CHAPTER 5

HYDRAULIC EVALUATION OF THE URGENT PLAN

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5-1 Hydraulic Model Test

Hydraulic model tests are aimed at examing the behavior of waves and currents which cause sand movement on the coral reef, and are also aimed at verifying the effects of preservation works against the present beach erosion. For the above purposes, firstly the actual phenomena will be discussed in this section based upon the field investigations carried out at Kuta, Nusa Dua and Sanur Beaches. Afterwards the data obtained by 2-dimensional hydraulic model tests using a wave flume 30 m long and 0.5 m wide will be analyzed mainly from the viewpoint of reproduction of actual phenomena. Finally, experimental model tests which were carried out for the model topography of Kuta and Nusa Dua Beaches using a wave basin 50 m long and 50 m wide will be described from the viewpoint of evaluating the planned countermeasures for beach erosion control.

5-1-1 Characteristics of the Actual Reef Beach

(1) Waves and Current

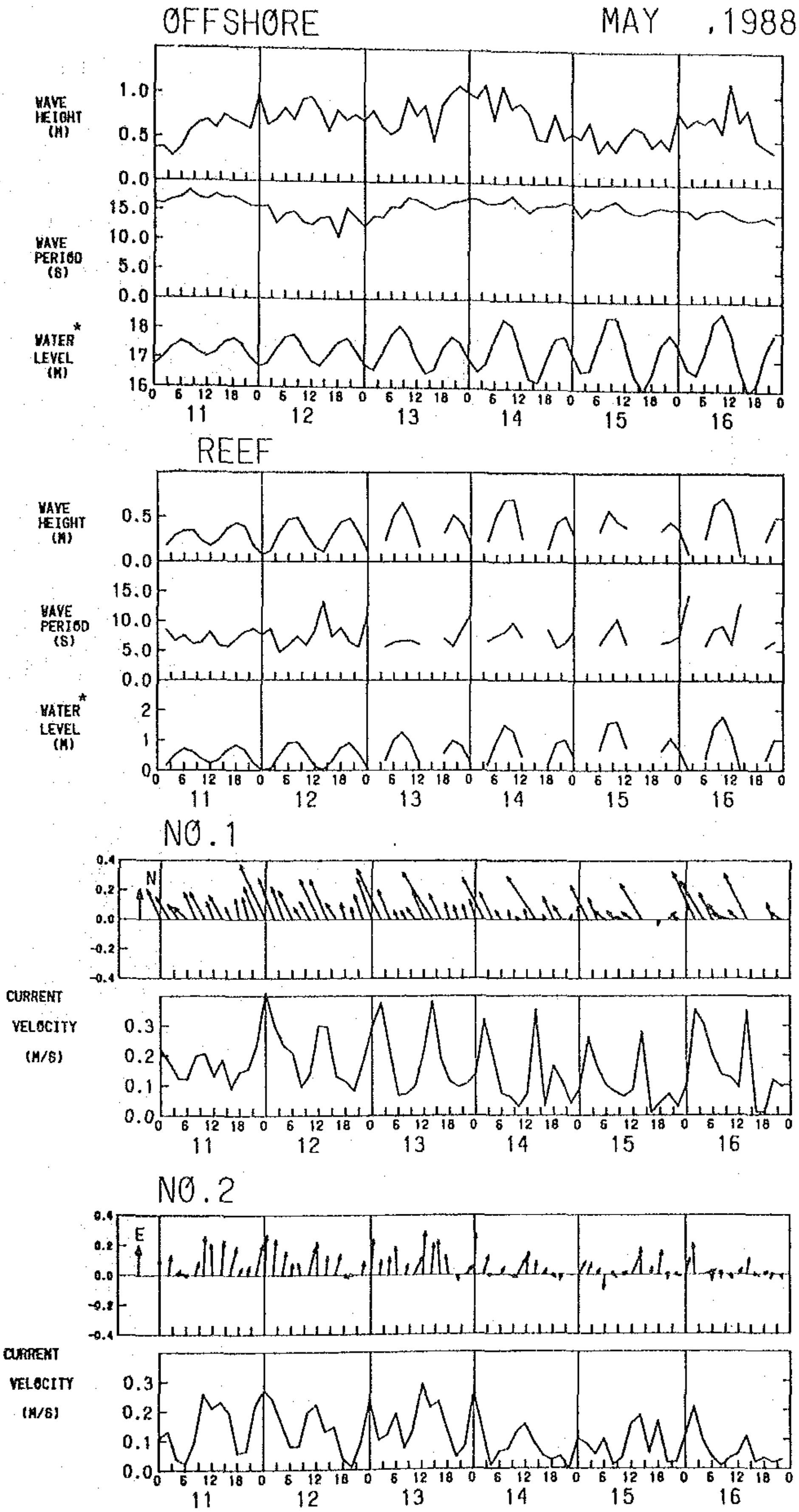
Figs. 2-3-3 ~5 represent the location of wave gauges and current meters installed at Nusa Dua, Kuta and Sanur Beaches, respectively. Observed data obtained simultaneously at each beach are shown in Fig. 5-1-1-1~5, where the wave height and period are expressed in terms of significant waves and the water level is the level at the installed position of each gauge with the observation time as the abscissa.

Fig. 5-1-1-1 shows the sample records measured at Nusa Dua Beach during May 11 to 16. This figure shows that waves with a significant height of about 1 m with a long period of beyond 15 sec approach the shore from the offshore region, but on the reef zone there appear smaller waves of about 0.5 m in height with a period shorter than that of offshore waves. In the figure, the lack of data on the reef is due to the fall of water level below the sensors of the gauges because of the changes of tidal level. However the fluctuations of water level both offshore and on the reef agree completely each other in both amplitude and phase. The records of current meters No. 1 and No. 2 are expressed on the lower part of this figure in terms of both vectors and resultant velocity. Taking into account the position of the current meters (refer to Fig. 2-3-4), it can be seen that the water on the reef flows out towards the offshore from the reef gap near the U-type breakwater. Moreover, it is found that the speed of this current at the reef gap is affected largely by the existing tidal stage, but the water is almost flowing out of the reef zone at all times even at rising tide and the speed at the south side is greater than that at the north side. As a result of this it seems probable that sands may flush out from the beach near the U-type breakwater and may not come back again to the beach.

Fig. 5-1-1-2 is the record when relatively big swell waves attacked Nusa Dua Beach. Waves on the reef zone are high at the high tide stage but low at the low tide stage. This means the natural reef is effective to protect the beach against the severe attack of big waves due to the shallow reef edge.

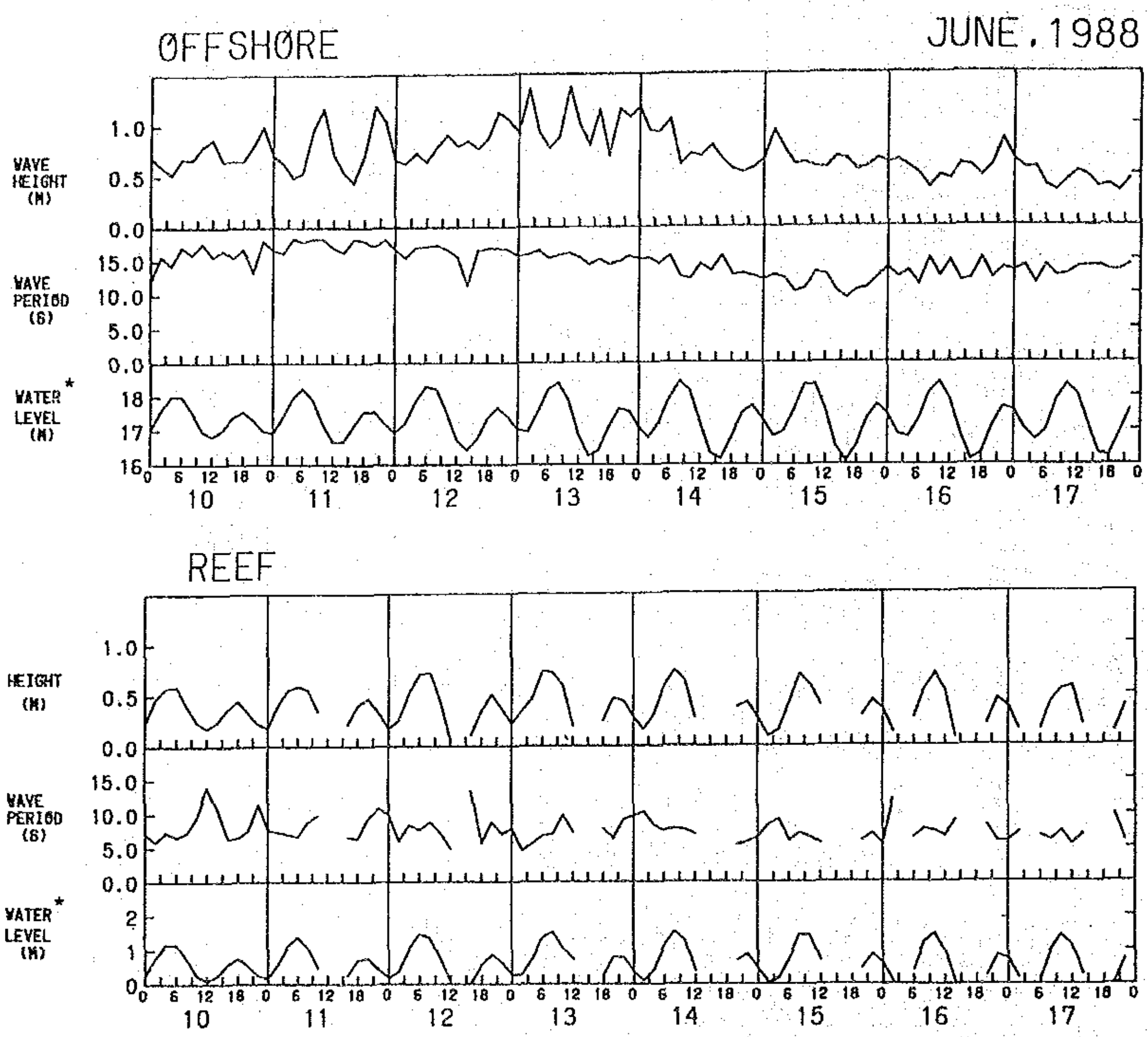
Figs. 5-1-1-3 ～4 are the records observed in March and June 1988 at Kuta Beach. During March 24 to 26 there occurred relatively strong currents flowing in the north direction. These were caused most likely not by the tide but by the incoming waves, for the change of tidal stage is not so large at that time. On the other hand, from the records in June, it can be seen that big waves above the height of 2.5 m attacked the site, but the heights of waves on the reef are not more than 1 m.

Fig. 5-1-1-5 represents the records at Sanur Beach. At this site offshore waves were not measured, so the records obtained at Nusa Dua Beach not far from Sanur Beach are illustrated together on the upper part. From the records of two current meters installed on both sides of the reef gap (refer to Fig. 2-3-5), the water is always flowing into the reef zone. This flow pattern of water is quite opposite to the pattern recognized at the reef gap of Nusa Dua Beach. These phenomena suggest that the reef gap is one of the important factors for the circulation of water on the reef from the viewpoint of water pollution for the reef beach. Accordingly the gap from where fresh water flows into the reef zone should not be closed.



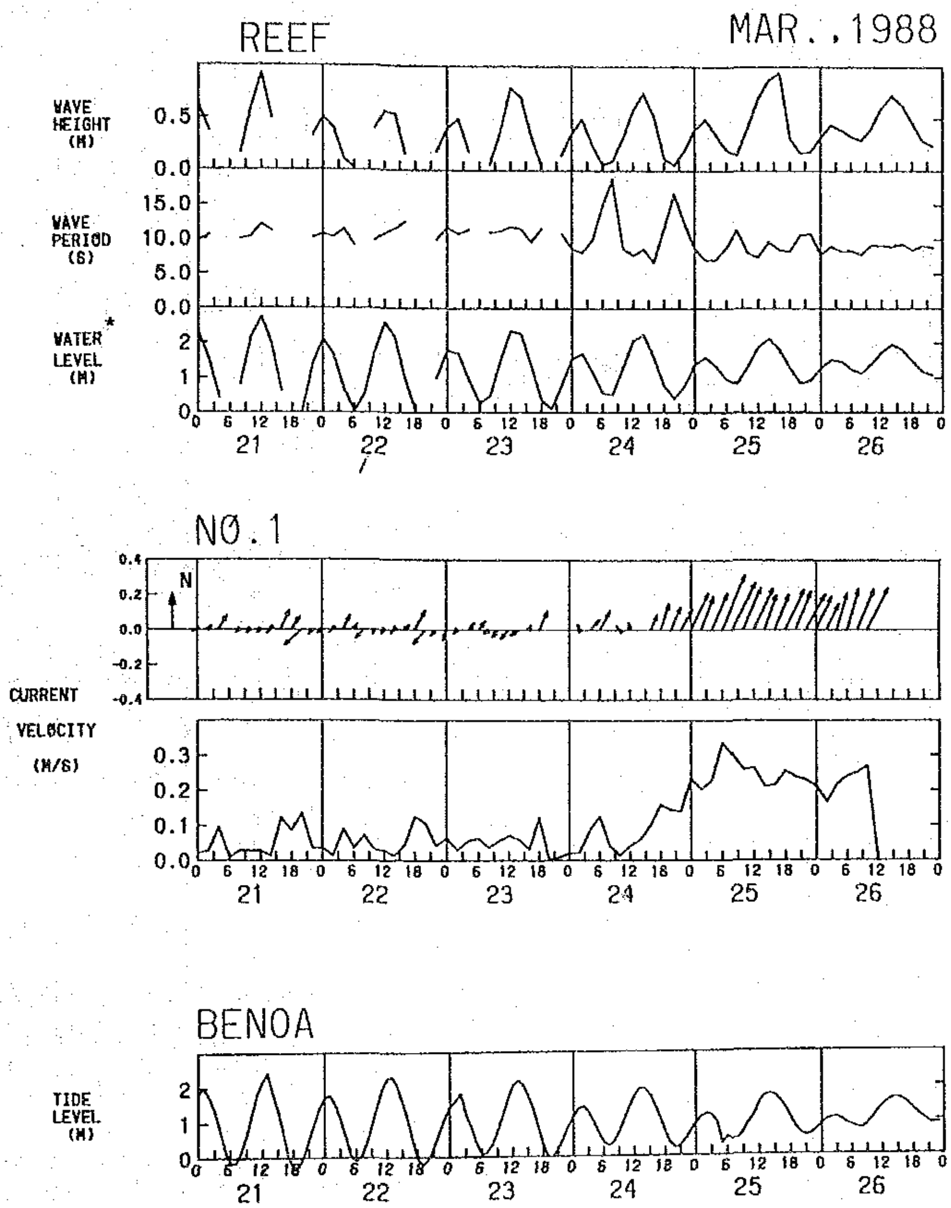
*) expressing sea level above the sensor of the wave gauge installed on the sea bed.

Fig. 5-1-1-1 Sample Records at Nusa Dua Beach



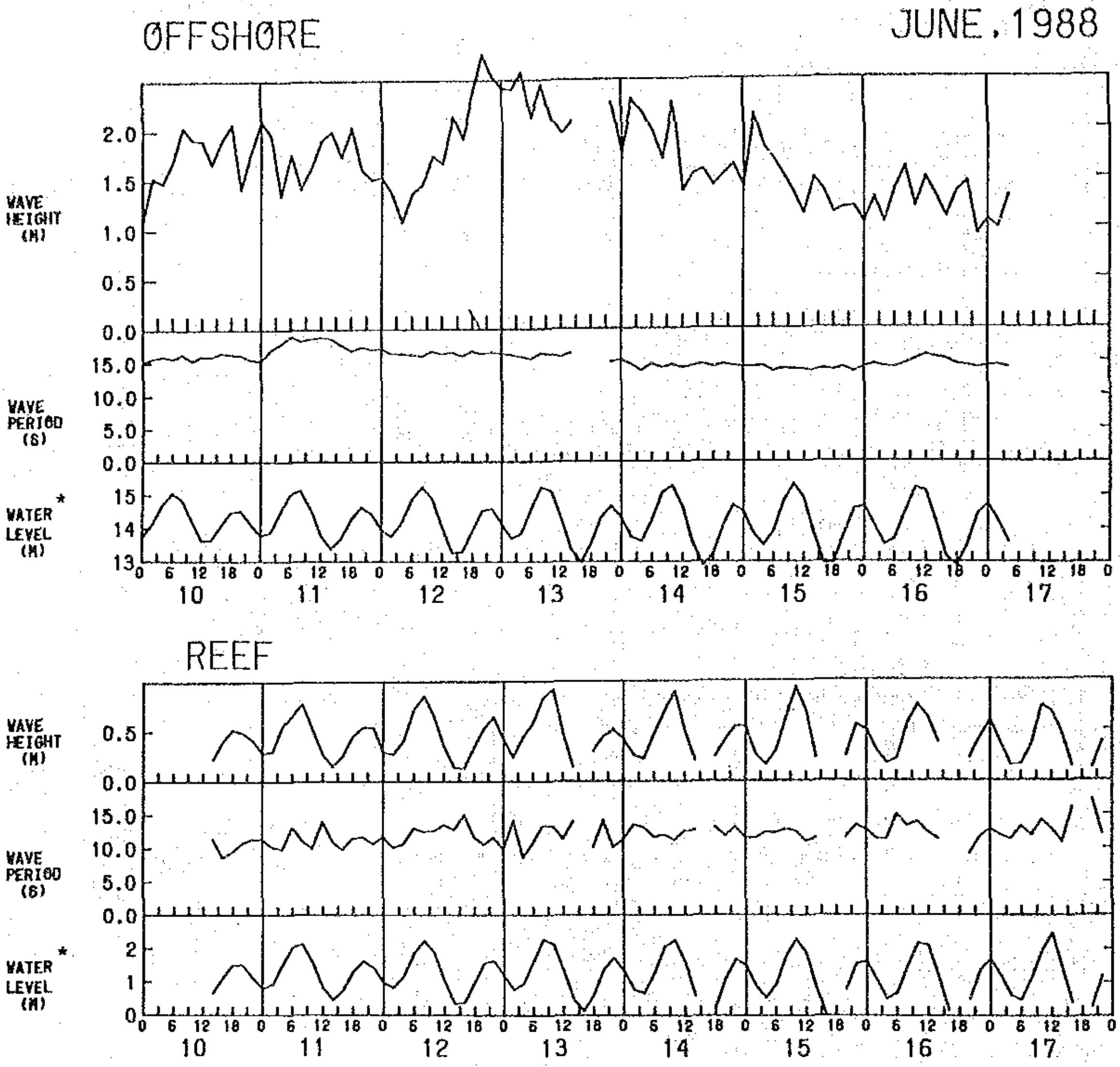
*) expressing sea level above the sensor of the wave gauge installed on the sea bed.

Fig. 5-1-1-2 Sample Records at Nusa Dua Beach



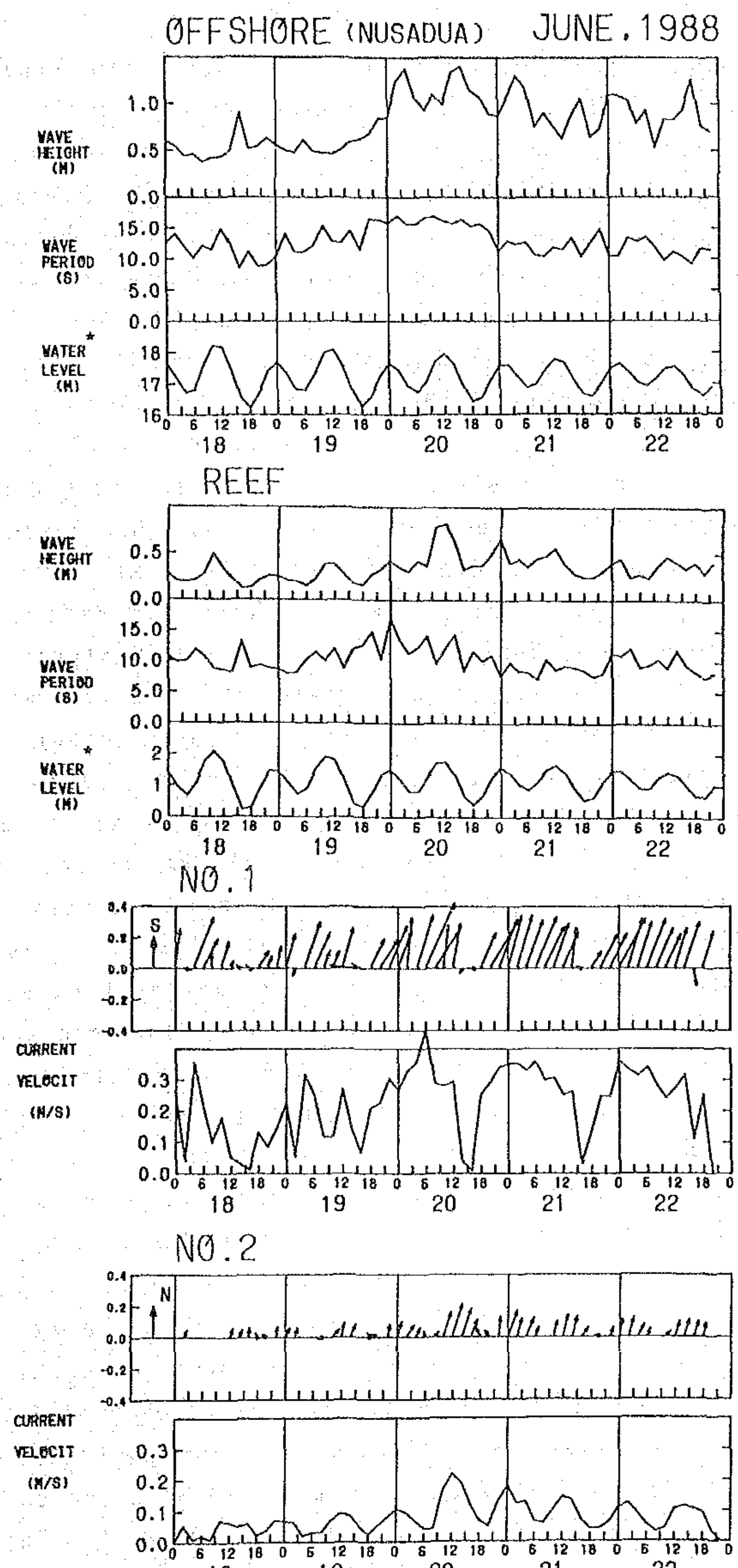
*) expressing sea level above the sensor of the wave gauge installed on the sea bed.

Fig. 5-1-1-3 Sample Records at Kuta Beach



*) expressing sea level above the sensor of the wave gauge installed on the sea bed.

Fig. 5-1-1-4 Sample Records at Kuta Beach



*) expressing sea level above the sensor of the wave gauge installed on the sea bed.

Fig. 5-1-1-5 Sample Records at Sanur Beach

The main statistical wave data which are relatively rough on the reef zone are summarized in Table 5-1-1-1. Based upon the value of this table, some relations between the wave height, period and the rise of mean water level are illustrated in Figs. 5-1-1-6 ~9. Fig. 5-1-1-6 is the relationship between the relative water depth and the wave period ratio, where Ho and To are significant offshore wave height and period and h the water depth on the reef. T is the significant wave period observed on the reef. From this figure it is found that the wave period on the reef zone is smaller than the one offshore. This may be due to the reformation of several small waves caused by the breaking of offshore waves near the reef edge. The data of Kuta Beach are located above those of Nusa Dua Beach in this figure. It is supposed that the reef edge at Nusa Dua is much higher or wider than at Kuta Beach, that is, Nusa Dua Beach is more effectively protected against the wave attack by the natural reef.

Fig. 5-1-1-7 is the relationship between the relative water depth and the wave height ratio based upon the field investigation, where H is the wave height on the reef and the other terms are the same as mentioned above. The data plotted in the figure tend to be linear and the line shows the equation obtained by the regression analysis, where r is the correlation coefficient. It can be understood that the wave height on the reef can be estimated well by using the regression line. In addition, neglecting the small value of the constant (0.08), the equation becomes $H = 0.37h$. This means that the wave height on the reef is determined only by the water depth on the reef zone. The height is about 40 percent of the depth and is not influenced by the offshore incoming waves.

Lastly the relations between the offshore wave and the rise of mean water depth will be discussed. The rise of the mean water level is one of the important factors because the depth of the reef including the rise of water level determines the wave height itself as mentioned above. The rise of mean water level can be calculated by using the relation of the depth between the offshore and the reef wave gauges, assuming that the differences of water level may be zero under calm sea conditions. The relations based upon the calculated value of mean water level are shown in Figs. 5-1-1-8~9. There is a tendency for the water level to increase in accordance with the increase of offshore wave heights, but the absolute value and the ratio of its rise vs. the offshore wave height are at most 12 cm and 15 percent under the conditions of our investigations. Using the results of regression analysis with regard to wave heights, the maximum rise of water level on the reef can be estimated to have brought about an increase of about 5 cm in the wave height on the reef.

Table 5-1-1-1 Wave Data Observed at Bali Beaches.

[NUSA DUA]

Month	Day	Time	Reef H (m)	Reef T (s)	Reef h (m)	Offshore Ho (m)	Offshore To (s)	Offshore ho (m)
May	13	6	0.52	6.4	1.48	0.54	15.8	18.30
		8	0.66	6.6	1.76	0.61	15.7	18.60
		10	0.47	6.7	1.42	0.96	17.4	18.21
	14	6	0.52	7.5	1.40	0.72	16.6	18.21
		8	0.69	8.1	1.99	1.10	16.8	18.84
		10	0.70	9.7	1.79	0.85	17.8	18.63
	16	8	0.64	8.7	1.93	0.78	15.8	18.81
		10	0.72	9.2	2.27	0.59	16.0	19.13
		12	0.57	6.1	1.62	1.15	15.2	18.46
June	12	5	0.53	8.4	1.52	0.73	17.0	18.36
		7	0.71	7.6	1.95	0.64	17.1	18.81
		9	0.72	8.8	1.85	0.79	17.3	18.72
	13	7	0.74	6.8	1.85	0.78	15.4	18.72
		9	0.72	7.0	2.03	0.88	15.8	18.90
		11	0.59	9.8	1.54	1.37	16.1	18.36
	14	7	0.58	7.5	1.60	1.05	15.6	18.42
		9	0.74	7.8	2.03	0.61	12.6	18.93
		11	0.64	7.6	1.77	0.71	12.2	18.66
	15	7	0.42	5.0	1.23	0.61	10.4	18.09
		9	0.70	7.1	1.93	0.63	10.8	18.84
		11	0.59	6.5	1.93	0.58	13.1	18.84
	16	9	0.55	7.7	1.70	0.37	15.2	18.60
		11	0.70	7.4	1.97	0.49	12.5	18.90
		13	0.52	6.6	1.44	0.46	14.8	18.36

[KUTA]

Month	Day	Time	Reef H (m)	Reef T (s)	Reef h (m)	Offshore Ho (m)	Offshore To (s)	Offshore ho (m)
June	11	4	0.56	9.9	2.00	1.35	17.9	14.99
		6	0.66	13.2	2.54	1.77	19.0	15.53
		8	0.78	11.1	2.62	1.42	18.3	15.63
		10	0.52	10.0	2.07	1.63	18.6	15.07
	12	6	0.72	13.0	2.38	1.37	16.2	15.38
		8	0.86	12.5	2.73	1.46	16.0	15.74
		10	0.65	12.6	2.38	1.75	16.7	15.38
	13	6	0.58	10.8	2.11	2.13	15.5	15.09
		8	0.83	13.4	2.77	2.45	16.3	15.73
		10	0.92	13.3	2.64	2.11	16.1	15.63
	14	8	0.69	12.0	2.56	1.71	14.1	15.56
		10	0.89	11.2	2.75	2.27	14.5	15.76
		12	0.50	12.6	2.09	1.38	14.1	15.13
	15	8	0.62	12.8	2.29	1.53	13.9	15.29
		10	0.93	12.5	2.79	1.35	13.8	15.81
		12	0.69	11.0	2.36	1.14	13.7	15.39
	16	8	0.56	13.3	1.98	1.60	14.5	14.98
		10	0.75	13.9	2.67	1.21	15.2	15.70
		12	0.62	12.3	2.60	1.49	15.8	15.60

[SANUR]

Month	Day	Time	Reef H (m)	Reef T (s)	Reef h (m)	Offshore * Ho (m)	Offshore * To (s)	Offshore * ho (m)
June	18	9	0.28	10.7	2.28	0.38	12.1	18.09
		11	0.49	8.8	2.58	0.42	11.5	18.72
		13	0.34	8.5	2.26	0.43	14.8	18.66
	19	9	0.22	11.5	2.05	0.47	15.3	18.48
		11	0.38	10.1	2.43	0.46	12.8	18.57
		13	0.38	12.0	2.30	0.51	12.6	18.06
	20	11	0.79	9.7	2.24	1.10	16.9	18.21
		13	0.82	12.2	2.26	0.99	16.1	18.45
		15	0.63	14.4	1.84	1.34	15.7	18.12
	21	11	0.48	10.4	2.01	0.90	10.4	17.94
		13	0.56	8.7	2.16	0.76	11.8	18.27
		15	0.39	9.3	1.92	0.63	11.5	18.18
	22	11	0.37	10.4	1.79	0.83	9.7	17.97
		13	0.47	9.1	1.94	0.83	11.1	18.03
		15	0.41	11.9	1.84	0.93	10.3	17.74

* : This data is observed at the offshore of Nusa Dua Beach.

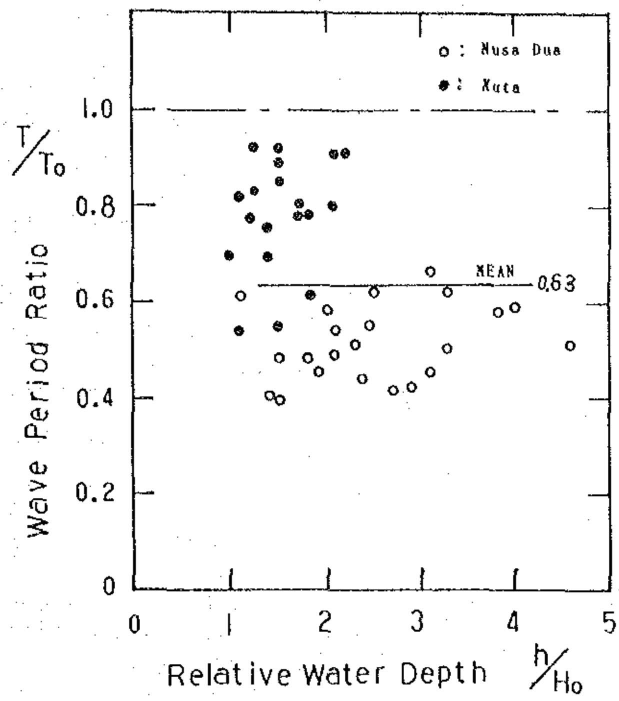


Fig. 5-1-1-6 Relation Between Wave Period Ratio and Relative Water Depth

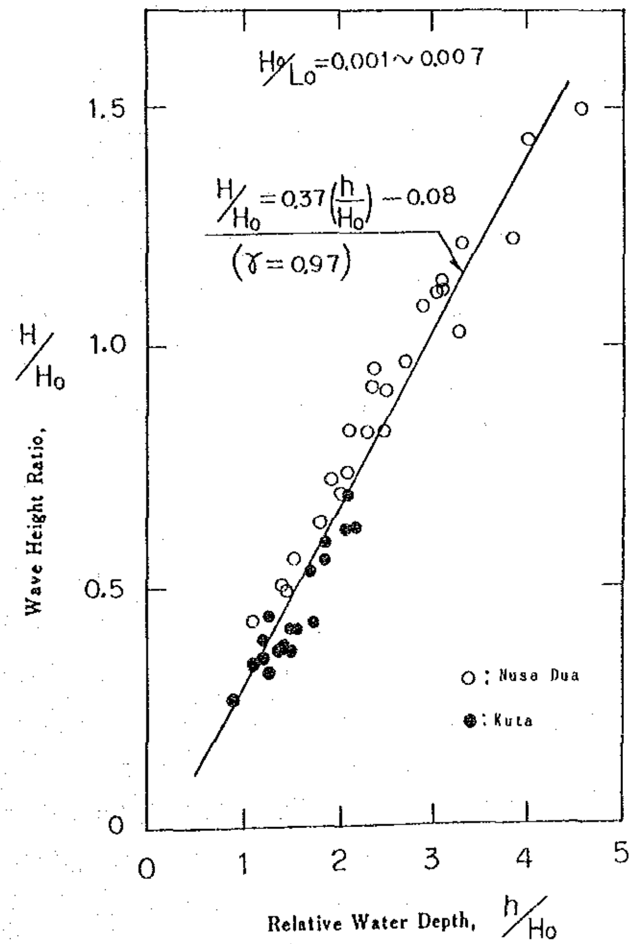


Fig. 5-1-1-7 Relation Between Wave Height Ratio and Relative Water Depth

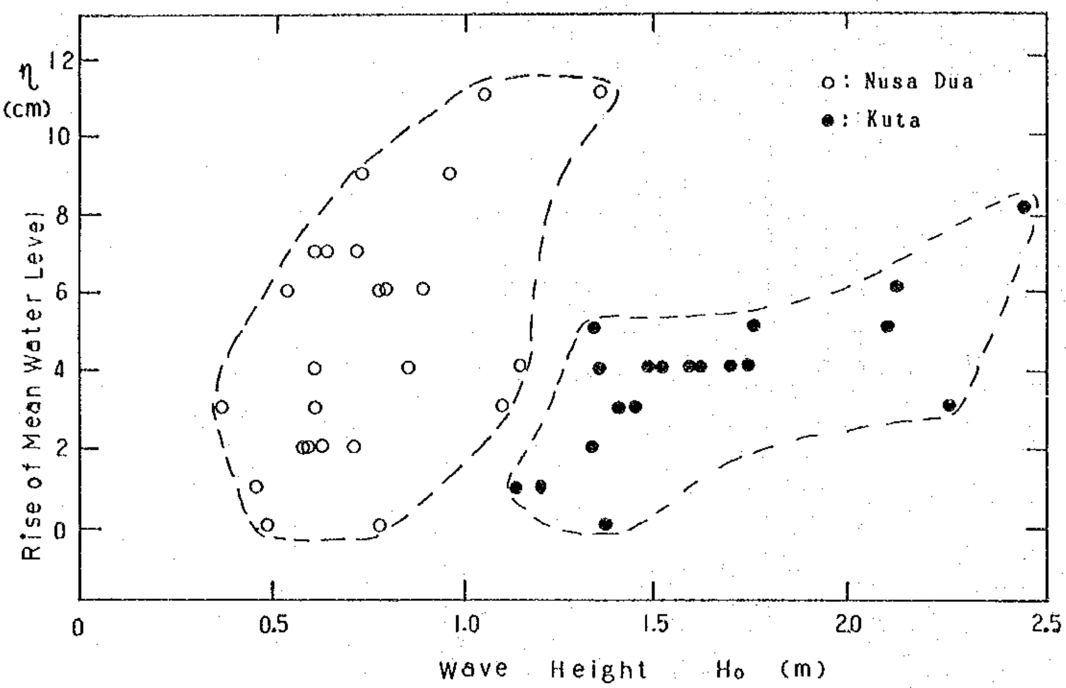


Fig. 5-1-1-8 Relation Between Rise of Mean Water Level and Wave Height

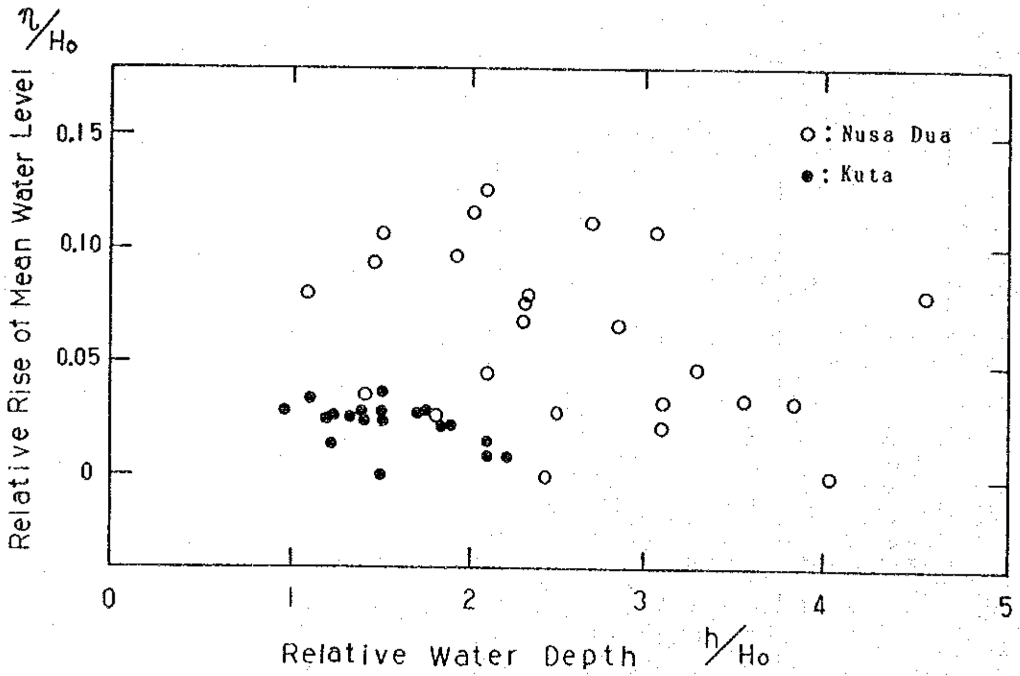


Fig. 5-1-1-9 Relation Between Rise of Mean Water Level and Relative Water Depth

(2) Tide

Tide is a very important factor not only to design coastal structures but also to estimate incoming wave characteristics on the reef zone. The main constituents of the tide at Bali region are obtained by a harmonic analysis as shown in Table 5-1-1-2.

Table 5-1-1-2 Principal Tidal Constituents

Symbol	Name of partial tides	Period in solar hours (hr:min)	Amplitude (cm)
M_2	Principal lunar	12:25	71
S_2	Principal solar	12:00	33
K_1	Luni-solar diurnal	23:56	25
O_1	Principal lunar diurnal	25:49	12

(from Hydrographer of the Navy; Admiralty Tide Tables and Tidal Stream Tables, Vol. 3, 1988)

In Bali Island tidal data have been recorded and also predicted by using the above constituents at Benoa Port north of Nusa Dua Beach. Comparisons of both data are given in Fig. 5-1-1-10; the prediction curve agrees well with the observed data in both phase and amplitude.

Fig. 5-1-1-11 indicates the tidal levels for this project. Here, MHW and MLW are obtained using the average height of all monthly waters and lowest waters during 1988. MHWST and MLWST are the mean high water and the mean low water of spring tides determined by the levels M_2 + S_2 above and below mean sea level, respectively. DL is defined by the levels $M_2 + S_2 + K_1 + O_1$ below mean sea level. Coastal engineers should generally apply MHW level (1.30 m above MSL) in order to examine the crown height and the stability of various coastal structures. And also the MHW level should be taken into consideration in the determination of water level associated with hydraulic model tests, because the highest wave reaches the reef zone and severely attacks the sandy beach at the time of high water.

In addition, comparisons of the tide at each beach will be examined to estimate the tidal differences. Figs. 5-1-1-12 show the variations of water level based upon the records observed simultaneously by wave gauges installed at Kuta (offshore) and Nusa Dua (offshore and reef) beaches with reference to predicted results at Benoa Port. It is found that all tidal variations agree well with each other and there is little difference in phase and amplitude. This means that the predicted long term data at Benoa Port are applicable for engineering use.

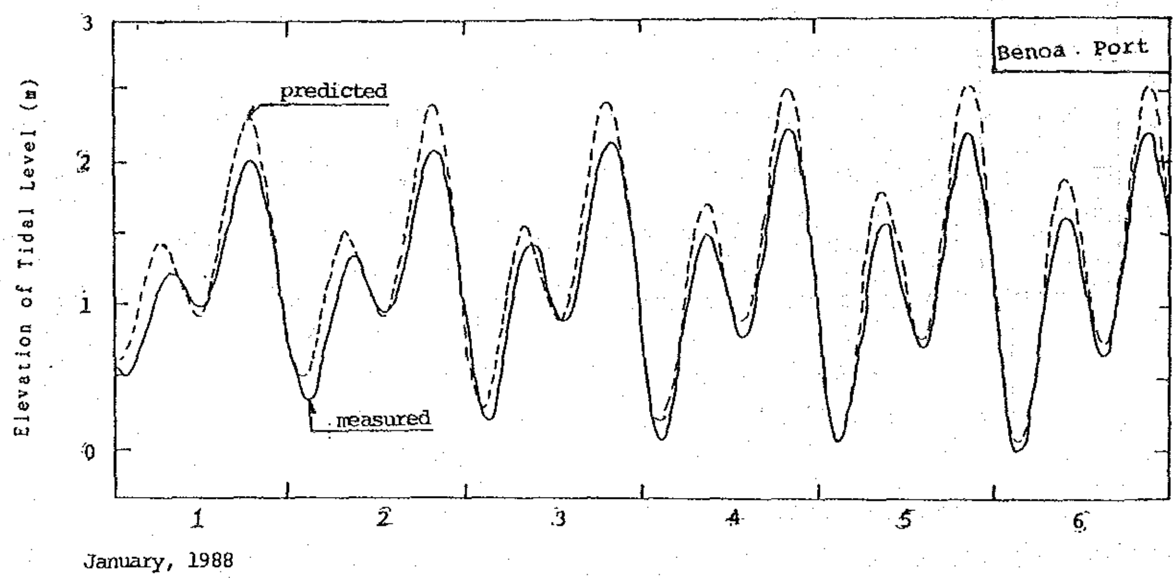


Fig. 5-1-1-10 Tidal Fluctuation at Benoa Port (1st to 6th, January, 1988)

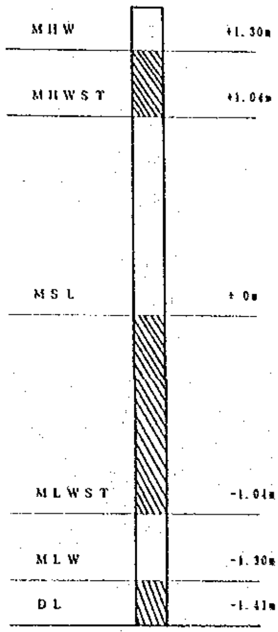
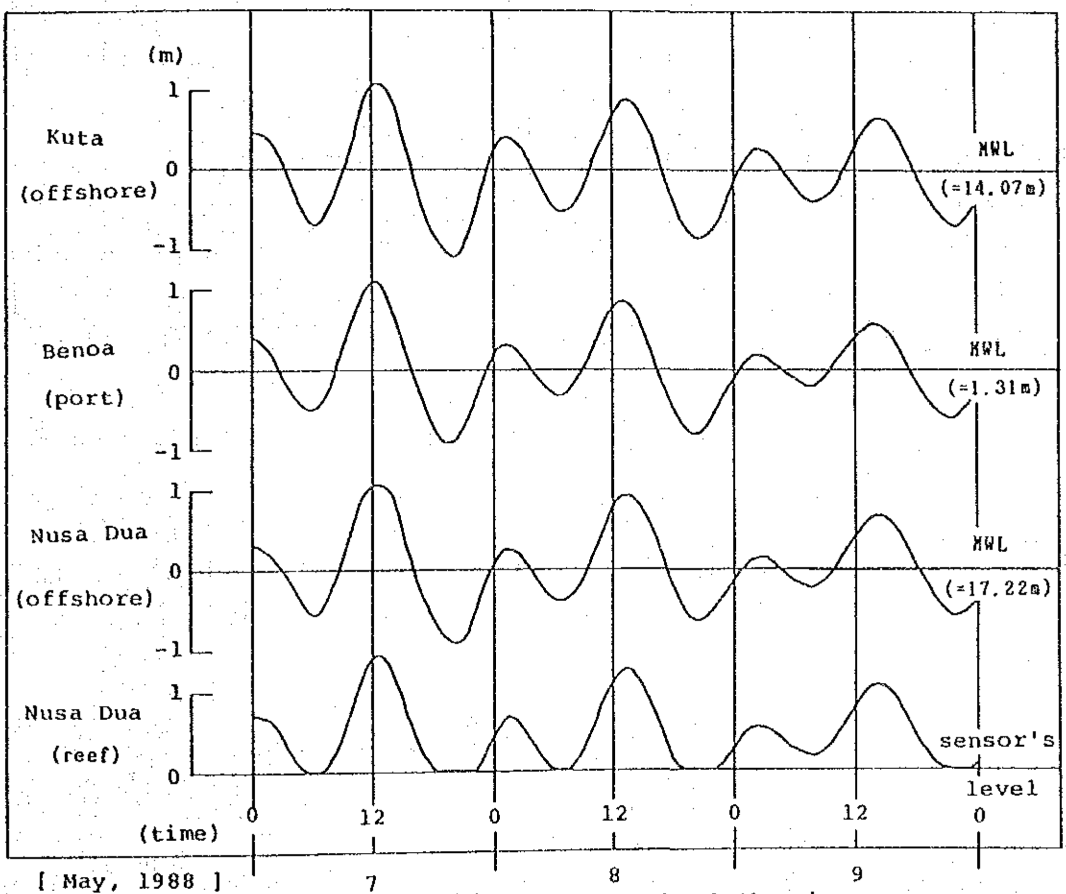
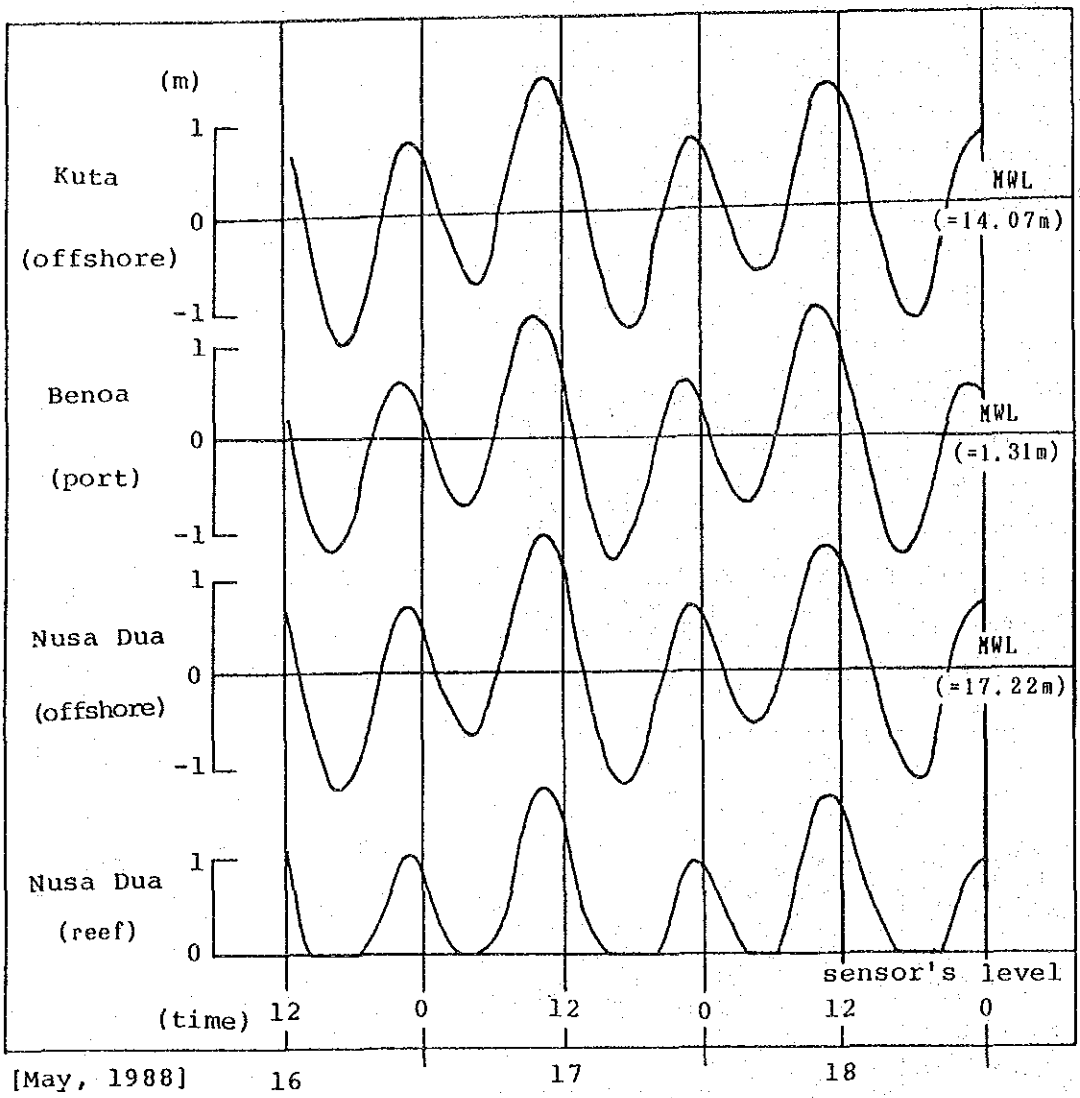


Fig. 5-1-1-11 Tidal Levels



*) MWL is the average depth of the above wave gauges.

