on adjacent beach is minimal, except for the erosion north of Maha Oya. This erosion can partly be attributed due to the breakwater scheme itself and partly due to the reduction in sediment discharge from Maha Oya as a result of extensive mining.

It would appear that tombolos trap more sand than foreseen at the design stage. This has resulted in larger recession of the coastline north of the fourth breakwater than expected. But, by comparing the rate of volumetric changes that have taken place between the bays in the reach, it seems that the system is getting stabilized.

An analysis of sea bed samples taken at -1.5m, -3.0m and -6.0m indicate that there is no sediment movement beyond -3.0m, thereby confirming the assumption made that the closure depth is at -3.0m even though it appears too small for such a sandy coastline.

The prediction of the coastline north of the fourth breakwater passing the estuary, which has been made in Ref /3/ is reproduced in Fig. 4. This has been done, using an approach on equilibrium shapes of bays as given by Silvester (1974) taking northern most breakwater and revetment at Ranweli hotel as the two headlands.

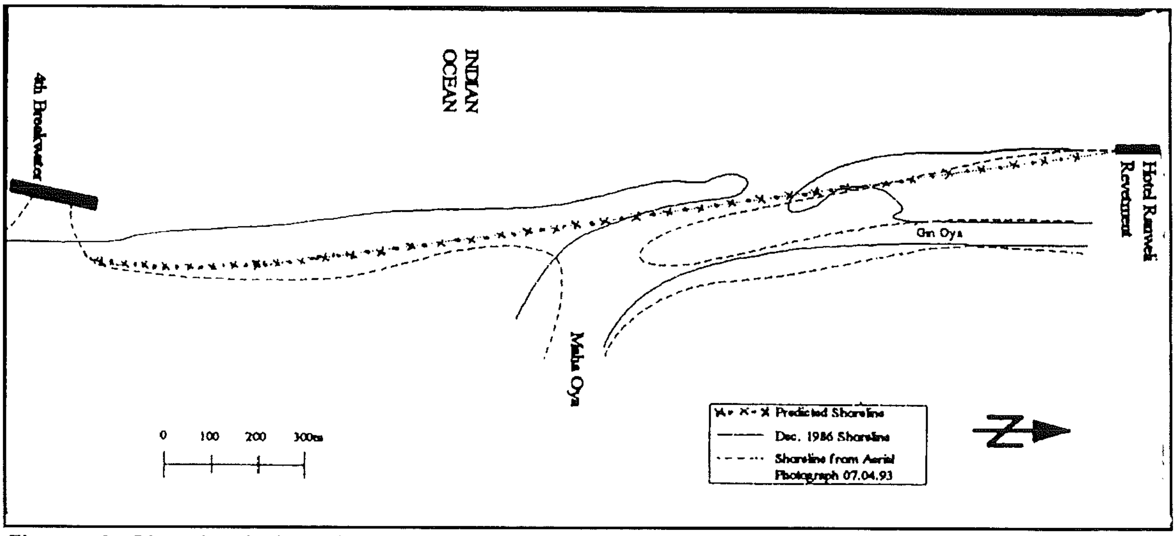


Figure 4: Sketch of shoreline development between the fourth breakwater and Ranweli hotel (actual & predicted)

Also, in some instances, it had been noticed that the shape of the tombolo formation has resulted in some recession in the coastline beyond the 1986 shoreline. This may be due to the large spacing between breakwaters.

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Dwg. 1

Shore-line developments 1987 - 1992

A - 1

Appendix:

