2.2.2 Physical and Natural Environment

(1) Climate

The Climate of the Maldives can be divided into two periods as follows:

- Northeast Monsoon	December - March
- Southwest Monsoon	end of April - October

Monthly climate data between 1986 and 1990 was collected in Hulule island, which is about 1.5 km from Male', and is shown in Fig. 2.2.5.
The mean monthly temperature of 31.7 °C is highest in April, and lowest in September at 25.1 °C. However, there is very little seasonal variation. In Hulule, the average annual rainfall is approximately 1,900 mm. The maximum mean monthly rainfall is over 200 mm in June, from August to October, and in December. The most frequent wind direction is northeastern in December through February and western in May through September as follows:

January and February	: North to east northeast wind
May and June	: West southwest to northwest wind
July to September	: West to northwest wind
December	: Northeast to east

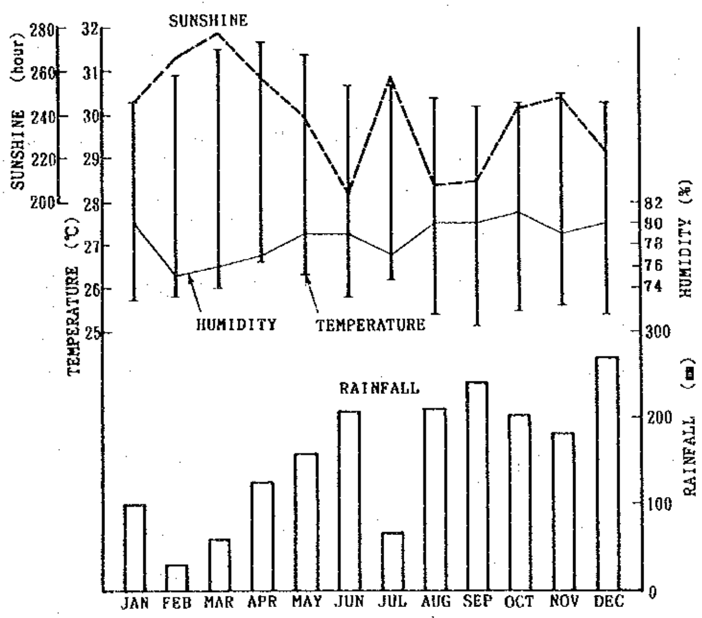


Figure 2.2.5 Monthly Average Climate in Hulule, 1986 - 1990

(2) Topography/Geology

The Republic of Maldives consists of 1,190 small coral islands out of which 200 are inhabited. The islands are formed in 26 natural atolls in the Indian Ocean. The island group of ring-shaped clusters, stretches for approximately 750 km from north to south and 120 km from east to west. The capital of the Maldives is located on Male' Island. Male' Island is approximately 1.9 km wide and 1.2 km long.

At present, Male' island has an area of approximately 180 ha. However, originally the island was surrounded by coral reef and the area of the island was about 108 ha. Some parts of the reef were reclaimed to cope with increasing population in the south and west. Changes of topography on Male' Island are shown in Fig. 1.2.1, and the corresponding changes of area are as follows:

Table 2.2.2 Changes of Area in Male' Island

Year	Area
1950	107.64* ha
1978	123.02
1986	177.25

* : originally

The ground level of Male' is 1.2 to 2 m above sea level and reclamation area is more than 1 m high. Higher area is distributed in the center and the northeast of Male'.

(3) Ground Water

a) Conditions of Ground Water

The conditions of ground water depends on the characteristics of porous coral rock, sea level and rainfall. According to Alasdair J.Edwards, "The Implications of Sea Level Rise for the Republic of Maldives, 1989", it is predictable that mean ground water level in Male' is 0.4 m above mean sea level. The thickness of ground water layer below mean sea level is 16 m. Variation of ground water level is similar to the tidal level.

b) Quality of Ground Water

Male' Water Sanitation Project has surveyed the quality of ground water by monitoring wells. The results indicated that the concentration level of chlorides in ground water depends on rainfall and sea level. Low concentration of chlorides is distributed in the center of Male'.

The JICA study team also has surveyed 5 wells in Male' on September 30, 1991. The concentration of chlorine is lower in the center and higher near the shore line wells. Colibacillus was detected in one well, which is in the south of Male'.