Fig. 5-1-1-12(1) Comparison between Mean Water Level Observed by Wave Gauges and Predicted Tidal Fluctuation at Benoa



*) MWL is the average depth above wave gauges.

Fig. 5-1-1-12(2) Comparison between Mean Water Level Observed by Wave Gauges and Predicted Tidal Fluctuation at Benoa

5-1-2 Preliminary Experiments in a 2-Dimensional Wave Flume

Preliminary experiments were carried out in a 30 m long, 0.5 m wide and 0.8 m high wave flume to investigate the characteristics of wave attenuation and the rise of mean water level on the reef (Fig. 5-1-2-1). In order to measure the wave height, period and mean water level, wave gauges are set both offshore and on the reef. Then, the experiments were conducted for many cases, varying the water level, the width of the reef edge and the offshore wave height and period with the scale of 1/50 for a representative reef beach profile; the crown elevation of the reef edge is 1 m below MSL (in the prototype), the reef is set uniformly at a depth of 2 m below MSL (in the prototype) and the offshore reef slope is 1/15 (refer to Fig. 5-1-2-1).

The experimental results are summarized in Table 5-1-2-1, where the dimensions of every item are converted into those of the prototype according to the Froude similarity law. In addition, the related ratios are also calculated in this table based upon the measured values. For example, Case No.1 is conducted under the representative condition that the offshore wave period is 15 sec, the reef edge is 10 m wide and the initial water depth is 1.3 m above MSL, generating the offshore waves of 2 m, 3 m, 4 m, and 5 m in height, respectively. In order to obtain accurate data, the waves were measured offshore as well as on the reef at the distance of 50 m, 100 m, 150 m, 250 m, 350 m and 450 m apart from the reef edge.

Fig. 5-1-2-2 shows the typical wave records at each measuring position (Case No.1; Ho = 4.87 m, To = 15.6 sec). It can be clearly understood that the regular waves at the offshore position become separated gradually into the smaller height and shorter period waves in accordance with the distance from the reef edge.

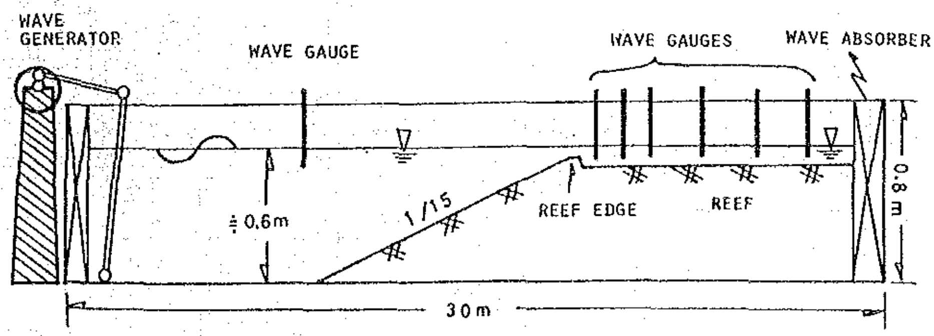


Fig. 5-1-2-1 Schematic View of Experimental Apparatus

Table 5-1-2-1 Results of 2 - Dimensional Model Test.

Case (No.-T-B)	Water Level (MSL+)	Offshore Wave H_0 (T_0)	Wave Steepness H_0/L_0	Position from Reef Edge: 50m H (T)	100m H (T)	150m H (T)	250m H (T)	350m H (T)	450m H (T)	Mean wave on Reef $\overline{H}$ ($\overline{T}$)	Set-up η	Depth of Reef h	Ratio: $\overline{H}/H_0$	$\overline{T}/T_0$	η/H_0	h/H_0
1-15-10		2.05(15.0)	0.006	1.69(15.0)	1.59(13.3)	1.23(10.9)	1.20(10.5)	1.23(10.4)	0.95(11.7)	1.12(10.9)	0.38	3.68	0.55	0.73	0.19	1.80
	+1.3m	3.07(15.2)	0.009	1.73(15.6)	1.61(15.3)	1.45(13.3)	1.26(9.3)	1.18(10.6)	1.15(11.4)	1.19(10.4)	0.54	3.84	0.39	0.68	0.18	1.25
		4.13(14.9)	0.012	1.80(15.4)	1.78(15.3)	1.60(12.8)	1.32(10.7)	1.44(10.8)	1.24(12.6)	1.33(11.4)	0.70	4.00	0.32	0.77	0.17	0.97
		4.87(15.6)	0.013	2.00(16.0)	1.90(15.1)	1.65(12.8)	1.43(10.2)	1.44(10.6)	1.43(10.9)	1.43(10.6)	0.84	4.14	0.29	0.68	0.17	0.85
2-15-10		1.76(15.4)	0.005	1.13(15.6)	1.13(15.4)	1.08(12.7)	1.02(9.9)	0.95(8.9)	0.80(9.6)	0.92(9.5)	0.57	3.27	0.52	0.62	0.32	1.86
	+0.8m	2.87(15.2)	0.008	1.40(15.5)	1.30(15.6)	1.24(14.0)	1.12(10.1)	1.13(9.5)	0.93(10.2)	1.06(9.9)	0.67	3.47	0.37	0.65	0.23	1.21
		3.82(15.4)	0.010	1.42(16.1)	1.35(15.7)	1.33(14.6)	1.13(10.1)	1.09(10.1)	1.05(9.7)	1.09(10.0)	0.83	3.63	0.29	0.65	0.22	0.95
		4.96(15.2)	0.014	1.57(16.0)	1.32(16.1)	1.31(15.4)	1.27(12.1)	1.17(10.9)	1.23(11.0)	1.22(11.3)	1.11	3.91	0.25	0.74	0.22	0.79
3-15-10	+0.3m	3.09(15.3)	0.008	—	—	—	1.00(10.6)	0.97(9.7)	0.85(8.1)	0.94(9.5)	0.68	2.98	0.30	0.62	0.22	0.96
		5.33(15.1)	0.015	1.62(16.2)	1.55(16.3)	1.51(15.0)	1.21(12.1)	1.19(10.5)	1.17(9.1)	1.19(10.6)	0.94	3.24	0.22	0.70	0.18	0.61
4-15-10	+0.0m	3.10(15.3)	0.008	—	—	—	0.83(11.1)	0.77(8.8)	0.72(8.6)	0.77(9.5)	0.77	2.77	0.25	0.62	0.25	0.89
		5.12(15.0)	0.015	1.45(16.2)	1.33(15.6)	1.29(14.6)	1.14(13.1)	0.99(9.4)	0.93(8.6)	1.02(10.4)	0.96	2.96	0.20	0.69	0.19	0.58
5-15-10	-0.5m	2.96(14.9)	0.009	—	—	—	0.70(9.6)	0.59(8.2)	0.47(7.3)	0.59(8.4)	0.65	2.15	0.20	0.56	0.22	0.73
6-15-10	-1.0m	3.01(14.8)	0.009	—	—	—	0.46(12.1)	0.39(7.6)	0.25(7.5)	0.37(9.1)	0.45	1.45	0.12	0.61	0.15	0.48
7-12-10	+1.3m	5.29(12.4)	0.022	2.01(13.0)	1.74(12.9)	1.79(13.0)	1.53(11.7)	1.38(13.0)	1.45(12.5)	1.45(12.4)	0.76	4.06	0.27	1.00	0.14	0.77
8-12-10	+0.8m	5.48(12.3)	0.023	1.85(12.9)	1.67(12.4)	1.69(12.5)	1.44(10.8)	1.43(11.8)	1.44(11.9)	1.44(11.5)	0.86	3.66	0.26	0.93	0.16	0.67
9-12-10	+0.3m	5.16(12.3)	0.022	1.49(13.3)	1.50(12.9)	1.37(11.7)	1.21(11.1)	1.16(11.0)	1.07(12.1)	1.15(11.4)	0.89	3.19	0.22	0.93	0.17	0.62
10-15-30		1.80(15.0)	0.005	1.15(15.1)	1.06(15.1)	0.85(11.5)	0.87(9.5)	0.97(8.9)	0.77(9.4)	0.87(9.3)	0.47	3.27	0.48	0.62	0.26	1.82
	+0.8m	2.64(15.3)	0.007	1.51(15.9)	1.46(14.6)	1.36(13.5)	1.11(9.6)	1.10(9.9)	1.01(10.3)	1.07(9.9)	0.61	3.41	0.41	0.65	0.23	1.29
		3.44(15.3)	0.009	1.57(15.9)	1.51(15.9)	1.53(13.4)	1.36(9.5)	1.20(9.6)	1.17(10.4)	1.24(9.8)	0.78	3.58	0.36	0.64	0.23	1.04
		4.52(15.4)	0.012	1.79(16.4)	1.65(16.2)	1.67(14.0)	1.34(11.1)	1.25(9.7)	1.32(10.7)	1.30(10.5)	0.98	3.78	0.29	0.68	0.22	0.84
11-15-50		1.72(15.5)	0.005	—	1.06(16.0)	0.91(16.3)	0.85(11.1)	0.78(9.2)	0.69(9.4)	0.77(9.9)	0.54	3.34	0.45	0.64	0.31	1.94
	+0.8m	2.77(15.3)	0.008	—	1.32(15.8)	1.20(14.6)	1.06(10.1)	1.04(9.9)	0.91(10.1)	1.00(10.0)	0.72	3.52	0.36	0.65	0.26	1.27
		3.63(15.3)	0.010	—	1.45(15.9)	1.47(13.9)	1.23(9.9)	1.09(9.3)	1.11(10.5)	1.14(9.9)	0.87	3.67	0.31	0.65	0.24	1.01
		4.58(15.6)	0.012	—	1.60(16.6)	1.60(15.6)	1.28(11.5)	1.26(10.5)	1.26(10.7)	1.27(10.9)	0.98	3.78	0.28	0.70	0.21	0.83
12-12-50	+0.8m	5.17(12.1)	0.023	—	1.46(12.8)	1.54(13.0)	1.49(11.8)	1.11(11.4)	1.23(10.9)	1.28(11.4)	0.91	3.71	0.25	0.94	0.18	0.72
13-15-10		1.90(15.5)	0.005	1.60(15.6)	1.20(14.3)	1.13(10.9)	1.20(9.8)	1.05(10.5)	1.23(9.7)	1.16(10.0)	0.41	4.21	0.61	0.55	0.22	2.22
	+0.8m	2.76(15.3)	0.008	1.88(15.6)	1.72(15.4)	1.50(10.6)	1.52(10.6)	1.34(12.4)	1.29(12.3)	1.38(11.8)	0.57	4.37	0.50	0.77	0.21	1.58
(dredged)		4.04(14.1)	0.013	2.02(14.6)	1.95(13.2)	1.92(12.7)	1.84(11.6)	1.66(11.1)	1.56(13.2)	1.69(12.0)	0.80	4.60	0.42	0.85	0.20	1.14
		4.61(15.4)	0.012	2.28(16.1)	2.11(16.0)	2.03(13.4)	1.83(11.0)	1.72(12.0)	1.56(12.2)	1.70(11.7)	0.89	4.69	0.37	0.76	0.19	1.02

Where , 1) No.-T-B : No. is the case number , T is a representative wave period(in second) and B is the width of reef edge(in meter).

2) H , T : H is a significant wave height(in meter) and T is a significant wave period(in second).

3) $\overline{H}$, $\overline{T}$: $\overline{H}$ and $\overline{T}$ are mean values of 250m , 350m and 450m position with wave height and period , respectively.

4) η : Wave set-up height averaged all over the reef (in meter).

5) h : Water depth on the reef including set-up height(in meter).

6) Water Level : The water level is initially set before generating waves.

7) Reef : The crown of reef edge is 1m high on the flat inner reef and the crown level is 1m below MSL from No.1 to No.12 Case. But only the case of No.13 is for dredging the inner reef ; the crown height is 1m below MSL and the depth of inner reef is 3m below MSL.

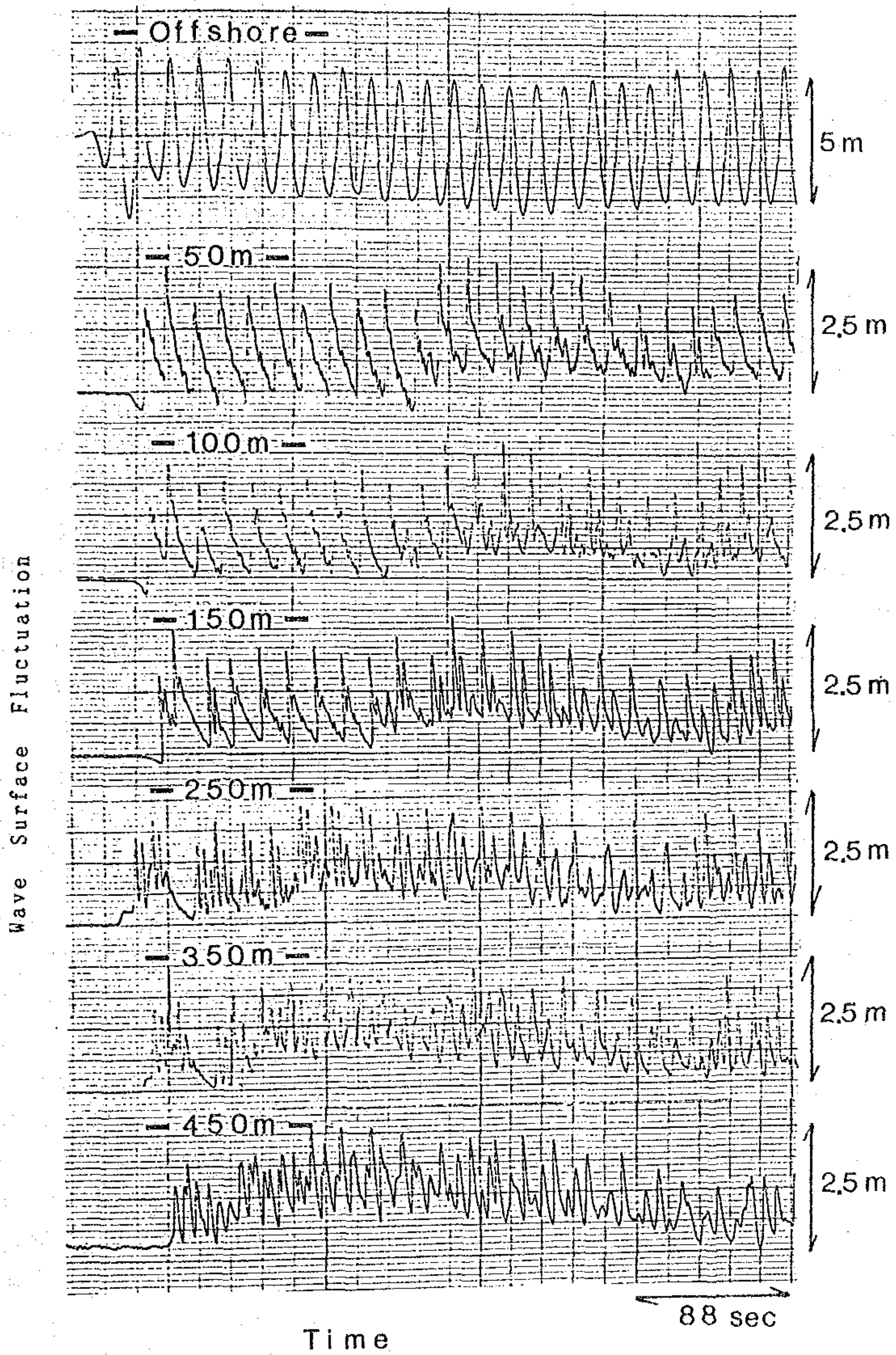


Fig. 5-1-2-2 Sample Wave Records

Fig. 5-1-2-3 shows an example of the wave height and period variation along the onshore-offshore direction. The waves approaching the reef slope increase in height due to the shoaling effect and break at the critical water depth a little offshore from the reef edge. The wave after breaking loses its energy, and hence the wave reduces its height greatly. However the reduction of wave height on the reef is relatively small. On the other hand, the wave period decreases in the inshore region compared with the offshore wave period.

Next, the change of wave characteristics due to the shallow reef is examined based upon the experimental results. The wave period ratio vs. the relative water depth are plotted in Fig. 5-1-2-4. It can be said that the scatter of data both in the model and in the actual field are almost the same comparing Fig. 5-1-2-4 with Fig. 5-1-1-6. Hence it is thought that the generation of shorter period waves comparing with the offshore wave period is caused at the actual reef as in the model.

Fig. 5-1-2-5 shows the wave height on the reef with respect to the offshore wave height. In any case, there is a tendency of increasing reef wave heights with the increase of offshore wave height. Comparing Case No.1 with No.2, it is found that the bigger waves appear on the reef with the increase of water level. Moreover comparing Case No.2 with No.13 which is the dredged case, it can be understood that the dredging of bed material on the reef should not be recommended because the wave height on the reef increases much more than without the dredging.

Fig. 5-1-2-6 represents the relations between the wave height ratio and the relative water depth, where the straight line is the regression curve obtained by using the field data in Fig. 5-1-1-7. There are slight differences between the field curve and the model test data, but they agree well with each other as a whole. Fig. 5-1-2-7 shows the effect of the reef edge width (B) by using the experimental results of case No.1 (B=10m), No.10 (B-30m), and No.11 (B=50m). As you can see, the wider width of reef edge is more effective in reducing the height of waves on the reef.

Fig. 5-1-2-8 shows the relation between the rise of mean water level and the offshore wave height. The mean water level rises gradually with the increase of offshore wave height. The order of water level rise is very large in comparison with the results of field observation; the maximum rise is about 0.7 m in the model but about 0.1 m in the field under the same condition that the offshore wave is 2.5 m in height. This extraordinary rise of water level occurring in the 2-dimensional model test is thought to be caused by the side wall which prevents the water on the reef from flowing away laterally.

Fig. 5-1-2-9 represents the relation between the relative rise of mean water level and the relative water depth. Comparing the results with the field observations (Fig. 5-1-1-8 ~9), the relative rise of water level in the model is also larger than in the field. Therefore it is necessary to check the water level rise by conducting the experiment using a wave basin.

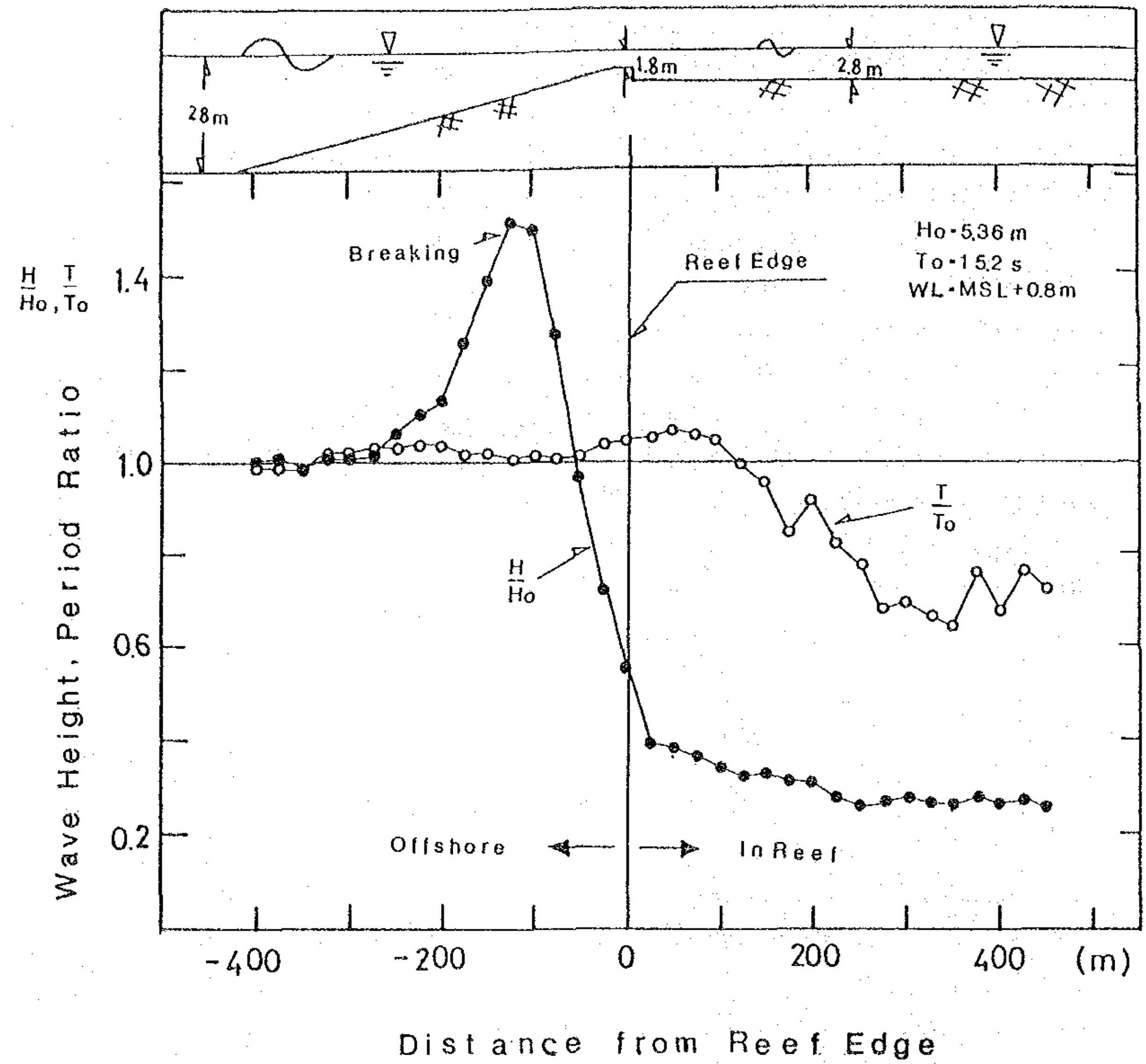


Fig. 5-1-2-3 Wave Height and Period Variation

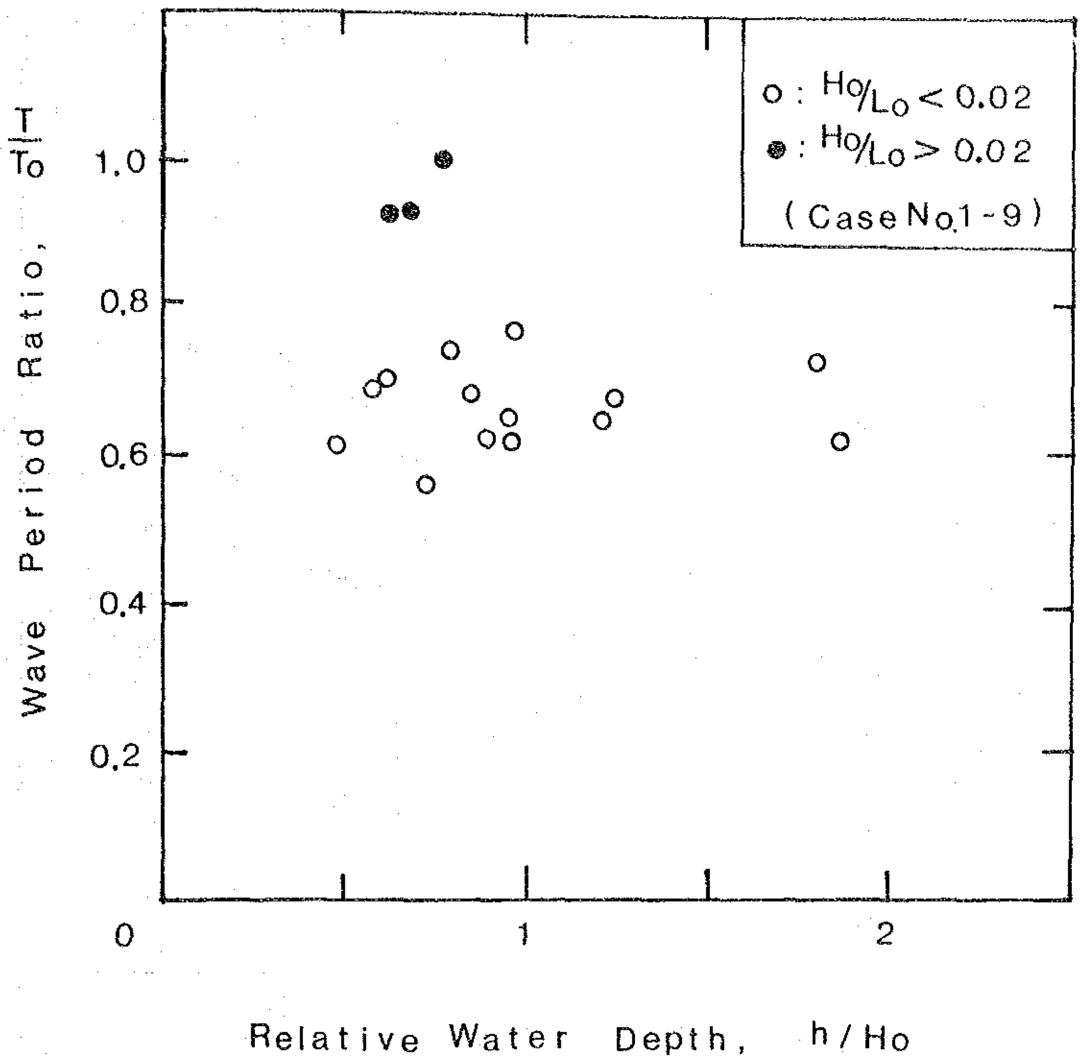


Fig. 5-1-2-4 Relation Between Wave Period Ratio and Relative Water Depth

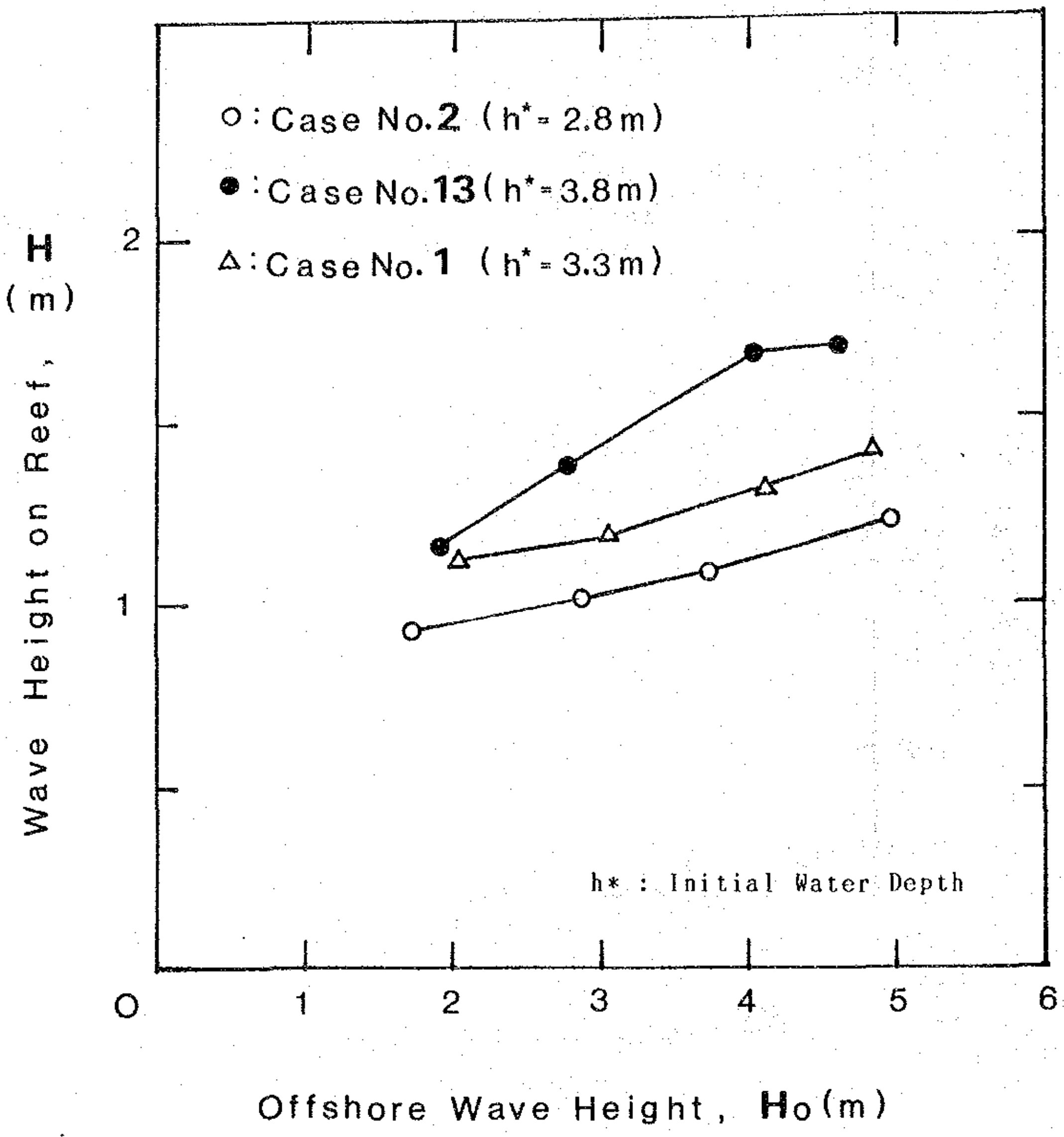


Fig. 5-1-2-5 Variation of Wave Height on Reef with Offshore Wave Height

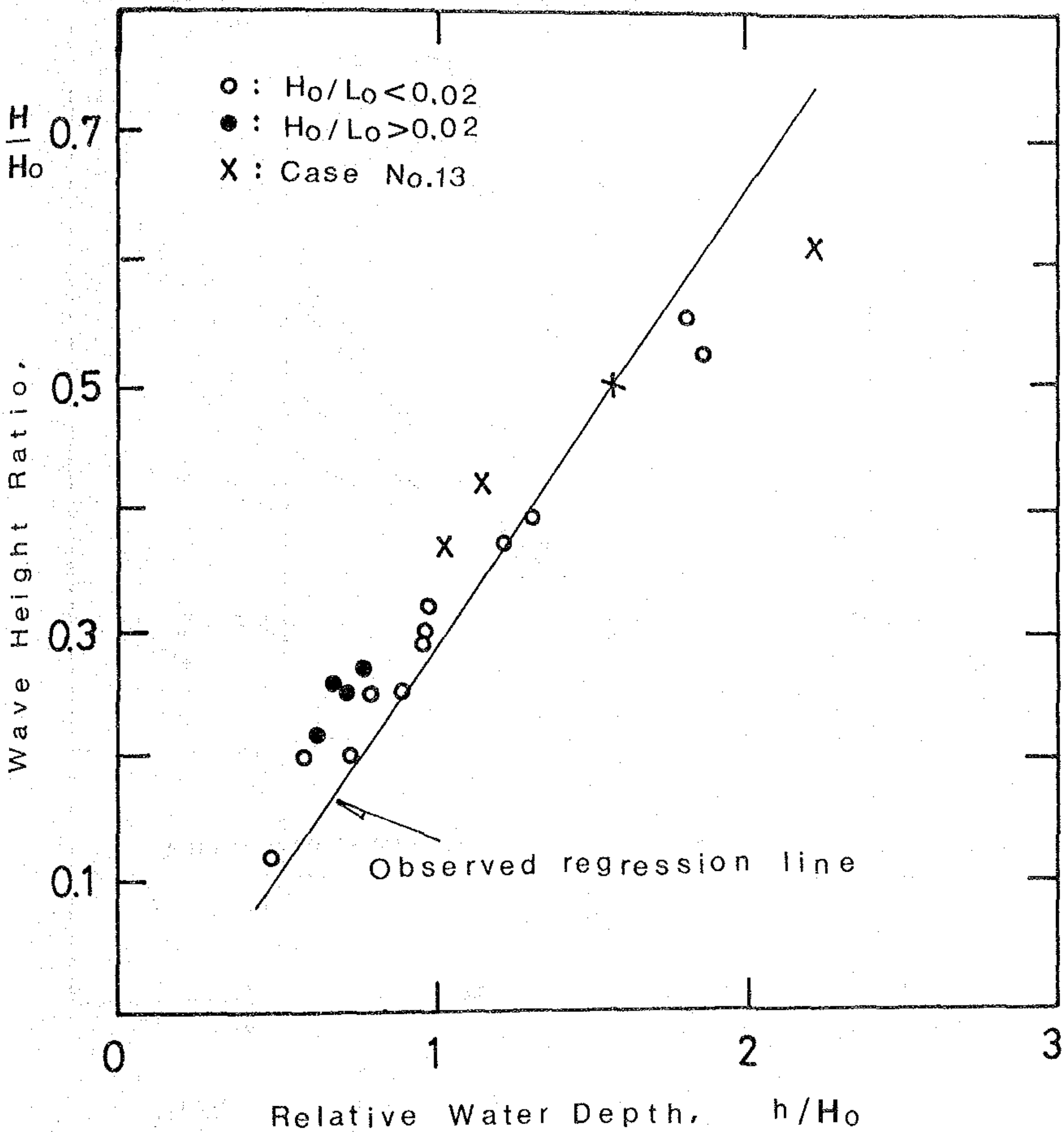


Fig. 5-1-2-6 Relation Between Wave Height Ratio and Relative Water Depth

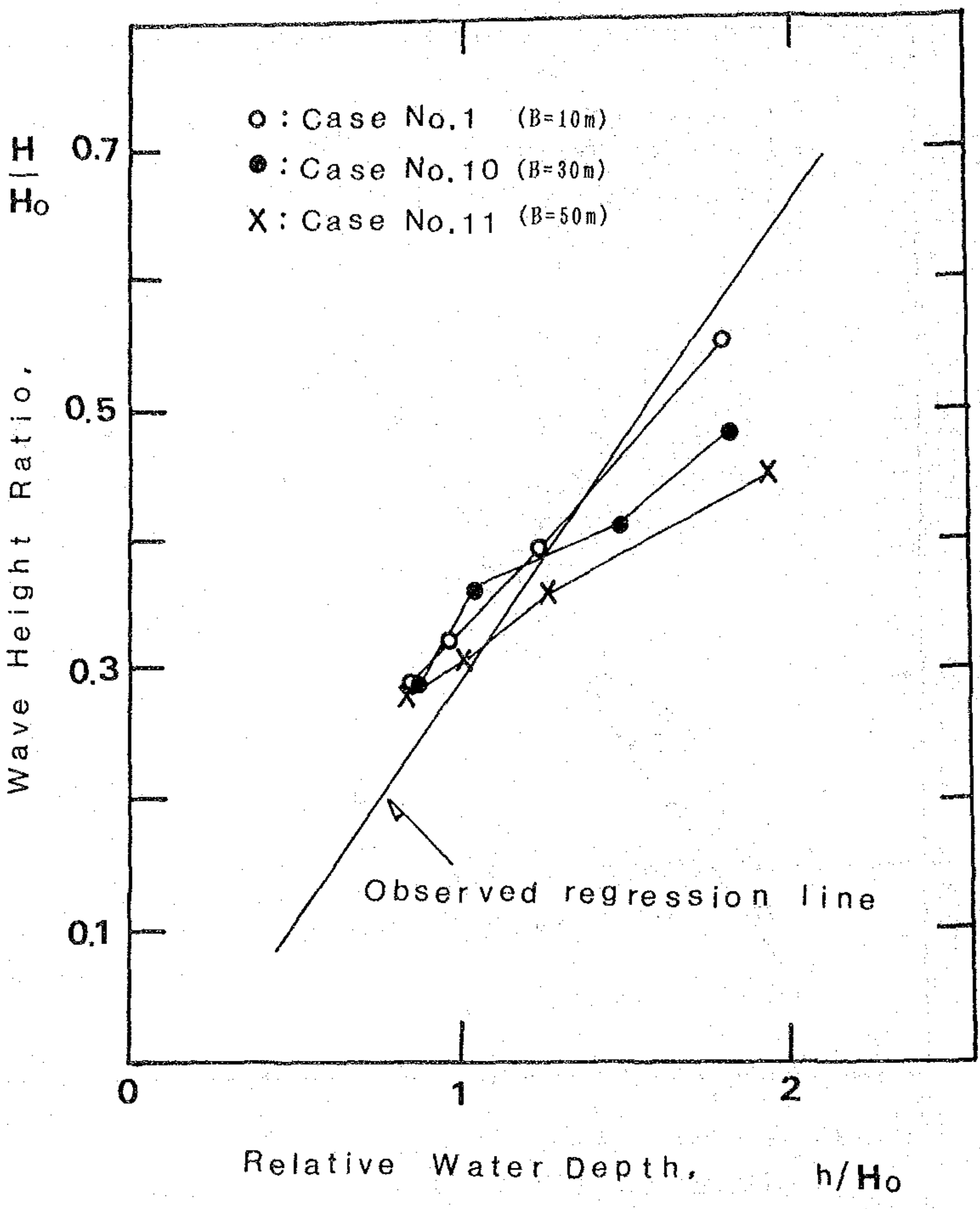


Fig. 5-1-2-7 Relation Between Wave Height Ratio and Relative Water Depth

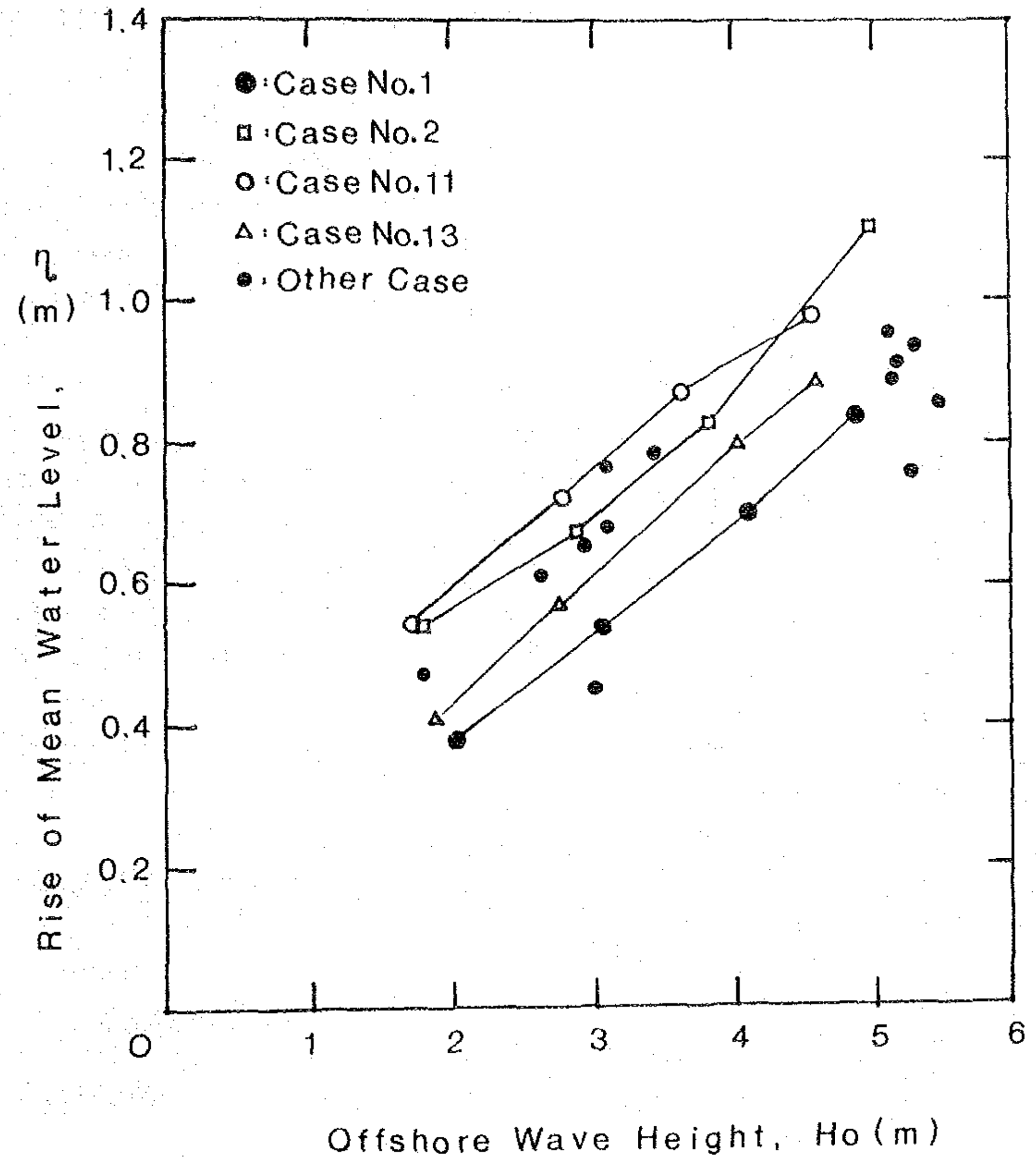


Fig. 5-1-2-8 Variation of Mean Water Level with Offshore Wave Height

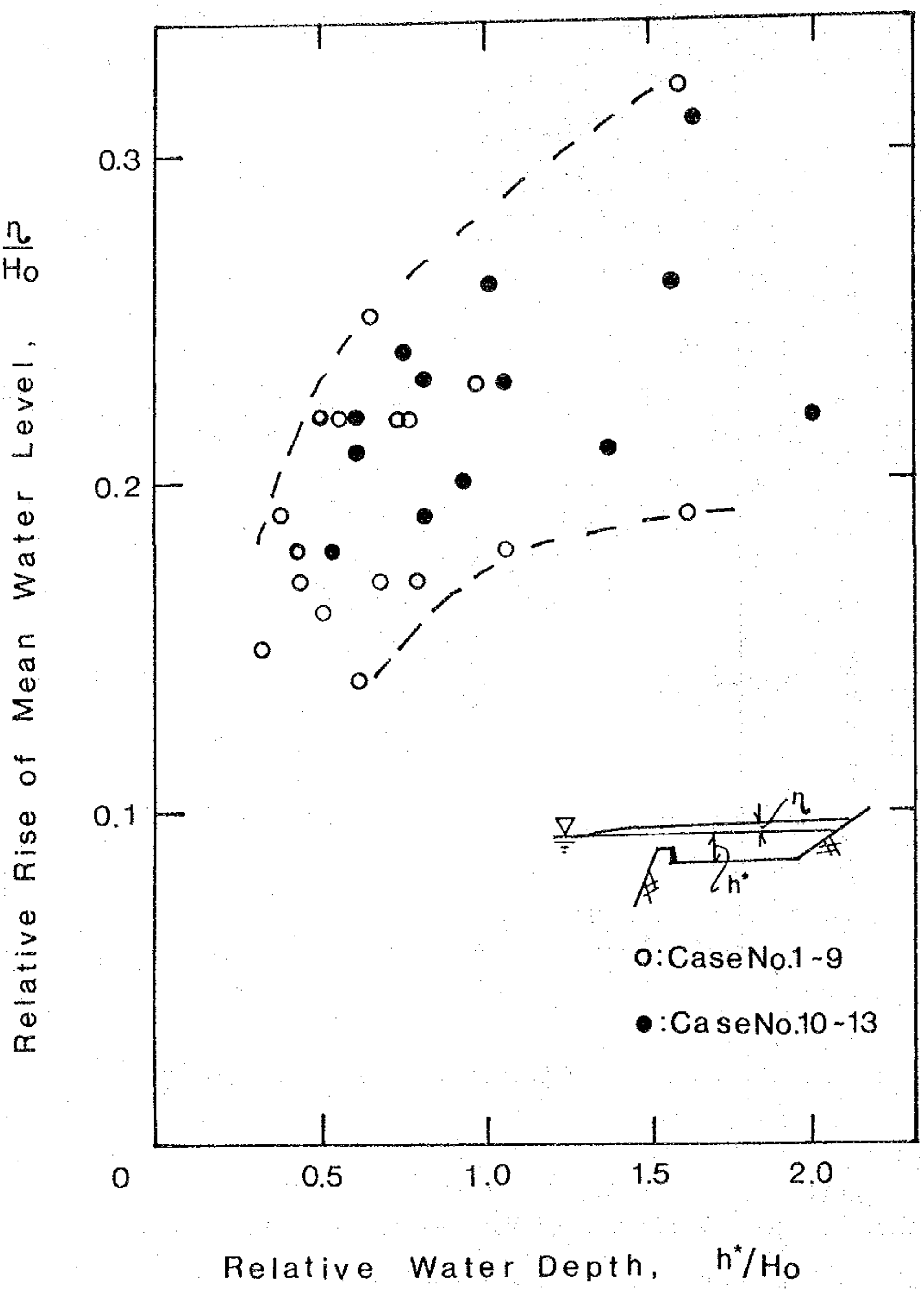


Fig. 5-1-2-9 Relative Between Relative Rise of Mean Water Level and Relative Water Depth

5-1-3 Experiments in a 3-Dimensional Wave Basin

Hydraulic model tests were carried out for the model topography of Kuta and Nusa Dua Beaches as shown in Fig. 5-1-3-1 using a 3-dimensional wave basin 50 m long, 50 m wide and 0.8 m deep. Waves in this experiment a the height of 10 cm and a period of 2.1 sec in front of the wave generator. As the scale applied in this experiment is the same 1/50 as in the 2-dimensional model test, the above values converted by the Froud similarity law are equivalent to the offshore wave height Ho = 5 m and the offshore wave period To = 15 sec in the prototype, respectively. On the other hand, the offshore wave direction is givnen at the depth of 20 m (in the prototype) in front of the wave generator based upon the calculated results of wave refraction analysis with the predominant offshore wave direction of SW at Kuta Beach and SE at Nusa Dua Beach. Moreover, the initial water level is set at MHW level (1.3 m above MSL). All values measured in the model test are converted for the prototype in the following according to the similarity law. The results obtained in the experiments both under the present condition and with the countermeasures at Kuta and Nusa Dua Beaches are descirbed below.