Statistical distribution of wave heights and wave periods - Western stretch

Significant Wave Height (m)	170.: 180.	180.: 190.	190.: 200.	200.: 210.	210.: 220.	220.: 230.	230.: 240.	240.: 250.	250.: 260.	260.: 270.	270.: 280.	280.: 290.	290.: 300.	300.: 310.	310.: 320.	320.: 330.	330.: 340.	340.: 350.	350.: 350	Total 530.
< .10																				
.10: .20																				
.20: .30																				
.30: .40						.09														.09
.40: .50			.06	.09	.03	.09														.28
.50: .60				.12	.12	.06	.03													.34
.60: .70				.12	.09	.09														.31
.70: .80				.18	.09	.15	.12		.06											.61
.80: .90			.03	.28	.09	.09		.03	.12	.03										.67
.90: 1.00			.03	.12	.28	.43	.28	.24	.12	.09										1.59
1.00: 1.20				.12	.61	1.56	.89	1.35	.92	.12										5.57
1.20: 1.40			.03	.18	.83	1.78	2.51	1.71	1.35	.43	.03									8.85
1.40: 1.60				.24	.70	2.66	3.83	2.51	1.25	.58	.06									11.86
1.60: 1.80				[illegible]	.70	2.94	4.44	3.95	2.30	1.07	.15									15.89
1.80: 2.00				.09	.77	2.33	4.04	5.02	2.54	1.25	.15	.03								16.22
2.00: 2.25				.06	.46	2.08	3.28	4.04	3.83	1.47	.34									15.55
2.25: 2.50					.15	.73	1.10	2.39	2.69	1.81	.73									9.61
2.50: 2.75					.03	.24	.46	1.07	2.33	1.35	.24									5.79
2.75: 3.00						.06	.12	.64	.80	.95	.31	.03								2.91
> 3.00						.03	.34	.61	1.71	.98	.21									3.89
Total			.15	1.96	5.02	15.43	21.43	23.57	20.02	10.13	2.23	.06								100.00

No. observations : 3267

Significant Wave Height (m)	170.: 180.	180.: 190.	190.: 200.	200.: 210.	210.: 220.	220.: 230.	230.: 240.	240.: 250.	250.: 260.	260.: 270.	270.: 280.	280.: 290.	290.: 300.	300.: 310.	310.: 320.	320.: 330.	330.: 340.	340.: 350.	350.: 350.	Total 530.
< .10					.08														.34	.41
.10: .20				.62	1.68	.03														2.32
.20: .30	.03		.08	1.86	5.54	.90	.08						.05							8.53
.30: .40			.18	1.03	7.01	3.07	.10	.13	.05	.03										11.60
.40: .50	.03	.05	.39	1.13	6.32	4.43	.34	.34	.15	.13										13.30
.50: .60	.03	.10	.54	1.39	4.95	3.69	.49	.28	.21		.10									11.78
.60: .70		.15	.41	1.03	3.56	2.04	.49	.31	.28	.10		.03								8.40
.70: .80		.03	.26	.72	2.66	1.39	.46	.54	.26	.28	.13	.13								6.86
.80: .90			.21	.31	2.09	1.08	.23	.52	.36	.13	.10	.15	.03							5.21
.90: 1.00	.03	.05	.15	.15	1.37	1.29	.90	.26	.23	.26	.15	.05	.13							5.03
1.00: 1.20			.23	.31	1.78	2.11	2.11	.70	.64	.46	.18	.05	.05							8.64
1.20: 1.40			.13	.49	.67	2.19	1.78	1.13	.54	.26	.28	.08	.05							7.61
1.40: 1.60				.28	.62	1.06	1.24	.82	.46	.13	.08	.15								4.85
1.60: 1.80				.13	.34	.49	.46	.39	.28	.28	.05		.03							2.45
1.80: 2.00					.13	.34	.13	.08	.15	.08	.08									.98
2.00: 2.25				.03	.10	.15	.23	.18	.03	.05		.03								.80
2.25: 2.50					.05	.18	.15	.10	.03	.05	.03	.08								.67
2.50: 2.75							.18	.03		.03	.03									.26
2.75: 3.00								.03	.03	.08										.13
> 3.00									.03	.15										.18
Total	.10	.39	2.58	9.49	38.93	24.44	9.38	5.83	3.74	2.50	1.21	.75	.34						.34	100.00

No. observations : 3879

Probability that waves occur in the given height and direction class. May-Sep (top), Oct-Apr (bottom)