(4) Marine Hydrology

a) Currents

Several currents affect the Maldives islands. These currents are divided mainly into ocean currents and tidal currents, with the ocean currents being stronger than tidal currents.

A general view of the seasonal current patterns in the Indian Ocean is shown in Fig. 2.2.6. The currents flow westward during the northeast monsoon period, and they flow eastward during the southwest monsoon period.

The ocean currents flowing by the Maldives islands are also driven by the monsoon winds. In the northern part of the Maldives, constant currents flow westward during the northeast monsoon period from December to April, and eastward during the southeast monsoon period from May to August.

Generally, the tidal currents are eastward in flood, and westward in ebb. The velocity, however, varies by island areas. The current patterns result from reef forms.

b) Tidal Level

According to "Tide Tables Vol. 2, 1991" published by the Hydrographer of the Navy, the harmonic constants for Male' are as follows:

Constant of tide

Z_0	M_2	S_2	K_1	O_1	
0.56	0.24	0.14	0.12	0.06	m

High Water Level (HWL)	D.L. + 1.34 m
Mean Sea Level (MSL)	D.L. + 0.64 m
Chart Datum Line (MSL-Z)	D.L. + 0.08 m
Lowest Astronomical Tide (LAT)	D.L. + 0.00 m

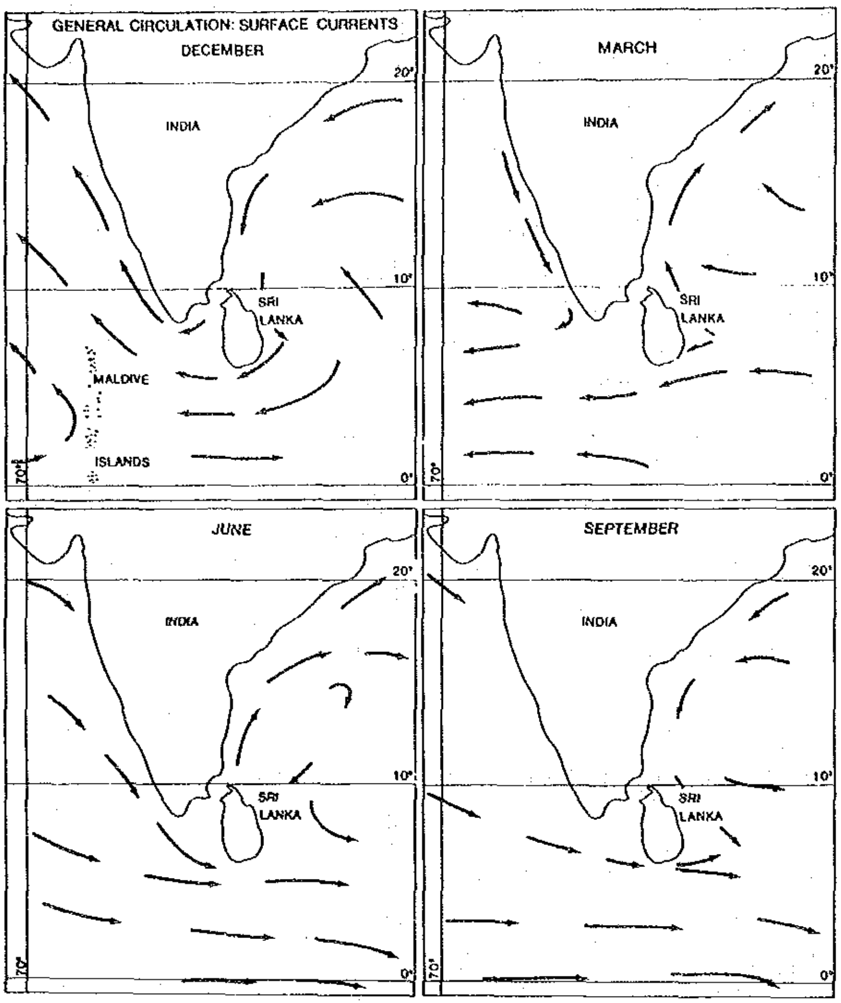


Figure 2.2.6 Surface Currents around Maldives
(by Bernard Swan)

(5) Marine Water Quality

Characteristics of surface water in the Maldives are shown in Table 2.2.3. Since there are no large rivers, volumes of surface water reservoirs are determined by rainfall and evaporation.