(1) Kuta Beach

1) Present Condition

The distribution of wave heights in the shallow water region as well as on the reef zone is shown in Fig. 5-1-3-2. From the scattering of data, it is recognized that wave heights less than 2 m appear on the southern part of the reef zone. Nevertheless, relatively big waves occur on the northern part where there is no coral reef. This means that the coral reef is a kind of natural breakwater against the attack of waves.

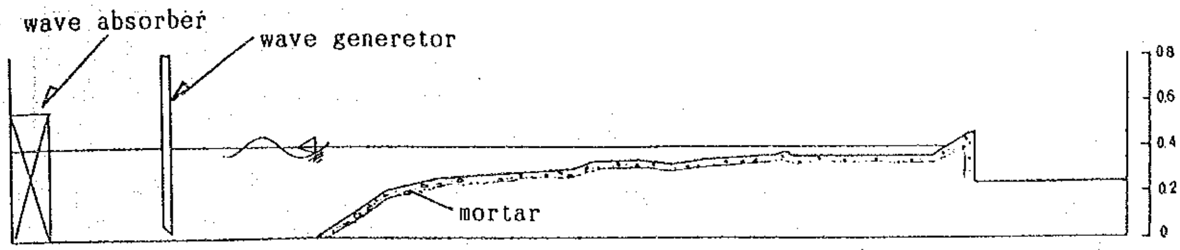
Fig. 5-1-3-3 represents the distribution of mean water level rise due to the wave approach to the beach. It is found that the water level rises over 0.3 m above MWL at most parts of the southern reef zone, but the rise of water level is relatively low in the north region. This gradient of water level suggests a pattern of water current towards the north, because the water in high water level areas tends to go down to the low water areas.

Comparing with the mean water rise of 0.84 m observed in the 2-dimensional wave flume under the same conditions, the data taken in the wave basin test show about half of the above values on the whole.

Fig. 5-1-3-4 shows the distribution of wave periods. It can be seen that the longer or shorter periods appear locally comparing with the offshore specific wave period (To = 15 sec). Judging from the visual observation, the region where the periods longer than 15 sec were measured corresponds with the areas where waves propagated from some different directions overlap each other. Therefore, the long period waves observed in the experiment are thought to be caused by the so-called clapotis which is generated by the superposition of incoming waves.

Fig. 5-1-3-5 represents the current field incoming waves. As you can see, the water on the reef flows mostly in the north direction along the shoreline. There is a strong current offshore on the southern reef zone, partly flowing out of the narrow reef zone. However, the current near the shoreline is not so strong considering the severe wave conditions.

Fig. 5-1-3-6 shows the comparison between measured and calculated wave heights. The wave height is calculated by using the equation H = 0.37 h (h is the water depth on the reef including the rise of mean water level) which is obtained by the regression analysis for the field data. It can be said that both wave heights agree generally with each other as a whole except for some big differences near the reef edge in spite of the complicated beach topography.



Profile of A-A' section

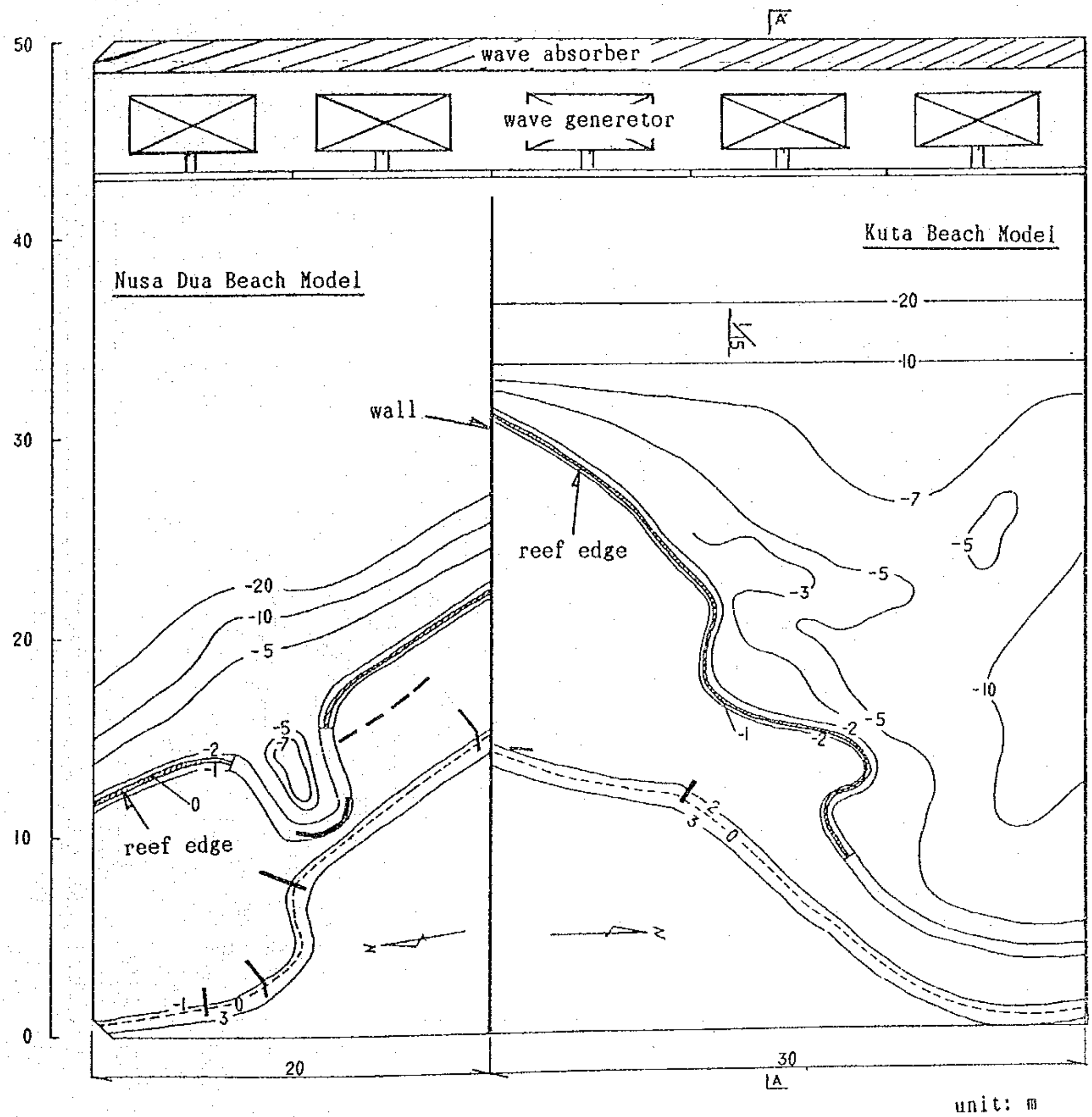


Fig. 5-1-3-1 Layout of 3-Dimensional Hydraulic Model Test

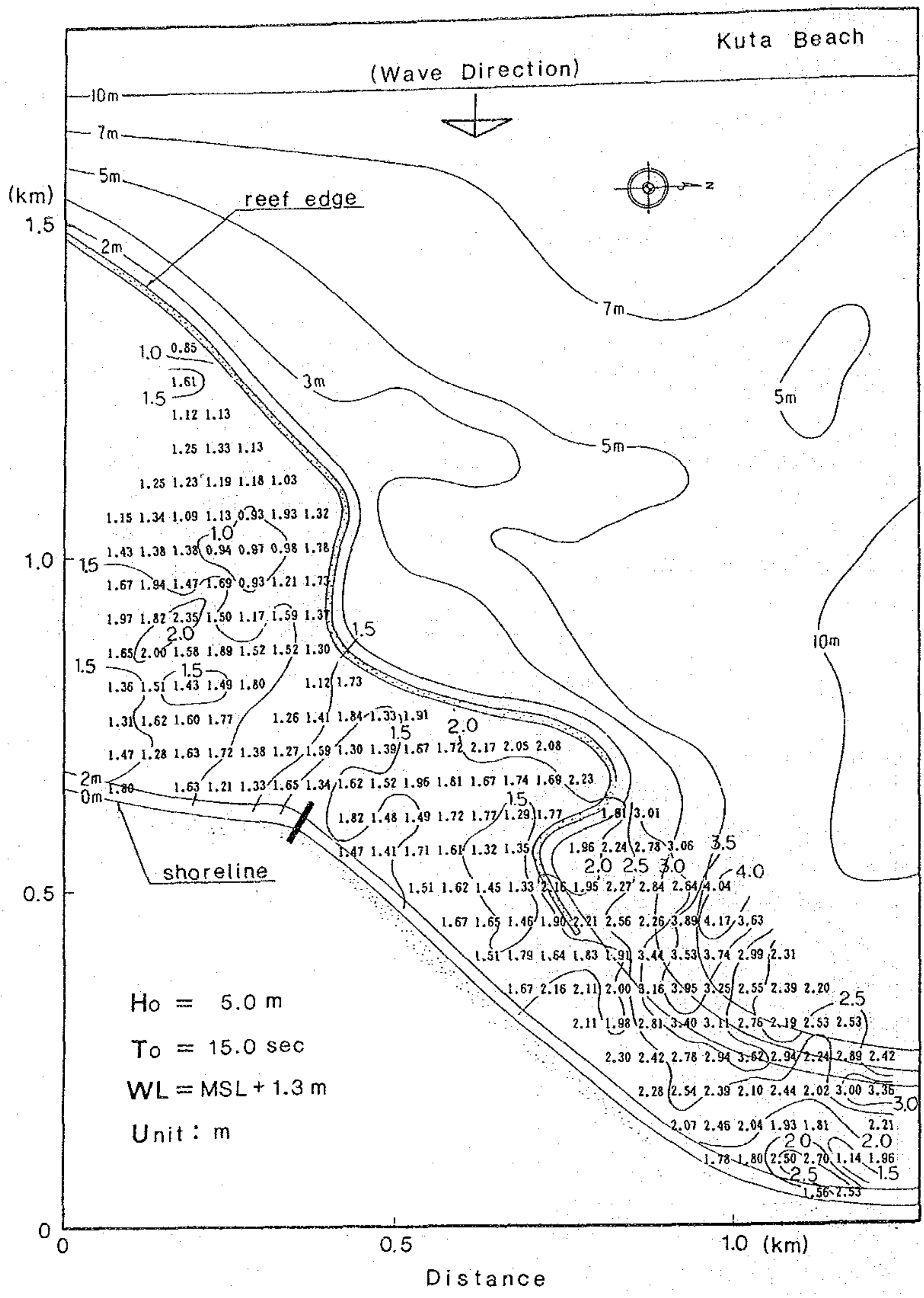


Fig. 5-1-3-2 Distribution of Wave Height under Present Conditions at Kuta Beach

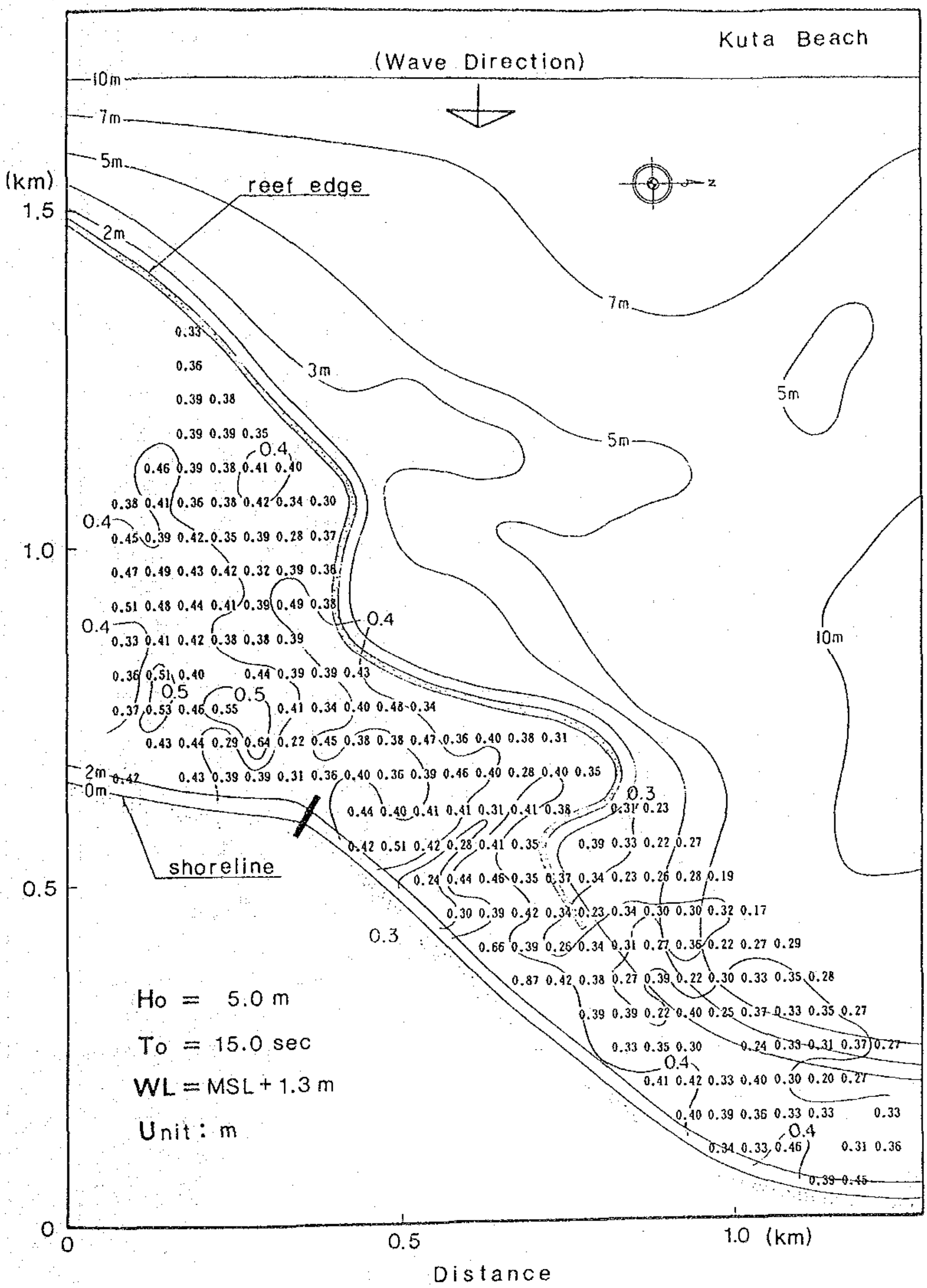


Fig. 5-1-3-3 Distribution of Mean Water Level Rise under Present Conditions at Kuta Beach

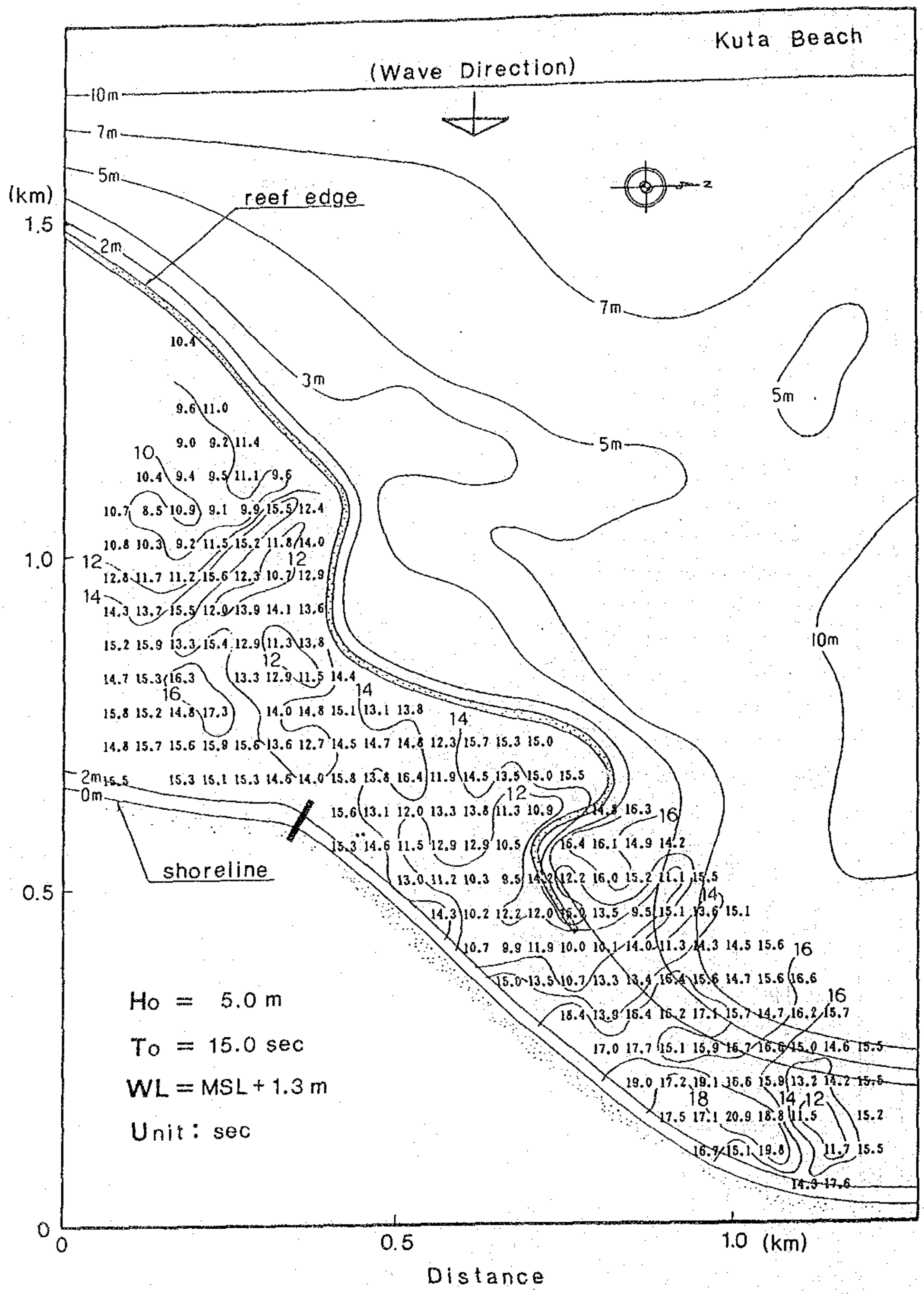


Fig. 5-1-3-4 Distribution of Wave Period under Present Conditions at Kuta Beach

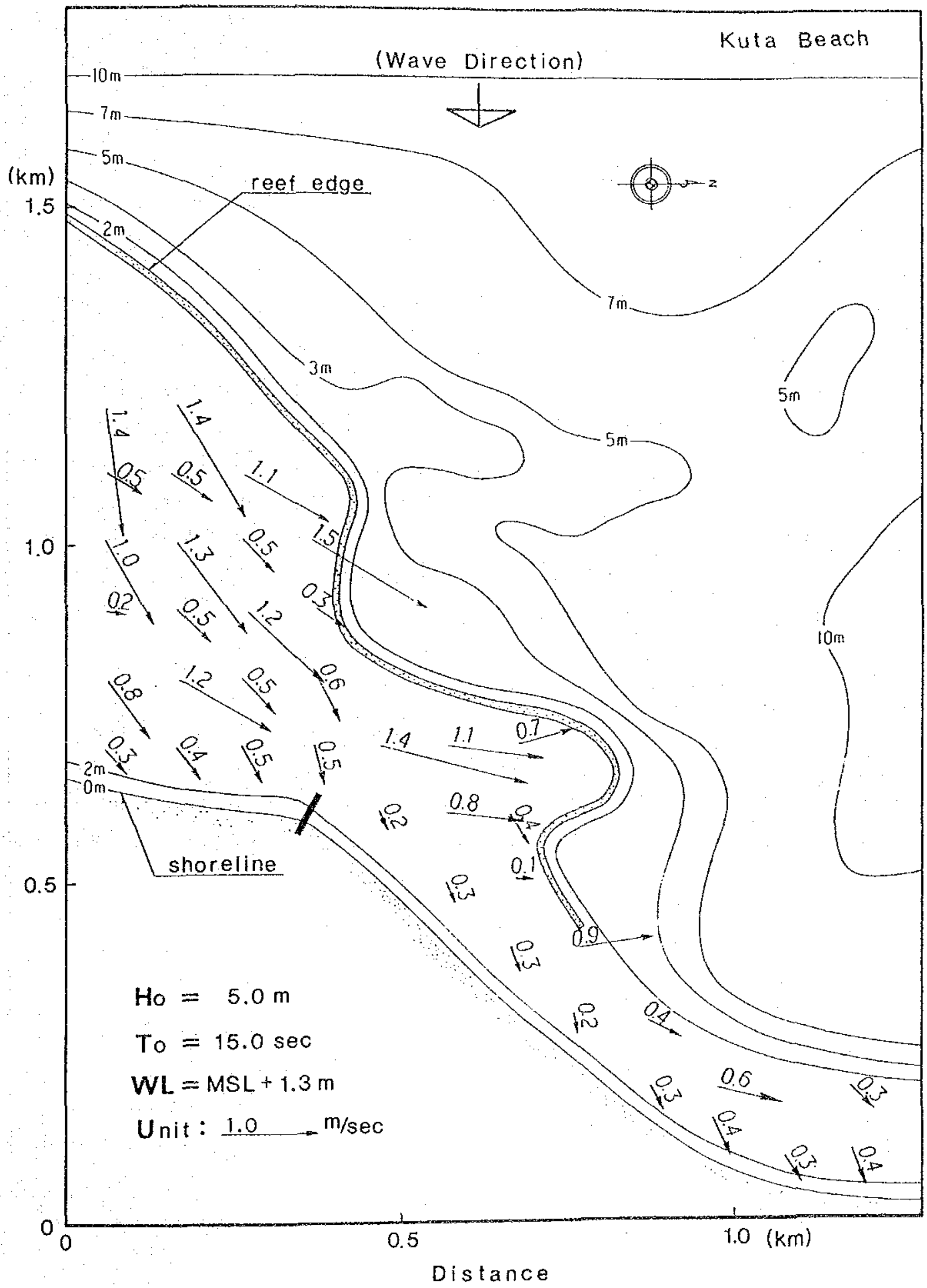


Fig. 5-1-3-5 Current Field under Present Conditions at Kuta Beach

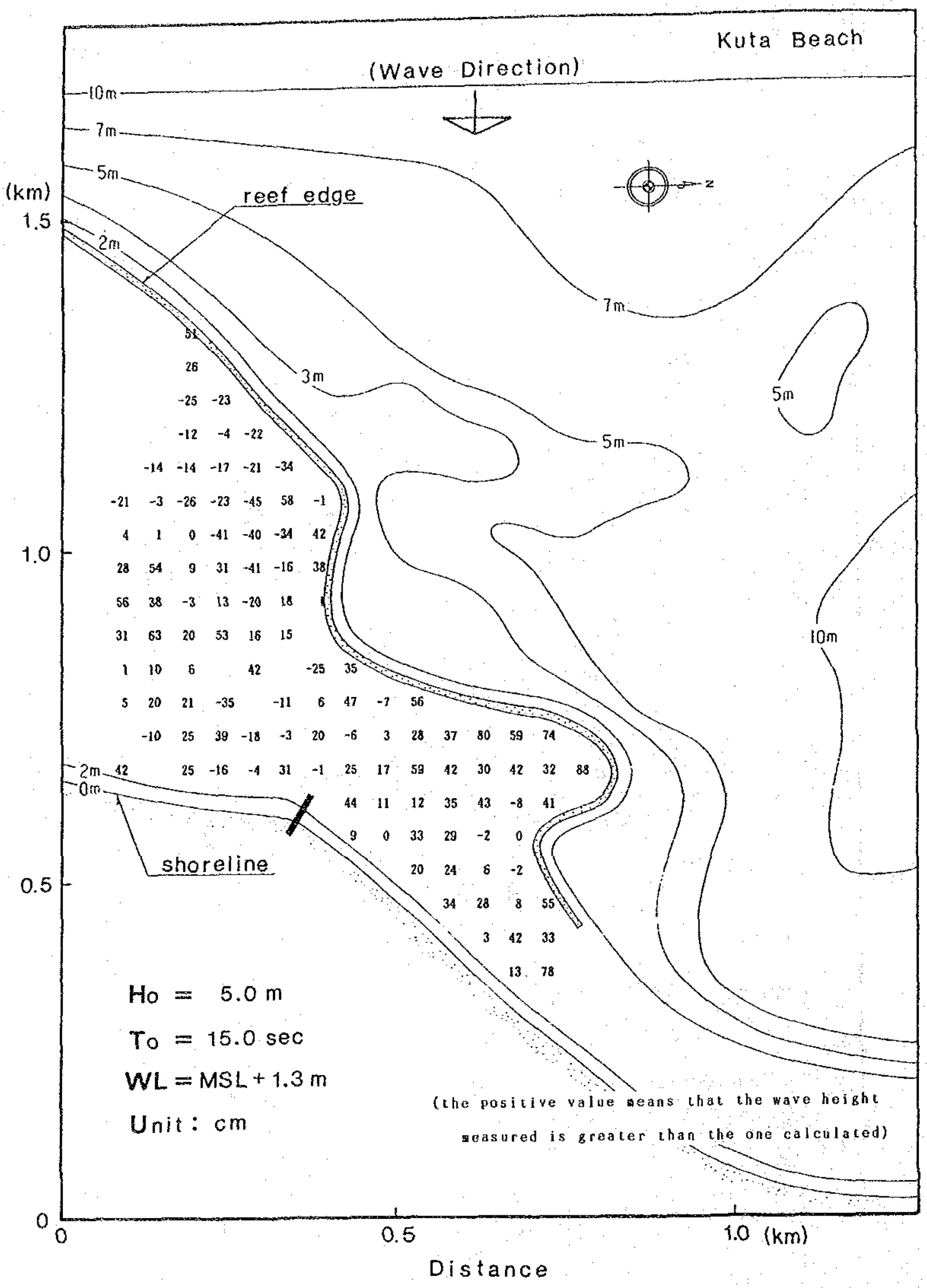


Fig. 5-1-3-6 Difference Between Measured and Calculated Wave Heights at Kuta Beach

2) Countermeasures

Fig. 5-1-3-7 shows the distribution of wave heights obtained for the case in which two T-type groins are arranged as shown in the figure. Comparing with the data under the present conditions (Fig. 5-1-3-2), the overall characteristics of big or low wave occurrence seem to be the same, but the sea condition is very calm behind the T-type groins.

According to the current field (Fig. 5-1-3-10), the predominant water current offshore of the southern T-type groin turns out of the reef at the narrow reef zone. Taking into account the effect of the groin which will trap the sediment transported by the wave induced current, the strong current flowing out of the reef is not desirable for beach preservation work. Based upon the above results, an additional experiment was conducted for an alternative plan.

Fig. 5-1-3-11 shows the current field measured for the new alternative plan in which the southern T-type groin is moved about 180 m to the south from the previous position and one straight type groin is set at the middle of two T type groins. From the current velocity represented in the figure, it can be understood that the T type groins in the alternative plan do not badly affect the offshore flow pattern. Nevertheless, it would be preferable to change the configuration of the straight type groin, for there is a relatively strong current towards the offshore direction at the south side of the straight groin.

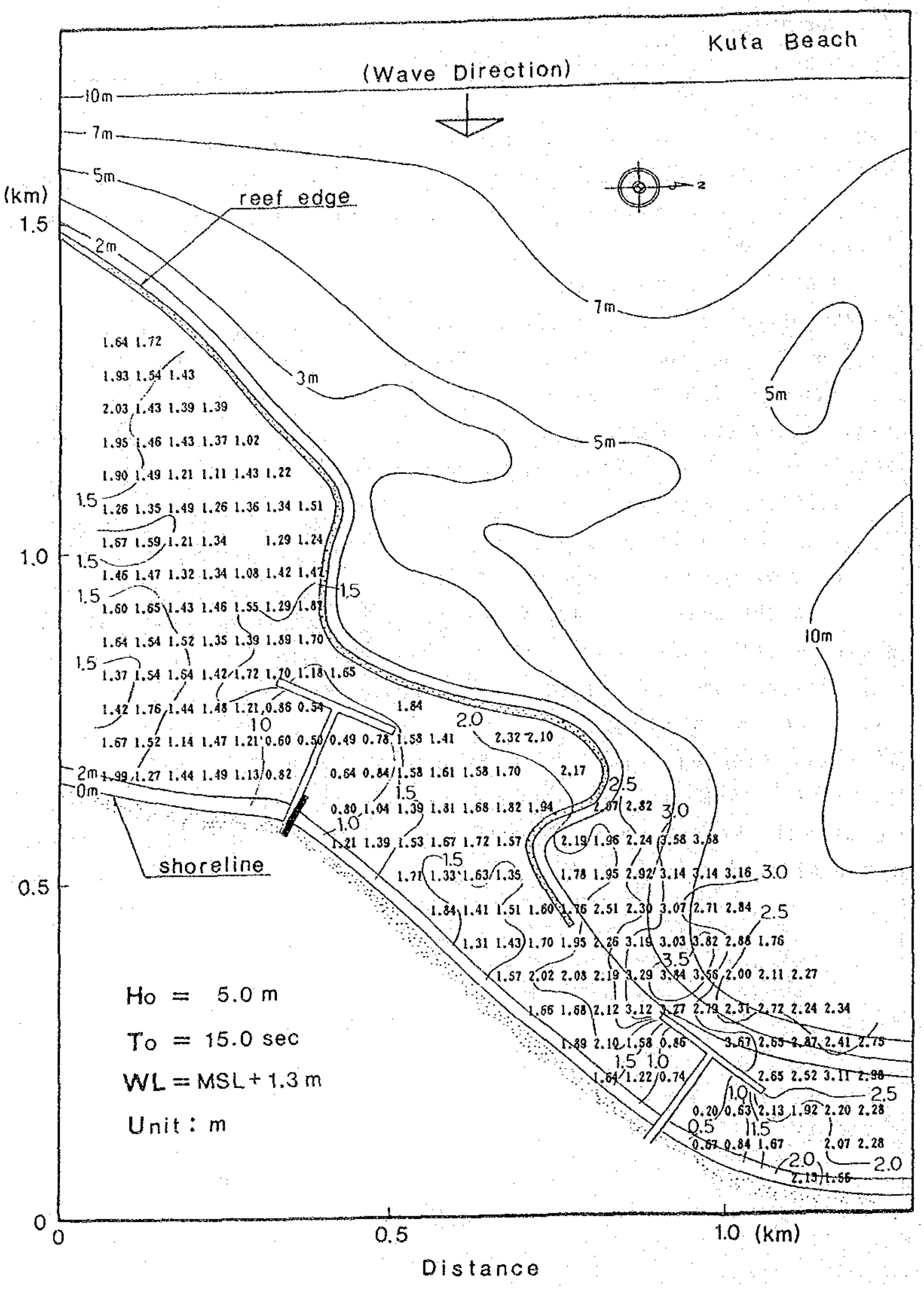


Fig. 5-1-3-7 Distribution of Wave Height with Countermeasures at Kuta Beach

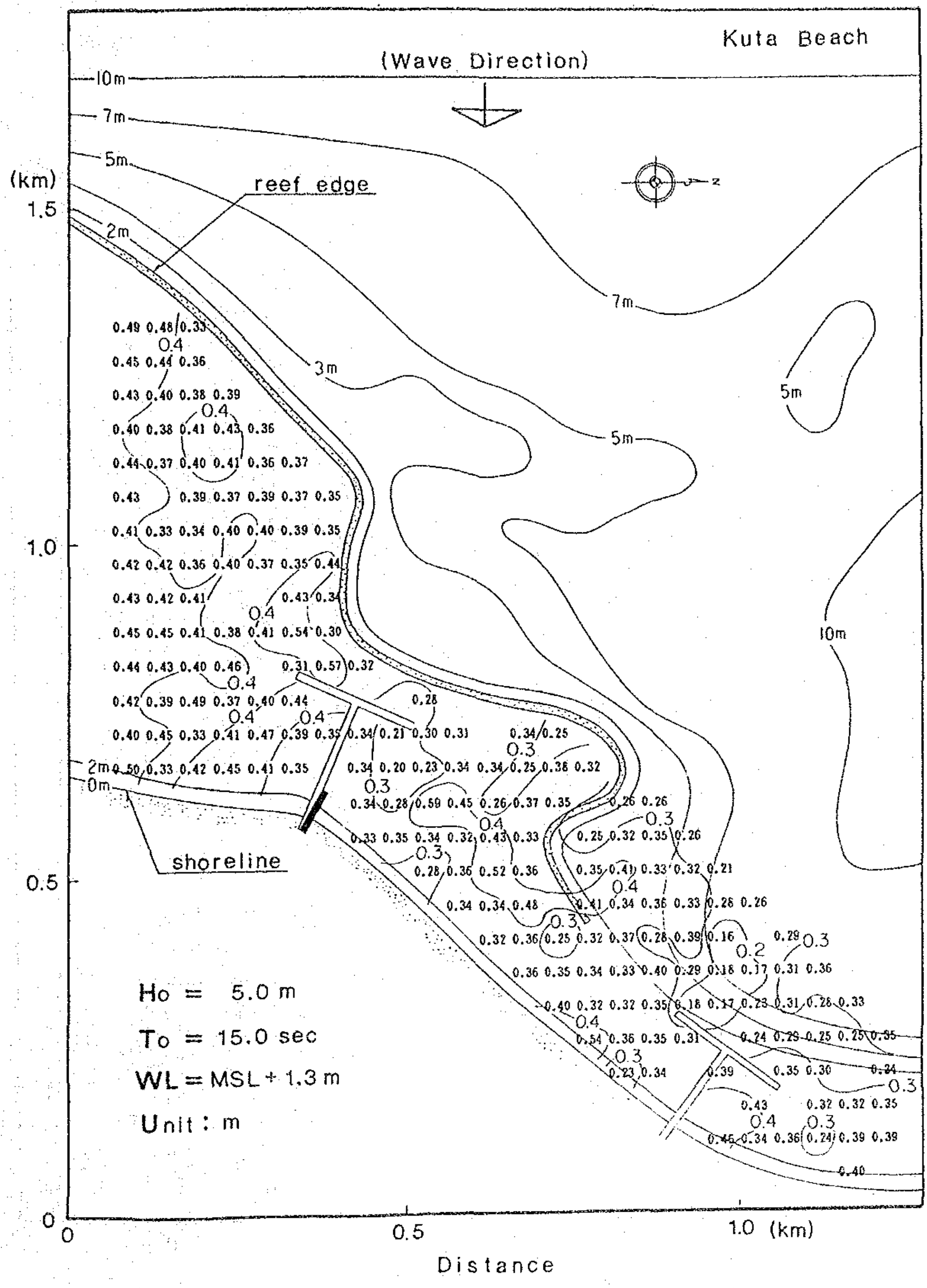


Fig. 5-1-3-8 Distribution of Mean Wave Level Rise with Countermeasures at Kuta Beach

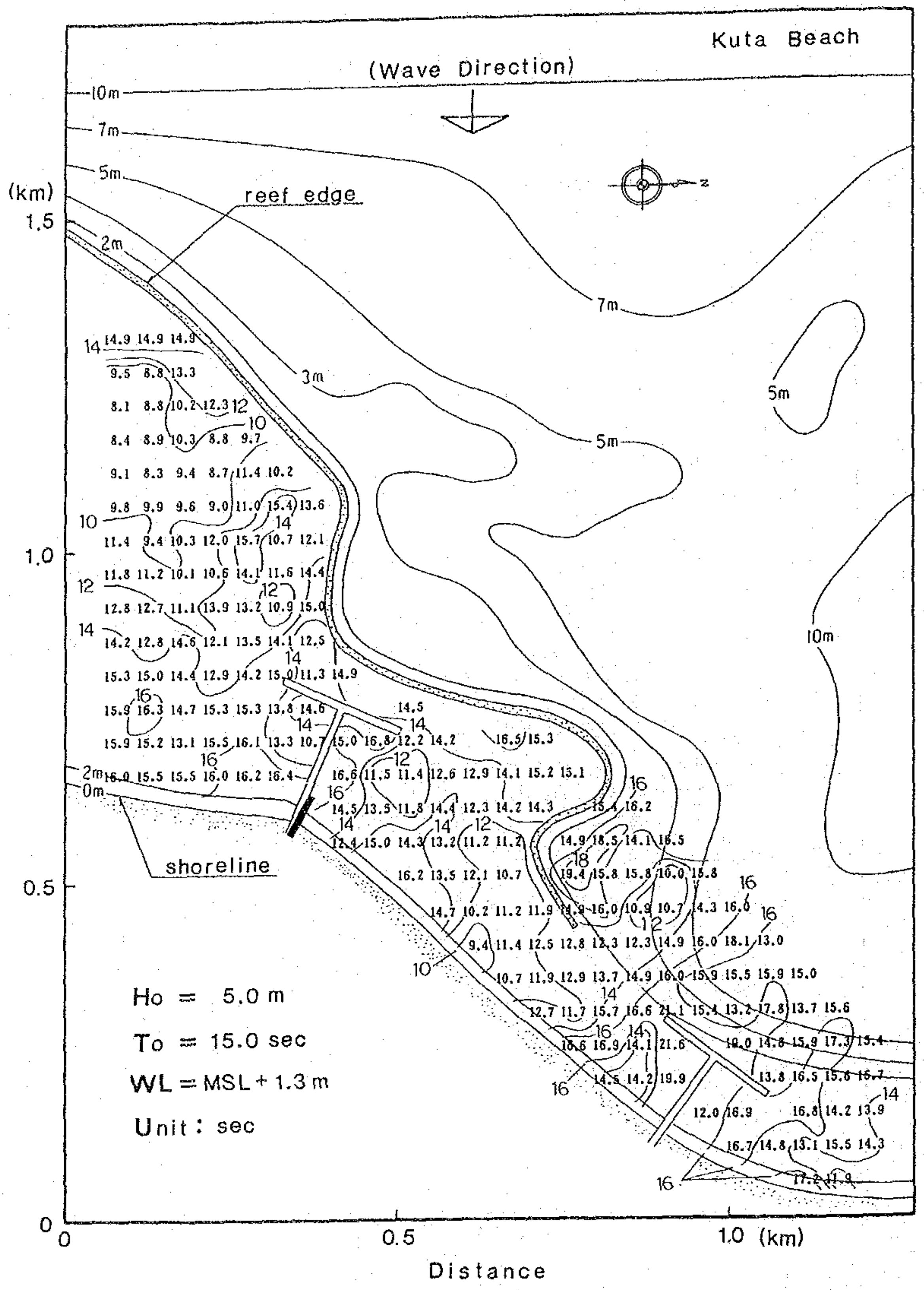


Fig. 5-1-3-9 Distribution of Wave Period with Countermeasures at Kuta Beach

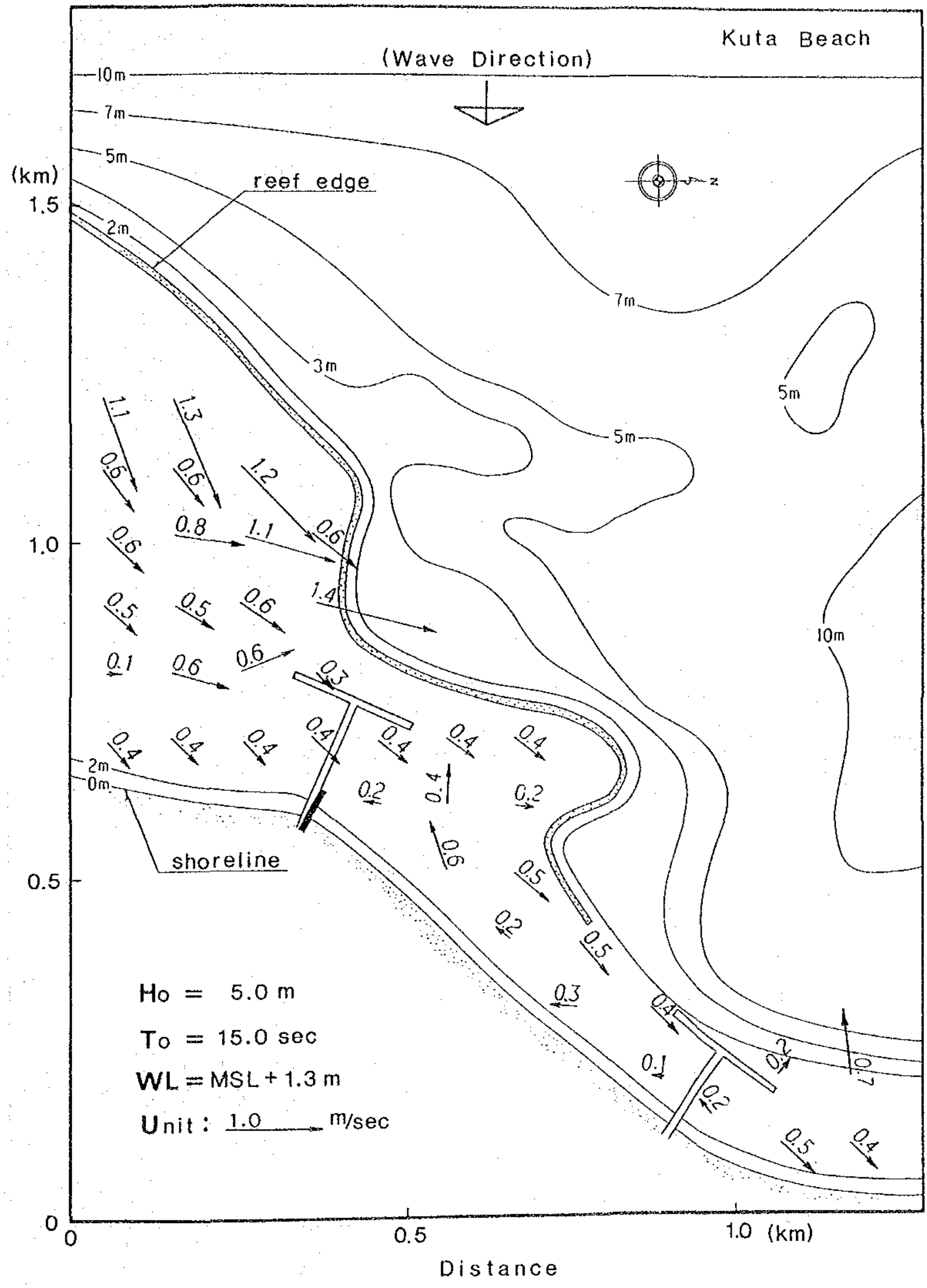


Fig. 5-1-3-10 Current Field with Countermeasures at Kuta Beach

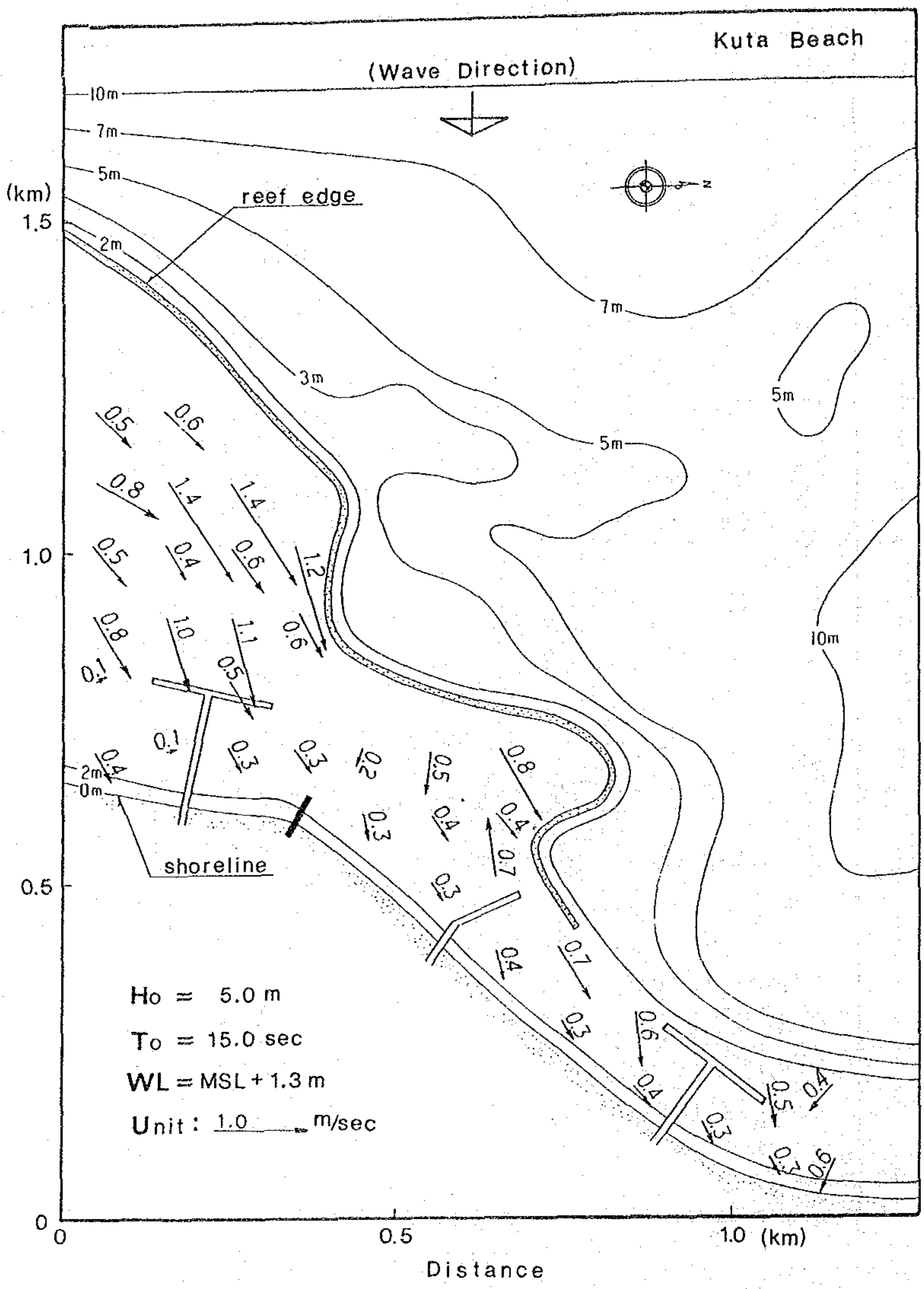


Fig. 5-1-3-11 Current Field with Alternative Countermeasures at Kuta Beach

(2) Nusa Dua Beach

1) Present Condition

The results of wave height, mean water level rise, water period and water current studies are shown in Figs. 5-1-3-12 ~15. It can be seen from Fig. 5-1-3-12 that high waves appear mainly in the area surrounding the reef gap, but low waves below 1 m in height appear in the shallow area near the north shoreline and behind the detached breakwater. Judging from the gradient of mean water level rise represented in Fig. 5-1-3-13, it is supposed that the predominant direction of water current on the reef zone will be from the north to the south. From the vector of water current in Fig. 5-1-3-15, it is found that the water flows strongly out of the reef at the reef gap which is situated offshore at the U type breakwater. On the other hand, the velocity of current in the inner reef zone is relatively small.