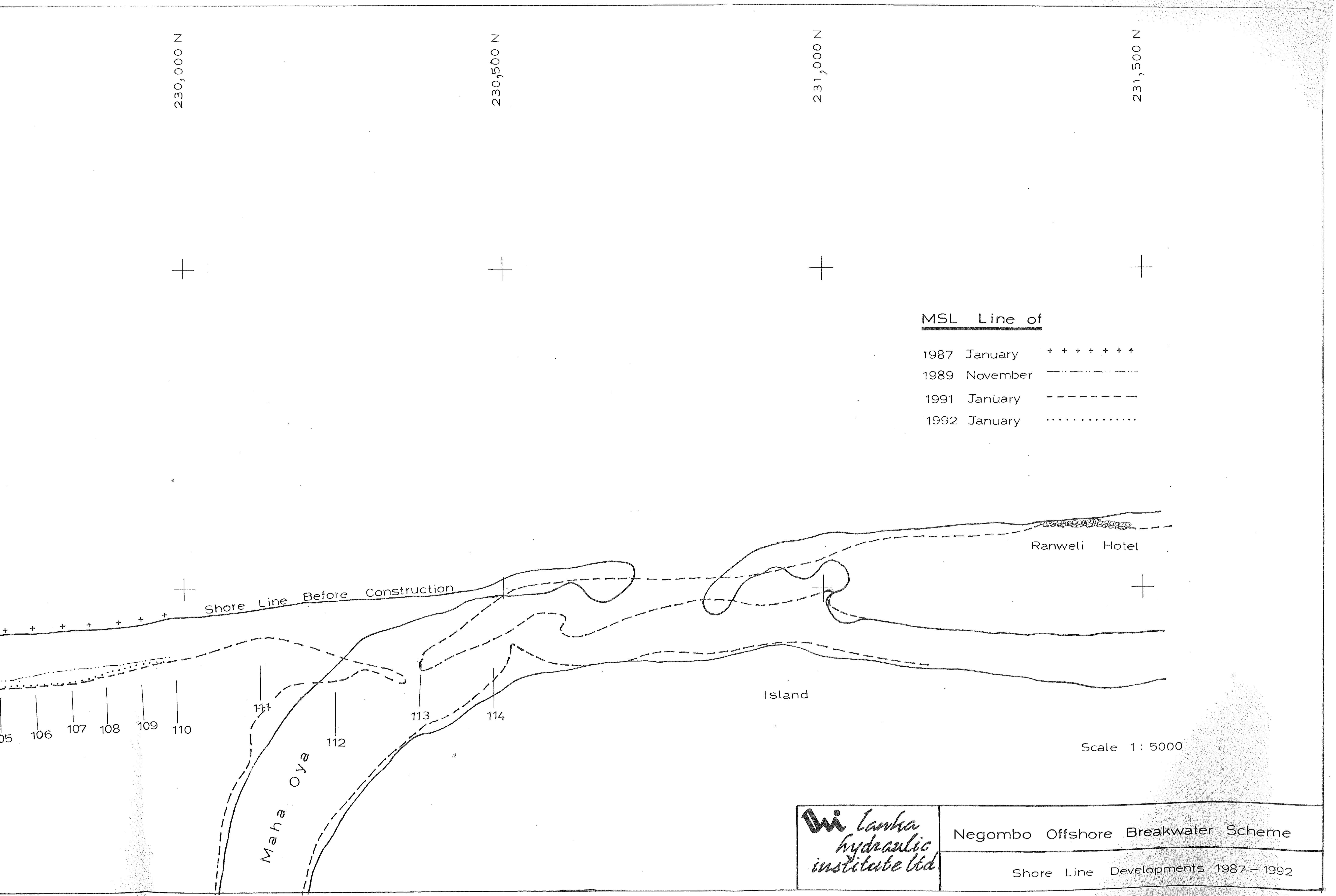
Significant Wave Height (m)	170.: 180.	180.: 190.	190.: 200.	200.: 210.	210.: 220.	220.: 230.	230.: 240.	240.: 250.	250.: 260.	260.: 270.	270.: 280.	280.: 290.	290.: 300.	300.: 310.	310.: 320.	320.: 330.	330.: 340.	340.: 350.	350.: 350.	Total 530.
< .10																				
.10: .20																				
.20: .30																				
.30: .40						21.25														21.25
.40: .50			4.50	7.67	9.00	21.25														11.64
.50: .60				5.75	9.25	13.13	5.00													8.30
.60: .70				8.00	9.33	10.08														9.02
.70: .80				7.17	5.67	8.25	6.75		4.00											6.41
.80: .90			6.00	7.33	6.67	5.67		4.00	4.00	4.00										6.05
.90: 1.00			6.00	7.00	6.74	6.66	4.85	4.50	4.75	4.00										5.75
1.00: 1.20				6.25	6.20	5.50	4.90	4.70	4.50	4.25										5.11
1.20: 1.40			6.00	6.00	6.00	6.25	5.17	4.93	4.61	4.79	6.00									5.33
1.40: 1.60				6.50	6.00	5.79	5.58	5.48	5.24	5.16	5.50									5.59
1.60: 1.80				6.73	6.22	6.13	5.97	5.78	5.39	5.43	5.20									5.85
1.80: 2.00				7.67	6.32	6.17	6.22	6.04	5.76	5.51	5.60	5.00								6.03
2.00: 2.25				7.50	6.53	6.54	6.44	6.26	6.07	5.77	6.36									6.26
2.25: 2.50					7.40	7.00	6.94	6.35	6.25	6.10	6.12									6.39
2.50: 2.75					7.67	7.13	7.33	6.77	6.47	6.20	6.00									6.56
2.75: 3.00						7.50	6.75	6.48	6.65	6.23	6.30	7.00								6.46
> 3.00						6.00	7.00	6.95	6.59	6.34	6.86									6.63
Total			5.40	6.88	6.43	6.41	5.96	5.90	5.84	5.80	6.10	6.00								6.02