Table 2.2.3 Characteristics of Surface Water in Maldives

Temperature	27.5	°C	in January
	28.9	°C	in May
Salinity	34.0	mg/l	in February
	35.5	mg/l	in August
Density	1,023	kg/m^3	

(by the Ministry of Health)

The Marine Research Section belongs to Ministry of Fisheries and Agriculture, and the JICA Study Team surveyed water quality in September and October, 1991. According to these surveys, the Inter-island Harbour and the Inner harbour of the south Male' have a higher concentration of turbidness than that around Male' island. However, other elements such as salinity and nutrient salt are varied among the stations.

Pollution of harbours in Male' was researched by the Marine Research Section, Ministry of Fisheries and Agriculture. Inner Harbour has some problems as follows:

- Ships generate pollution from oil spill, bilge water, contamination from fish blood, and dead fish bait.
- Discharging garbage and night soil from the residential boats due to lack of toilets on the boats

Other sources of pollution are:

- Six raw sewage outfall pipes without treatment
- Garbage dumping areas on shore

(6) Marine Fauna and Flora

There are more than 250 species of coral on Maldivian reefs. Corals built the reefs and islands of Maldives. Coral is used as building material for houses and coastal protection structures.

The JICA Study Team surveyed coral reefs on the east, the west, and the south sides of Male' island using the Manta Tows method. Two 20 m long line-transects were set up on the south side. The results of the line transects survey are described in the Supporting Report.

a) East Side

The reef gently slopes away from shore some distance towards the east. In the south of the east side, the bottom, which was 12 m deep, was mostly dead Porites with live Acropora hyacinths and cytheria, and significant amounts of Pocillopora. When the Acropora became rare, the community was dominated by *Pocillopora verucosa* on otherwise bare and gently undulating coral rock pavement. Cover in both cases was about 15-20 %. In the north of the east side, there are live coral thinned, and massive Porites alive and dead were common. There were some bug stands of Porites, much of which was in poor shape. Heavy turf algae was the dominant cover.

b) West Side

The reef top was narrow and sloped gradually to the edge at 2 m depth whence it plunged straight down to 20 m where there was a ledge (old sea level). On the shelf at 20 m there were many cans and coral boulders fallen from above. There was a second ledge at 22 m. The slope moderated a bit but remained very steep until 30 m where a sand/rubble slope of about 30 degrees began. At this point, there was an accumulation of dead coral boulders fallen from above.

About 50 % of the top was covered with medium size (0.5-0.8 m diameter) massive coral boulders resting on a flat coral rock base with coarse sand in between the boulders. Live coral cover on top was about 99 % heavy algal turf growing on dead, mostly loose massive coral skeletons (mostly Porites but some other e.g.*Leptoria phrygia*). Live coral of all sorts on top was 1 % or less and consisted of: *Pocillopora verucosa* (dominant), with occasional Tubastrea, Dendrophyllia, Favia, *Acropora hyacinthus*, *A.Humilis*, Montipora, Astreopora, massive Porites, *Leptoria phrygia*, and encrusting soft coral. At all depths there is massive atrophying and encrusting in form and the Acroporas were less than 10 cm in diameter. The only reef top invertebrate seen was *Diadema setosum*.

c) South Side

In the east of the south side, heavy turf algae on dead coral is the dominant life form. Live coral cover was estimated at 15 %. Small Acropora (humilis group, hyacinthus, cytheria) was dominant on the reef top. On the shoulder and upper slope Acropora was still dominant, but massive porites (about 75 cm diameter, with some 2 m head to the west) was occupied some patches. *Pocillopora verucosa* was on top as was the encrusting soft coral (sinularia ?). There was a patch of broken coral on the reef top substrate to the reef edge. One large (about 5X10 cm) dying and fragmenting colony of *Pavona clavus* was seen, also with long axis normal to the reef edge. In general, the Acropora and Pocillopora seemed to be surviving well, while the massive corals seemed to be in worse condition.