Fig. 5-1-3-16 shows the comparison beween measured and calculated wave heights based upon the regressive euqation as mentioned above at Kuta Beach. Taking into account the scattering of negative and positive values in this figure, the equation ($H = 0.37\ h$) is though to be applicable to estimate roughly the wave height in the reef zone.

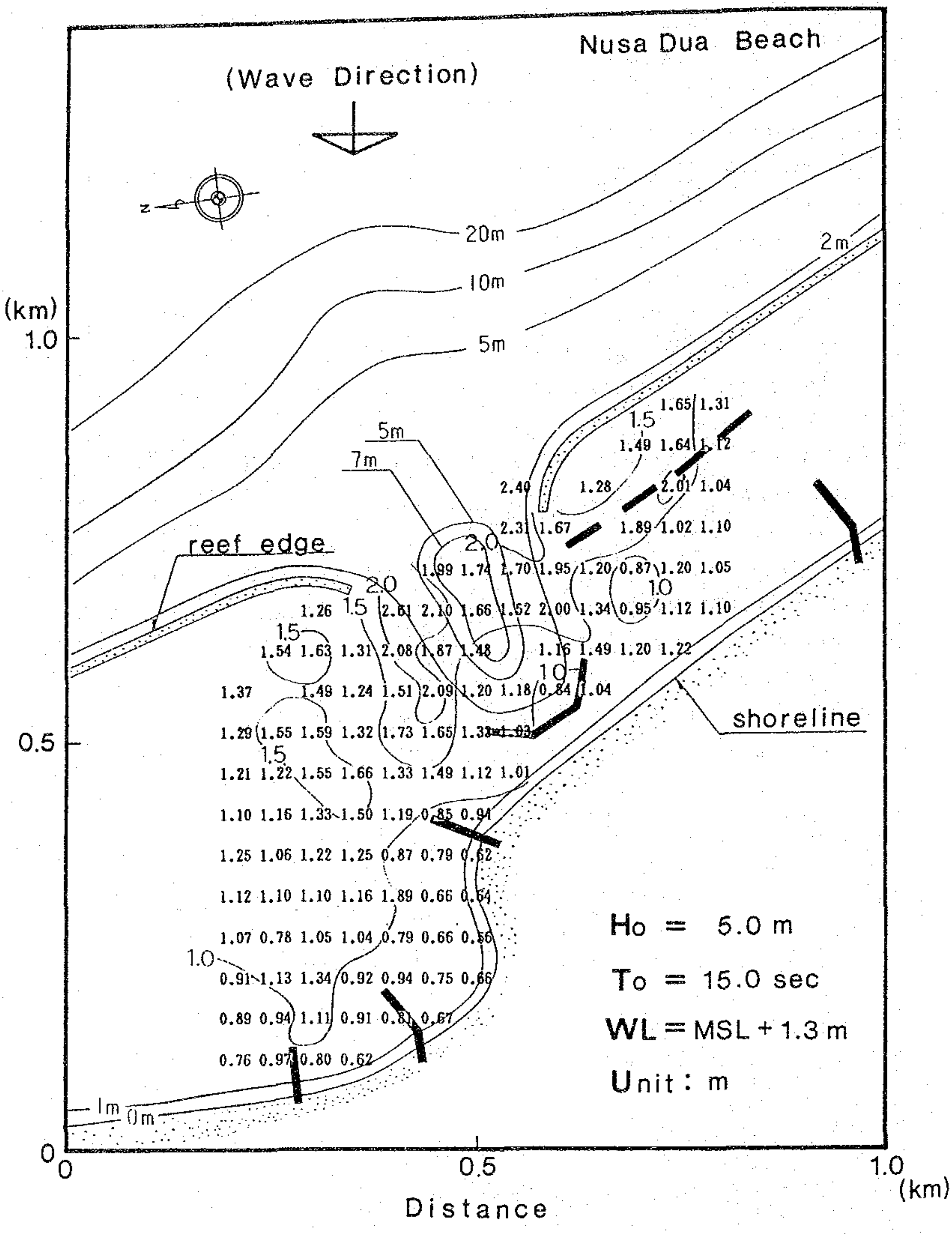


Fig. 5-1-3-12 Distribution of Wave Height under Present Conditions at Nusa Dua Beach

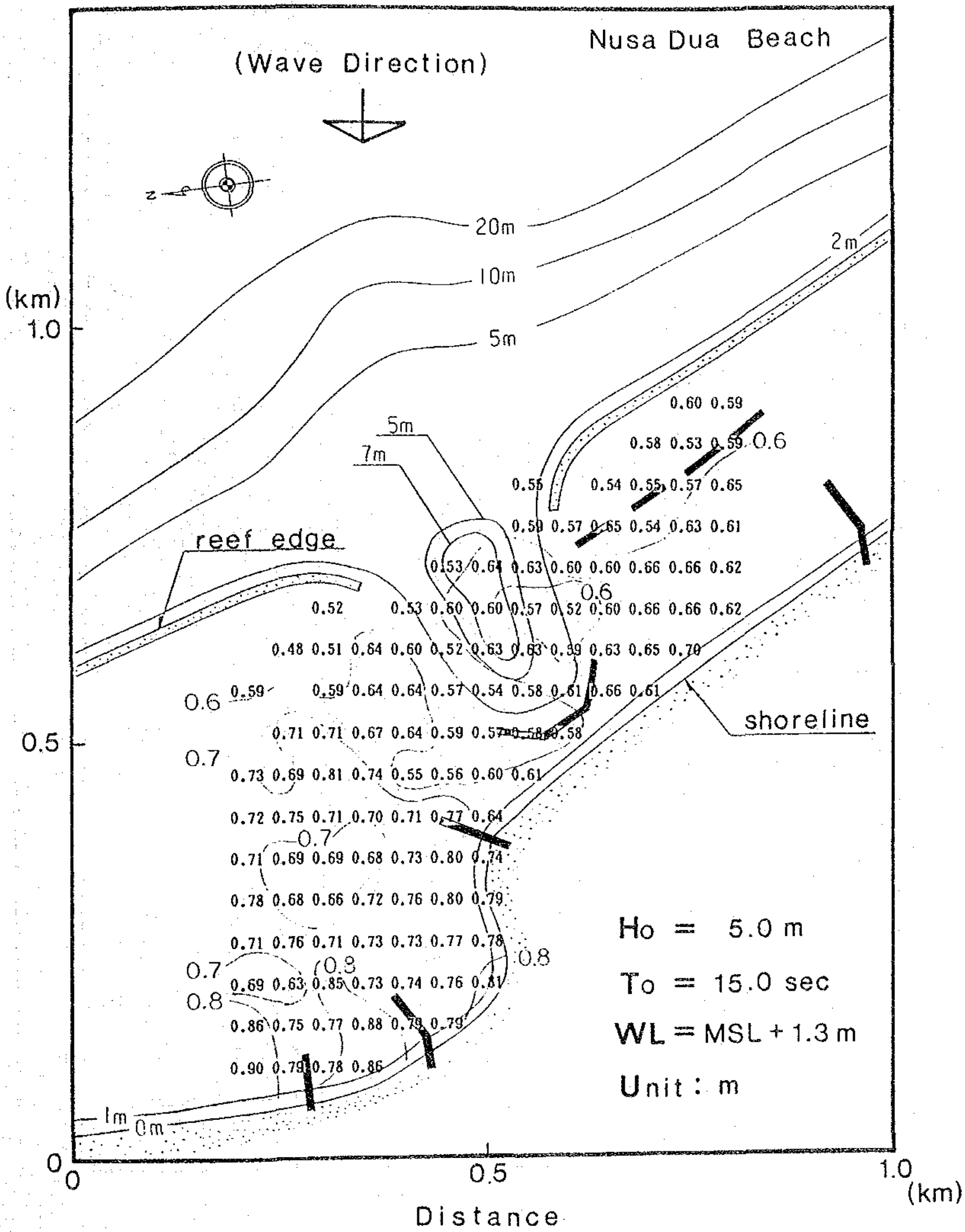


Fig. 5-1-3-13 Distribution of Mean Water Level Rise under Present Conditions at Nusa Dua Beach

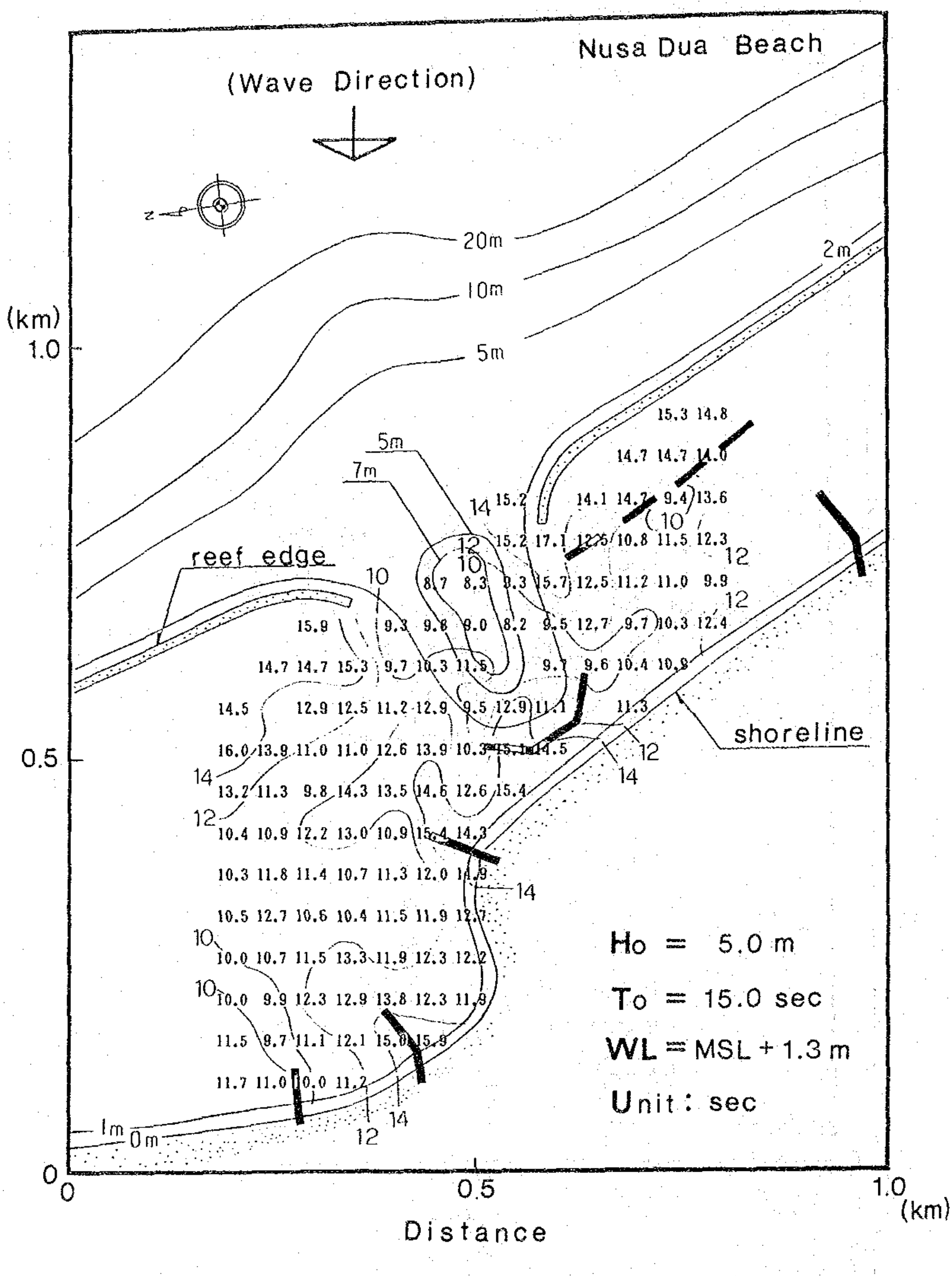


Fig. 5-1-3-14 Distribution of Wave Period under Present Conditions at Nusa Dua Beach

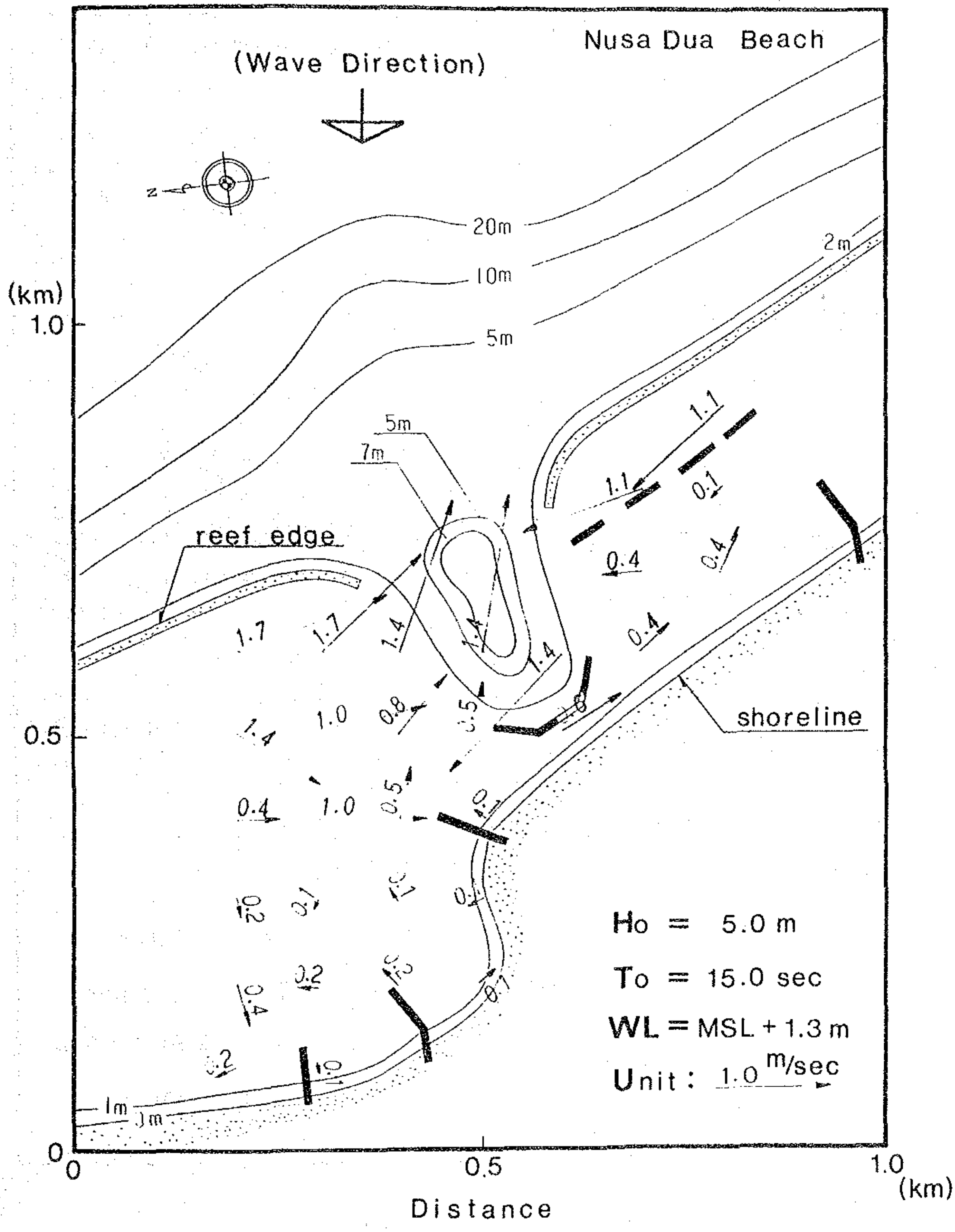
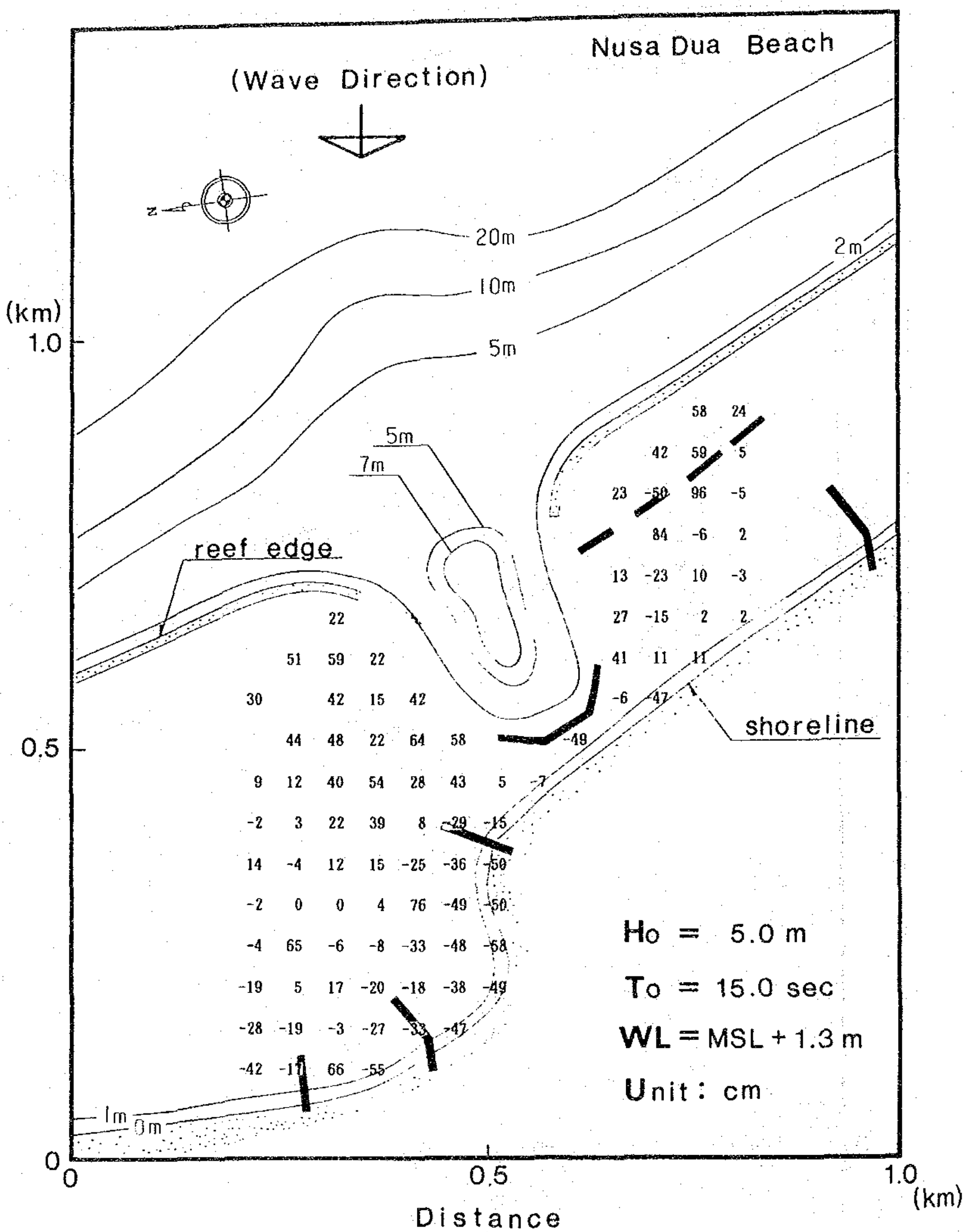


Fig. 5-1-3-15 Current Field under Present Conditions at Nusa Dua Beach



(the positive value means that the wave height measured is greater than the one calculated)

Fig. 5-1-3-16 Difference Between Measured and Calculated Wave Heights at Nusa Dua Beach

2) Countermeasures

The data obtained in the model test with regard to the countermeasures are shown in Fig. 5-1-3-17 ~ 20. As countermeasures at Nusa Dua Beach, the U type breakwater will be extended offshore as a submerged breakwater and the existing north groin near the U type breakwater will also be extended offshore as shown in the figures. Furthermore the existing four detached breakwaters are to be taken away.

From the measured wave height data, it is found that small waves less than 1 m in height appear in all the areas near the shoreline. This calm sea condition is thought to be generated mainly by the elongation of the U type breakwater which will prevent offshore waves from coming directly through the reef gap. It is also found that the existing four detached breakwaters are not so effective in comparison with the elongation of the U type breakwater, because much of the wave energy at this site comes into the reef zone through the reef gap.

According to the current field represented in Fig. 5-1-3-20, the pattern of water flowing out of the reef gap is almost the same as under the present condition. Taking into consideration that the submerged breakwater will prevent bed materials from falling down in the deep region, it is rather preferable for the water to only flow out of the reef gap in the offshore direction and to be exchanged with fresh water coming over the reef edge by wave action.

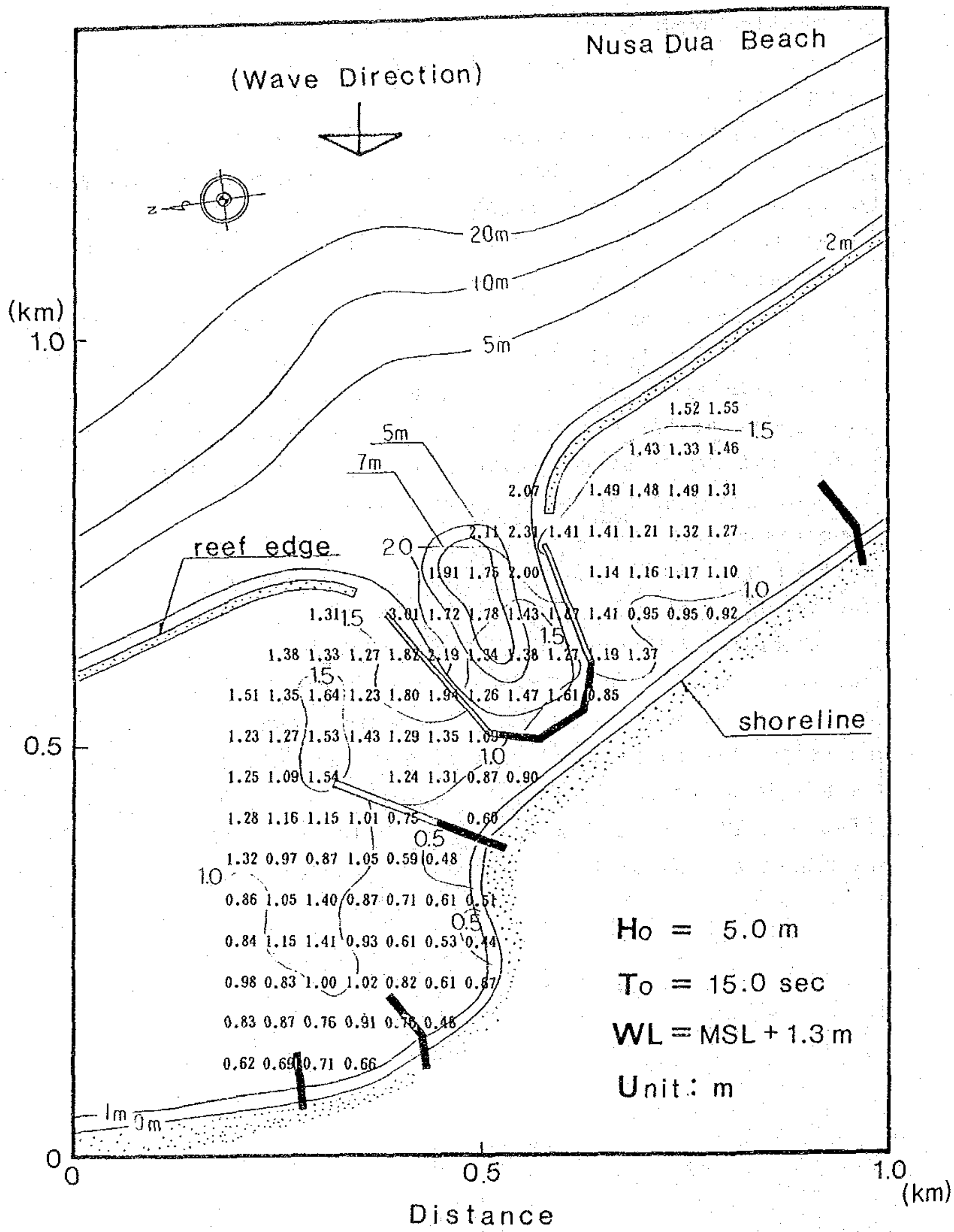


Fig. 5-1-3-17 Distribution of Wave Height with Countermeasures at Nusa Dua Beach

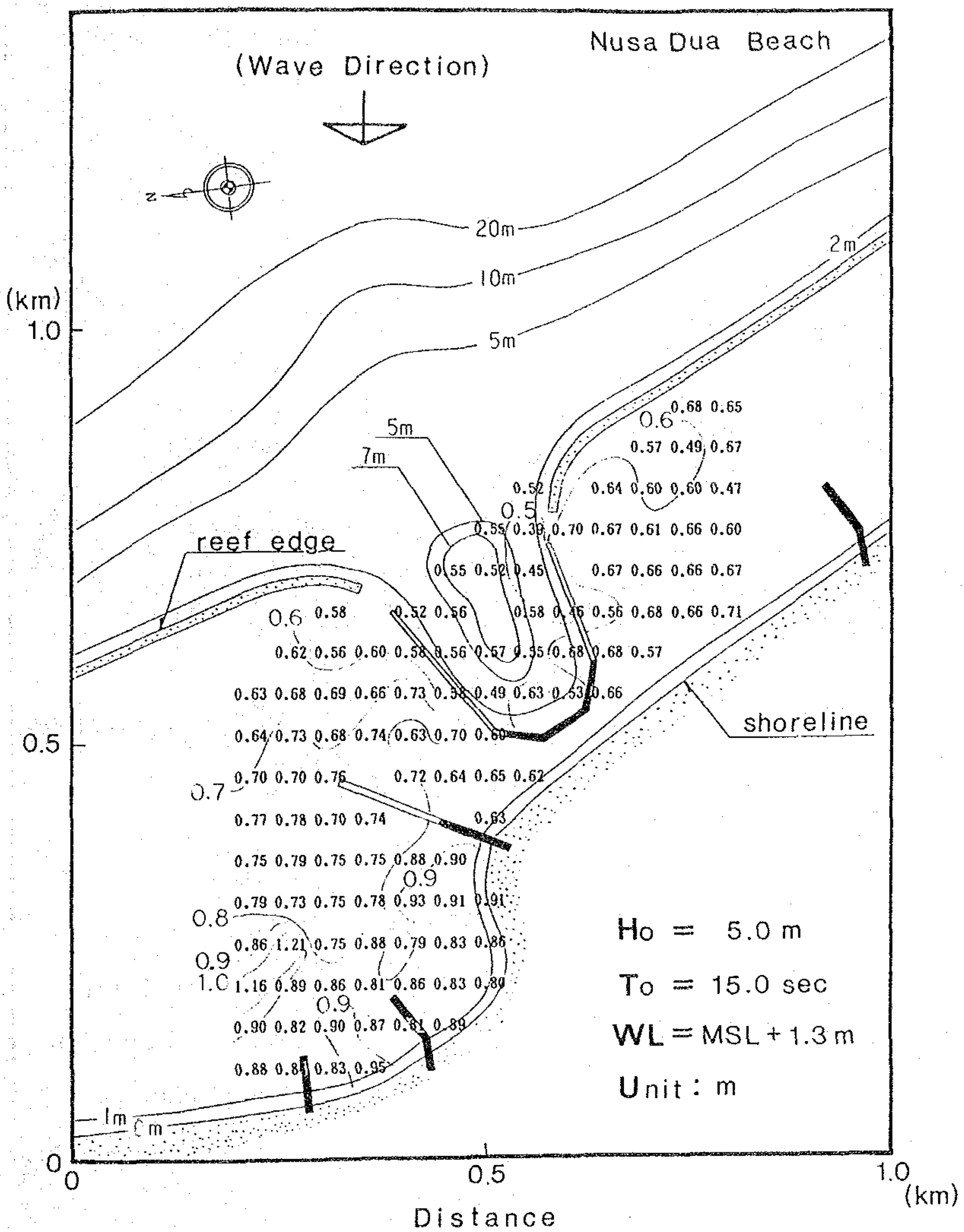


Fig. 5-1-3-18 Distribution of Mean Water Level Rise with Countermeasures Nusa Dua Beach

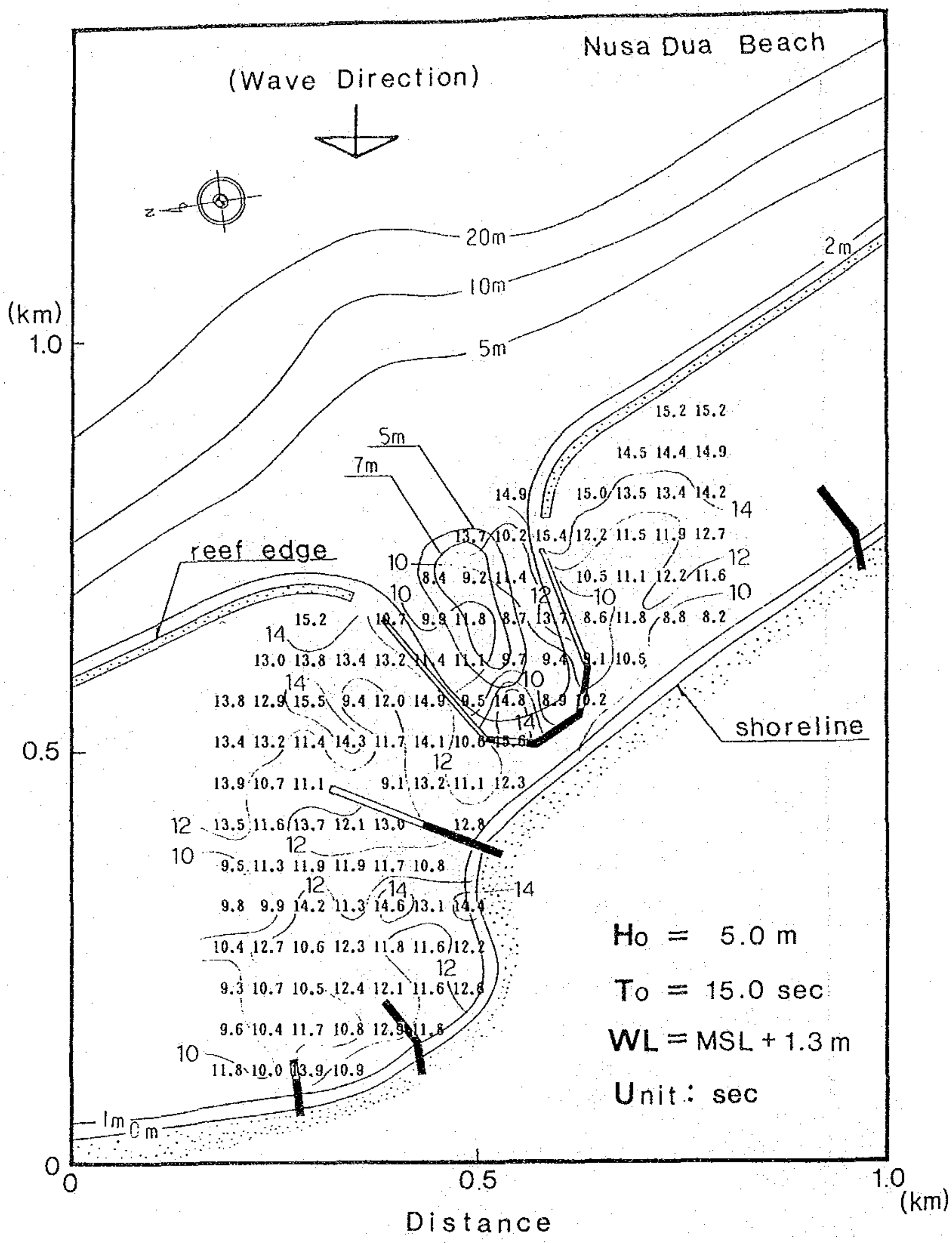


Fig. 5-1-3-19 Distribution of Wave Period with Countermeasures at Nusa Dua Beach

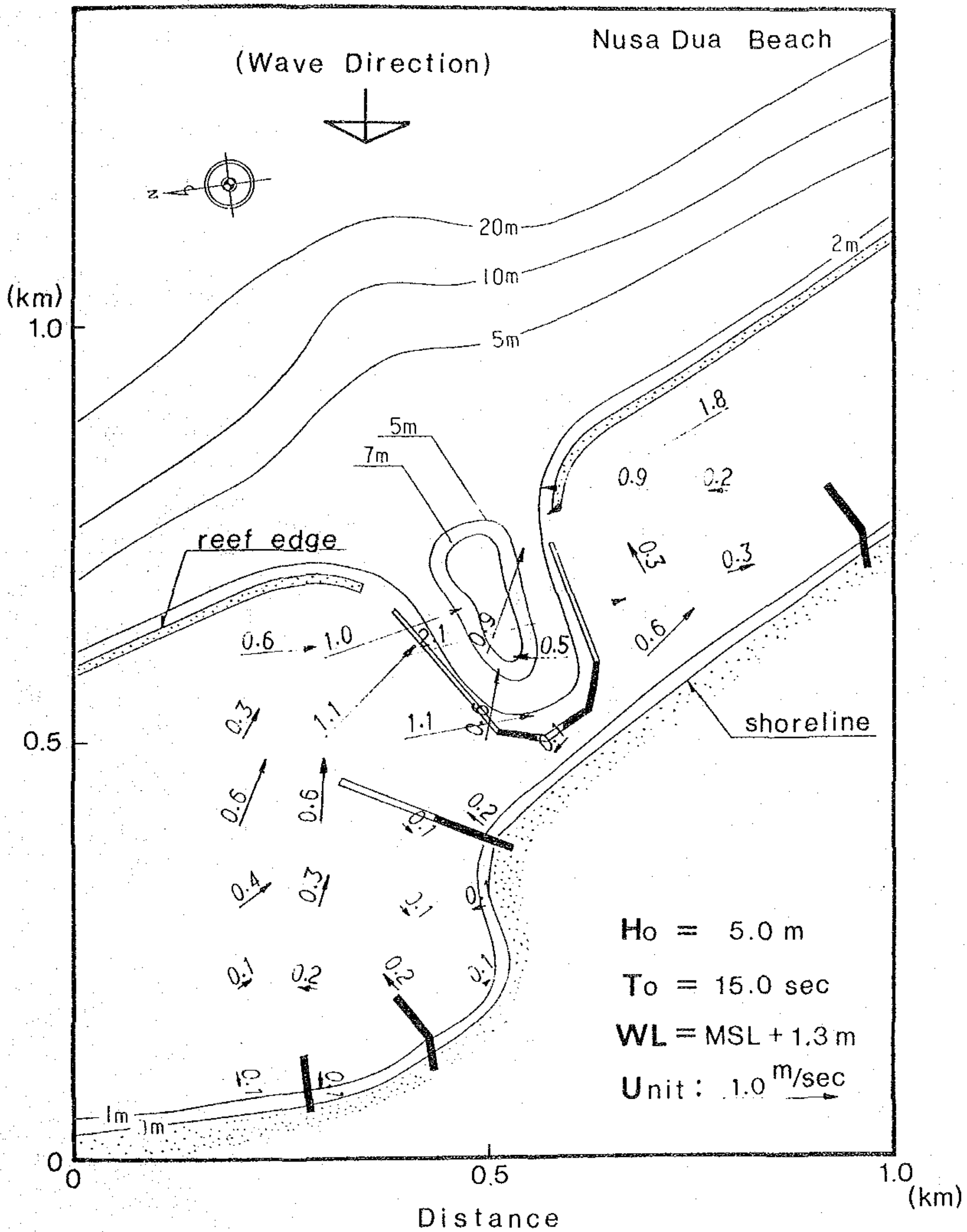


Fig. 5-1-3-20 Current Field with Countermeasures at Nusa Dua Beach

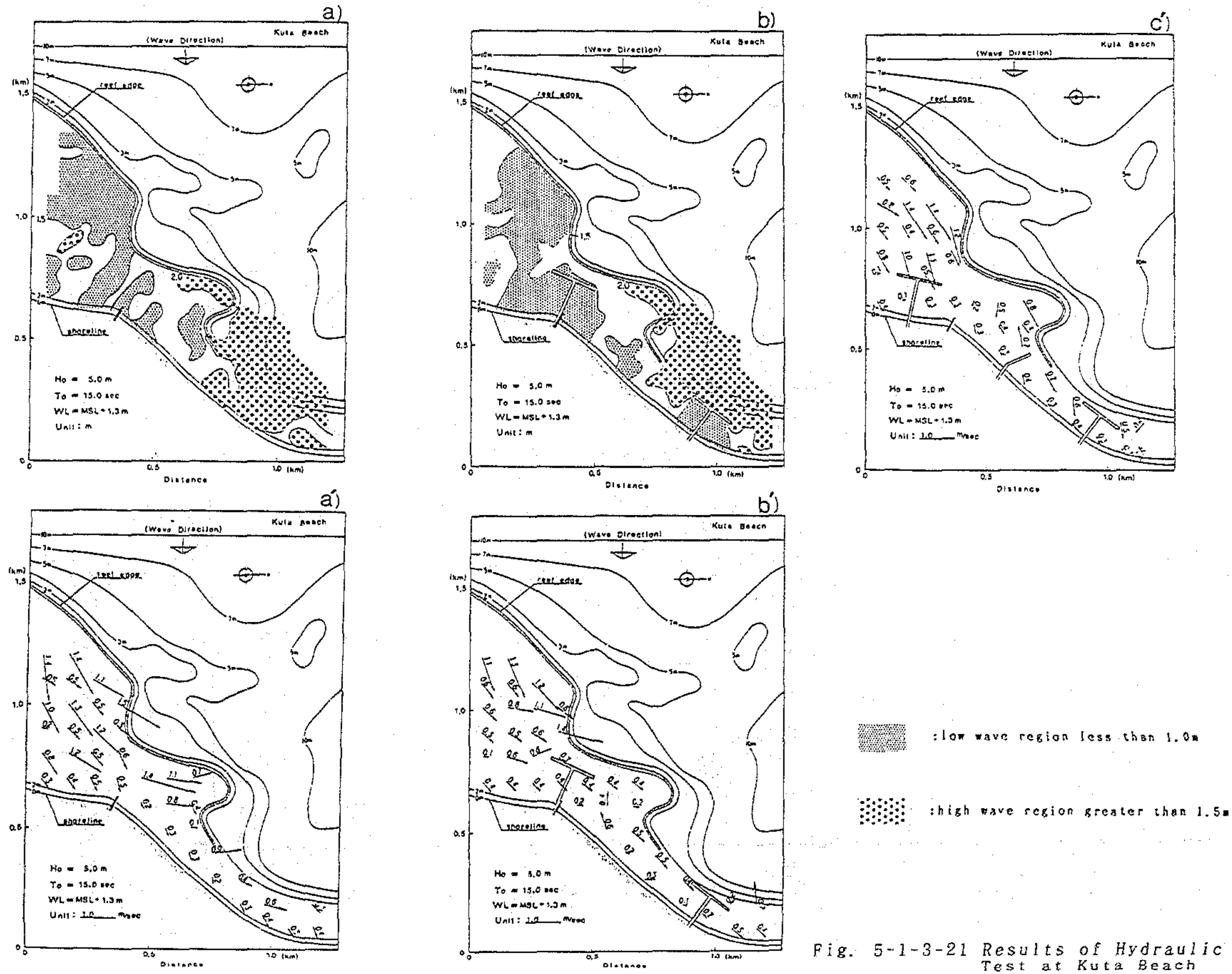
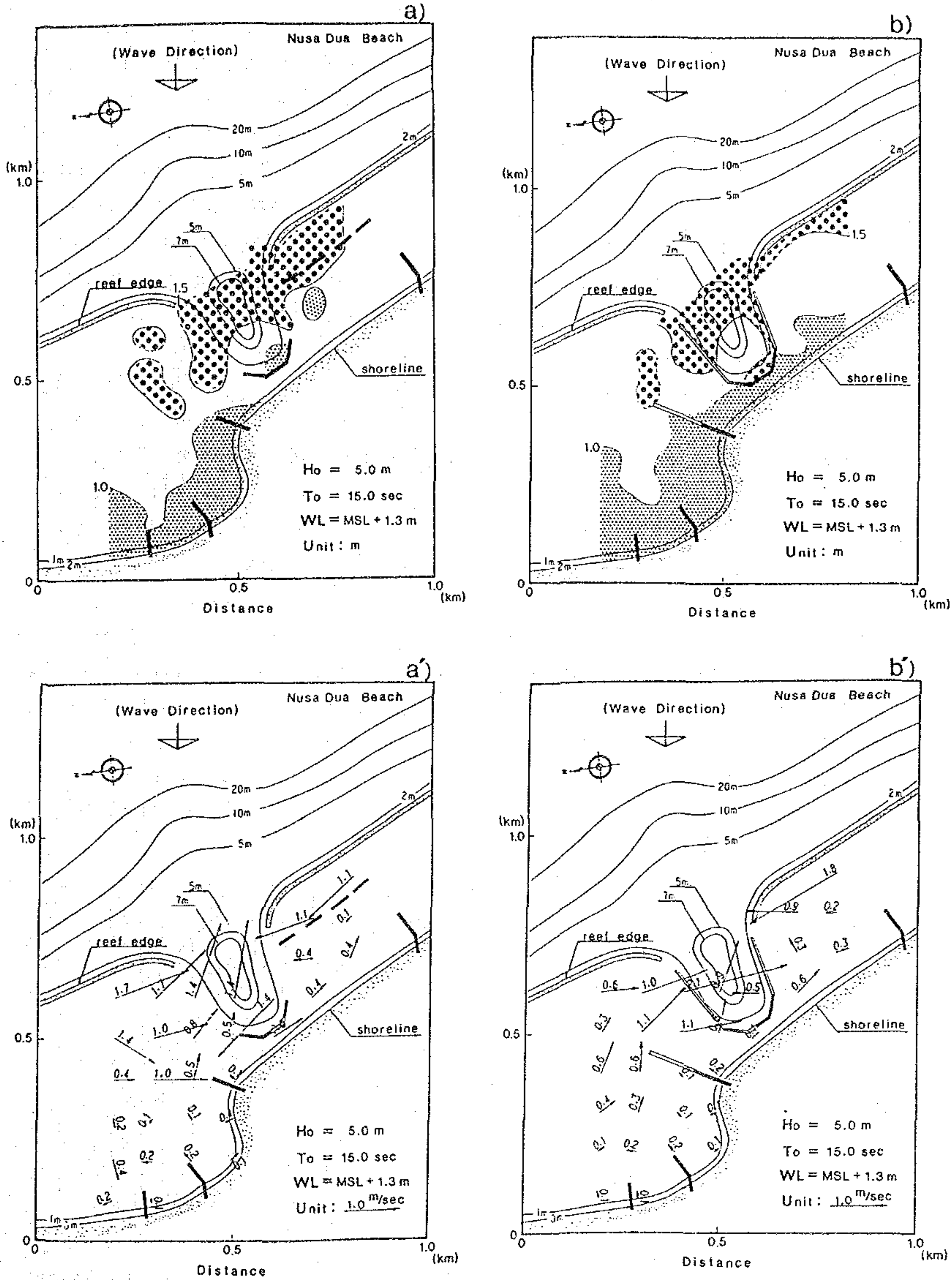


Fig. 5-1-3-21 Results of Hydraulic Model Test at Kuta Beach



:low wave region less than 1.5m :high wave region greater than 2.0m

Fig. 5-1-3-22 Result of Hydraulic Model Test at Nusa Dua Beach

(3) Evaluation

The main results obtained in the 3-dimensional experiment are summarized in Figs. 5-1-3-21 and 22. Taking into account the wave height distribution at Kuta Beach, a calm wave condition will be generated behind the T type groin, sufficient to deposit beach sands even at the beach area without the coral reef as well as at the beach area surrounded by the reef. If a T type groin is set on the reef, the position near the narrow reef zone seems not to be suitable because it causes a strong current towards the offshore zone. Therefore, the arrangement of the T type groin apart from the narrow reef position is preferable at Kuta Beah as in c') as shown in Fig. 5-1-3-21.

Judging from the wave height distribution and the current field at Nusa Dua Beach, the proposed plan for the prevention work against beach erosion is thought to be effective in maintaining the beach sand on account of generating a wide calm wave field near the shoreline.

Lastly the run-up height on the sandy beach due to waves incoming on the reef zone is examined based upon the data obtained by the experiments with countermeasures. Assuming that the measured wave heights H = 1.5 m at Kuta Beach and H = 1.0 m at Nusa Dua Beach and the measured wave period T = 12 sec on the reef in front of the shoreline will correspond to the offshore wave heights and periods, the run-up height (Ru) above the water surface can be obtained approximately as Ru = 1.2 m at Kuta Beach and Ru = 1.0 m at Nusa Dua Beach from Fig. 5-1-3-23 using the mean slope of the foreshore cot β = 15 measured by the topographic survey.

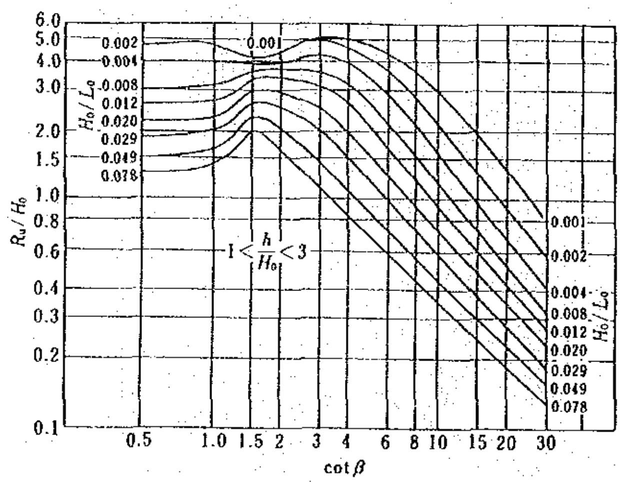


Fig. 5-1-3-23 Diagram for run-up height (from Saville)

Taking into account the mean water level rise of about 0.4 m at Kuta Beach and about 0.6 m at Nusa Dua Beach and the water level of MHW (= MSL + 1.3 m), the actual run-up of waves on the foreshore beach goes to the same level of MSL + 2.9 m at Kuta and Nusa Dua Beaches, respectively. Therefore, under such severe condition as Ho = 5 m, To = 15 sec and WL = MSL + 1.3 m, waves incoming on the reef are thought to run up nearly to the level of MSL + 3.0 m on the foreshore beach. This means that the crown elevation of the nourished beach profile should be MSL + 3.0 m at least.

According to the wave flume tests, the dredging of bed material on the reef is not desirable because the wave height on the reef would increase much more than without dredging.

5-2 Computer Simulation

5-2-1 Introduction

The word "simulate" used to mean to imitate. When high-speed digital computers appeared in the 1950s, the meaning of simulation began to change, because "simulation" then came to signify the use of mathematical models that could be manipulated by computers to perform kinds of experiments. Simulation is thus a class of techniques that involve setting up a model of a real situation and then performing experiments on the model.