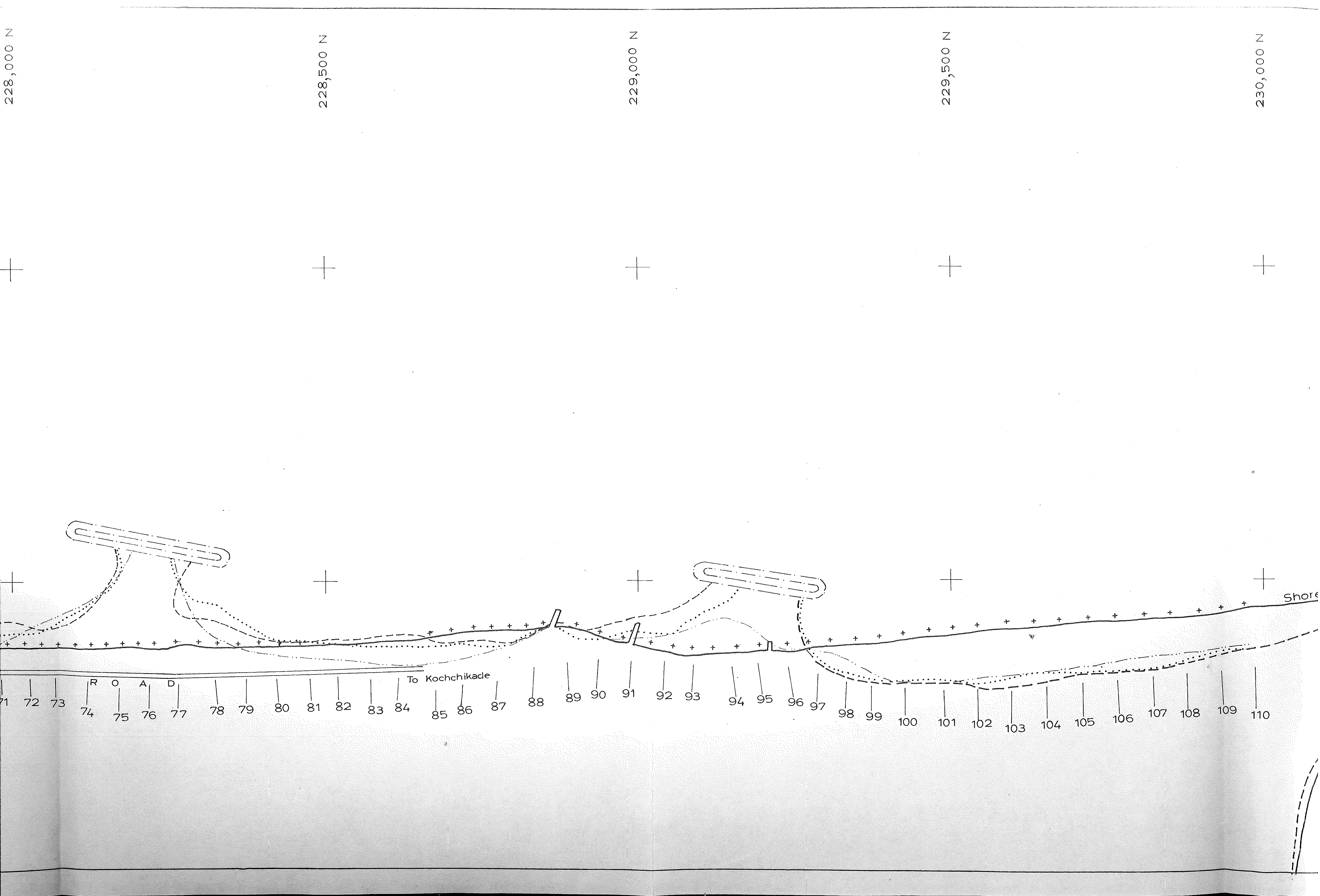
No. observations 3267

Significant Wave Height (m)	170.: 180.	180.: 190.	190.: 200.	200.. 210.	210.: 220.	220.. 230.	230.: 240.	240 250.	250.: 260	260 270.	270. 280	280. 290	290 300	300 310	310 320	320. 330.	330. 340	340.. 350	350.: 350	Total 530.
< .10					21.25														1.25	5.00
10: 20				9.79	11.66	21.25														11.27
.20: .30	3.00		5.00	9.88	10.65	16.91	6.00						3.00							10.97
.30: .40			5.71	9.38	10.89	16.86	6.25	6.40	6.00	5.00										12.08
.40: .50	4.00	3.50	5.33	7.20	10.57	16.44	6.85	6.31	6.17	3.40										11.60
50: 60	3.00	4.50	5.29	6.28	10.74	16.39	5.00	5.27	4.63		4.50									11.13
.60: .70		4.50	5.25	6.53	10.37	15.50	5.16	4.58	4.91	4.00		4.00								9.99
.70: .80		5.00	5.80	6.36	9.67	12.18	6.94	4.76	4.80	4.55	5.00	4.60								8.38