Examination of massive corals showed that these are heavily parasitized and the live tissue area seemed to be generally receding. On the reef top small burrowing urchins (Diadema) were common and one Heterocentrotus was seen. Covered live coral declined dramatically at about 30 m where sand was the dominant substrate and soft coral was relatively abundant. Down deeper in the sea, encrusting (e.g. Favia) and foliose (e.g. Echinopora, Leptoceris) forms were observed more dominant among hard corals.

d) North Side

There are the breakwaters over the seawall on the north side. The area between the breakwaters and the seawall is used by small vessels for anchorage. This area is used nursery place for small fishes.

Offshore from the breakwaters, there is narrow reef flat. Reef flat of the north side is narrower than other sides. Reef flat in the central of the north side is 5 - 15 m wide and in the east of the north side has a width of 20 - 30 m, and reef is plunged down from the reef edge. Top of the reef flat, sand is accumulated in the several places so that growth conditions of coral is not good.

(7) Marine Fishery Resources

Fishery is one of the most important economic industrial sectors in the Maldives, and accounts for approximately 15 % of the GDP.

a) Method of Fishing

Zaha Waheed has surveyed the method of fishing in North Male' Atoll. Results of this survey are as follows:

As for day-time fishing, 2-5 fishermen work on one fishing boat, which goes out in the atoll towards the outer rim and in the atoll rim channel. The men work with a single-hook handline, and use live bait fish such as Caesionidae, Apogonidae, and Pomacentridae.

As for early morning and night, Bokkuraa(s) (row boats) are operated with one or two fishermen during early morning and night as follows:

Full-time fishermen	from 8 p.m. to 3 a.m.
Part-time fishermen	from 8 p.m. to around midnight or from 3 a.m. to 4 a.m.

Sometimes, fisherman go out fishing twice a day. The main fishing gear is a handline with a small sinker and a hook.

b) Fish Species Caught

In Male', the amount of fish landed was 4,953 tons in 1990 (Table 2.2.4). The main fish caught was skipjack. Skipjack landed was 4,084 tons or 82 % of the total amount of fish caught with pole and line vessels (Table 2.2.5).

Table 2.2.4 The amount of Fish Landed, 1990

Unit:tons

	Total	Skipjack	Yellowfin	Other tuna related Species	Other marine fish
Total	76,373	59,898	5,279	5,185	6,011
Male' Atoll	5,278	4,622	402	137	117
Male' Island	4,953	4,084	373	322	174

(by the Ministry of Planning and Environment)

Table 2.2.5 Fish Catch by Fishing Method, 1990

Unit:tons

	Total	Skipjack	Yellowfin	Other tuna related Species	Other marine fish
Total	76,373	59,898	5,279	5,185	6,011
Pole and Line Vessels	72,148	59,191	5,065	3,808	4,084
Trolling	3,877	703	213	1,362	1,599
Long Line	15	0	0	2	13
Hand Line	4	4	0	0	0
Fixed Gillnets	9	0	1	3	5
Miscellaneous	320	0	0	10	310

(by the Ministry of Planning and Environment)

c) Biomass

According to the estimation by FAO, biomass in North Male' Atoll was 2,600 - 3,500 tons. Biomass of the Snapper A. virescens was estimated between 488 and 656 tons, 572 tons on average.

(8) Terrestrial Fauna and Flora

a) Fauna

In Male', colourful garden lizards, geckos, house mice and black rats can be seen everywhere.

b) Flora

There are no native plants. Vegetation is very rare on Male' island. Some plants were put in house gardens, schools, and parks. The main plants are mango trees, casuarinas (Fithuronu) and wild hibiscus (Dhiggaa). However, the ratio of green cover is lower than the other islands.

(9) Natural Disaster

In Male' island, there has not been any recent natural disasters such as floods, droughts or land slides because of the climate and topography. Male' Island, however, has experienced following natural disasters.

- Storm
- Earth tremors
- Inundations

2.3 Topographic/Bathymetric Surveys

2.3.1 Survey Method

(1) Base Line

In order to set up basing points and lines along the coast of Male' Island, a closed traversing survey was carried out by using a theodolite and an automatic distant meter as shown in Fig. 2.3.1.

The coordinates and elevation of the base points are tabulated in Table 2.3.1.

(2) Topographic Survey

Topographic survey, covering an average width 50 meters, was performed by using a plane table surveying equipment and levelling instrument along the shore line. The results indicating boundaries of the facilities, roads and buildings were directly drawn on a plastic sheet in the scale of 1 to 500.