The shoreline-erosion problem in general involves a huge area and a considerably long period of time, and hence hydraulic model experiments on such problems are apt to become on a large scale and costly. In this Feasibility Study, the hydraulic model experiments cover not all the study areas but only some portions of special interest at Kuta and Nusa Dua. Hydraulic model experiments also have difficulty in dealing with sediment movement in view of scaling. Hence to evaluate the effects of shore-protection measures the computer simulation will be an essential tool.

There are a number of models to be employed in the simulation. A model is available to simulate the nearshore (2-dimensional) sediment transport by computing the fields of wave and current generally in a large area of interest, but is costly. In view of the nature of the study and the available data, we use the so-called one-line model (App. 5-2-1). The one-line model is one-dimensional and deals with the advancement and retreat of the shoreline along a sandy coast. In case that a more detailed study is required with more detailed data in the future, a more sophisticated model may be called for.

The procedure in the simulation with the one-line model is now briefly discussed. The basis of the model is described in App. 5-2-1. The first task is to find the wave and associated parameters that would best reproduce the shoreline evolution undergone from a previous time t_1 (say, 10 years ago) to a later time t_2 (say, the present). The model wave thus found will in the forecast run bring about the shoreline change with the proposed countermeasure structures to be encountered from the time t_2 to a later time t_3 (say, 10 years from t_2).

Oceanographic data and sediment properties serve to find the model wave. In this study, however, such data available is far from sufficient, and we resort to the data on shoreline change. At Kuta and Sanur the shoreline data are available for the year of 1978 and at Nusa Dua for 1983. These data are used as the initial state for the shoreline evolution up to 1988 when the shoreline survey was done at each site in this study.

The sediment grain-size analyses show that the medium grain size in the surf zone is approximately 0.15 mm at Kuta (see Fig. 2-5-2-8), 1.0 mm at Nusa Dua (Fig. 2-5-2-10) and 0.3 ~1.0 mm at Sanur (Fig. 2-5-2-12). From the sediment material analyses we find that heavy magnetite is 5 ~ 15% at Kuta (Fig. 2-5-2-9), less than 3% at Nusa Dua (Fig. 2-5-2-11), less than 2% at Sanur and more than 90% on the south and north of the heliport in front of Hotel Bali Beach (Fig. 2-5-2-13), respectively. The grain properties govern the mobility of sediment; heavier and greater particles move less under the same wave action.

The offshore wave climate in the Indian Ocean to the south of Bali (Fig. 2-3-2) is used to discuss the nature of waves incoming to the island of Bali in the next section.

5-2-2 Nature of Incoming Waves

Among a variety of waves it is swell incoming from the Indian Ocean that is the most effective on the sediment transport. The U.S. Navy Marine Climatic Atlas of the World Ⅲ Indian Ocean (1976) provides the statistics on the height, period and direction of the waves at a number of areas in the Indian Ocean. One of the areas is located to the south of the island of Bali (Fig. 2-3-2) and the data will be used here. The statistics are based on visual observations by various U.S. Naval Weather Fleet Units and field activites during as long as 120 years up to 1976.

The swell has a period of 8 seconds, a height of 2 m on energy-weighted average, and a direction of SE to SW. The swell is known, when propagating on the ocean, to increase in period and decrease in height mainly due to dispersion. Bretschneider gives a rough estimation of this effect. It follows that when propagating from the observation site to Bali, the height reduces roughly by 75% and the period increases by 25%. Accounting for this, we now pick up the periods of 10 and 15 seconds, the latter also representing the observation just off the reef edge in the study, and the directions of SE, S, and SW.

The waves change in direction and height due to refraction where the ocean is shallower than half the wavelength. Fig. 5-2-2-1 plots the sea-depth contours near the study sites along with the locations of output for the wave incoming to each site. The wave rays for 6 combinations (2 periods x 3 directions) are plotted in Figs. 5-2-2-2～7(a). Note that longer waves with a greater period are more greatly refracted. Figs. 5-2-2-2～7(b) plot the resulting wave height distribution corresponding to the six cases. The numbers indicate the ratio of the wave height at the location to that of the original swell.

Table 5-2-2-1 tabulates the direction and the waveheight ratio at the points shown by circles where the waves incoming to the sites are evaluated. In Table 5-2-2-1 k is the waveheight ratio and θ is the angle measured from S toward E by degrees. It follows that the typical wave is likely to arrive from the direction of:

-59 ～ -36°	at Kuta
8 ～ 64°	at Nusa Dua
14～ 59°	at Sanur
-54 ～ -16°	at Tanah Lot.

The waveheight depends greatly on the incoming-swell direction. The swell from SE affects Kuta and Tanah Lot much less than Nusa Dua and Sanur, and the one from SW affects Sanur much less than Kuta and Tanah Lot.

The output points, 18 to 26 m deep, are located off the edge of the shallow coral reef, 1 ～ 2 m deep. Breaking at the edge, waves reduce both of their height and period through nonlinear mechanisms. In calculating the nearshore wave propagation accounting for refraction, diffraction and shoaling, the linear approximation is employed. Hence to represent the wave in the surf zone responsible for the sediment transport, we will adopt a smaller wave period to begin with in the nearshore wave calculation.

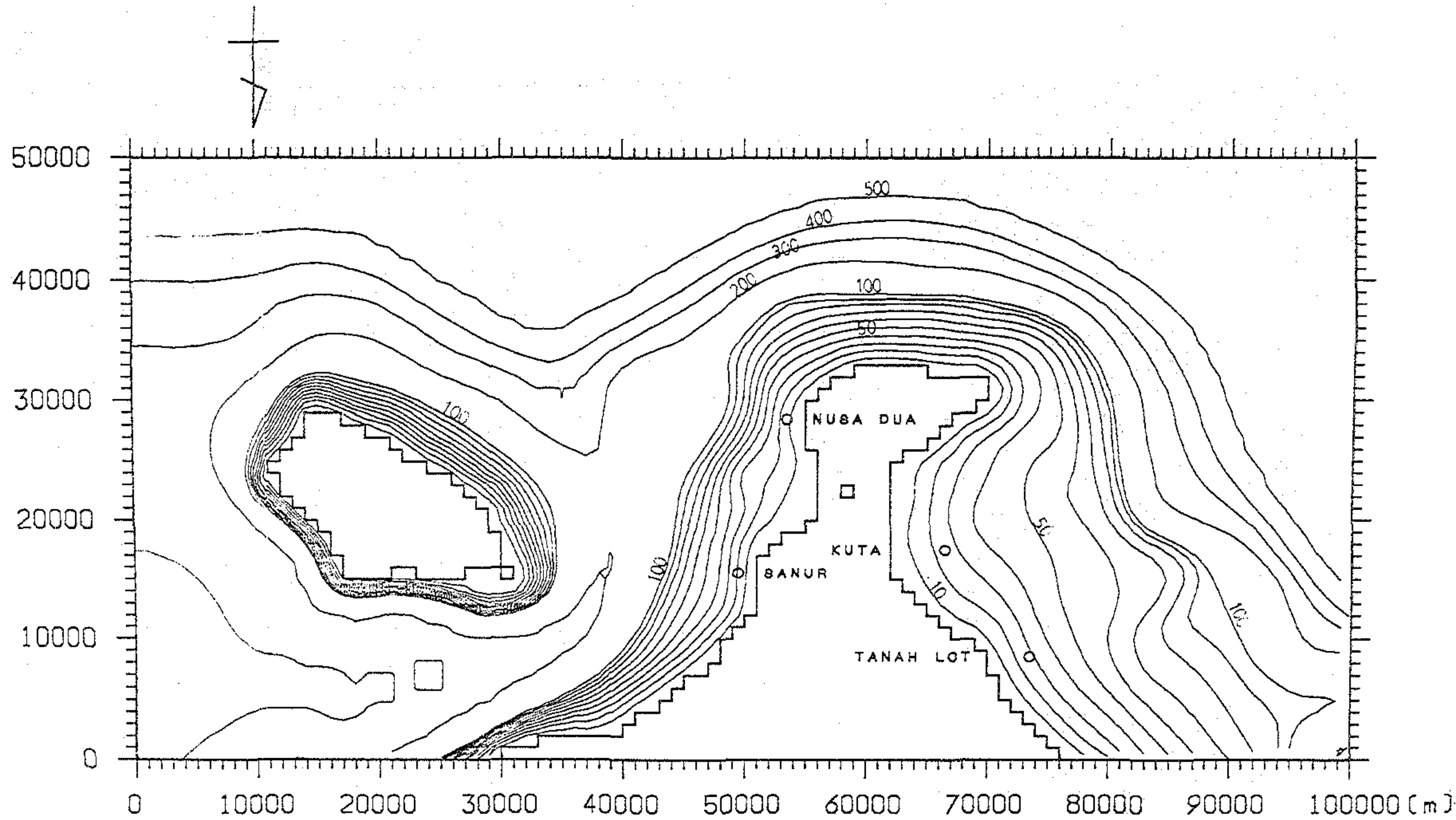


Fig. 5-2-2-1 Sea-Depth Contours Near the Sites and Output Points(○) for Wave Incoming to Each Site (depth in meters)

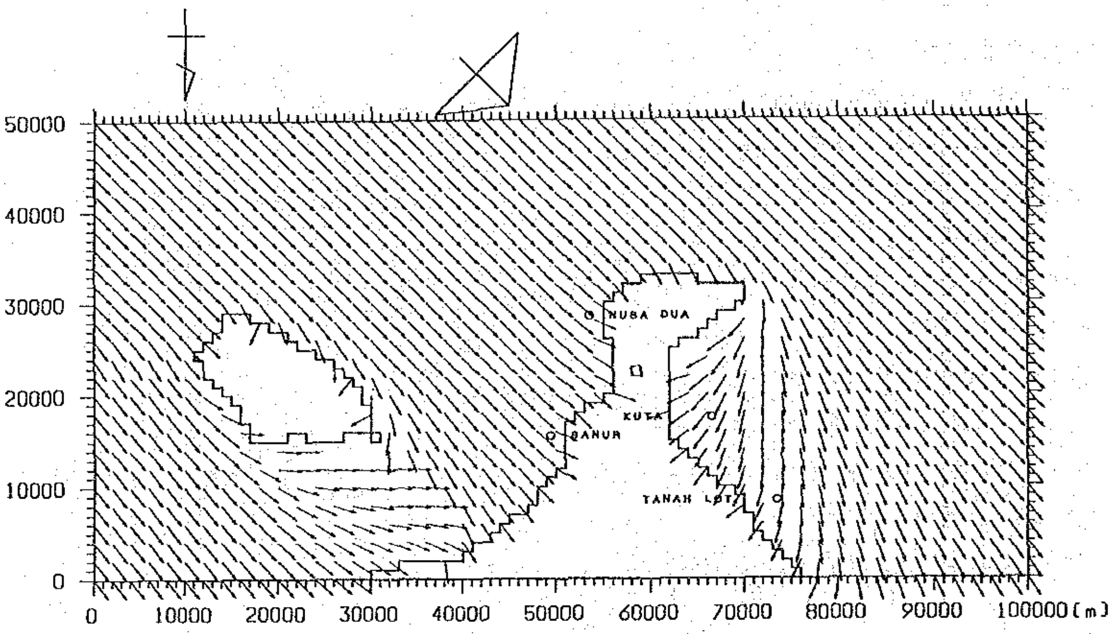


Fig. 5-2-2-2(a) Wave Rays (10 seconds, SE)

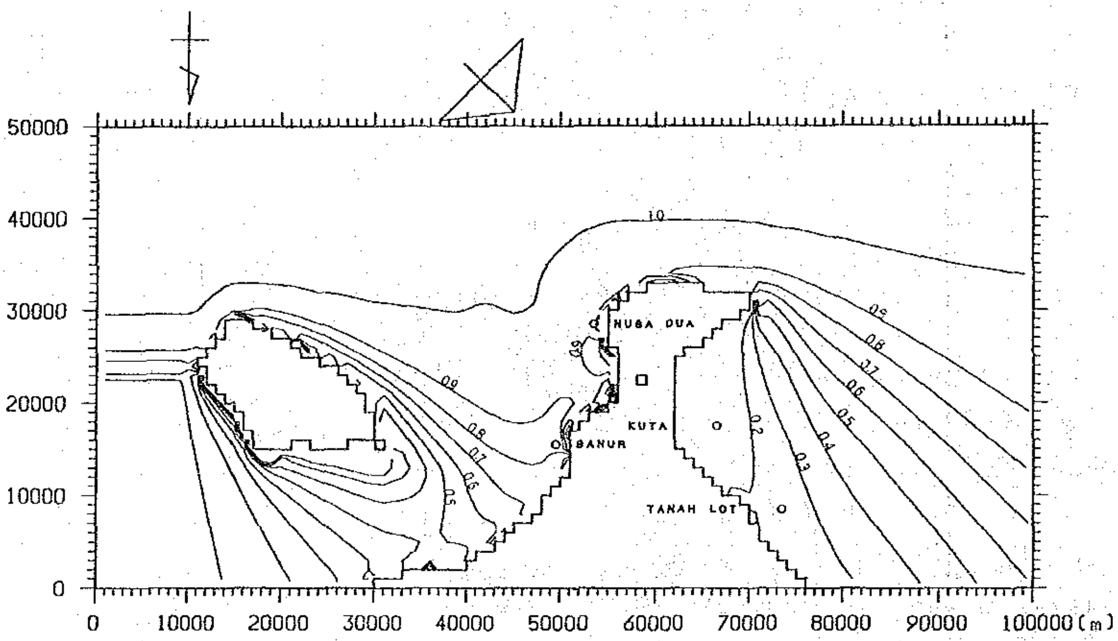


Fig. 5-2-2-2(b) Wave Height Ratio (10 seconds, SE)

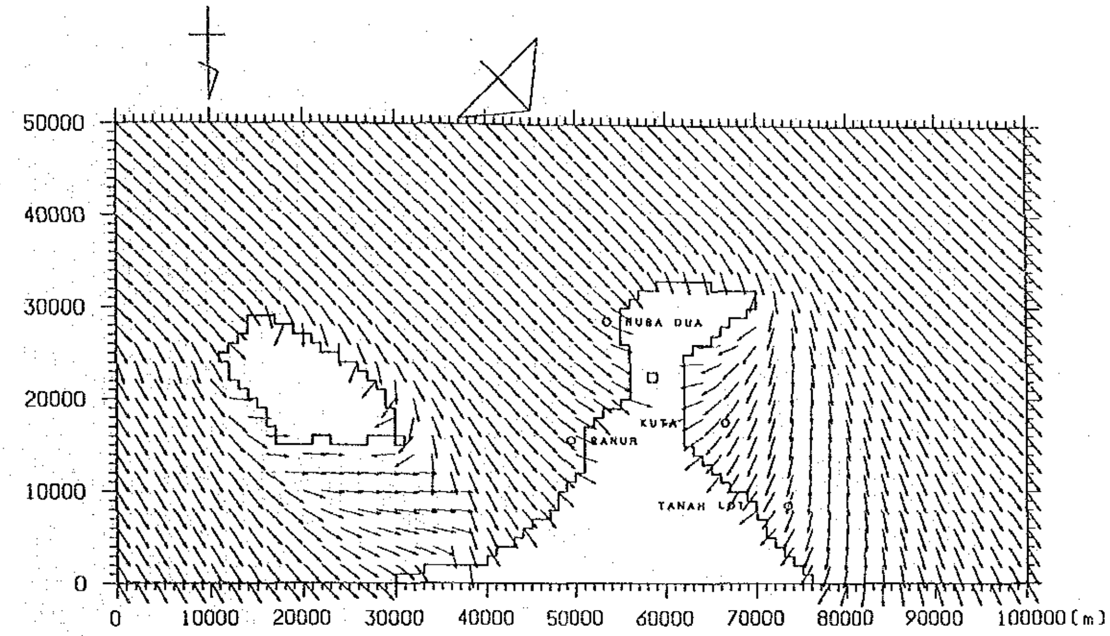


Fig. 5-2-2-3(a) Wave Rays (15 seconds, SE)

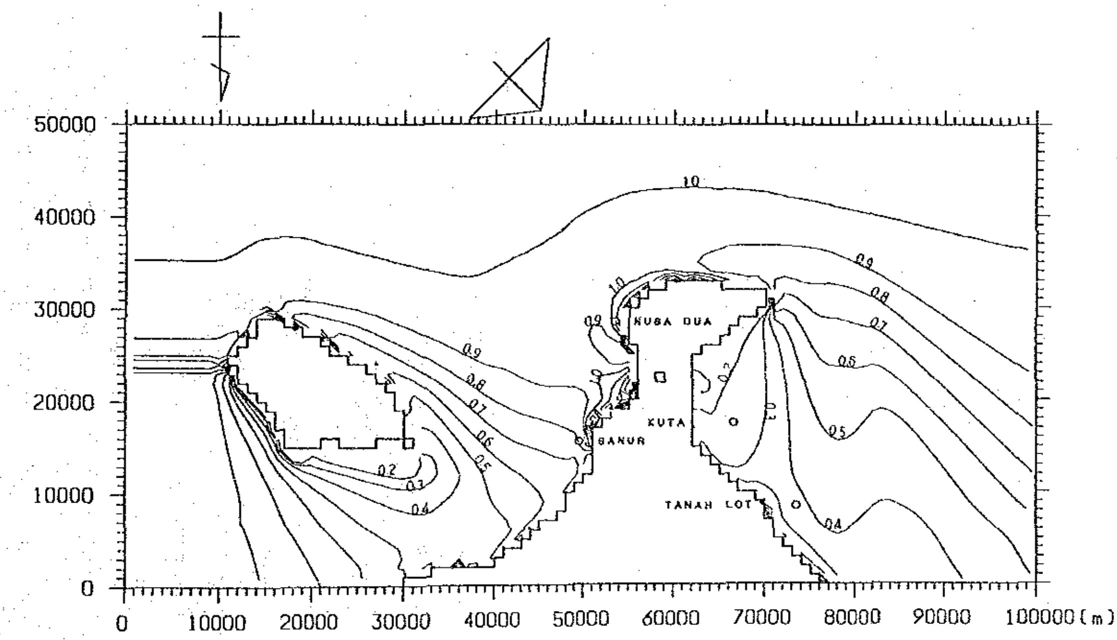


Fig. 5-2-2-3(b) Wave Height Ratio (15 seconds, SE)

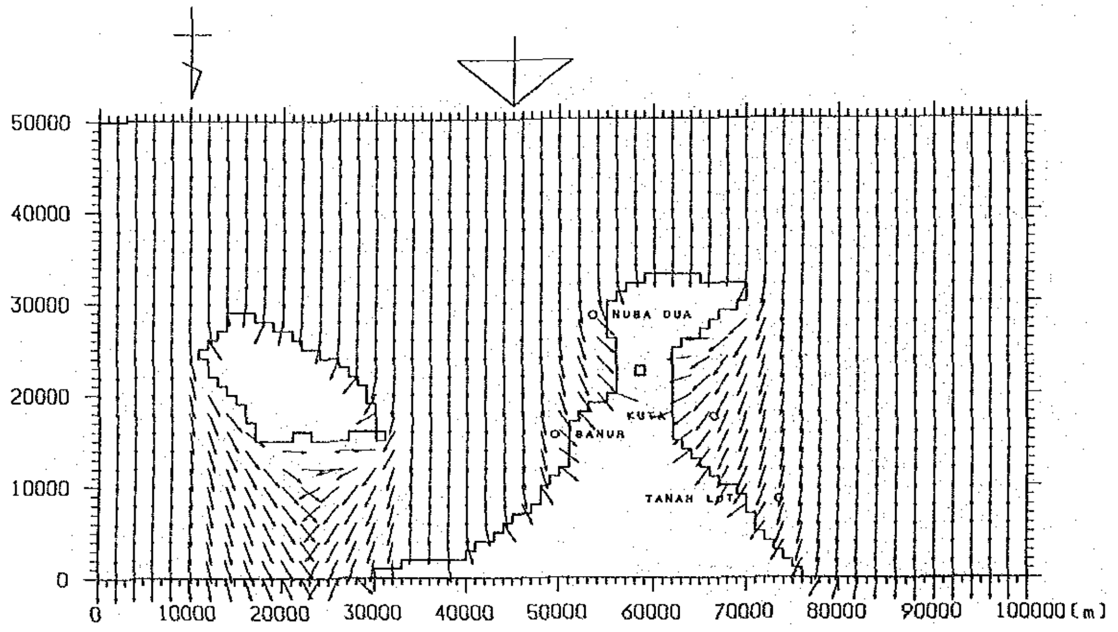


Fig. 5-2-2-4(a) Wave Rays (10 seconds, S)

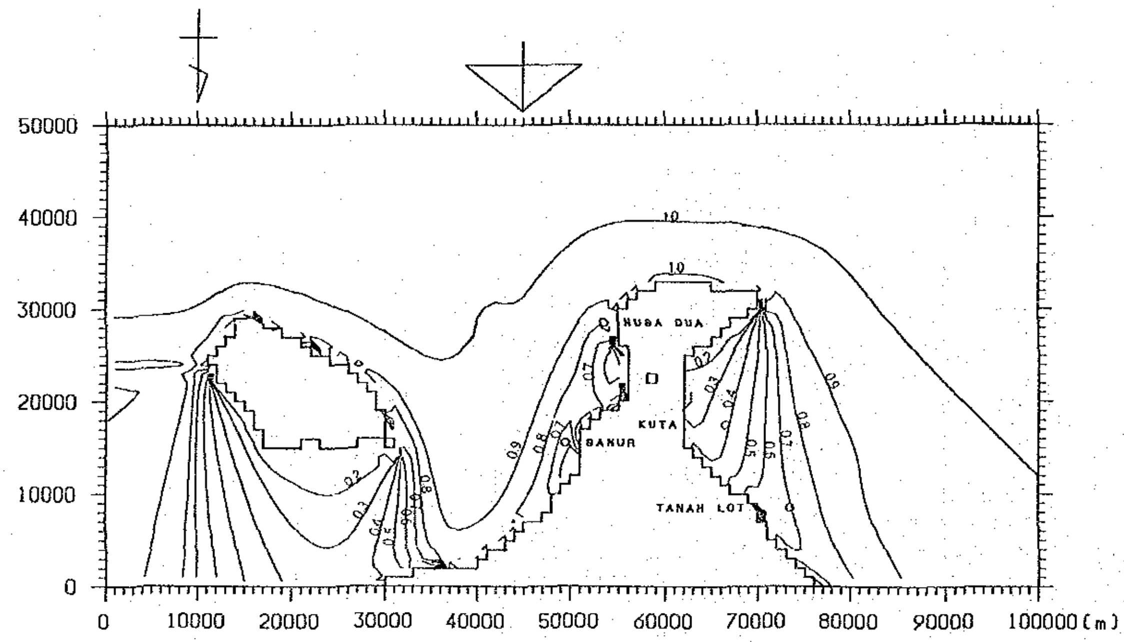


Fig. 5-2-2-4(b) Wave Height Ratio (10 seconds, S)

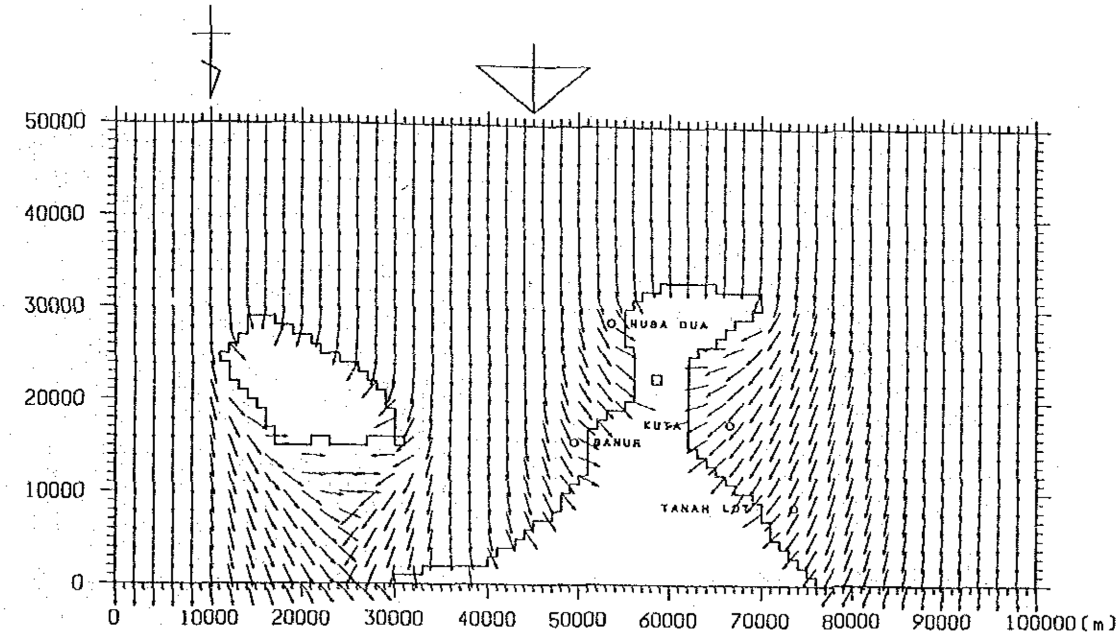


Fig. 5-2-2-5(a) Wave Rays (15 seconds, S)

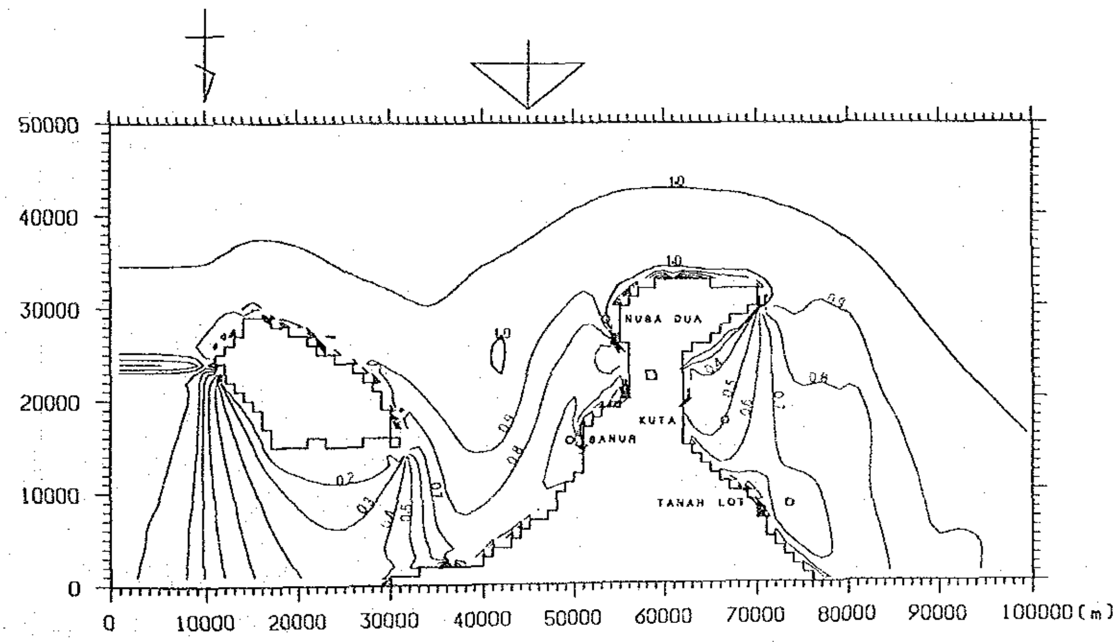


Fig. 5-2-2-5(b) Wave Height Ratio (15 seconds, S)

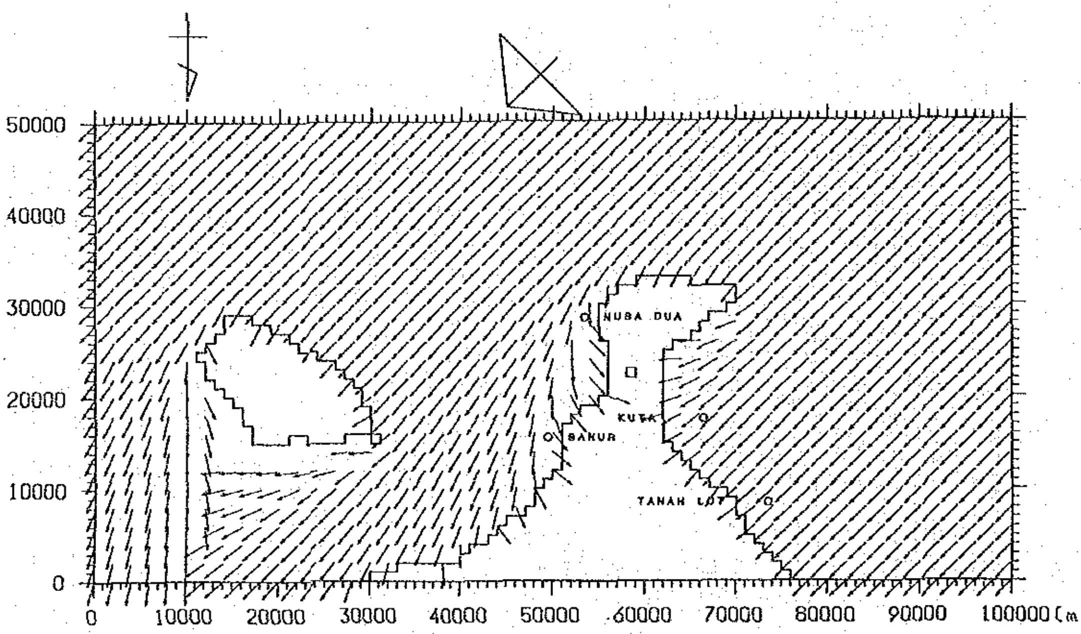


Fig. 5-2-2-6(a) Wave Rays (10 seconds, SW)

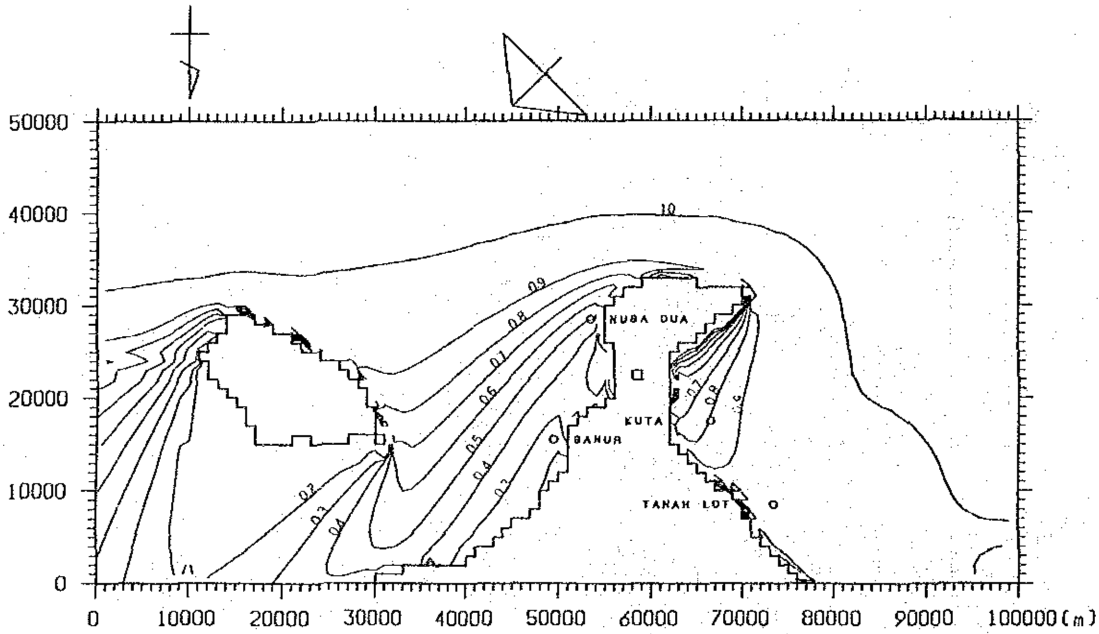


Fig. 5-2-2-6(b) Wave Height Ratio (10 seconds, SW)

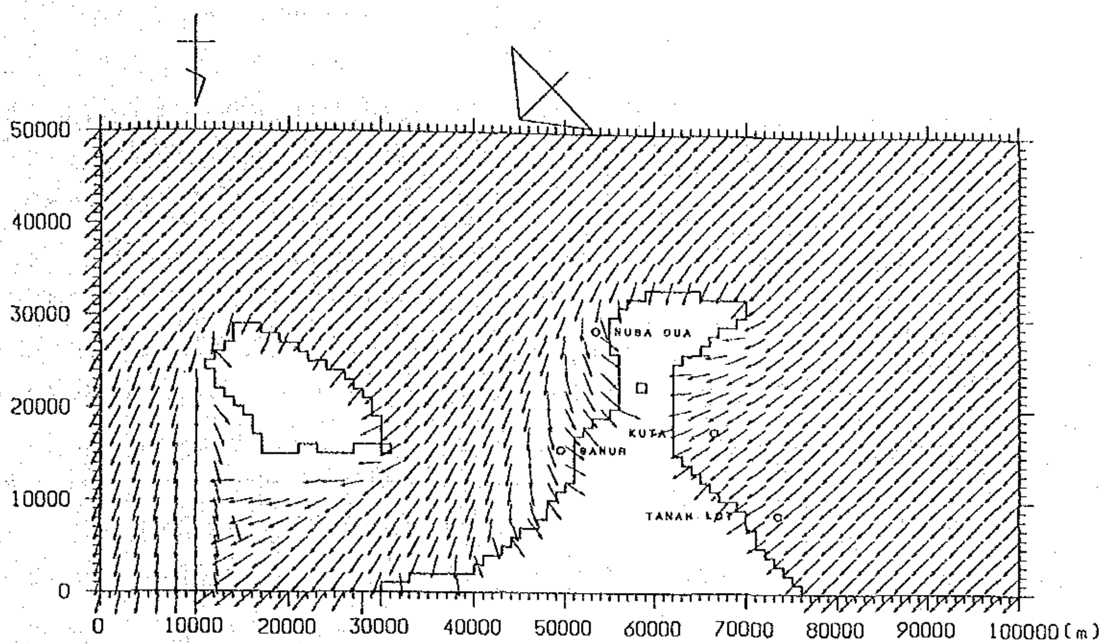


Fig. 5-2-2-7(a) Wave Rays (15 seconds, SW)

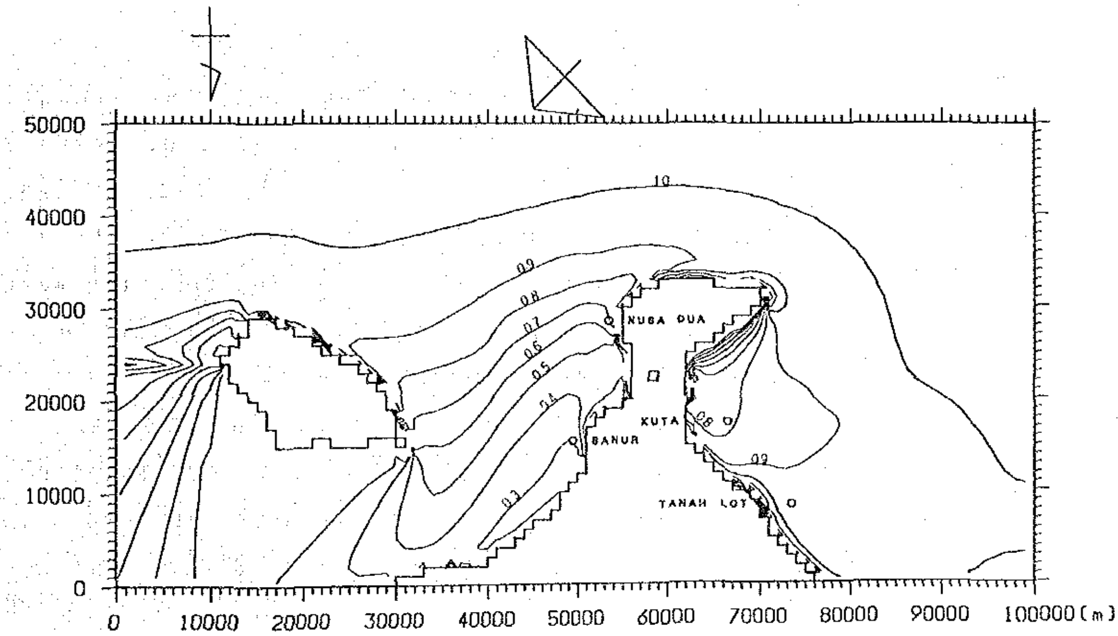


Fig. 5-2-2-7(b) Wave Height Ratio (15 seconds, SW)

Table 5-2-2-1 Wave Characteristics Incoming to the Study Sites

Site		SE		S		SW	
		θ	k	θ	k	θ	k
NUSA DUA 18m - deep	10	58	0.92	26	0.79	8	0.48
	15	64	0.96	43	0.86	29	0.62
SANUR 26m - deep	10	53	0.81	24	0.66	14	0.25
	15	59	0.75	44	0.64	38	0.29
KUTA 21m - deep	10	-36	0.13	-37	0.37	-54	0.80
	15	-44	0.22	-47	0.50	-59	0.78
TANAH LOT 23m - deep	10	-16	0.22	-20	0.67	-50	0.93
	15	-29	0.38	-34	0.66	-54	0.96

5-2-3 Model Wave

The model wave is defined in the one-line model (App. 5-2-1) as the one that reproduces the shoreline evolution by acting steadily during the period. Therefore the model wave is a sort of averaged wave on the basis of the effects on the shoreline evolution. Higher waves have greater effects. No standard way has been established to find the average in this sense over the ensemble of the incoming waves discussed in the previous section, but the model wave should not differ substantially from the waves obtained there.

On the other hand comparison between shorelines at two separate points of time yields the longshore sediment transport accumulated in the duration, on the assumption that the long-term shoreline evolution is due to the longshore sediment transport (App. 5-2-1). The one-line model relates the longshore sediment transport rate to the energy flux of the breaking wave in front of the shoreline. Therefore we compute several runs of the nearshore wave propagation with parameters within the range obtained in the previous section, apply the one-line model to the outcome, and compare the resulting shoreline evolution with the observed one. The model wave is determined after modifying the one that best fits the observation. The other parameters involved in the one-line model are also determined (App. 5-2-1).

It must be pointed out that the model wave is not uniquely determined from just the comparison between the shorelines of two separate points of time. If the shoreline is not stable and changes, it generally tends to reorient so that it parallels the incoming wave crests. The process thus involves saturation. Knowing the shorelines at two separate points of time, we have no means to determine the characteristic time, namely, how quickly this process advances.

The following presents the model waves for Kuta, Nusa Dua and Sanur, and discuss how well these waves reproduce the observed shoreline evolution and some other aspects observed.

Incoming waves normally break twice, at the reef edge and near the shoreline, the latter responsible for the shoreline evolution, since no sand is at the reef edge. In the subsequent sections "breaking" thus refers to the one near the shoreline.

(1) Kuta

Fig. 5-2-3-1 plots the nearshore topography at Kuta. A wide coral reef is found about 2 km alongshore from the airport runway. Figs. 5-2-3-2 and 3 show the wave rays and waveheight distribution when a wave with the period of 8 seconds and height of 1.1 m is incoming from -90 ° (west) at the top of the figures. The height 1.1 m equals the energy-weighted average of the waves calculated in section 5-2-2. No attenuation has been assumed. The x-axis is in the N-S direction and nearly along the shoreline. The wave experiences an abrupt change in direction (refraction) at the reef edge, and tends to reorient normal to the depth contours and shoreline. The wave shown here turns out to best represent the model wave at Kuta with a slight modification although the direction is greater than anticipated in Section 5-2-2. Note again that in reality the incoming waves are random with a spectrum in direction, and period, and that the shoreline responds to this diverse wave climate. The model wave does not necessarily correspond to a single monochromatic wave.

The duration of simulation is from August, 1978 to May, 1988. Fig.

5-2-3-4 plots the initial shoreline observed in August 1978, and the present (May, 1988) shorelines observed and calculated to be compared with each other. The vertical line segments stand for the groins and the oblique one for the detached breakwater. The calculation is well close to the observation. Fig. 5-2-3-5 shows the angles from the y-axis of the shoreline normal (□) and the breaking wave direction (bold line), both in 1988. The plus sign indicates the second quadrant (west to south) and the minus the first quadrant (west to north). If the curve for the shoreline direction is found above the one for the wave direction, at present (1988) the wave brings about the longshore sediment transport from right (north) to left (south). If both are close to each other, the shoreline is stable at present. It is observed that Kuta beach is at present fairly stable except near $x=1,100$ and $2,100 < x < 2,500$. Fig. 5-2-3-6 plots the breaking waveheight, about 1m, along the x-axis. The waveheight does not change abruptly except near structures such as groins. Fig. 5-2-3-7 shows the accumulated longshore sediment transport. The plus sign means from left to right. For the recent 10 years the sediment has moved from right to left for $x < 1,000$ and from left to right for $x > 1,000$. Thus the area near $x = 1,000$ on the north of Pertamina Cottage has eroded.

Note that from the shore where the coral reef is narrow ($1,600 < x < 2,500$), some amount of sediment is believed to have been permanetly lost to the greater depths. Without any knowledge of this amount, however, we have no means to allocate the total sediment loss to each of the offshore and longshore modes. We here assume no loss to a greater depth but ascribe all the sediment transport to the longshore mode. In the future with some information on the offshore transport we may improve on the model. Mathematically the boundary conditions for the longshore sediment transport Q are: no transport at the runway ($Q=0$ at $x=0$) and the shoreline evolves at the same rate at the right end ($\partial^2 Q / \partial x^2 = 0$ at $X=2,500$).

(2) Nusa Dua

The nearshore topography at Nusa Dua is shown in Fig. 5-2-3-8. A wide coral reef develops with a submarine canyon in front of the U-shaped submerged groin. Figs. 5-2-3-9 and 10 show the wave rays and waveheight distribution when a wave with a period of 8 seconds and height of 1.4m is incoming from 45° (SE) at the top of the figures. The height 1.4m is the average over the outcome of the swell propagation. Waves which have entered the canyon diverge onto both sides due to refraction. This wave with a slight modification turns out to best reproduce the observed shoreline evolution.

The duration is from January, 1983 to May, 1988. Fig. 5-2-3-11 plots the initial and present shorelines, observed and calculated. The calculation is well close to the observation except for $x < 500$ where the shoreline normal is far from parallel to the y-axis. The beach has in general advanced thanks to the sand fills of 102,000 m^3 from February, 1986 to January, 1988. Fig. 5-2-3-12 plots the directions of shoreline normal and breaking waves in 1988, and the beach is stable except $x < 500$. Fig. 5-2-3-13 plots the breaking waveheight, which is about half the waveheight at Kuta, since the reef depth is about half. Fig. 5-2-3-14 plots the accumulated longshore sediment transport. The annual transport rate is one order smaller than that at Kuta. Again any cross-shore transport is not accounted for. Mathematical boundary conditions for Q are: the shoreline is stable at the left end ($\partial Q/\partial x=0$ at $x=0$) and no transport at the right end (island) ($Q=0$ at $x=2,000$).

(3) Sanur

Fig. 5-2-3-15 illustrates the nearshore topography on Sanur beach with two main submarine canyons at x=2,000 and 6,500. In Figs. 5-2-3-16 and 17 shown are the wave rays and waveheight when the a with the period of 10 seconds and height of 1.2 m is incoming from 45 ° (SE) at the top. The waveheight of 1.2 m is again the average. This wave proves to best reproduce the observed shoreline evolution.

The duration is from March, 1978 to May, 1988. Since the shoreline in the study area is long and curved, it is divided into two regions A and B, in which independent coordinates are defined (Fig. 5-2-3-18). Figs. 5-2-3-19(a),(b) show the initial and present shorelines for A and B, respectively. The calculation is well close to the observation. Figs. 5-2-3-20(a),(b) plot the directions of shoreline normal and breaking wave in 1988. The beach is at present fairly stable. Figs. 5-2-3-21(a),(b) show the breaking waveheight, nearly equal to the one at Nusa Dua and much smaller than at Kuta. The accumulated longshore sediment transport is shown in Figs. 5-2-3-22(a),(b), and is smaller than at Kuta by one order. The boundary conditions are: the shoreline evolves at the same rate at the northern end ($\partial^2 Q / \partial x^2 = 0$ at x=0, in A) and no sediment transport at the southern end ($\partial Q / \partial x = 0$ at x=1,700 in B).

In region B, the sediment has moved from right to left for x < 12,000 which reflects the shoreline currently observed: on the right of the groin at x=400 the sediment has been accumulated. It should be pointed out that this feature may be just seasonal because the sediment movement appeared to be in the opposite direction in February, 1988, when the field survey was executed.