.80: .90			5.25	6.67	10.09	10.46	5.11	4.90	4.93	4.80	4.50	5.00	5.00							8.26
.90: 1.00	4.00	3.00	5.50	6.50	8.91	8.97	5.34	4.90	4.78	5.40	4.83	5.00	5.00							7.18
1.00: 1.20			5.56	5.92	8.69	7.30	5.57	5.00	4.84	4.94	5.00	5.00	5.00							6.50
1.20: 1.40			5.60	5.68	6.74	6.58	5.45	5.16	4.95	5.40	5.18	5.33	4.50							5.81
1.40: 1.60				5.45	6.33	5.95	5.73	5.47	5.11	5.40	5.00	4.83								5.69
1.60: 1.80				6.00	5.85	5.89	6.00	5.13	5.18	5.18	4.50		4.00							5.58
1.80: 2.00					5.80	5.92	5.60	5.33	5.00	5.00	5.00									5.53
2.00: 2.25				6.00	6.25	7.17	6.33	6.00	6.00	5.00		5.00								6.26
2.25: 2.50					8.50	7.57	6.33	6.00	6.00	5.50	6.00	5.67								6.62
2.50: 2.75							6.14	6.00		6.00	6.00									6.10
2.75: 3.00								6.00	6.00	6.00										6.00
> 3.00									6.00	6.00										6.00
Total	3.50	4.20	5.41	7.64	10.28	12.92	5.46	5.07	4.91	5.04	4.96	4.37	4.54						1.25	9.28