Table 2.3.1 List of Base Points

Unit : Meter

B. P.	X	Y	Elevation	B. P.	X	Y	Elevation
T- 1	2,000.000	5,000.000	+2.258	T- 5	925.496	3,572.251	+1.968
T- 1A	2,072.704	4,853.235	+2.067	T- 6	944.131	3,807.982	+2.126
T- 2	2,091.237	4,740.967	+2.110	T- 6B	994.147	4,246.102	+2.406
T- 2A	2,079.093	4,553.408	+2.039	T- 6C	993.405	4,385.926	+2.187
T- 2B	2,131.784	4,269.167	+2.226	T- 6D	1,039.476	4,568.509	+2.798
T- 2C	2,175.211	4,208.202	+2.199	T- 6E	1,108.871	4,826.292	+2.790
T- 2D	2,181.800	4,107.229	+1.755	T- 7	1,183.346	5,100.234	+2.804
T- 2E	2,119.100	3,979.762	+1.773	T- 7A	1,293.154	5,140.362	+2.787
T- 2F	2,068.853	3,884.221	+1.545	T- 7B	1,536.171	5,141.111	+2.766
T- 3	2,223.509	3,792.799	+2.298	T- 8	1,812.100	5,141.965	+2.773
T- 3A	2,155.085	3,664.359	+2.509	T- 8A	1,892.627	5,121.699	+2.797
T- 3B	1,998.193	3,739.187	+1.770	T- 8B	1,983.967	5,129.851	+2.789
T- 3C	1,925.309	3,589.698	+1.759	T- 8C	2,032.289	5,084.379	+2.205
T- 3D	2,016.979	3,511.270	+1.985	T- 8D	2,047.506	4,998.911	+2.096
T- 4	1,821.581	3,396.605	+1.857				
T- 4A	1,299.690	3,256.101	+2.561				
T- 4B	1,306.206	3,442.653	+1.311				

(3) Bathymetric Survey

A boat equipped with an echo sounder kept straight on from offshore to shore by being guided by a surveyor using a theodolite on the temporary bench marks. Sounding was continuously recorded by an echo sounder and the position was checked at an interval of about 50 m by a positioning meter. Soundings were carried out at an interval of 10 m along the shore line. Sounding records were adjusted by tide records.

In the area of shallow coral reef, the measurement was made by using a level and tape basing at the temporary bench marks.

KEY PLAN (MALE' ISLAND)