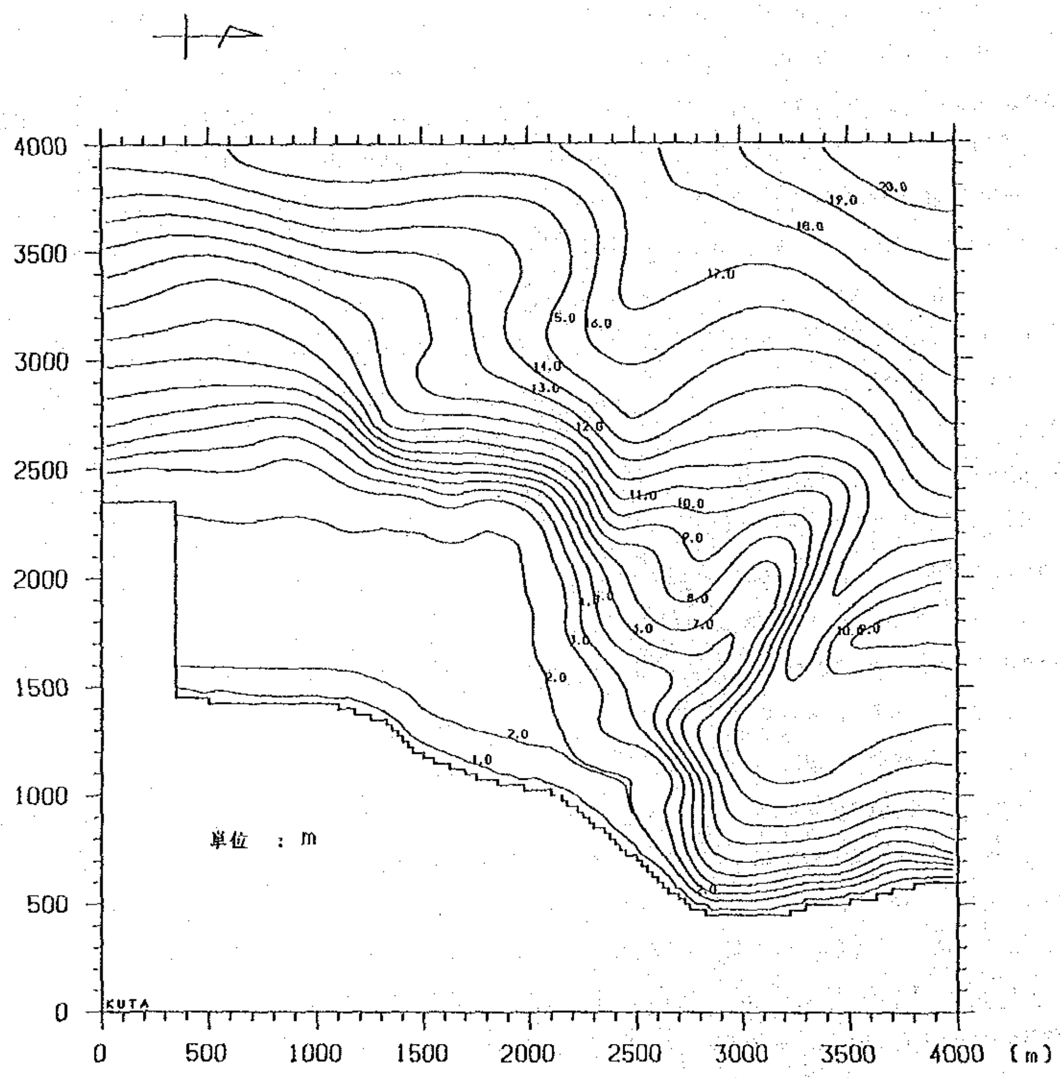


Fig. 5-2-3-1 Nearshore Topography (Kuta)

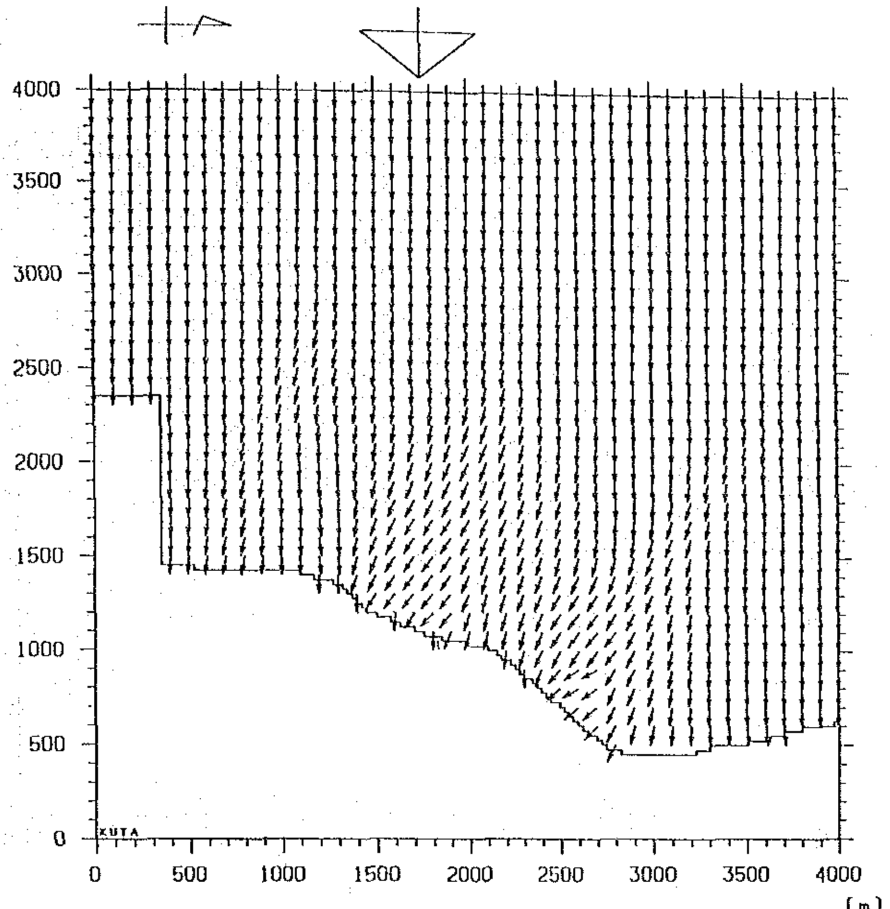


Fig. 5-2-3-2 Wave Rays (Kuta)

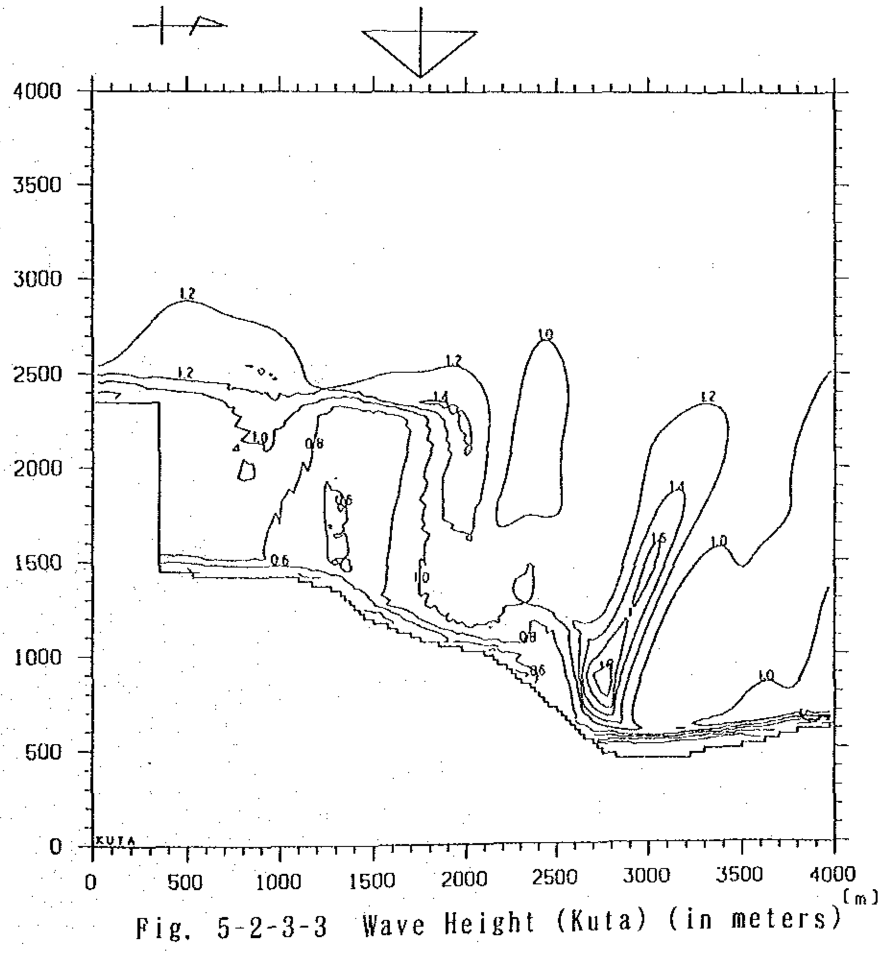


Fig. 5-2-3-3 Wave Height (Kuta) (in meters)

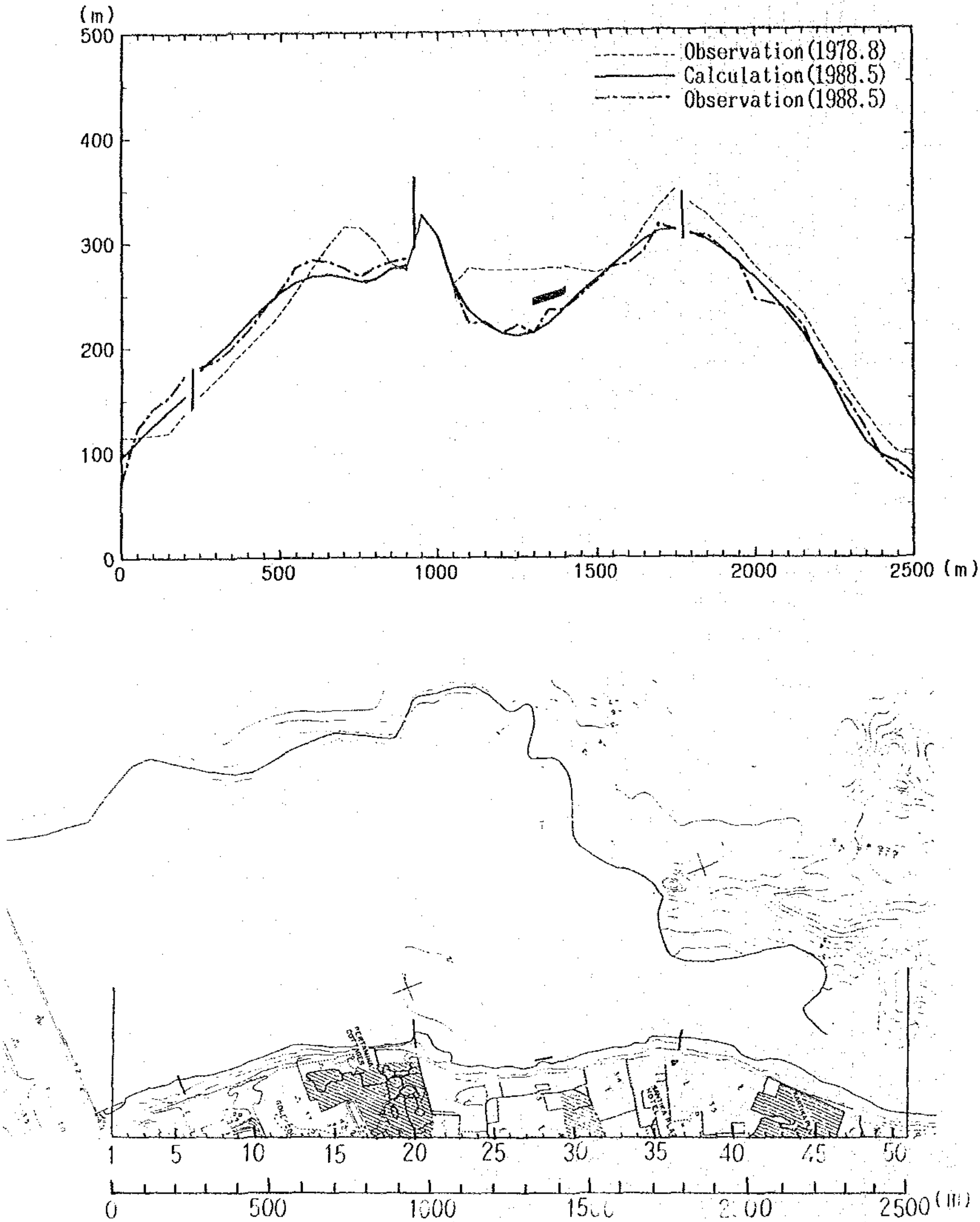


Fig. 5-2-3-4 Shoreline Evolution (Kuta)

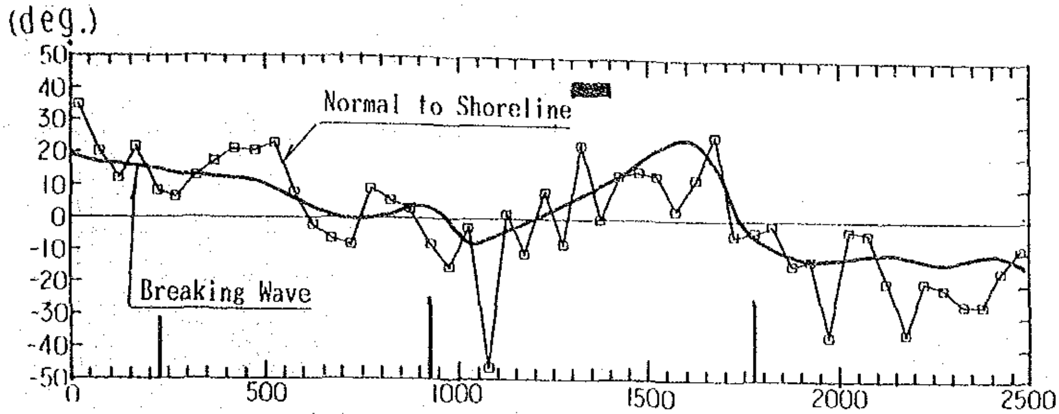


Fig. 5-2-3-5 Direction of Shoreline and Breaking Wave (Kuta)

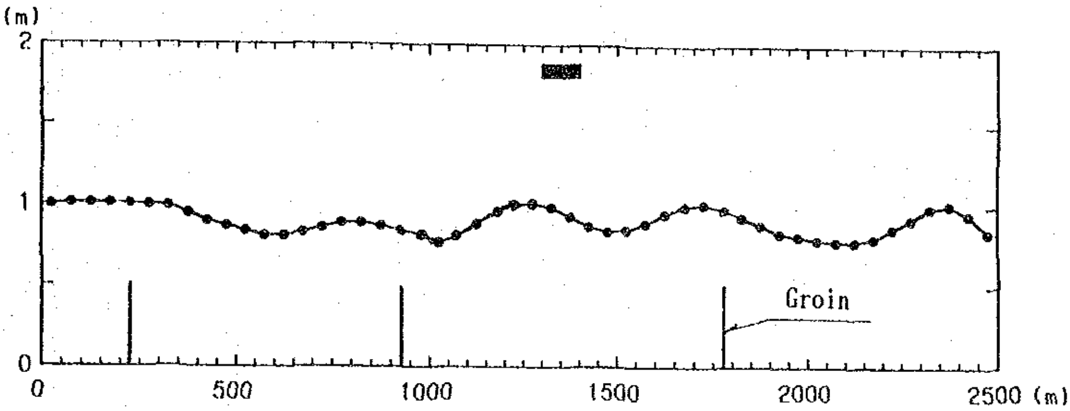


Fig. 5-2-3-6 Breaking Wave Height(Kuta)

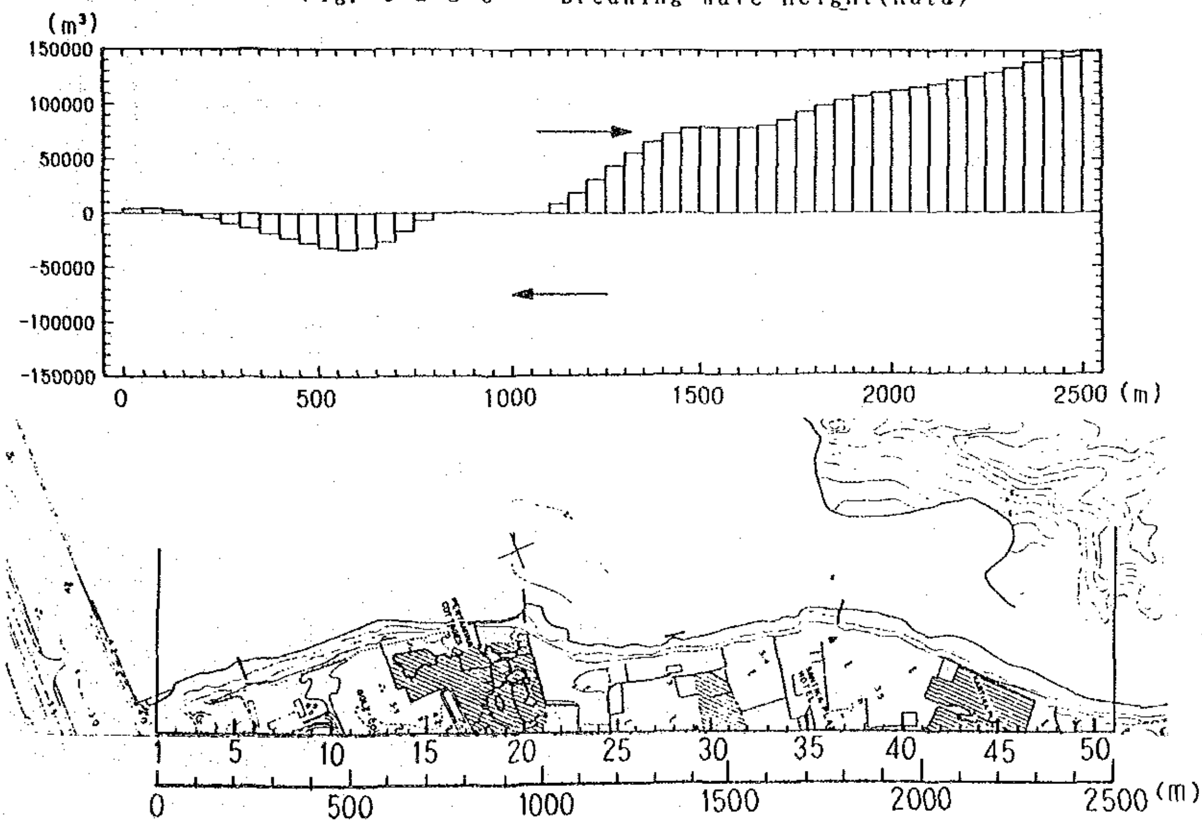


Fig. 5-2-3-7 Accumulated Longshore Sediment Transport(Kuta)

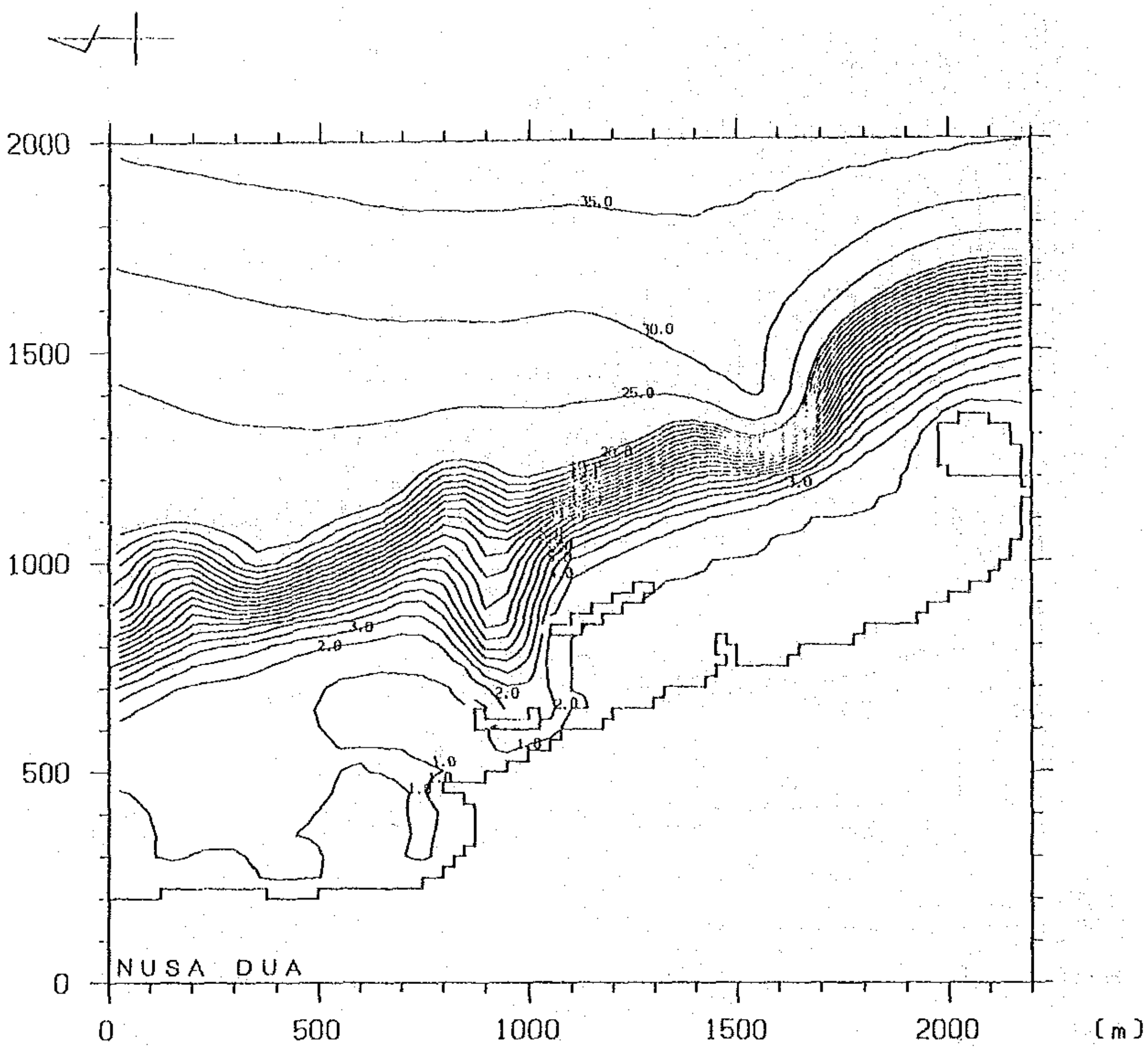


Fig. 5-2-3-8 Nearshore Topography (Nusa Dua)

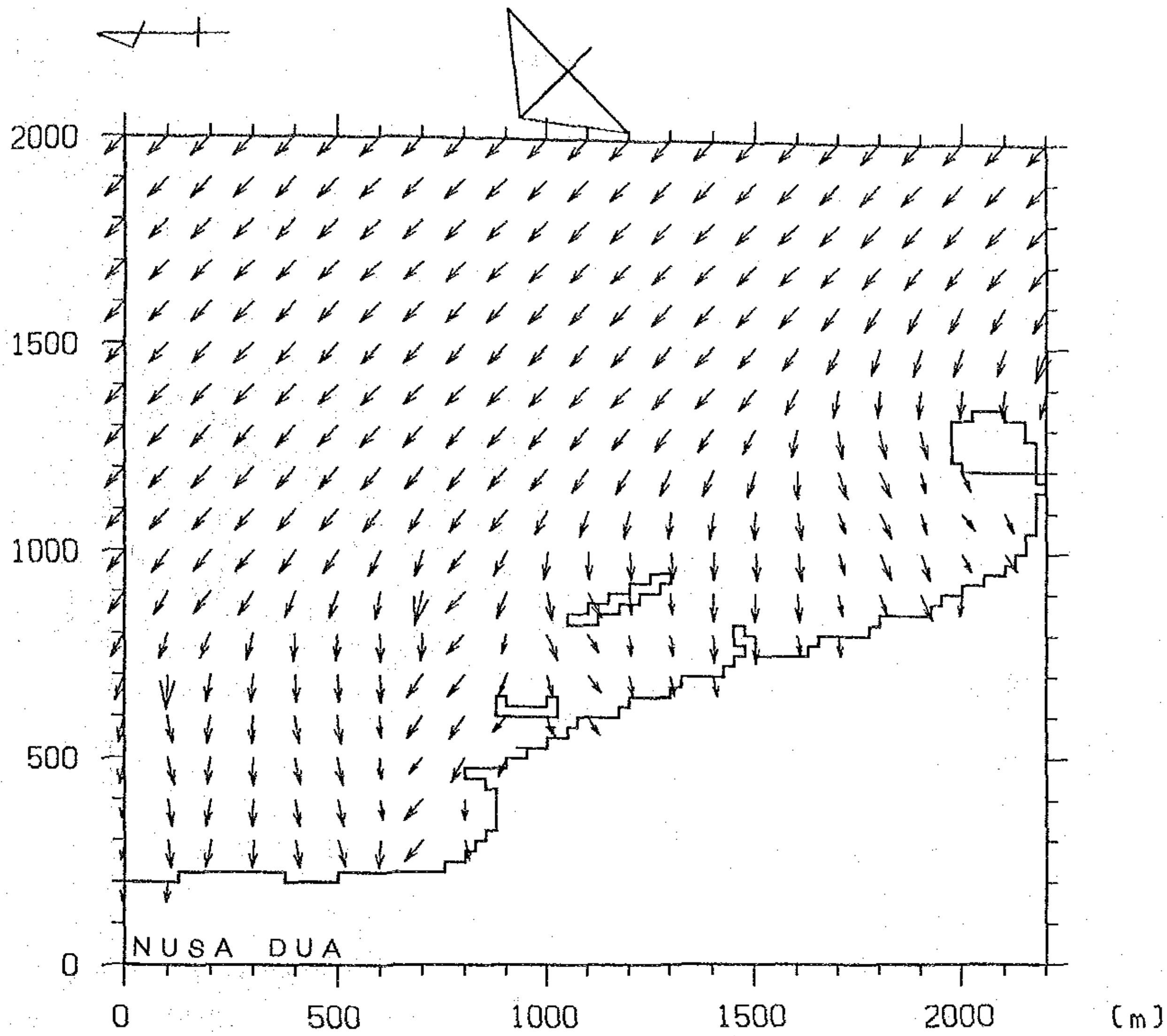


Fig. 5-2-3-9 Wave Rays (Nusa Dua)

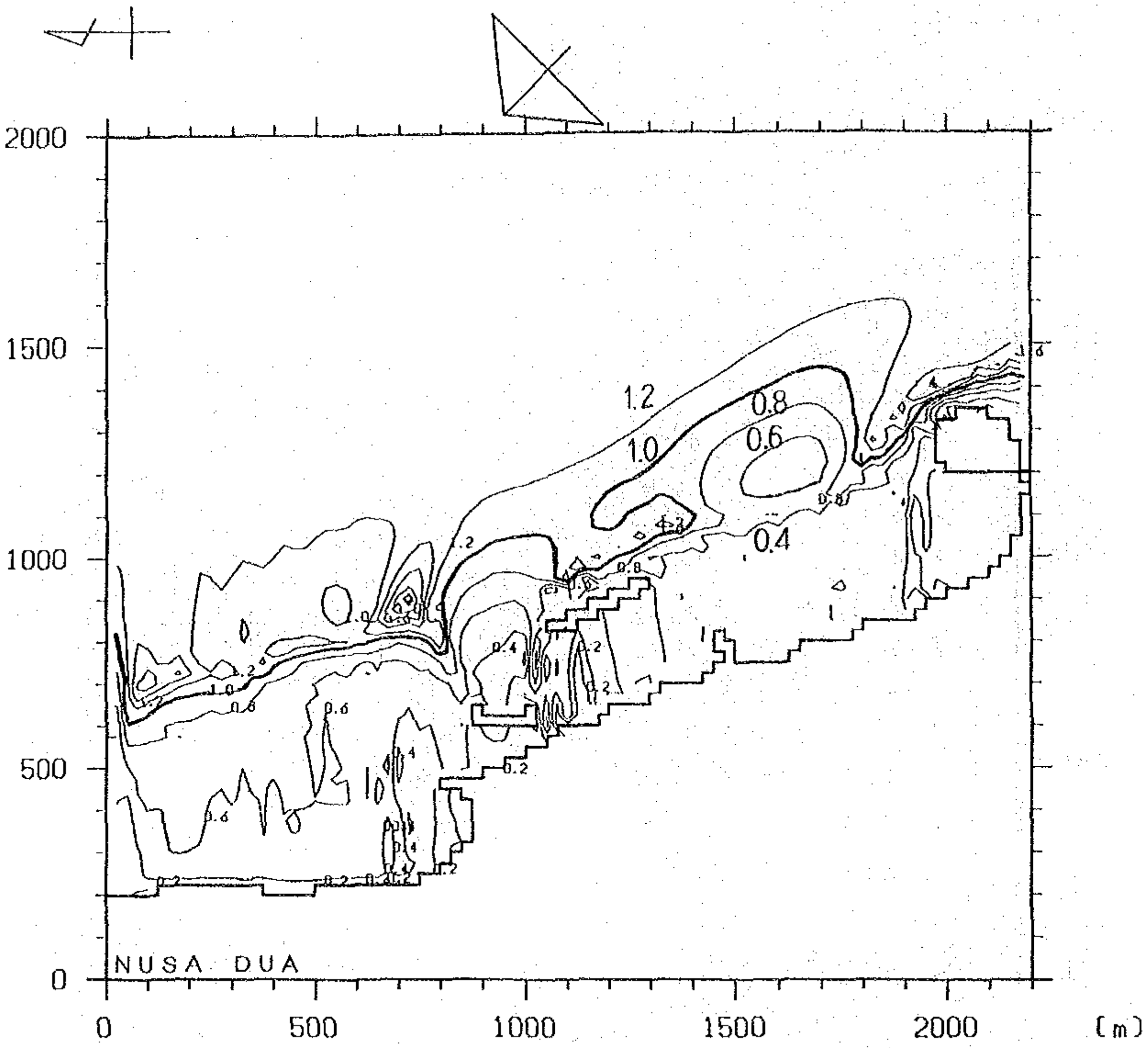


Fig. 5-2-3-10 Wave Height (Nusa Dua) (in meters)

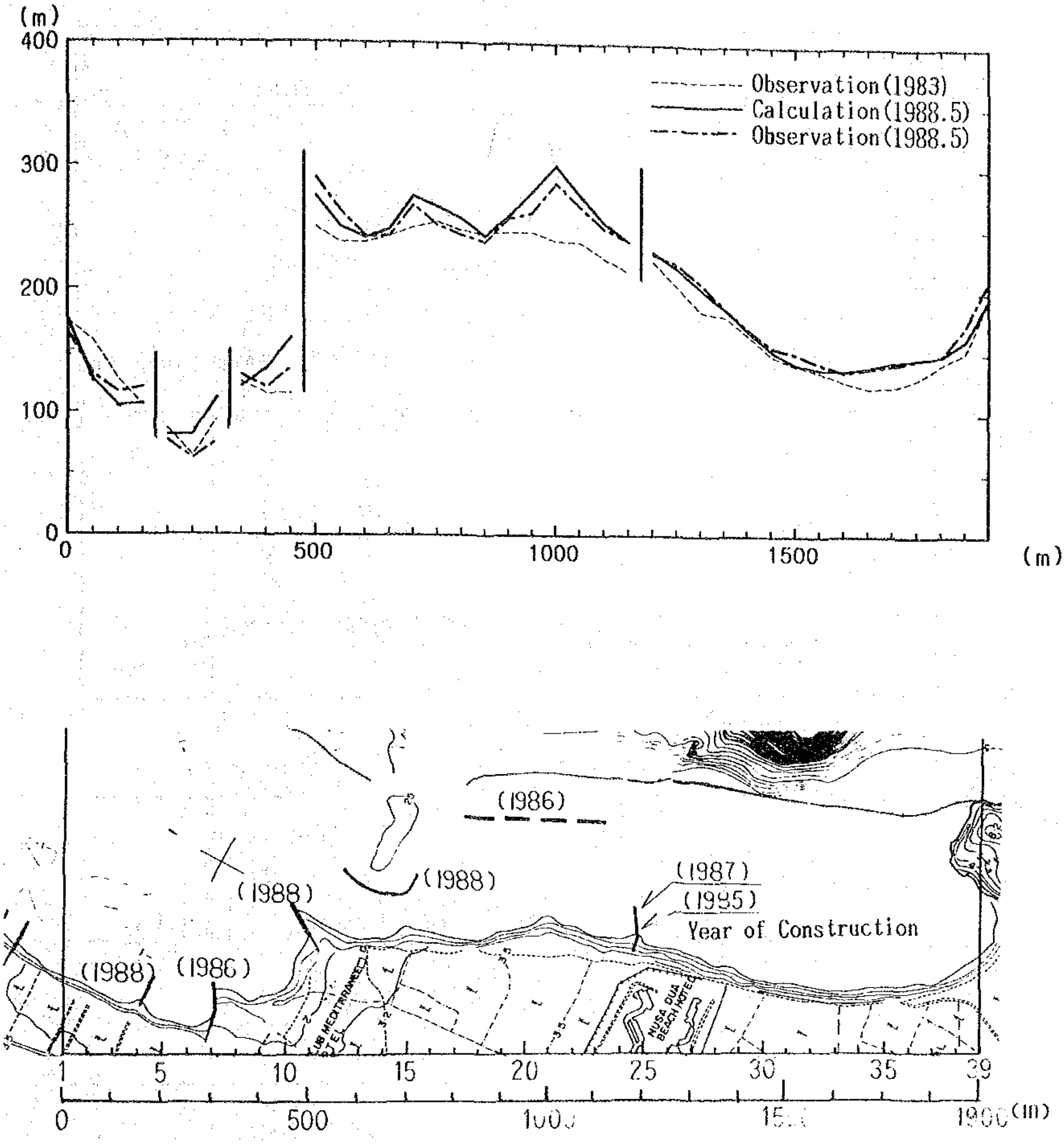


Fig. 5-2-3-11 Shoreline Evolution (Nusa Dua)

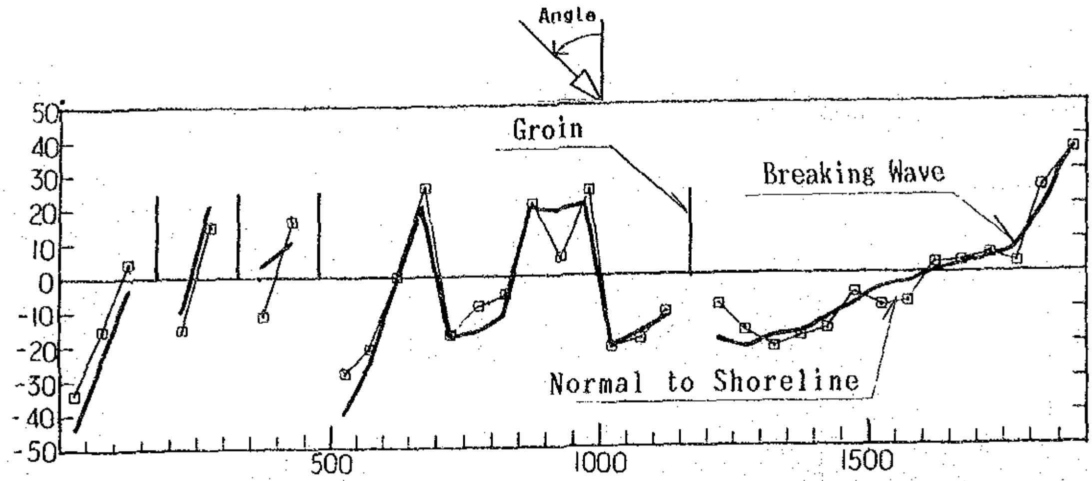


Fig. 5-2-3-12 Direction of Shoreline and Breaking Wave (Nusa Dua)

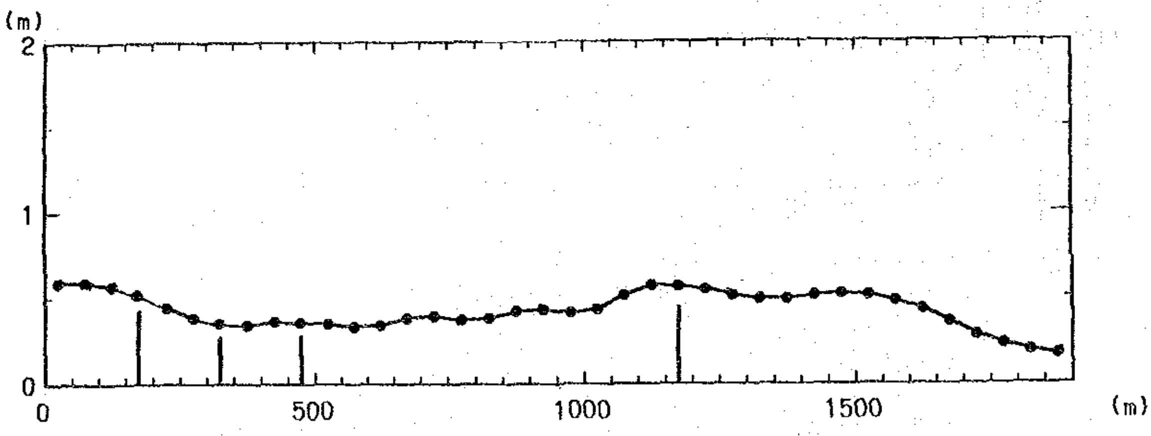


Fig. 5-2-3-13 Breaking Wave Height (Nusa Dua)

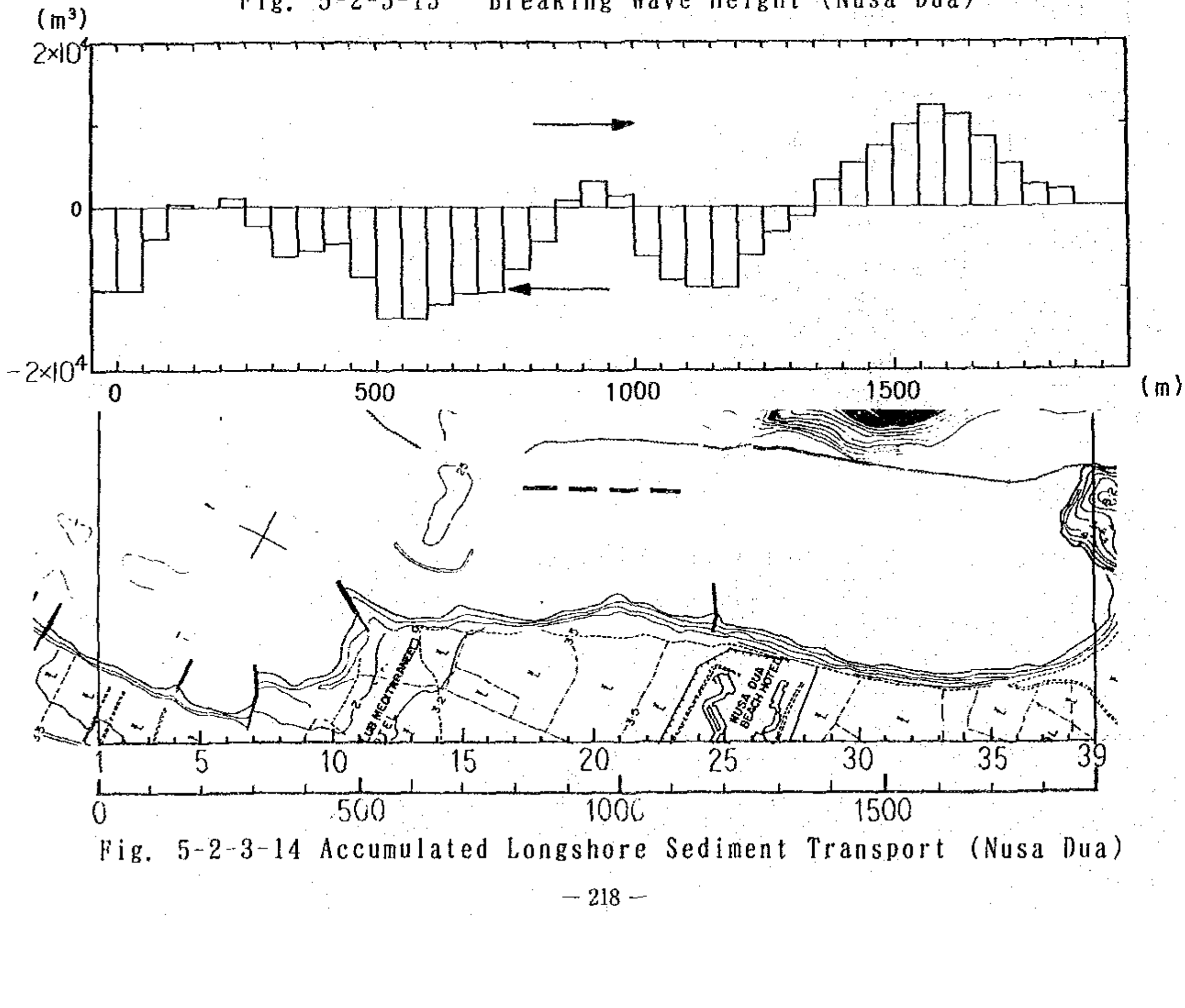


Fig. 5-2-3-14 Accumulated Longshore Sediment Transport (Nusa Dua)

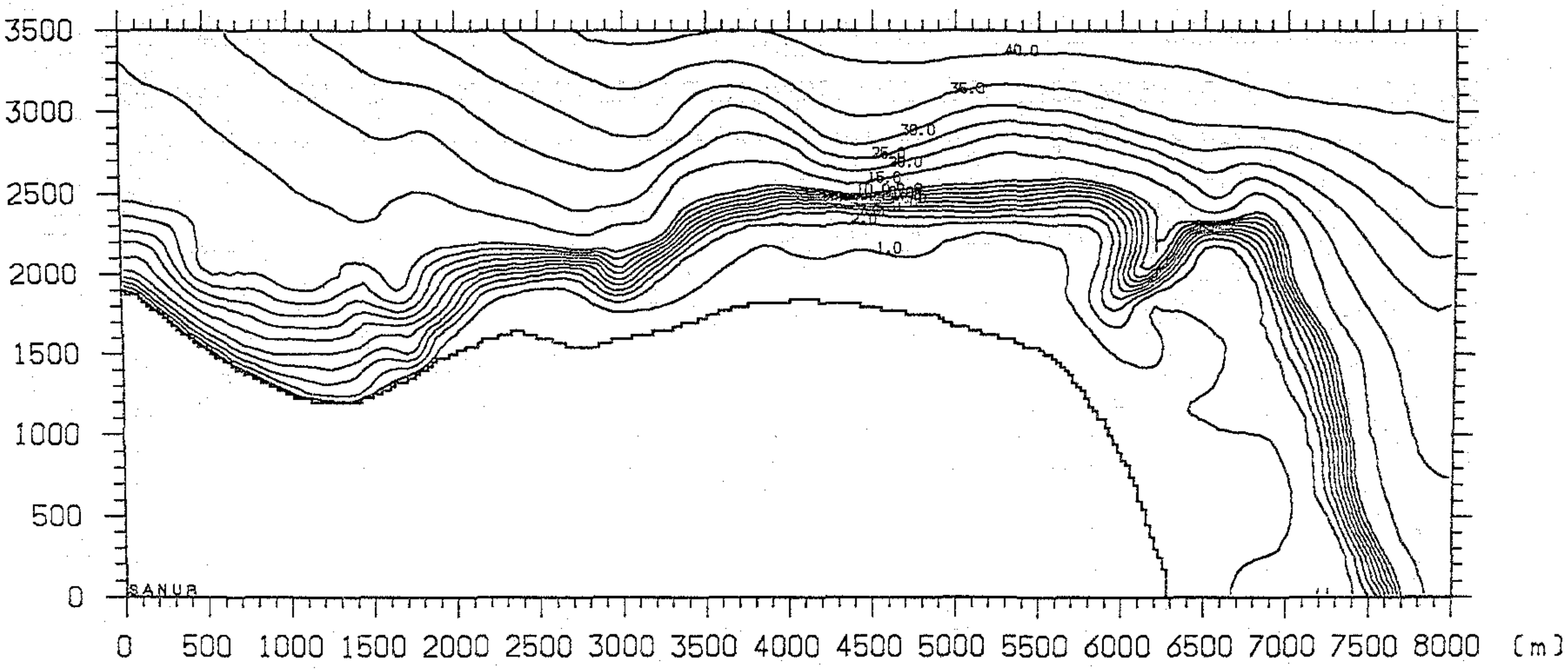


Fig. 5-2-3-15 Nearshore Topography (Sanur)

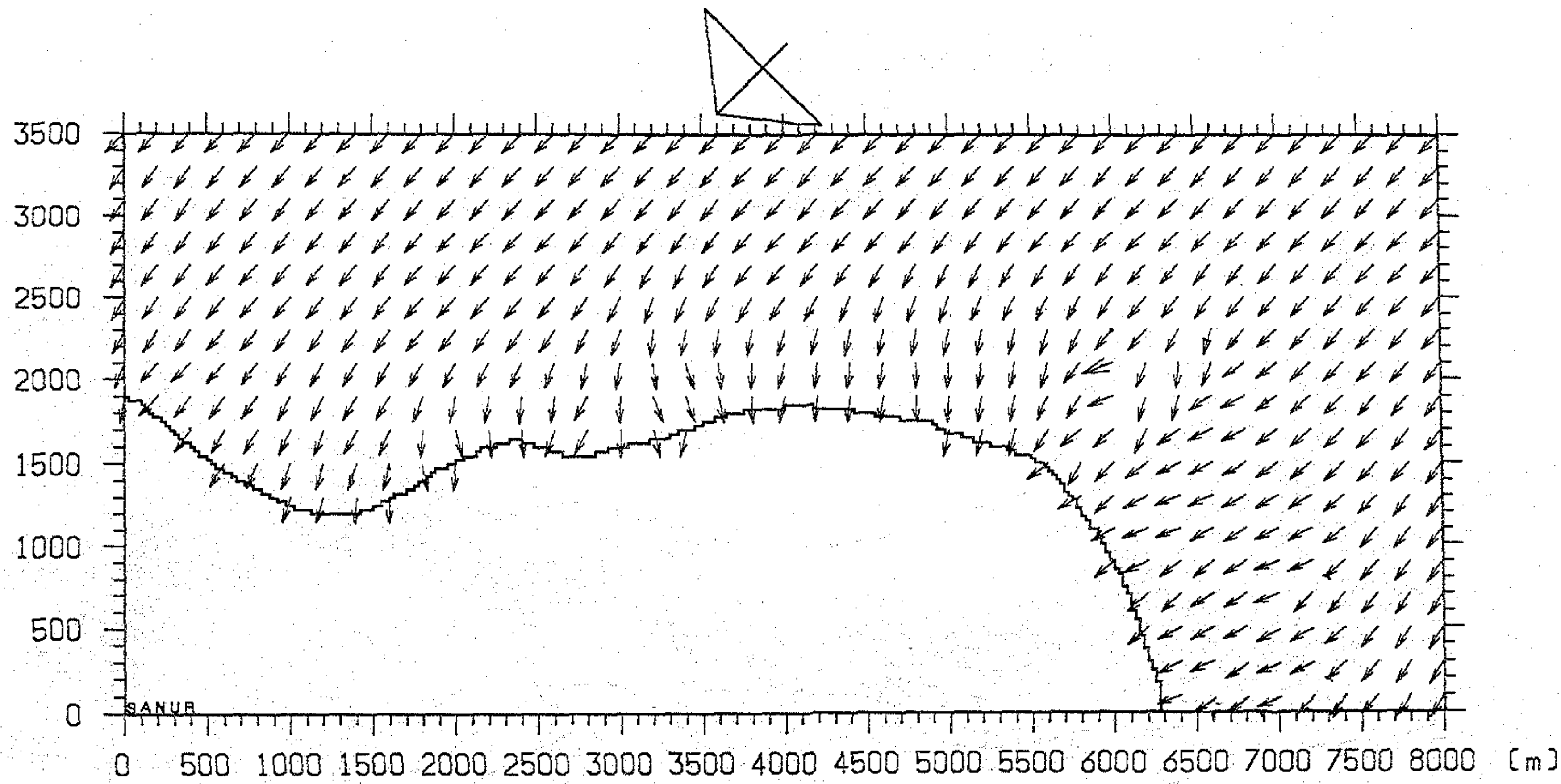


Fig. 5-2-3-16 Wave Rays (Sanur)