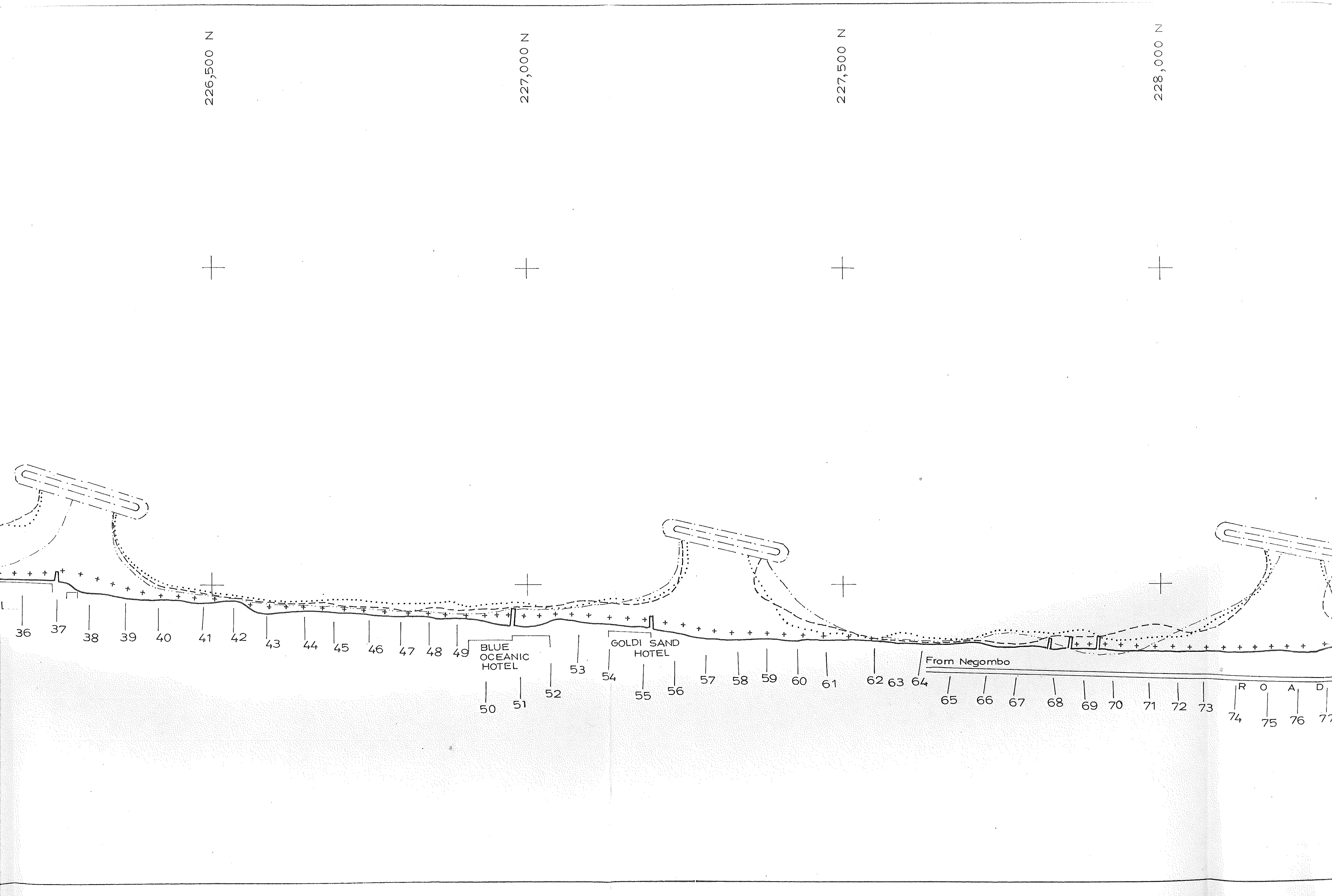
No. observations 3879

Mean wave period for waves in each height and direction class. May-Sep (top), Oct-Apr (bottom)