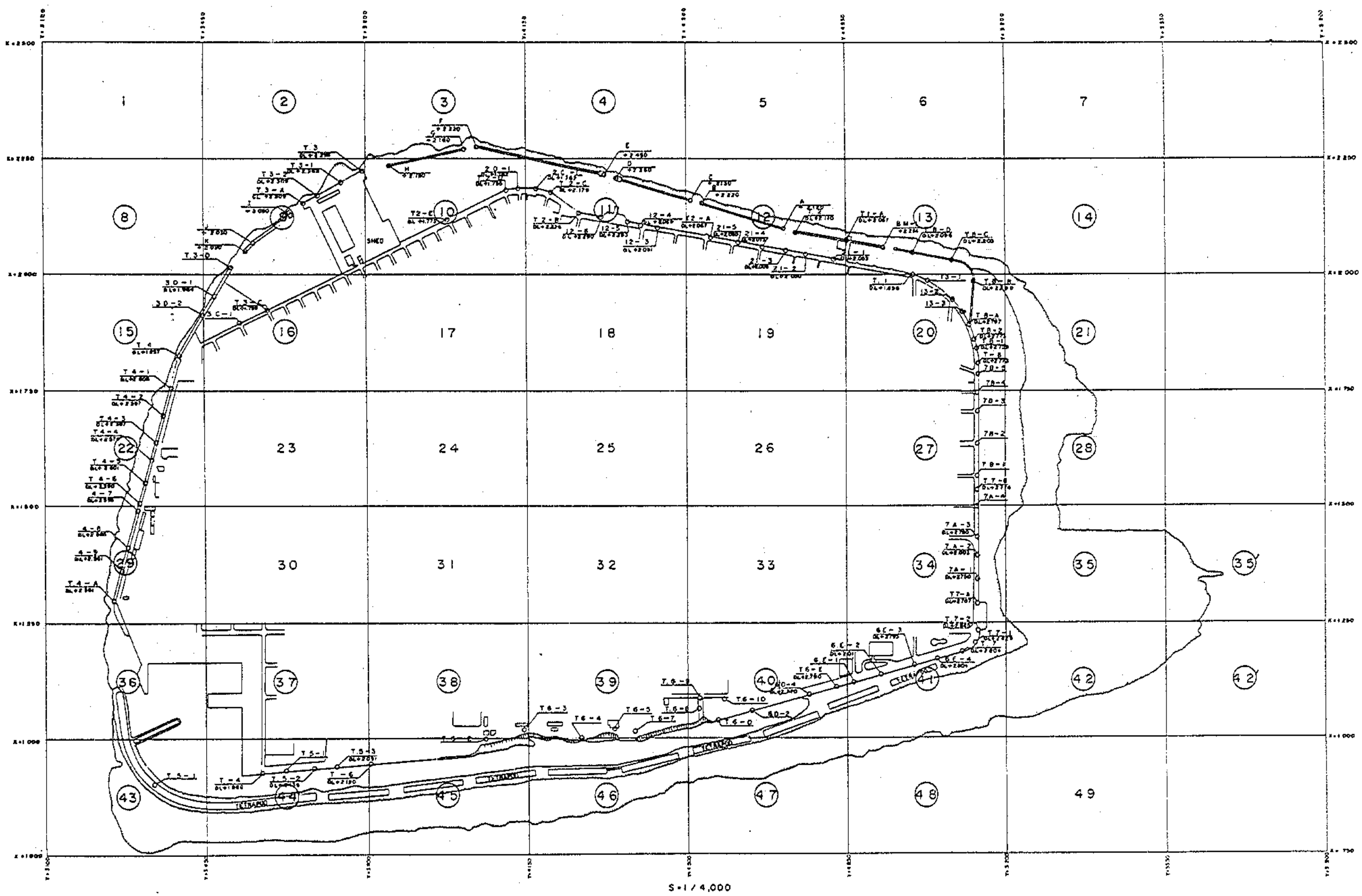


Figure 2.3.1 Base Line and Mapping Sheet Number

2.3.2 Survey Equipment Used

Main survey equipment used for the survey work is listed below:

- Echo Sounder	:	SENBON DENKI PDR401 (230, 210, 190 and 170 kz)
- Automatic Distant Meter	:	TOPCON GUPPY GTS-310
- Positioning Meter	:	PULSE RANGER 10-71004
- Theodolite	:	TOPCON TL-10DF (10 sec. reading)
- Automatic Level	:	TOPCON AT-F2
- Plane Table	:	1 set
- Sextant		
- Steel Tape	:	100 m
- Transceiver	:	2 sets

2.3.3 Mapping and Drawings

The topographic and bathymetric survey results were mapped and compiled as Supporting Data I.

The list of maps is as follows.

		Original Scale	Reduced Scale	
Male' Island				
	- Key Plan	1/4,000	(1/8,000)	
	- General Map	1/4,000	(1/8,000)	
	- Path of Soundings	1/2,000	(1/4,000)	North Coast East Coast South Coast West Coast
	- Bathymetric Maps	1/500	(1/1,000)	No. 2 --------No. 4 No. 8 --------No. 16 No. 20 --------No. 22 No. 27 --------No. 29 No. 34 --------No. 48
	- Cross Sections	V = 1/100 H = 1/500	(1/200) (1/1,000)	No. N-1 -------No. N-27 No. E-1 -------No. E-23 No. S-1 -------No. S-11 No. W-1 -------No. W-10

Funadhoo Island

- Key Plan	1/1,000	(1/2,857)	
- General Map	1/1,000	(1/2,857)	
- Path of Soundings	1/1,000	(1/2,857)	
- Bathymetric Maps	1/500	(1/1,000)	
			No. 1 -------- No. 6
- Cross Sections	V = 1/100	(1/200)	
	H = 1/500	(1/1,000)	
			No. N-1
			No. E-1
			No. S-1 ------- No. S-3
			No. W-1

2.3.4 Survey for Notches on the Coral Cliff

On the coral cliff of the west coast, many notches were found. In order to survey the exact location and size, a special survey was made by divers. The results are as indicated in Fig. 2.3.2 and 3. The notches are very variable in size and exist at a depth of 5 m to 15 m. In designing shore protection facilities, these notches should be taken into consideration.