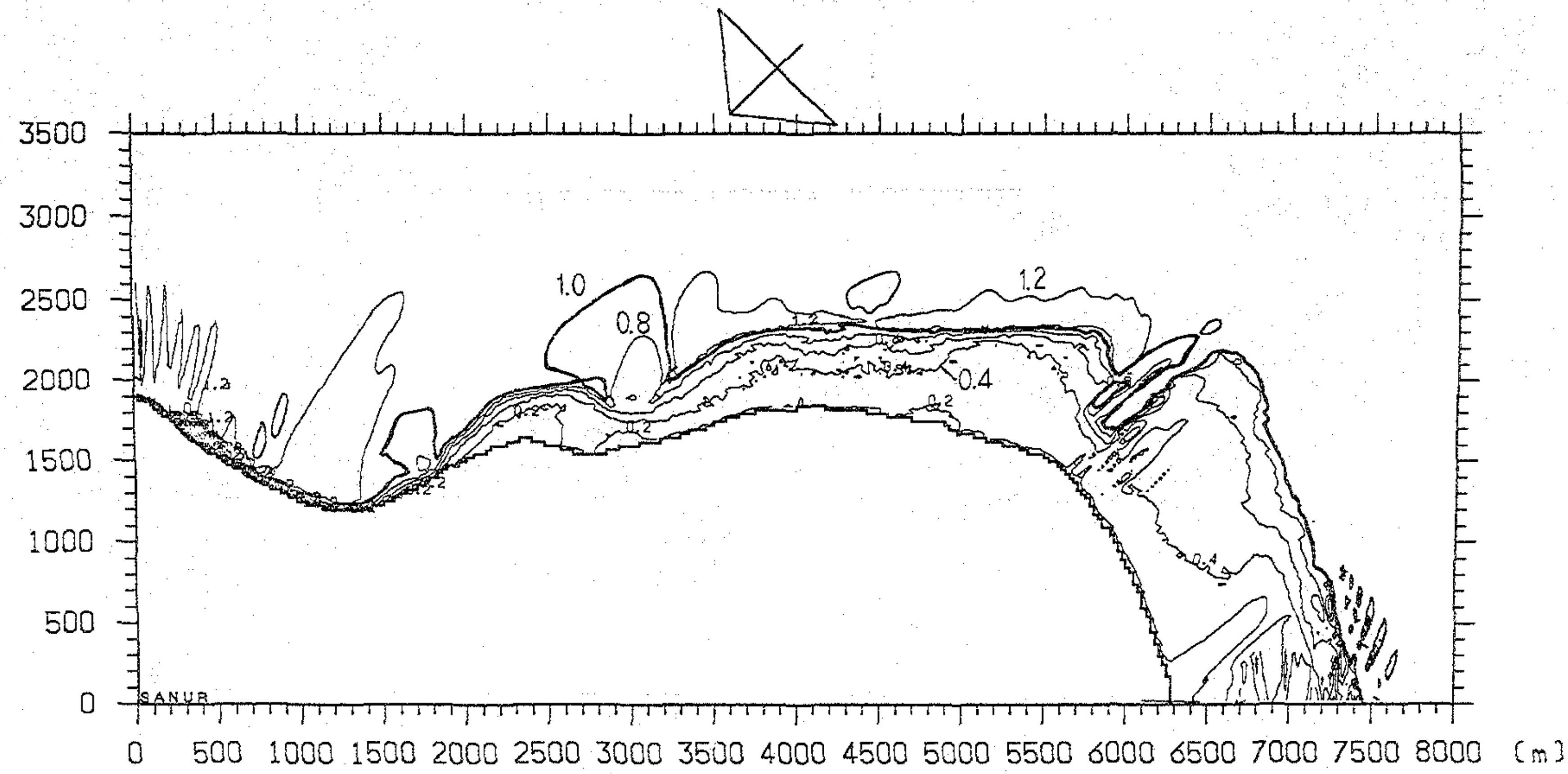


Fig. 5-2-3-17 Wave Height (Sanur) (in meters)

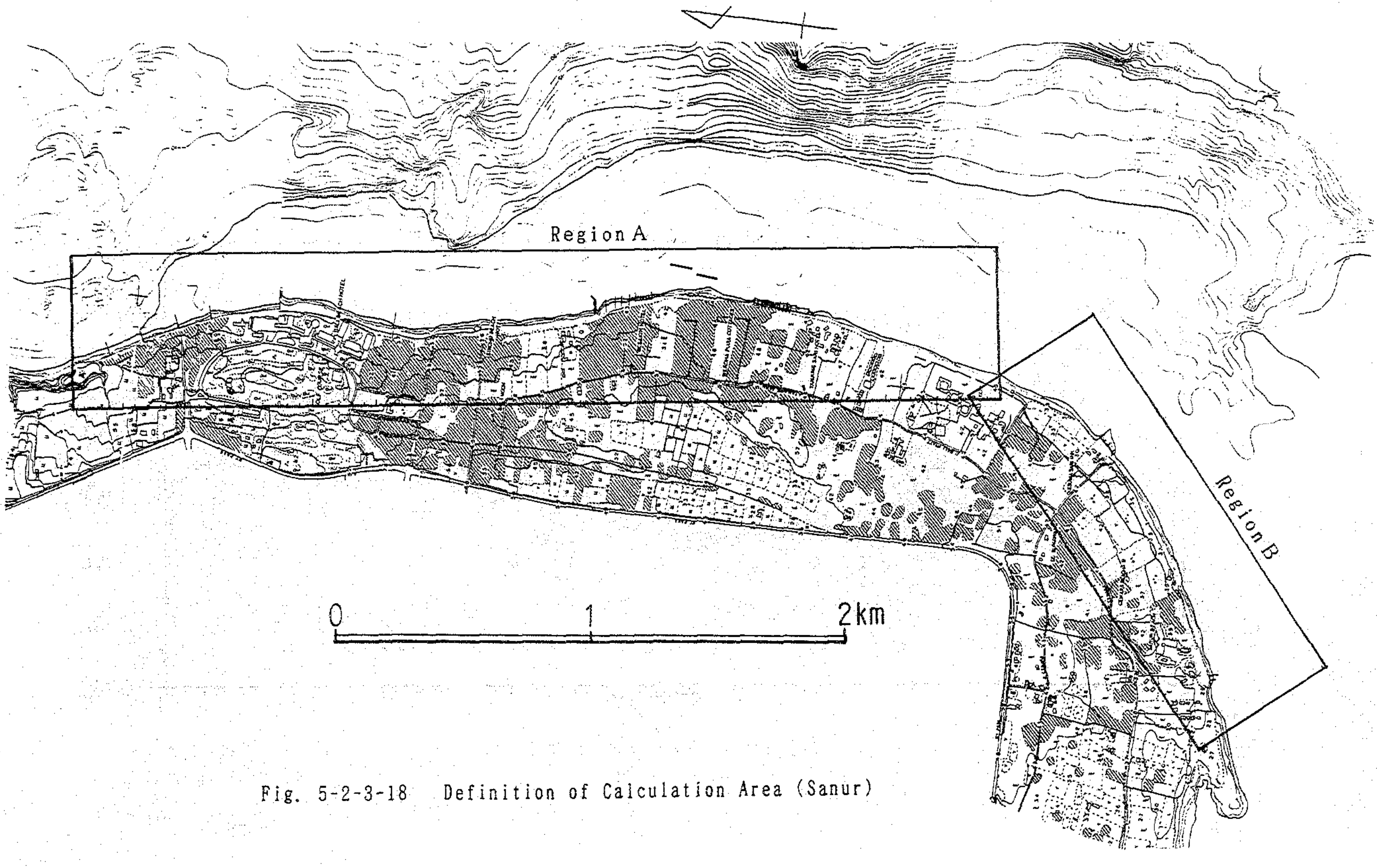
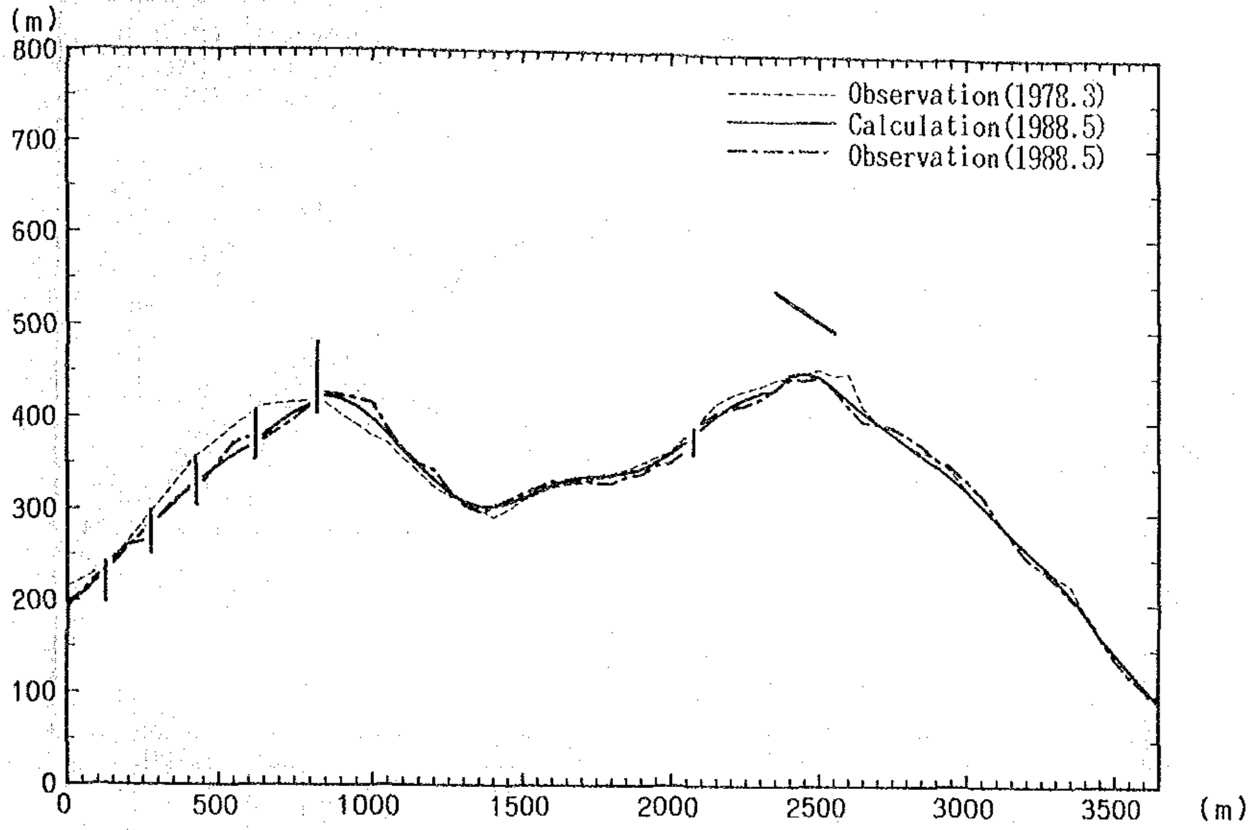


Fig. 5-2-3-18 Definition of Calculation Area (Sanur)



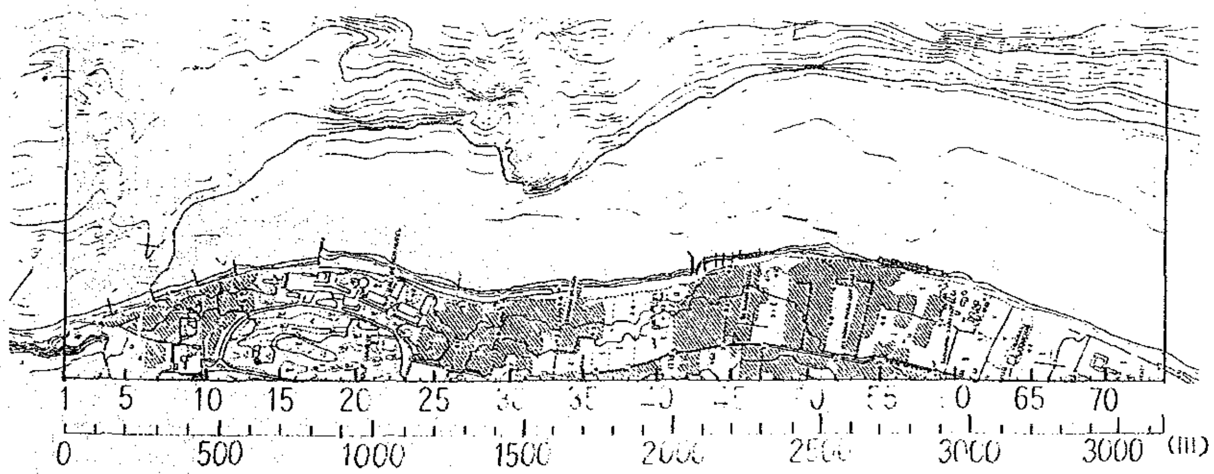


Fig. 5-2-3-19(a) Shoreline Evolution (Sanur, A)

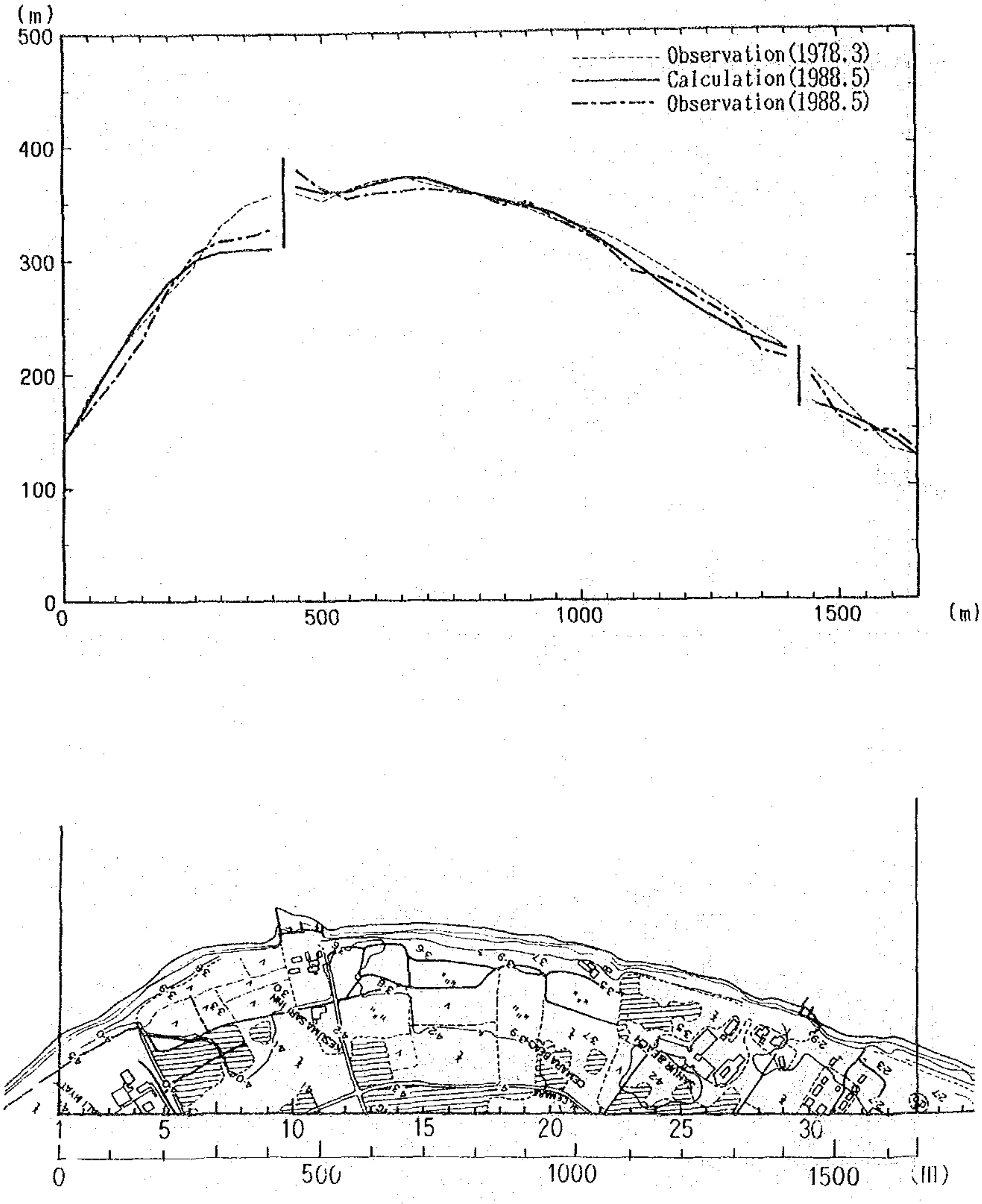


Fig. 5-2-3-19(b) Shoreline Evolution (Sanur, B)

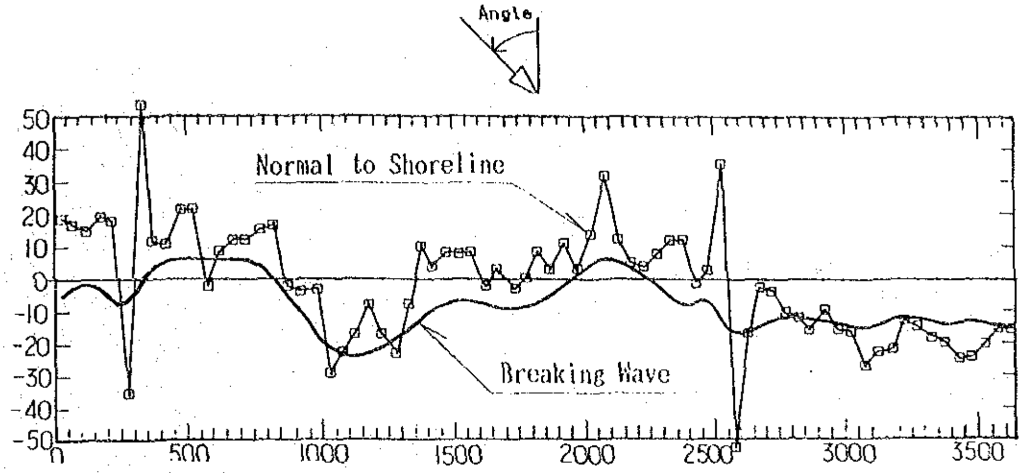


Fig. 5-2-3-20(a) Direction of Shoreline and Breaking Wave (Sanur, A)

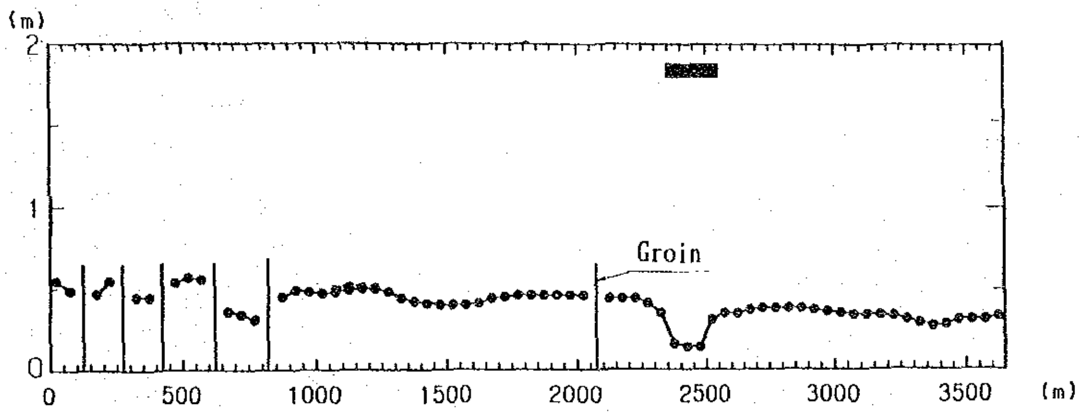


Fig. 5-2-3-21(a)Breaking Wave Height (Sanur, A)

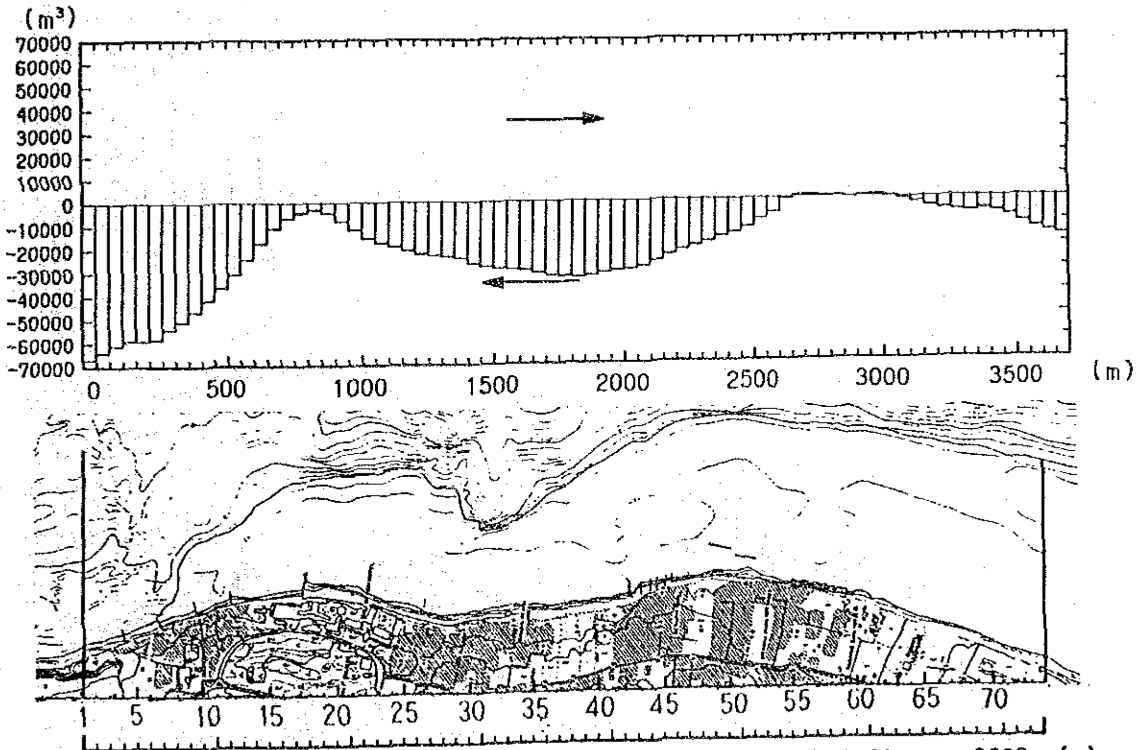


Fig. 5-2-3-22(a)Accumulated Longshore Sediment Transport(Sanur, A)

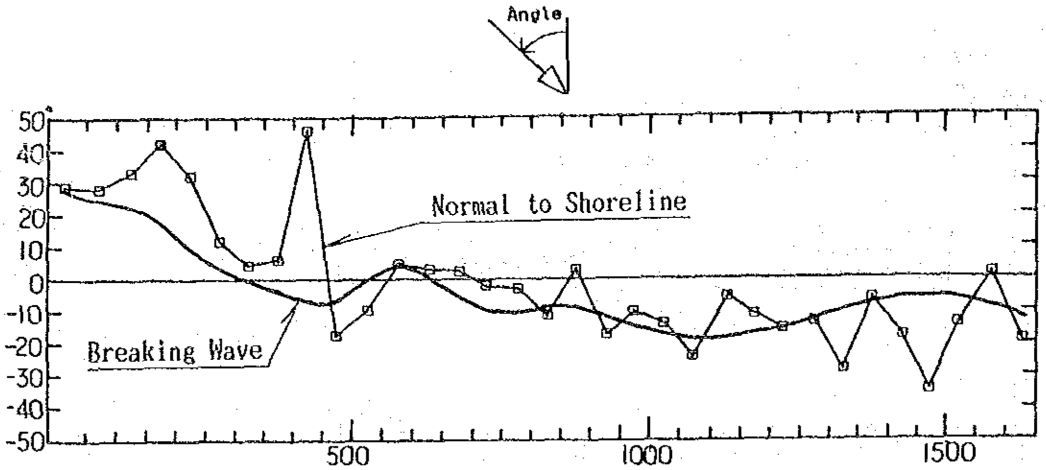


Fig. 5-2-3-20(b) Direction of Shoreline and Breaking Wave (Sanur, B)

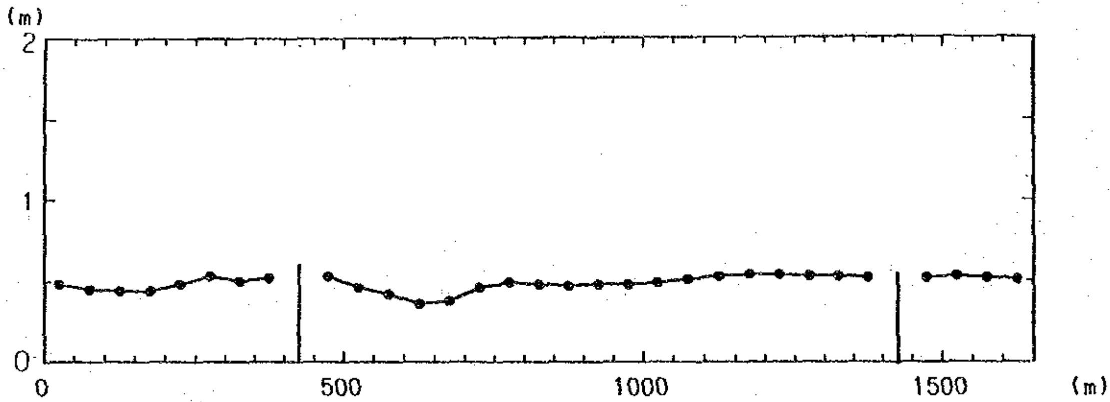


Fig. 5-2-3-21(b)Breaking Wave Height (Sanur, B)

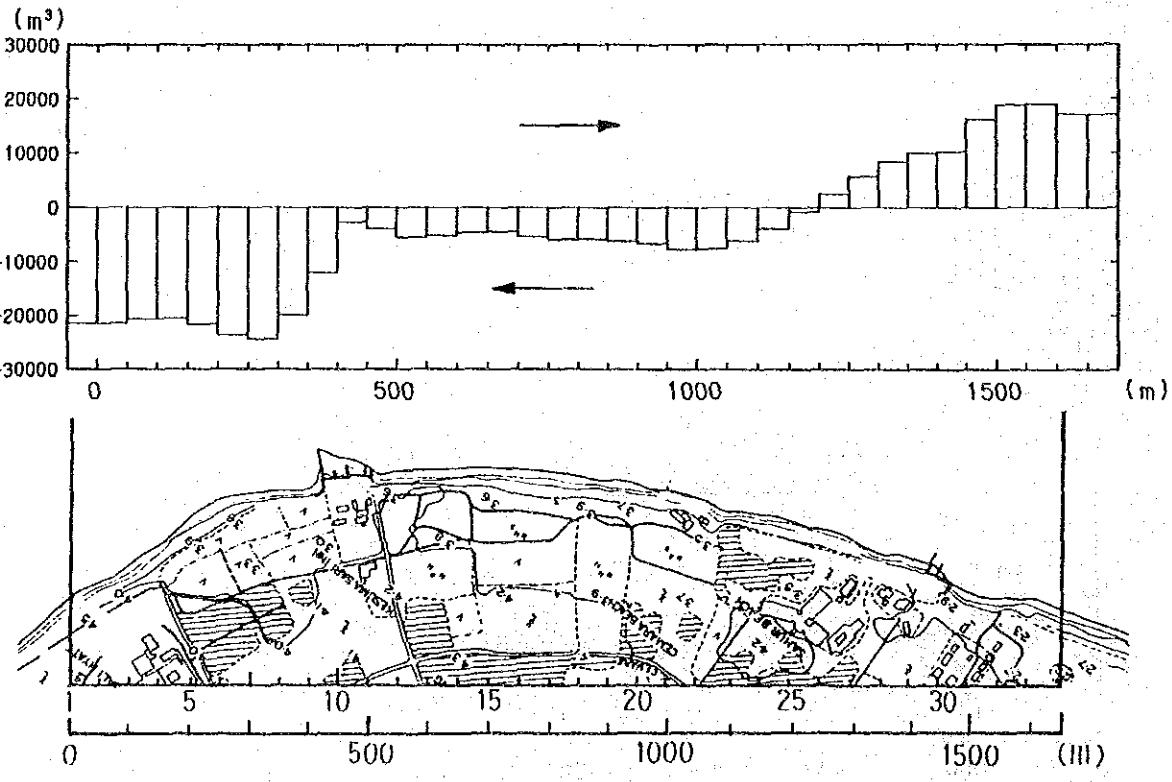


Fig. 5-2-3-22(b) Accmulated Longshore Sediment Transport (Sanur, B)

5-2-4 Hydraulic Evaluation of Proposed Plans

We have seen that the computer simulation here with the one-line model deals with the long-term shoreline evolution due to the longshore sediment transport. It had been conjectured that on each of the beaches some amount of sand has been lost to a greater depth. This mechanism of cross-shore transport was in this study partly confirmed by the field surveys and hydraulic model experiments. However, the outcome is still insufficient to quantitatively simulate the process. The hydraulic evaluation on the proposed plans by the computer simulation here will therefore be concerned with just the mode of longshore transport.

The model wave found for each beach will now be used to forecast the shoreline evolution over 10 years with the structures proposed in our plans. On the basis of the calculations the proposed plans will be evaluated from the hydraulic point of view.

(1) Kuta

In Fig. 5-2-4-1 shown are the countermeasure structures proposed for Kuta beach: three T-shaped and two straight groins (see section 6.2) to protect beach fills. The area where the structures would be distributed extends over the region ($x > 2,500$) in which no shoreline data was available for 1978. It is said that the shoreline has not undergone significant erosion or accretion. We then assume that the shoreline has been stable for the last 10 years and that the amount of longshore transport (from left to right) has been the same along this region.

Fig. 5-2-4-2 plots the shoreline evolution with and without the planned measures. The bold and dotted curves represent the final shorelines after 10 years with and without the measures. Fig. 5-2-4-3 plots the accumulated longshore transport. This calculation tells that:

1) The erosion would progress without new countermeasure structures.
2) In order to trap the sediment that would leak alongshore, sufficiently long would be the groins except the rightmost one.

3) Sand trapped between a pair of groins tends to be distributed in the region so that the resultant shoreline parallels the incoming crests. Fig. 5-2-3-5 indicates that the present shoreline is not parallel to the crests for $x > 1,500$) so that the longshore transport is from left to right.

As was discussed in section 5-2-3 (1), the longshore transport has possibly been overestimated neglecting the cross-shore sediment loss. We therefore point out that the rightmost groin may be too short to cut the longshore transport. To be more definite we must await a further analysis or experiment. Except for this point the groin system would work in view of preventing the longshore loss, provided that the new shoreline with the sand fills be formed following the bold curve in Fig. 5-2-4-2, oriented in parallel to the incoming crests. The cross-shore transport should be studied in the future.

It was pointed out by Professor Y. Tsuchiya and confirmed by the model experiment that the intermediate T-shaped groin is located too close to the submarine canyon so that it might enhance the unfavorable offshore current. Thus Plan 2 is to move the T-shaped groin 180 m left (Fig. 5-2-4-4). The corresponding longshore transport is shown in Fig. 5-2-4-5. The stable shoreline between the leftmost and intermediate T-groins is more advanced than that with Plan 1; Plan 2 is better also in view of the longshore transport.

(2) Nusa Dua

Fig. 5-2-4-6 illustrates the plan proposed for Nusa Dua (see section 6-3). Fig. 5-2-4-7 plots the shoreline evolution, and Fig. 5-2-4-8 the corresponding longshore transport. The following can be seen from the forecast run with new structures. It is seen that stable would be the region ($1,200 < x < 1,900$) between the island and the rightmost groin. Between the groin and the U-shaped groin the wave energy would be uniform with no detached breakwaters and a stable shoreline could be formed if oriented properly as shown in Fig. 5-2-4-7. Also in the region ($300 < x < 600$) between the U-shaped groin and the extended straight groin at $X = 300$, a significant amount of sand transport would take place.

(3) Sanur

Figs. 5-2-4-9 (a),(b) illustrate the plan proposed for Sanur beach (see section 6-4). Figs. 5-2-4-10(a),(b) plot the shoreline evolution. The following can be seen from the forecast run with the new structures. The shoreline would be fairly stable if oriented properly in each region between a pair of groins. The longshore sediment transport shown in Figs. 5-2-4-11(a),(b) would be again small, but would not vanish completely.

(4) Comments on Crossshore Sediment Loss

The hydraulic evaluation by the computer simulation here is concerned with just the longshore sediment transport. Without data available on the crossshore sediment transport, the sediment loss to a greater depth was assumed to vanish on every beach.

The computer simulation has thus shown that the proposed structures could trap sediment that would leak alongshore, but has predicted nothing about the loss to a greater depth. It is strongly recommended that a supplementary survey and analysis be conducted in the future on the crossshore sediment transport especially where the seabottom slope is great.

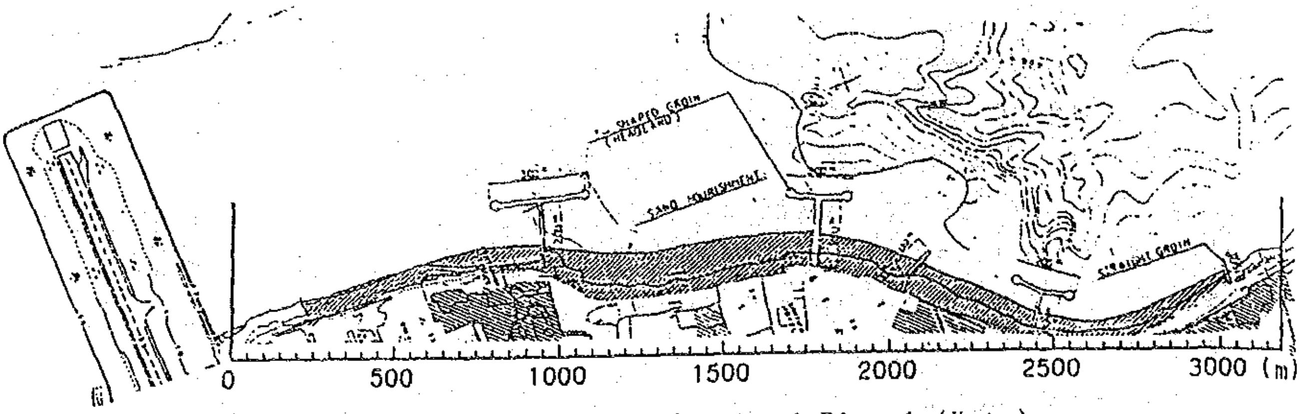


Fig. 5-2-4-1 Proposed Plan 1 (Kuta)

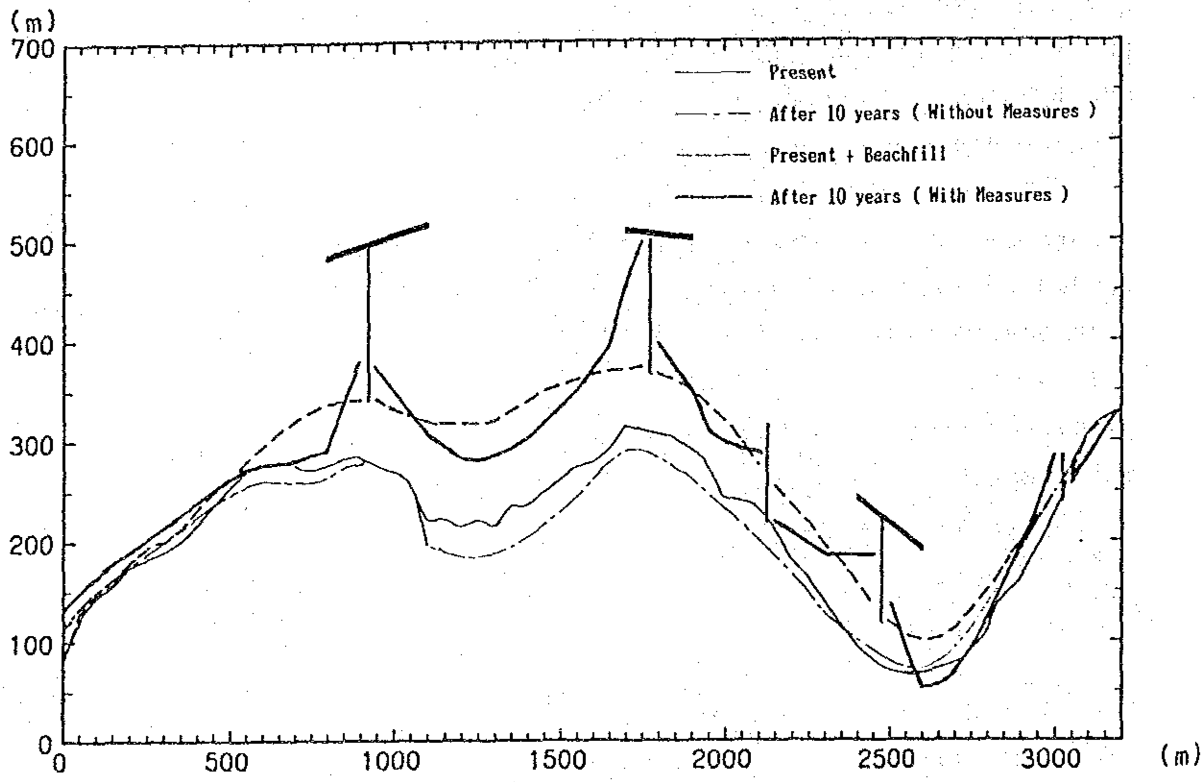


Fig. 5-2-4-2 Shoreline Evolution with Plan 1 (Kuta)

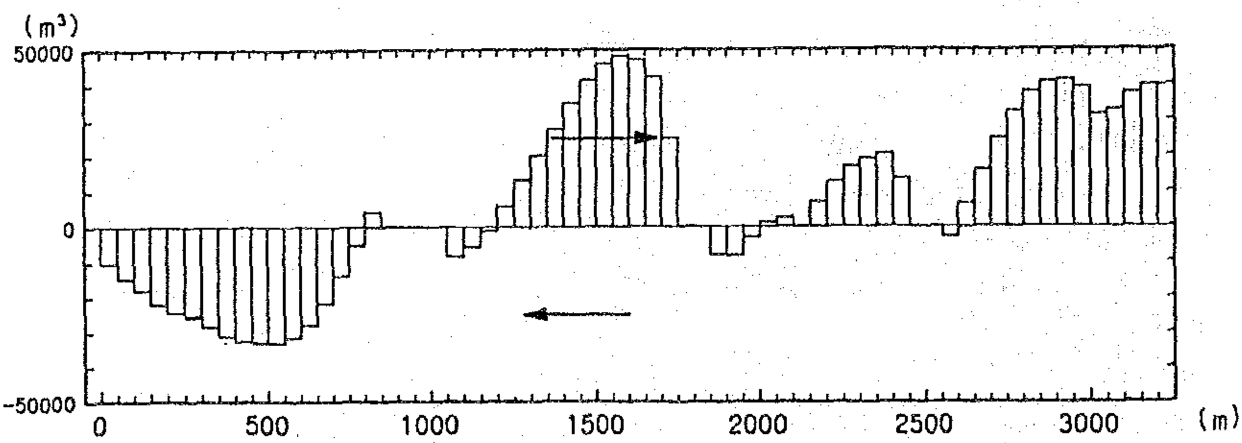


Fig. 5-2-4-3 Accmulated Longshore Transport(Kuta)

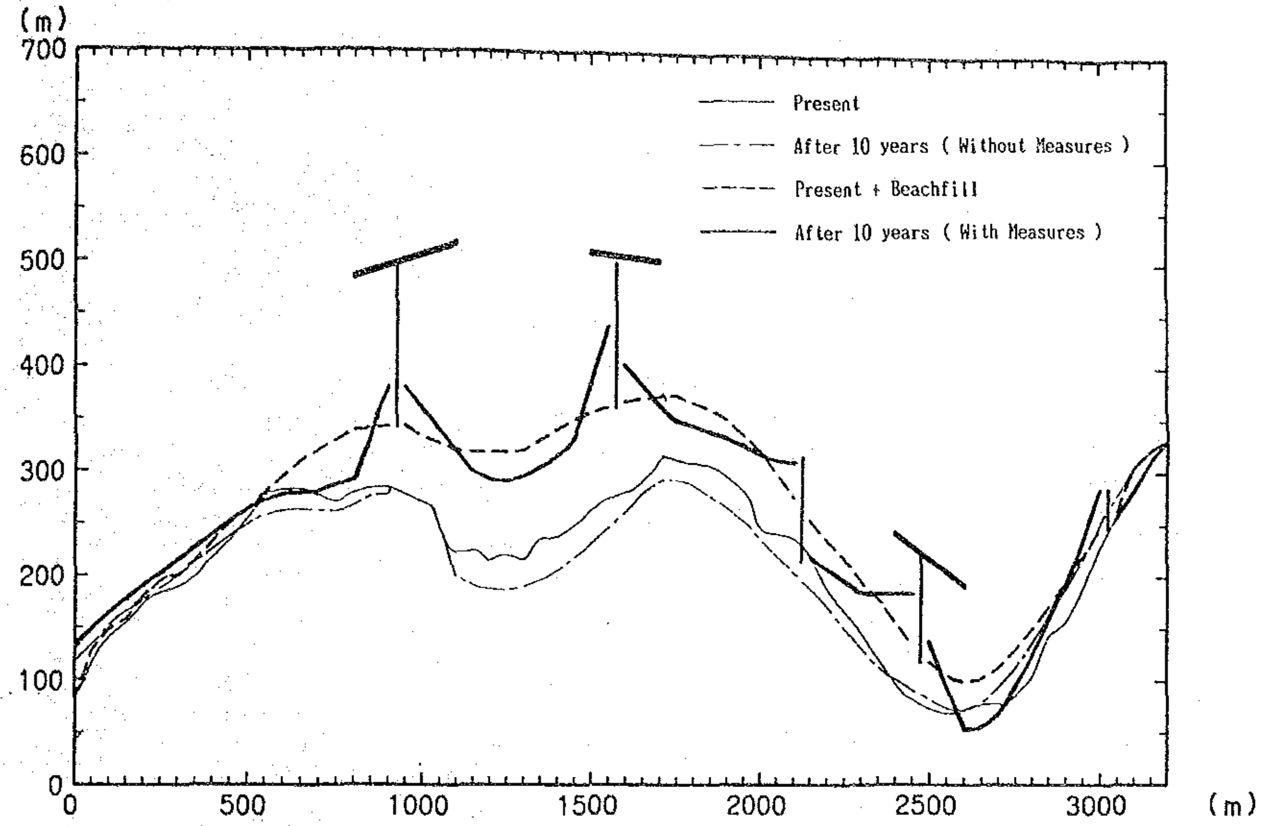


Fig. 5-2-4-4 Shoreline Evolution with Plan 2 (Kuta)

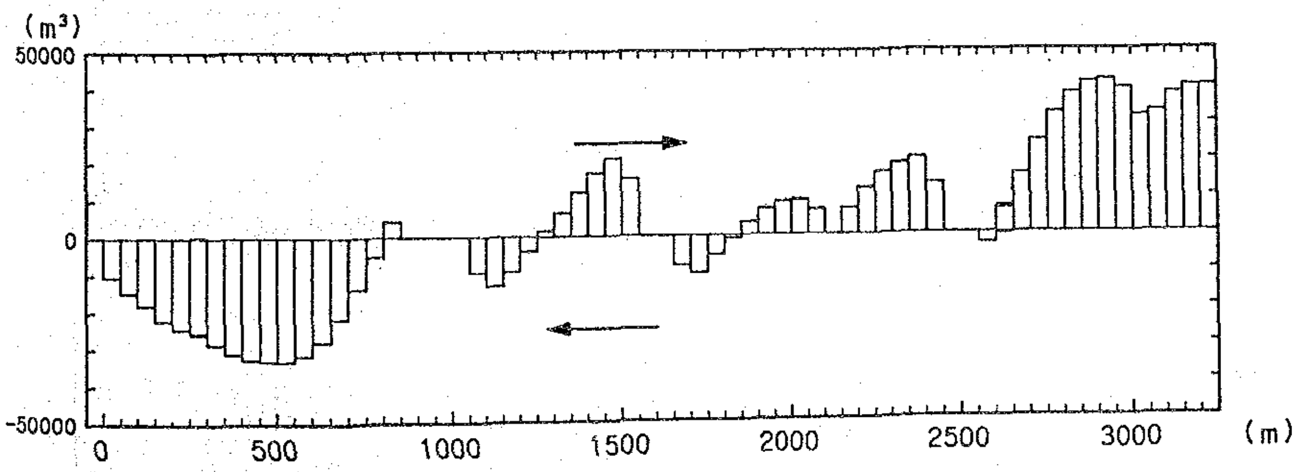


Fig. 5-2-4-5 Accumulated Longshore Sediment Transport (Kuta)

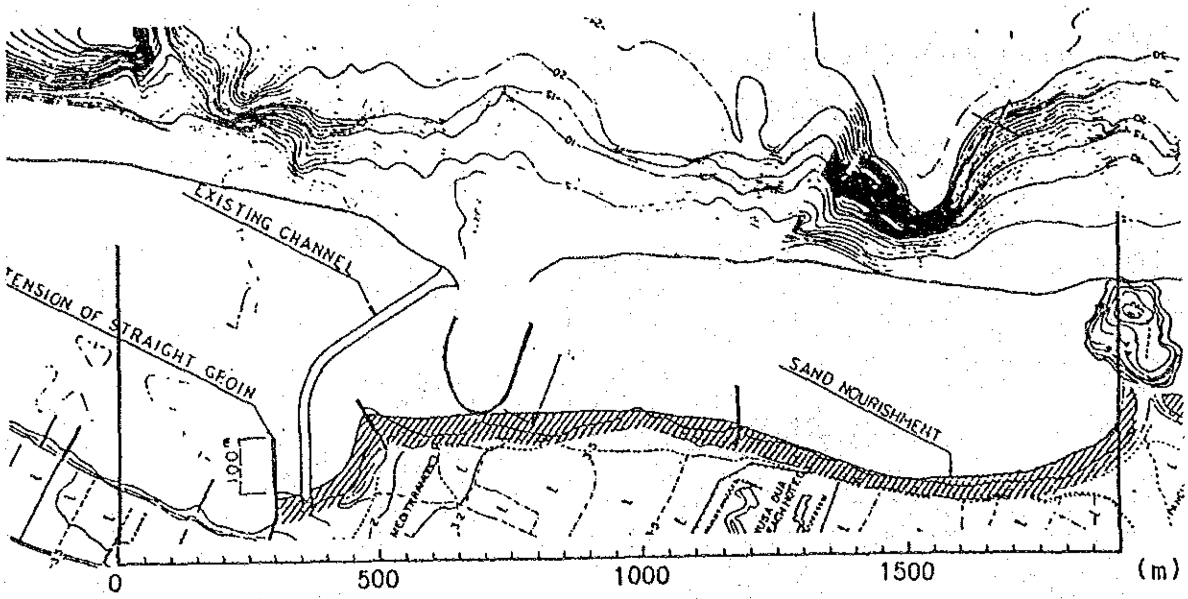


Fig. 5-2-4-6 Proposed Plan (Nusa Dua)