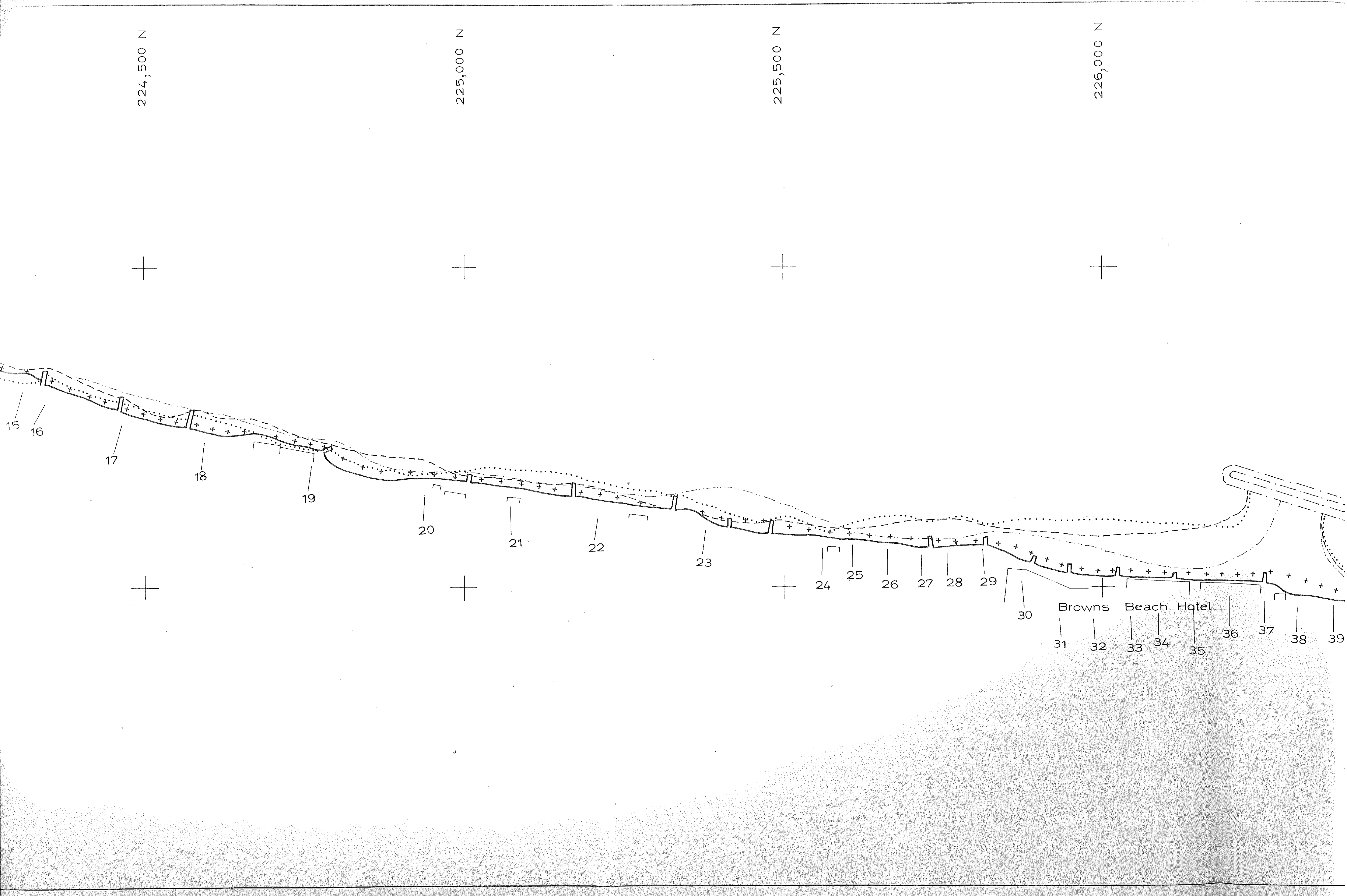

230,000 N
230,500 N
231,000 N
231,500 N
MSL Line of
1987 January
1989 November
1991 January
1992 January
Ranweli Hotel
Shore Line Before Construction
Island
Maha Oya
05
106
107
108
109
110
111
112
113
114
Scale 1 : 5000
lanka hydraulic institute ltd.
Negombo Offshore Breakwater Scheme
Shore Line Developments 1987 – 1992



228,000 N
228,500 N
229,000 N
229,500 N
230,000 N
Shore
R O A D
To Kochchikade
71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110



226,500 N
227,000 N
227,500 N
228,000 N
36
37
38
39
40
41
42
43
44
45
46
47
48
49
BLUE
OCEANIC
HOTEL
50
51
52
53
54
GOLDI SAND
HOTEL
55
56
57
58
59
60
61
62
63
64
From Negombo
65
66
67
68
69
70
71
72
73
74
R O A D
75
76


224,500 N
225,000 N
225,500 N
226,000 N
15
16
17
18
19
20
21
22
23
24
25
26
27
28
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30
Browns Beach Hotel
31
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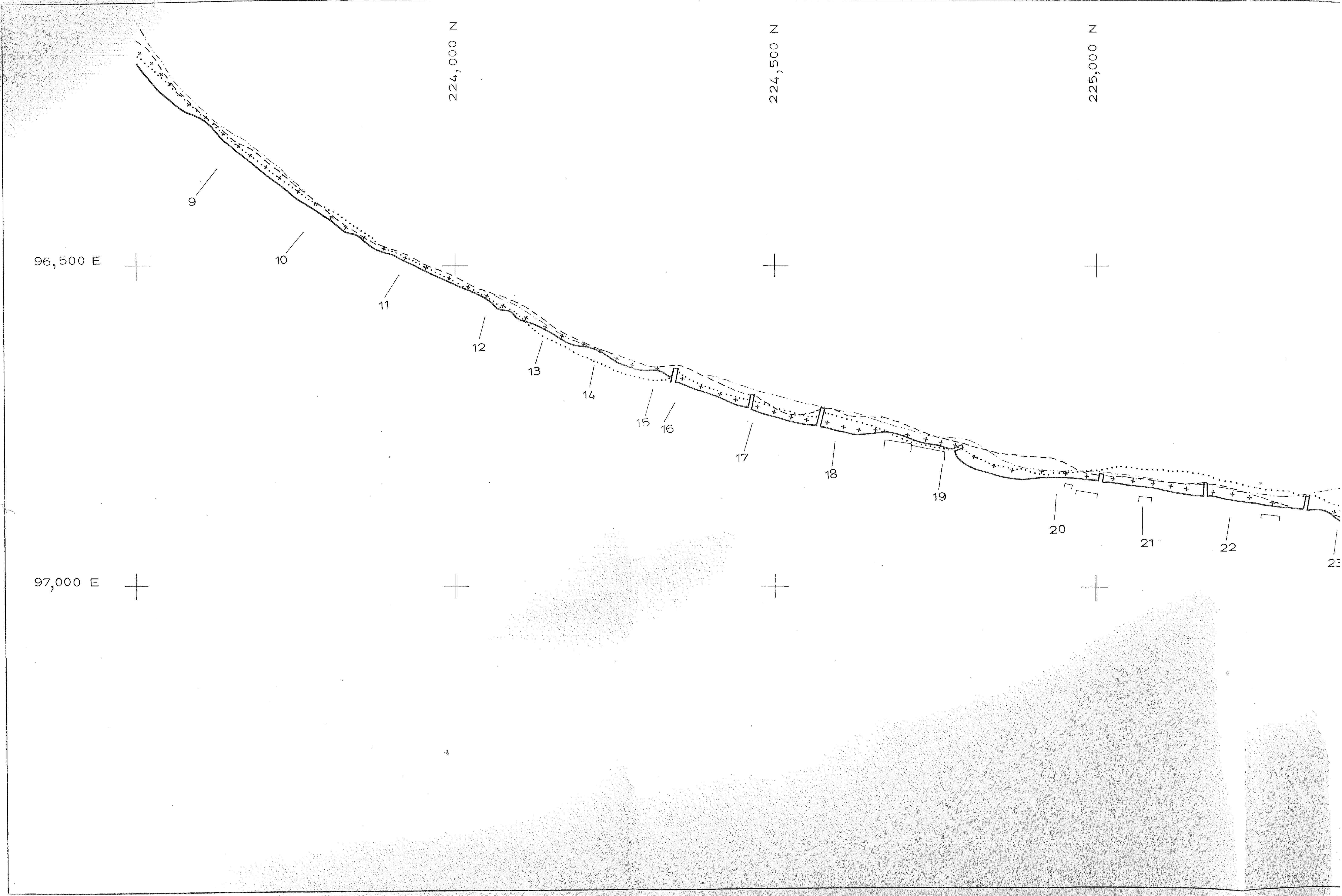
224,000 N
224,500 N
225,000 N
96,500 E
97,000 E
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23