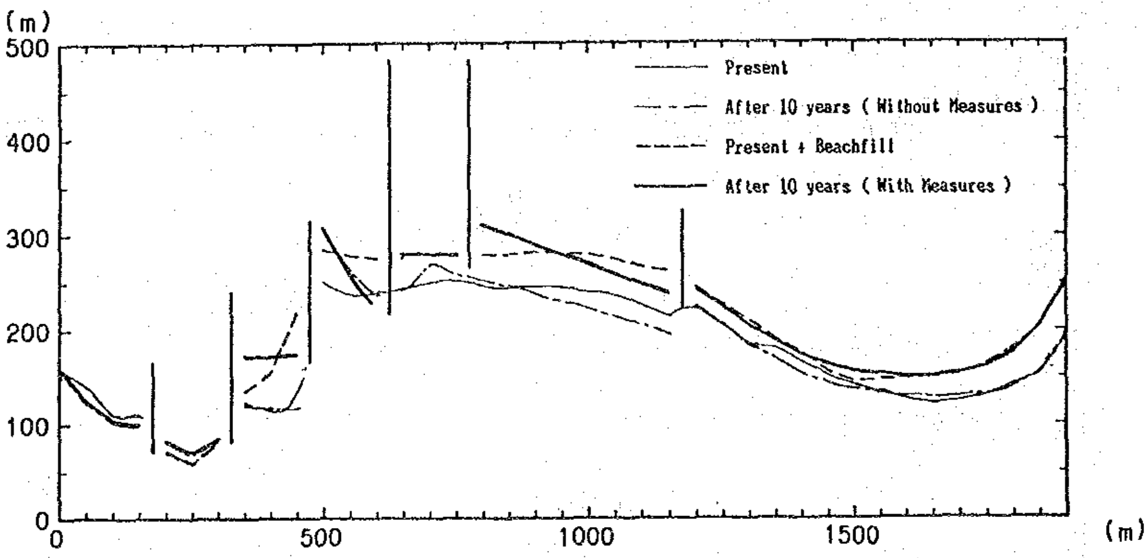


Fig. 5-2-4-7 Shoreline Evolution (Nusa Dua)

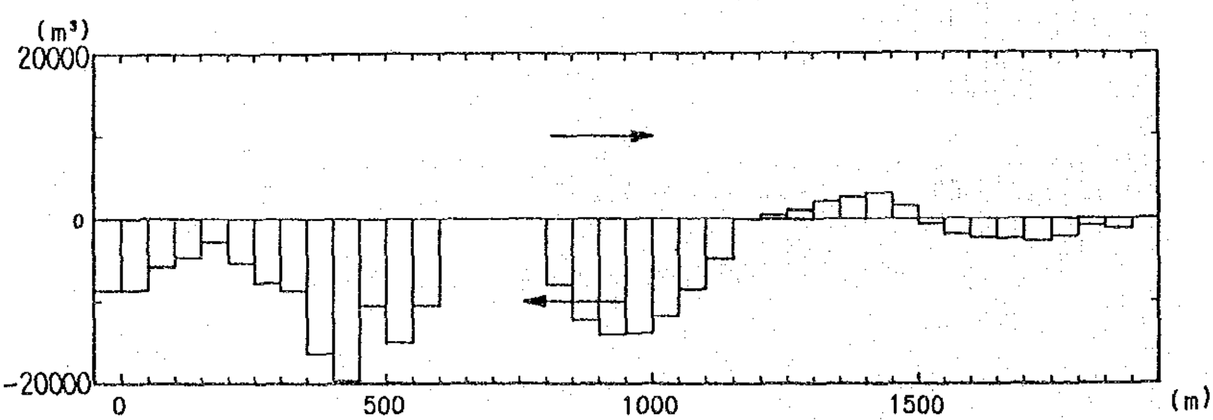


Fig. 5-2-4-8 Accumulated Longshore Sediment Transport (Nusa Dua)

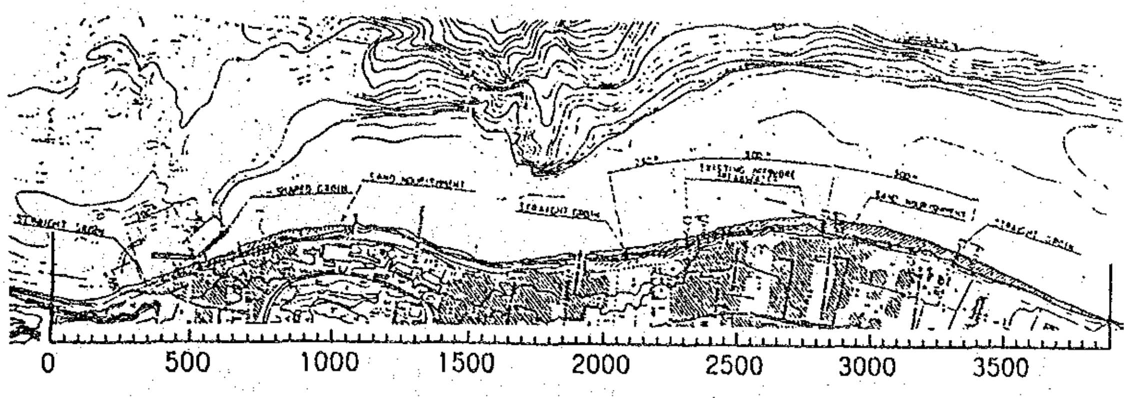


Fig. 5-2-4-9(a) Proposed Plan (Sanur, A)

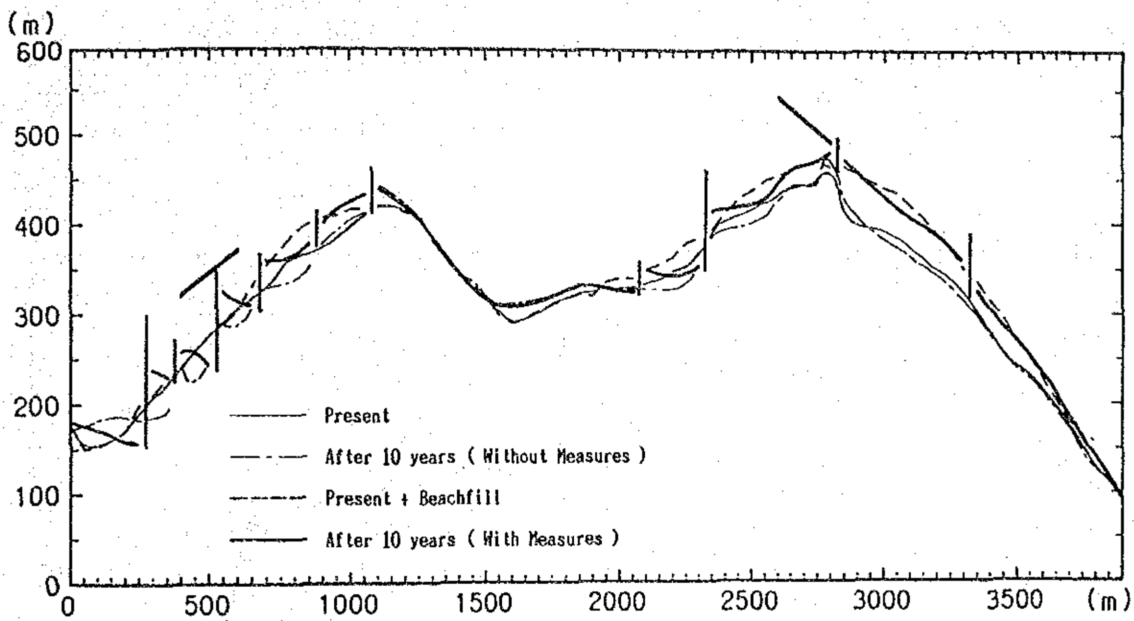


Fig. 5-2-4-10(a) Shoreline Evolution (Sanur, A)

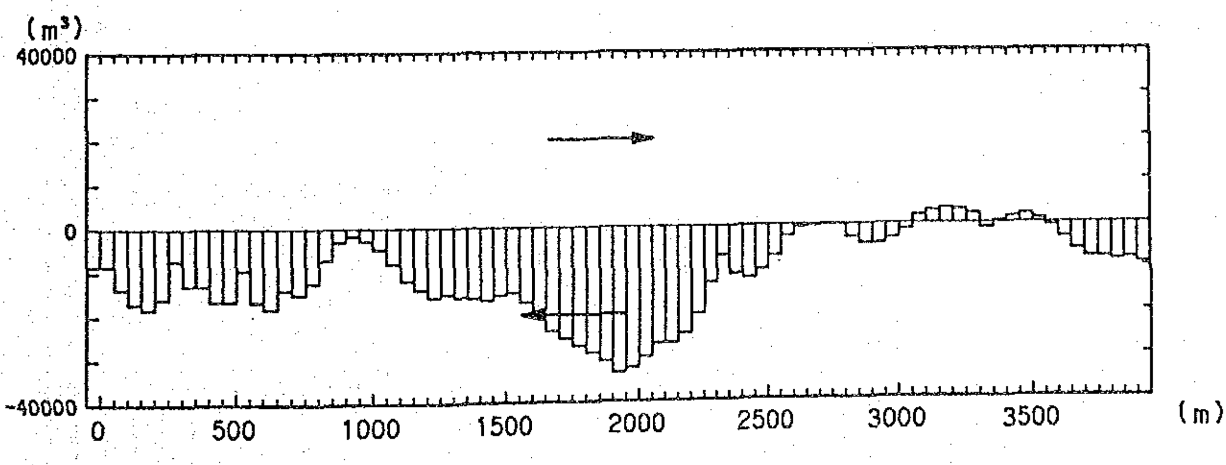


Fig. 5-2-4-11(a) Accumulated Longshore Transport (Sanur, A)

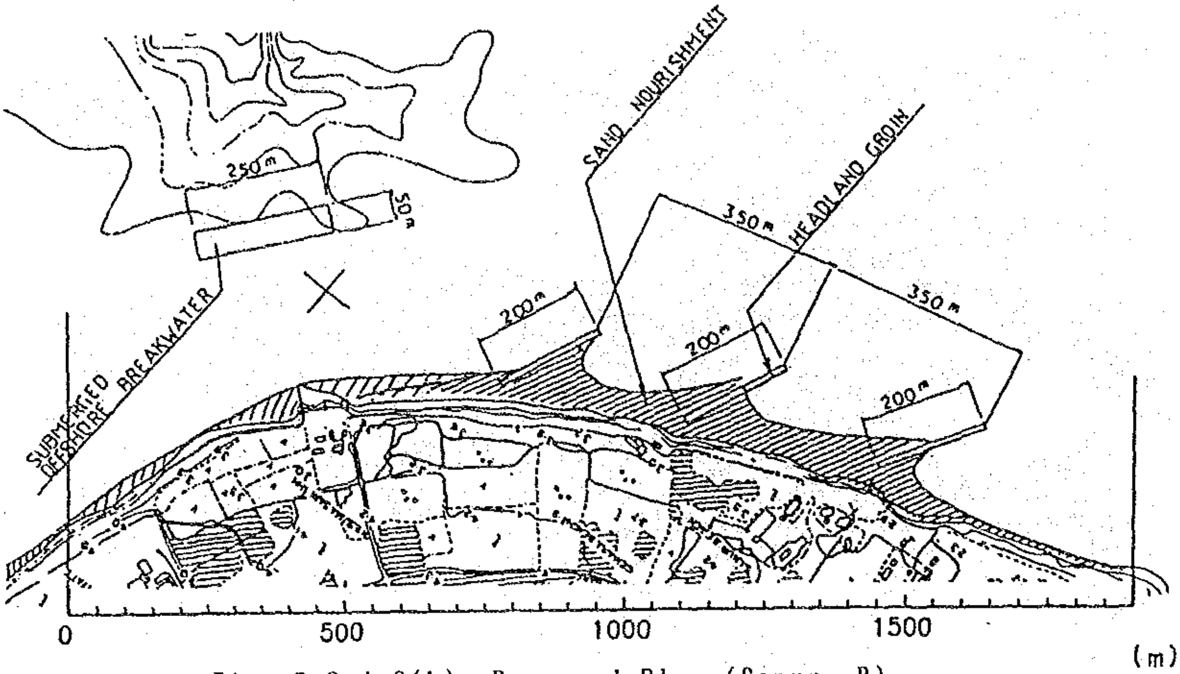


Fig. 5-2-4-9(b) Proposed Plan (Sanur, B)

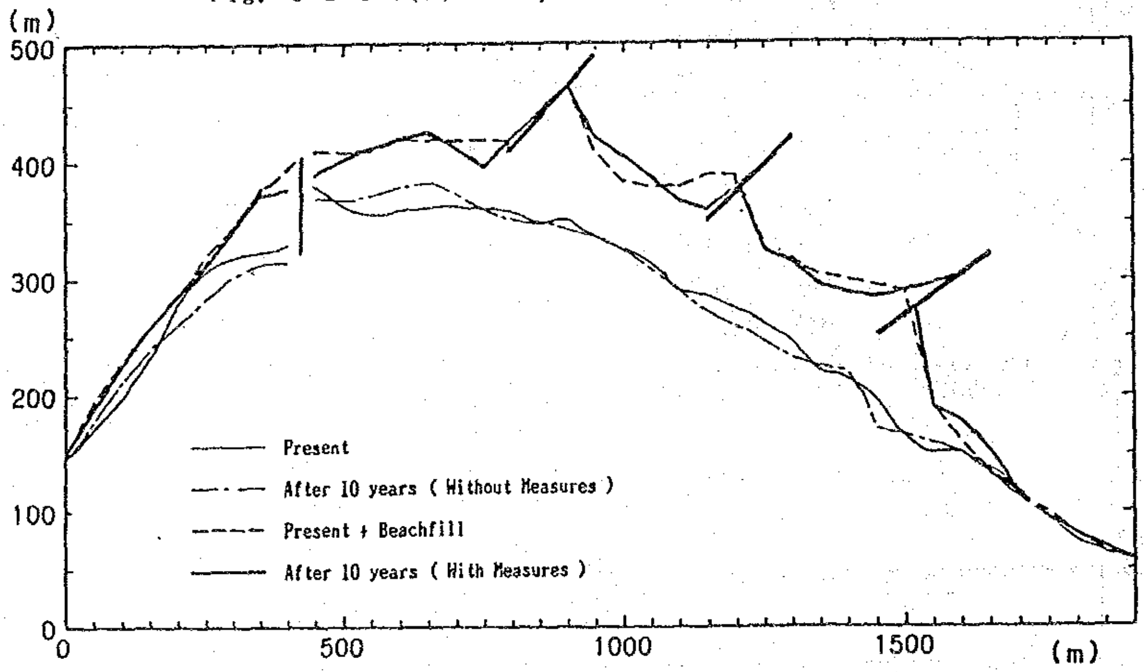


Fig. 5-2-4-10(b) Shoreline Evolution (Sanur, B)

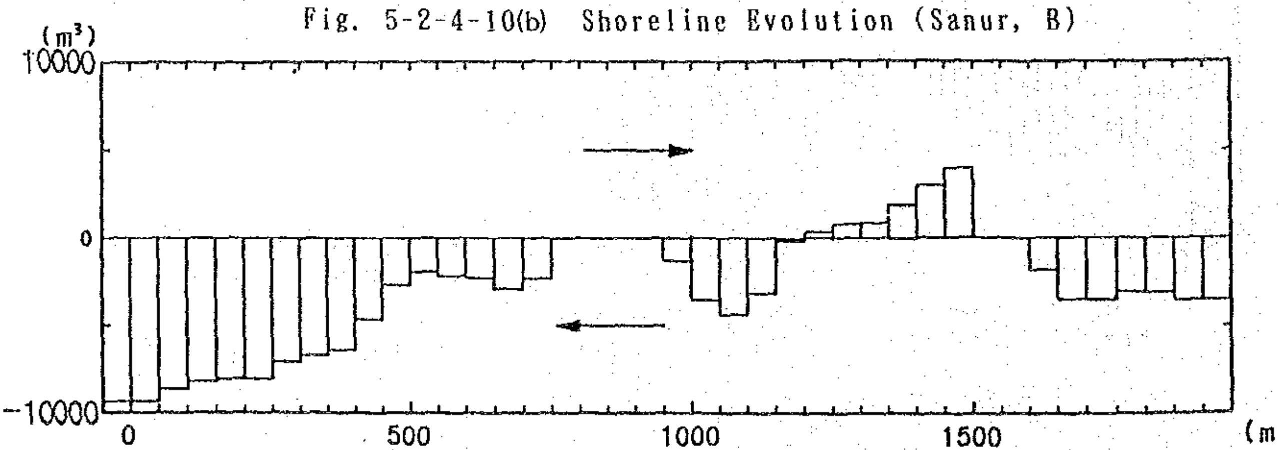


Fig. 5-2-4-11(b) Accumulated Longshore Transport (Sanur, B)

CHAPTER 6

URGENT PLAN

CHAPTER 6 URGENT PLAN

6-1 Basis of the Urgent Beach Conservation Plan

6-1-1 Selection of the Optimum Countermeasures

Due to the various kinds of interruption of northward longshore transport to the study area and the limited volume of sediment material supply from coral, the present beach erosion may continue or progress to adjacent areas unless beach sand is artificially provided.

Fortunately a large amount of sand is available, and can be dredged from the sea bottom, transported, dumped and carried by pump to the eroded beach zone.

But even if sand is carried to the beach, it is projected that waves may attack the beach and damage the backshore area year by year. Then countermeasures should be planned to satisfy the compouned requirements as follows.

1) Protect and stabilize the beach, which is subject to excessive storm waves and longshore current.

2) Reduce the rate of longshore transport out of the area by reorienting the shore line to an alignment more nearly perpendicular to the predominant wave direction.

3) Reduce the loss of fill material out of the area by compartmenting the beach, usually into relatively short sections of artificially nourished beach.

Considering the functions and the possibilities to satisfy these compound requirements, there are various alternative approaches that would provide a long-term solution, as follows.

1) Sand nourishment.
2) Sand by-passing.
3) Revetment work with slopping rubble.

4) Groin.

5) Offshore breakwater.

6) Headland and pocket beach.

Considering the effectiveness against the strong tendency of northward longshore transport, minimum maintenance, and the beautification of the marine scenery, the construction of several series of reoriented pocket beaches artificially nourished with a large amount of sand and divided by T-shaped headlands into compartments would be the most appropriate plant.

The work flow for the facility planning is shown in Fig. 6-1-1.

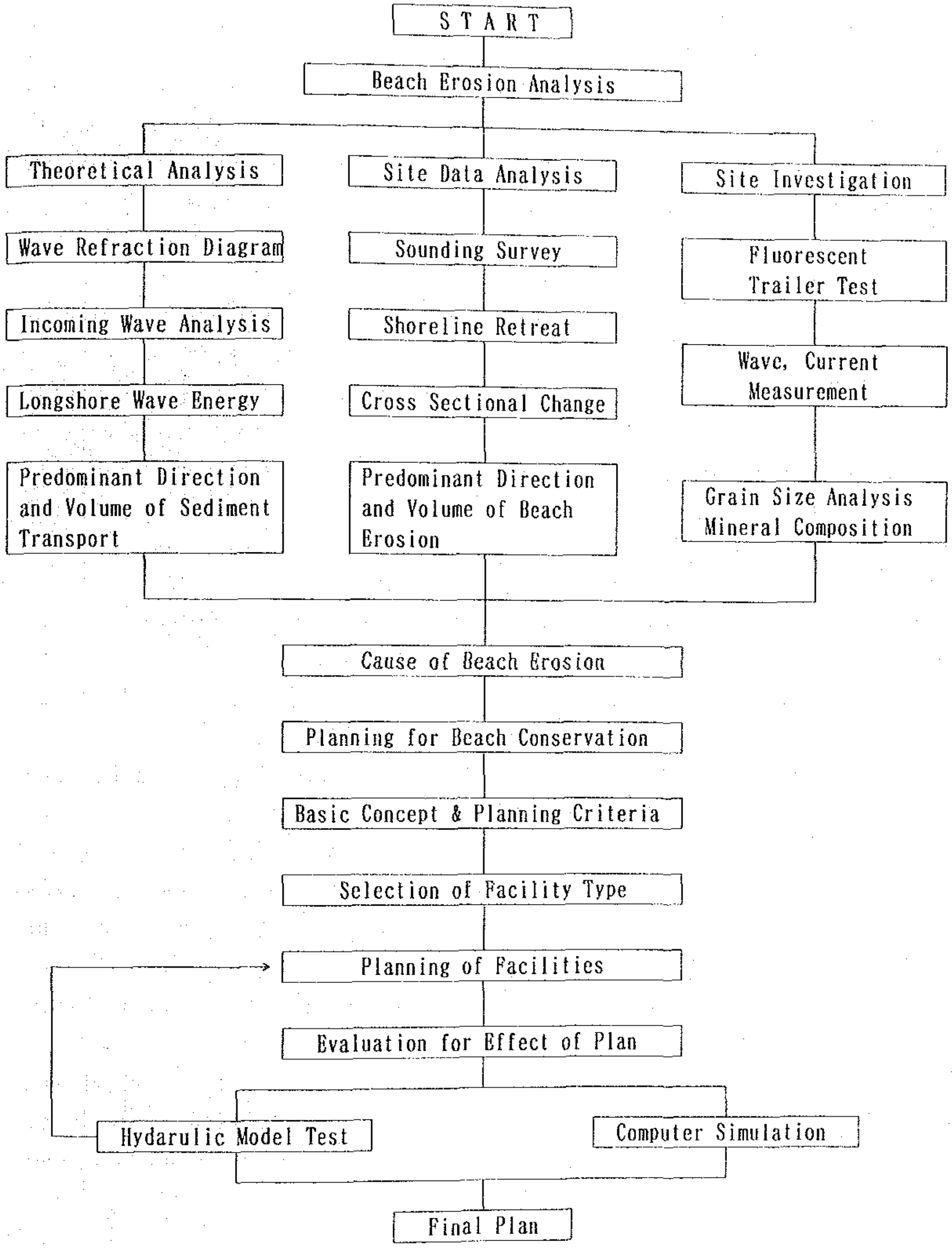


Fig. 6-1-1 Work Flow of the Facility Planning

6-1-2 Basis of the Beach Conservation Plan

This urgent plan was made to propose means of conservation of the present beautiful coral sand beach and to cope with the progressing beach erosion. The urgent countermeasures and locations were planned mainly based on the coastal engineering aspects as follows.

(1) Artificial Sand Nourishment

By providing sand to the eroded beach, the lost beach could be artificially recovered and thus counteract the progressing erosion. In this project, the sand nourishment is planned as the minimum required width and length to protect the existing structures along the coastline from collapse and to protect property from scouring due to wave actions. This would conserve the beach space for international tourism.

(2) Facilities for Reduction of the Longshore Sediment Movement

By provision of man-made groins constructed perpendicular to the shoreline at appropriate intervals, the amount of longshore sediment movement will be reduced or stopped and the beaches between groins will be stabilized, as pocket beaches. The strong offshore current from the reef gap is investigated as one of the important causes of the negative balance of sediment movement. The series of groins are planned to reduce the incoming wave height, to change the wave direction, and to weaken the current velocity. At the same time, the longshore sediment transport induced by wave and current will be trapped there. Consequently, in order to stop the progress of beach erosion to adjacent areas and stop the retreat of the shoreline, T-shaped groins are the most suitable facility considering the rough sea conditions of Kuta Beach and straight groins are designed as the most suitable facility for the relatively shallow and moderate sea conditions at Sanur Beach and Nusa Dua Beach.

Table 6-1-2 Basis of the Urgent Beach Conservation Plan

Outline of plan (Plan / Beach)			Urgent Bali Beach Conservation Plan											
			Kuta Beach				Nusa Dua Beach				Sanur Beach			
			I	II	III	Total	I	II	III	Total	I	II	III	Total
1. Existing Beach Profile	1) Area of erosion	(km)	0.4	0.8	0.7	1.9	0.6	0.8	0.95	2.35	2.0	2.0	1.0	4.0
	2) Shoreline retreat	(m)	-50	-60	-20		0	0	0		-10	-10	-20	
	3) Eroded volume	(m^3/year)	4.300	9.400	2.400	16.100	0	0	3.800	3.800	2.800	3.100	3.200	9.100
	4) Beach width	(m)	10	40	50		20	30	20		10	20	20	
	5) Beach slope	( )	1/20	1/20	1/29		1/8	1/8	1/8		1/8	1/14	1/9	
	6) Direction of sand move	( )	south	north	north		north	north	north		south	north	north	
	7) Diameter	(φ 0.42mm over)	10 ~ 15%				50 ~ 60%				80 ~ 85%			
	8) Gravity	(g/cm^3)	2.70	2.74	2.74		2.68	2.73	2.77		2.72	2.68	4.48	
2. Proposed Beach Profile	1) Beach length	(km)	0.7	0.8	1.2	2.70	0.60	0.80	0.95	2.35	2.0	2.0	0.7	4.70
	2) Shoreline	(Offshore. m)	50	50	0		30	20	30		30	15	20	
	3) Beach width	(m)	50	50	50		50	50	50		30	30	30	
	4) Beach area	(m^2)	45.000	80.000	104.000	229.000	30.000	40.000	47.500	117.500	60.000	60.000	32.000	152.000
	5) Top elevation	(+m)	+3.0	+3.0	+3.0		+3.0	+3.0	+3.0		+3.0	+3.0	+3.0	
	6) Beach slope	( )	1/17	1/17	1/17		1/7	1/7	1/7		1/7	1/7	1/7	
	7) Sand volume	(m^3)	52.000	409.000	322.000	783.000	28.000	56.000	145.000	229.000	238.000	114.000	96.000	448.000
	8) Diameter	(φ 0.42mm over)	10 ~ 15%				50 ~ 60%							
	9) Gravity	(g/cm^3)	2.74	2.74	2.74		2.77	2.77	2.77		2.72	2.72	4.66	
	10) Wave run up	(+m)	+3.0	+3.0	+3.0		+2.6	+2.6	+2.6		+2.6	+2.6	+2.6	
	11) Ground elevation	(+m)	+3.0	+3.0	+3.0		+3.0	+3.0	+3.0		+3.0	+3.0	+3.0	

6-2 Urgent Plan for Kuta Beach

At Kuta beach, the supply of littoral drift was reduced after the construction of the Denpasar Airport runway and the interruption of the northward longshore sediment transport which is generated by the continuous invasion of swell from the Indian Ocean. Consequently at the retreat of the eroded shoreline is estimated more than 50 m over the last 10 years and more than 100 m since 1960. Accordingly, urgent countermeasures are needed for controlling the severe erosion.

The basic concept of the Kuta beach conservation plan is to recover the lost beach by sand nourishment and maintain it. The countermeasures necessary for the beach conservation are planned as follow.

(1) Sand Nourishment

Nourished area	:	From 300 m (near Pertamina Cottages) to 3,000 m North (near Kuta Sea View Cottages) of the Airport. Beach lenth = 2,700 m
Beach width	:	Average 50 m
Slope of foreshore	:	About 1/17
Sand volume	:	783,000 m^3

The beach length and the beach width are planned considering the conditions of erosion and tourism use.

The area to be nourished is about 2.7 km long covering Division I through Division Ⅲ. The entire stretch is eroded, especially Division Ⅱ. The beach width must be at least 50 m considering the recovery and use of the beach.

The planned slope of the forershore, about 1/17 follows the figure of the existing foreshore slope.

(2) Maintenance of the Nourished Beach

The nourished sand will be eroded and lost if there are no maintenance facilities.

In order to reduce the maintenance cost after completion of the beach, structures like groins are preferable to continuous sandbypassing.

The basic concept of the beach conservation is to divide the whole streach of the beach into a series of sections and to stabilize the beach within each section. Each section will thus be comprised of a stable pocket-beach.

Groins will be used as maintenance facilities because the sections should be separated from each other and the longshore sand drift should be enclosed within the sections.

Offshore breakwater will not be suitable in this case because the tombolo behind the breakwater is not stable, and is easily changed by wave action, and therefore it is difficult to hold the sand within the section.

The groins should be T-shaped because of the following reasons.

① To reduce the incident wave energy by the lateral part of the groin.

② The area behind the lateral part of the groins is expected to be calm and this prevents sand loss offshore.

③ Reduciton of the incident wave energy into the section makes it easy to form a pocket-beach.

④ The groins can be utilized for inspection patrol and by tourists.

The interval of the groins is determined considering the expected shape of the pocket-beach. The minimum beach width should be maintained in each section.

The locations of the groins are determined considering the wave energy distribution and the longshore current along the shoreline.

4 sets of headlands using T-shaped groins are necessary to stabilize the filled sand and reduce the wave impact by forming pocket beaches between these headlands.

One small groin is planned to maintain the filled sand at the northern end of the sandfill area.

The location and scale are shown in Fig. 6-2-1.

The filled sand will deform sharply in the initial stage (one or two years), but is expected to stabilize later on approaching the form of a stable pocket-beach.

6-3 Urgent Plan for Nusa Dua Beach

At Nusa Dua beach, 3 groins, an offshore breakwater and a U-shaped offshore breakwater have already been constructed with sand nourishment of about 100,000 m^3 for protection of erosion between Nusa Kecil and Hotel Club Med. Due to the northward longshore sediment transport, the beach is narrow in width and steep in slope.

In order to reduce the erosion, and to maintain this beach in good condition for conservation and touristic use, the sand nourishment and countermeasures are planned as follows.

(1) Sand Nourishment

Nourished area	:	From groin No.3 (near Culb Med Hotel)to Nusa Besar Beach length = 2,350 m
Beach width	:	Average 50 m
Slope of foreshore	:	Average 1/7
Sand volume	:	229,000 m^3

The nourished area is determined considering the utilization of the beach and the condition of beach erosion. The beach between the two islands, Nusa Besar and Nusa Kecil, is included in the beach nourishment because of it's importance for tourism and the present insufficient beach width.

The beach width is determined based on the shore protection function and tourism use. The slope of the planned beach follows the average existing foreshore slope.

(2) Maintenance of the Beach

The basic concept of beach concervation at Nusa Dua beach is that the whole reach of the beach will be divided into a series of sections and the beach will be stabilized within each section.

As for Divition Ⅰ, no facilities are needed to stabilize the beach because the beach is enclosed by two islands and will form a pocket beach easily.

At Division Ⅱ, the beach is expected to stabilize within this reach. Based on the wave refraction diagram, the incident wave direction is nearly perpendicular to the existing shoreline. The beach is roughly in the form of a stable beach. The beach between Nusa Kecil groin No.1 will become stable without any new structures.

At Division III, extension of the U-shaped offshore breakwater is necessary to stop the sediment movement through the gap of the reef and to obstruct the refracted waves coming in from the reef gap. A pocket beach is expected to form between groins No.2 and No.3. Extension of the existing groin No.3 is planned to retain the filled sand.

(3) Modification of Existing Offshore Breaker

The height of the existing offshore breakwater is planned to be reduced to the mean sea water level, just like the existing U-shaped breakwater, judging from the wave difraction diagram and the condition of wave concentration coming in through the reef gap.

The locations and dimensions are shown in Fig. 6-3-1.

6-4 Urgent Plan for Sanur Beach

At Sanur Beach, a shoreline retreat of about 10 m is observed. The beach width is narrow and the slope is steep.

The basic concept of the beach conservation plan is to recover and develop the lost beach by nourishment up to 50 m of beach width and maintain it by a series of headlands. The countermeasures necessary for beach conservation are planned as follows.

(1) Sand Nourishment

Nourished area	:	① From the Bali Beach Hotel Pier to 700 m North Beach length = 700 m ② From 1700 m (near Sindhu Hotel) to 5,700 m South (near Sanur Beach Hotel) of the Bali Beach Hotel Pier Beach length = 4,000 m
Beach width	:	Average 30 m
Slope of foreshore	:	About 1/7
Sand volume	:	448,000 m^3

The nourished area, Division I, II and III, is determined considering the condition of beach erosion and the utilization for tourism. The planned slope of the foreshore, 1/7, is roughly the same as the existing slope.

(2) Maintenance of Nourished Sand

The predominant direction of the longshore sediment transport is northward in the northern part and southward in the southern part of Sanur beach.

Because of the existence of the reef, the amount of longshore sediment is not large and therefore large-scale structures like those at Kuta Beach will not be necessary for maintenance.

In Division I, 3 sets of headlands are planned to form a stable shoreline against the incoming wave direction. In Division II, 3 sets of groins are necessary to stabilize the filled sand.

In Division III, L-shaped groins and straight groins are planned to prevent the filled sand from falling to the reef gap.

A submerged offshore breakwater at the coral reef gap is necessary to stabilize the filled sand and reduce the wave impact against the beach near Kesuma Sari Inn. The shape and scale are determined considering the effects on wave breaking and the expected shoreline change.

The locations and dimensions are shown in Fig. 6-4-1.

6-5 Urgent Plan for Tanah Lot

The existing conservation plan using concrete blocks around the island is suitable in order to protect the island from erosion by waves.

The locations and dimensions are shown in Fig. 6-5-1.

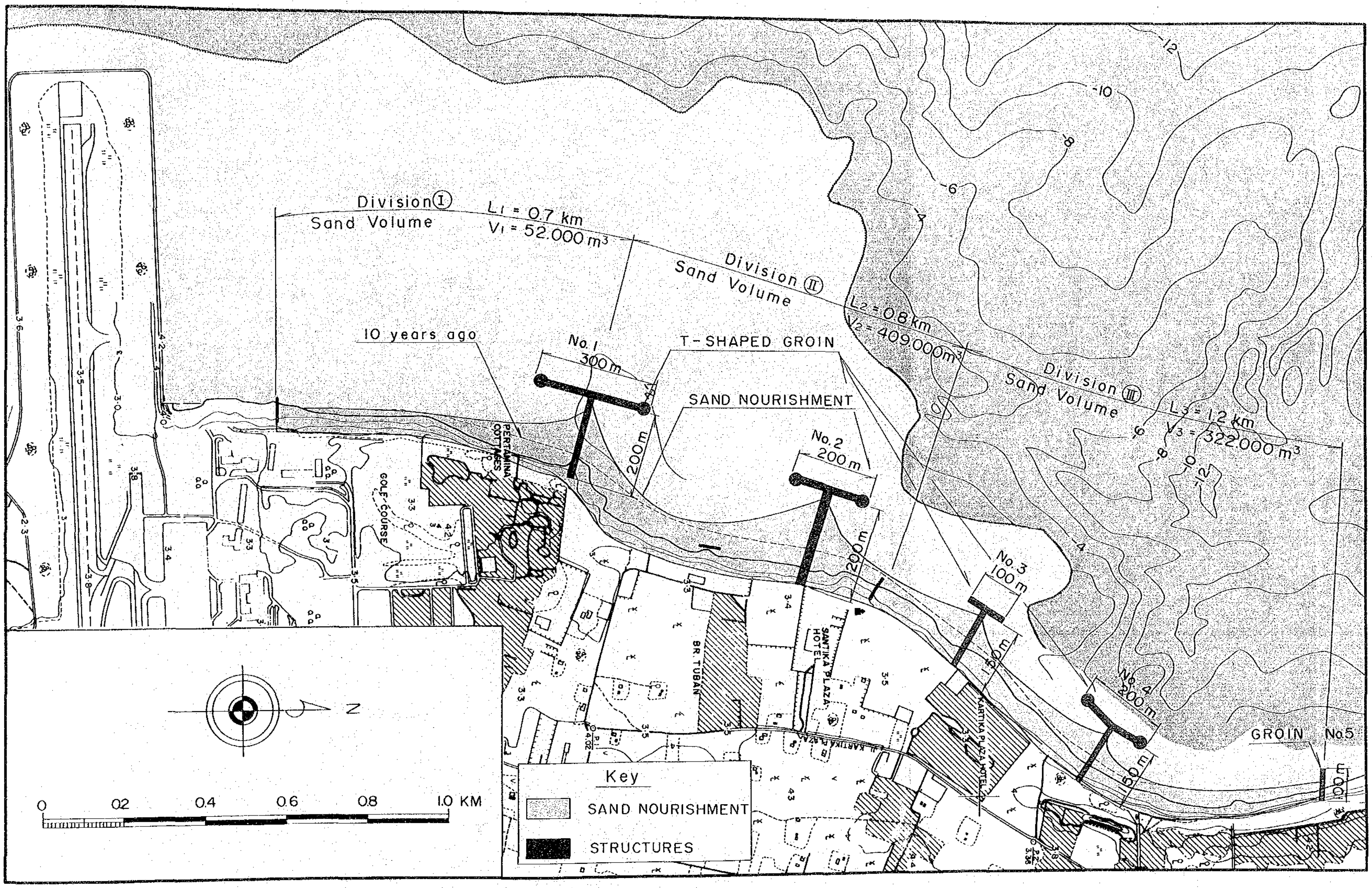


Fig. 6-2-1 Urgent Plan for Kuta Beach

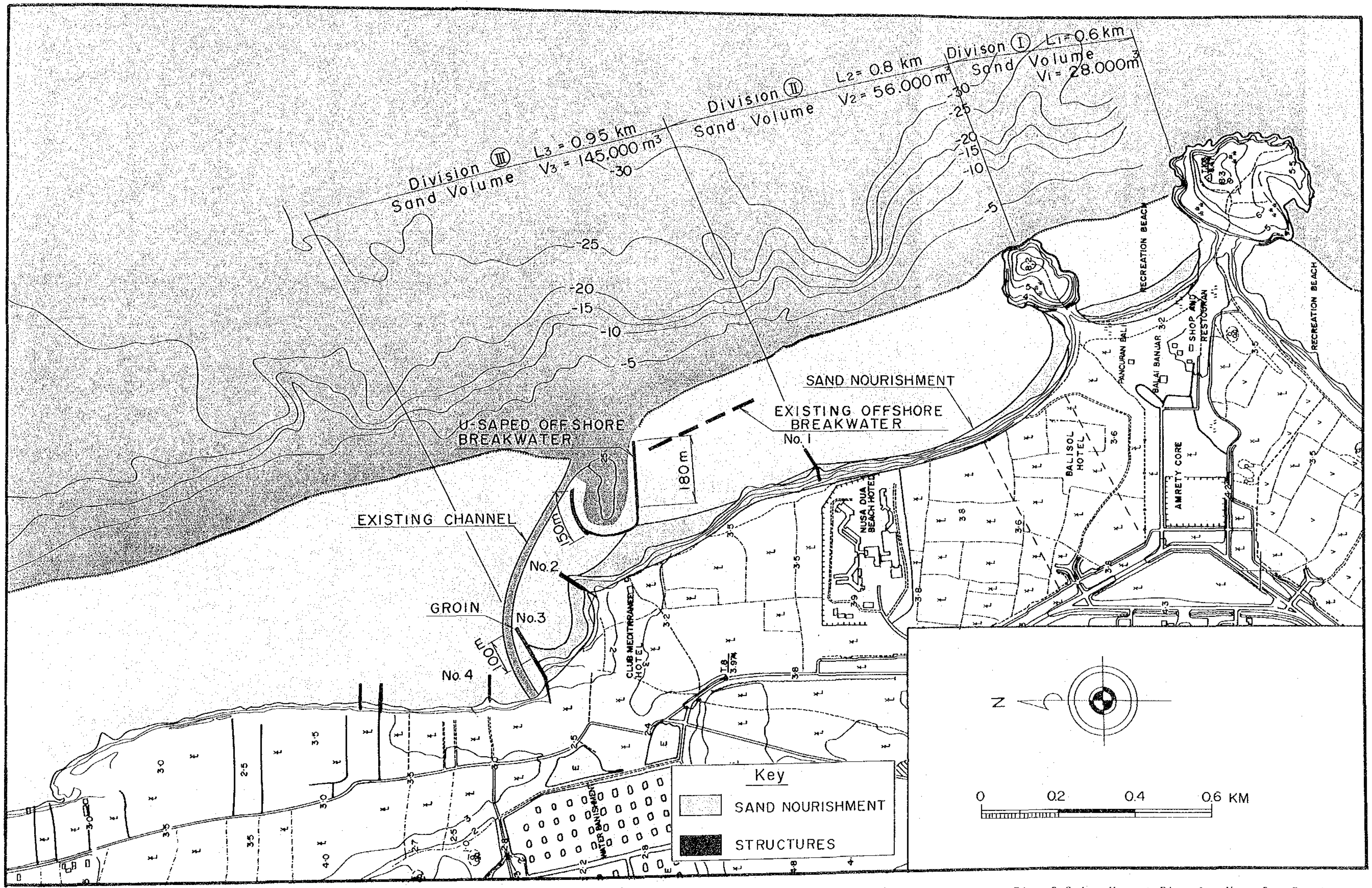


Fig. G-3-1 Urgent Plan for Nusa Dua Beach

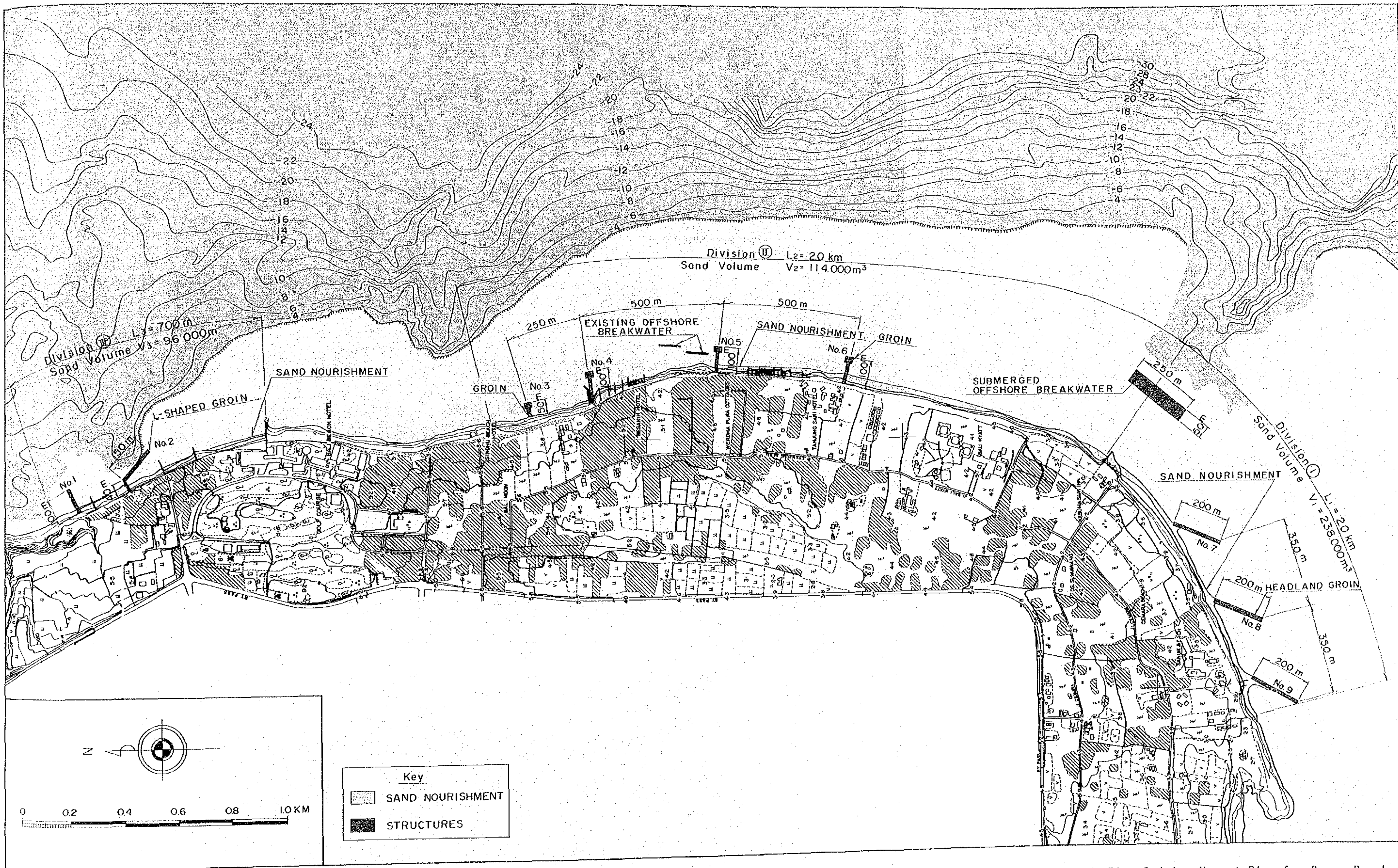


Fig. 6-4-1 Urgent Plan for Sanur Beach

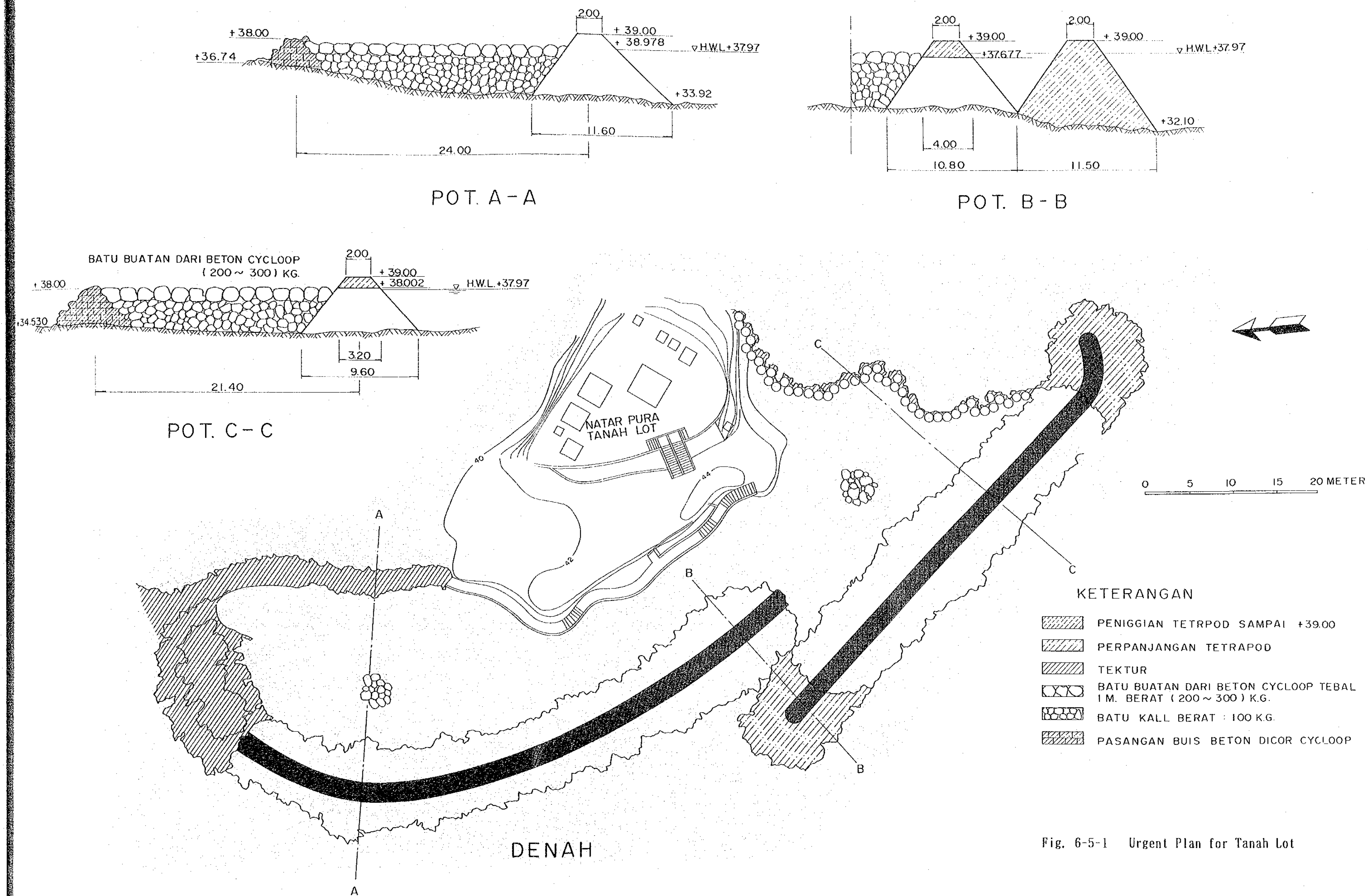


Fig. 6-5-1 Urgent Plan for Tanah Lot