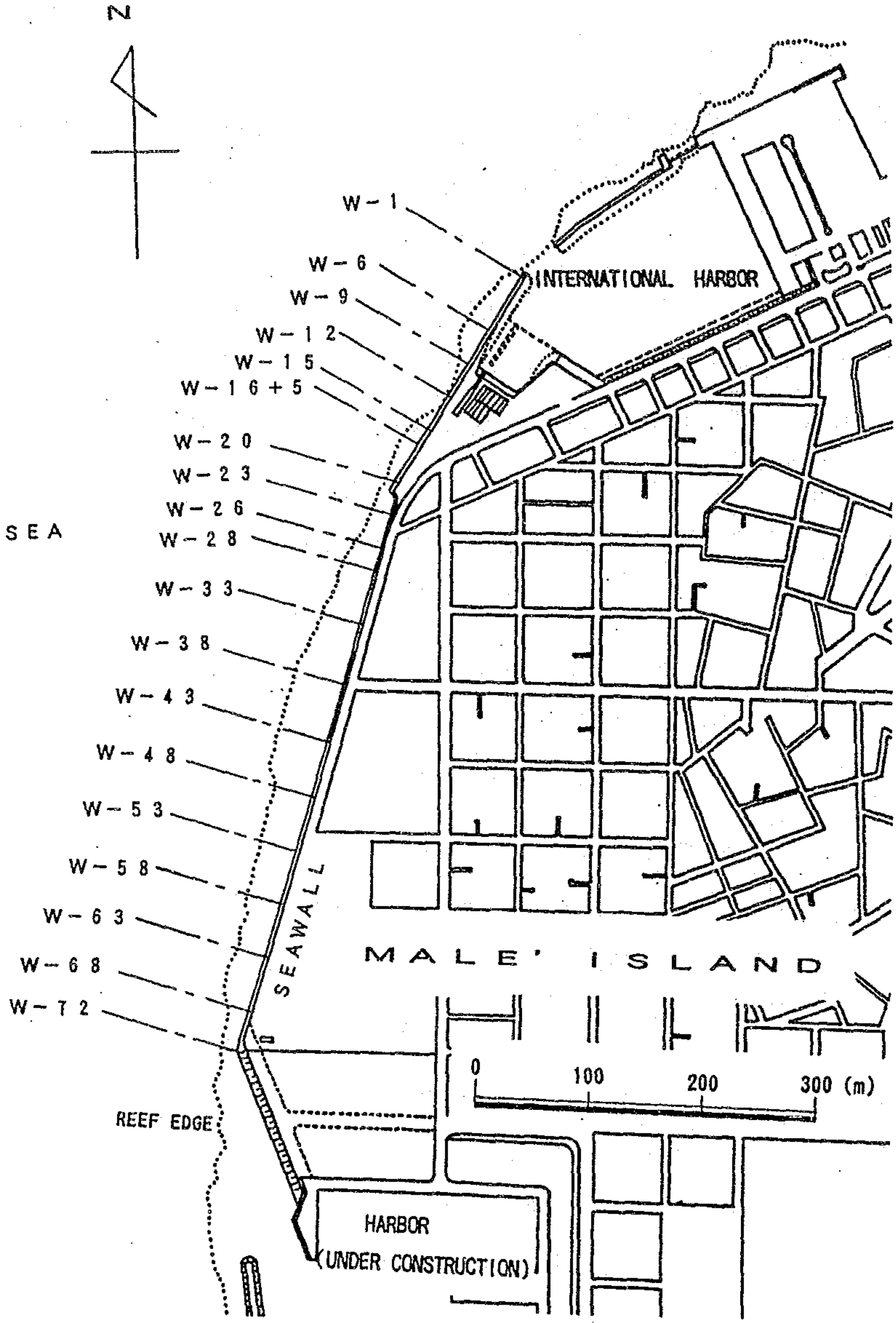


Figure 2.3.2 Location Map for Notch Survey

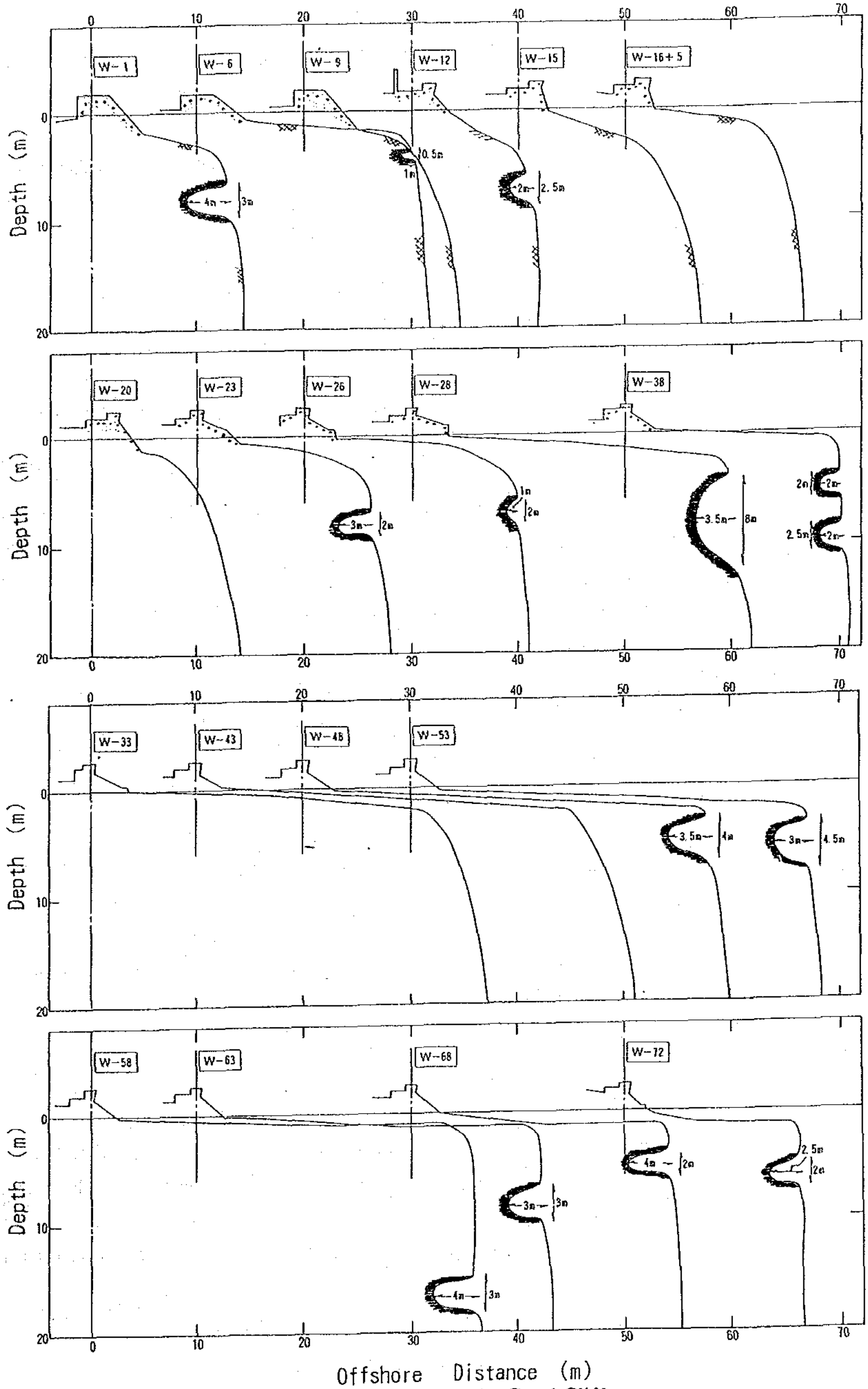


Figure 2.3.3 Notches in the Coral Cliff

2.4 Soil Conditions

A Geological/Soil/Material Survey was carried out to obtain geotechnical information as well as sub-surface soil characteristics of the proposed seawall alignments on the east, south and west coasts of Male' Island. The main work items of the above mentioned survey cover previous data collection, geological survey, core drilling, geotechnical analysis and material tests.

(1) Previous Data Collection

Previous data concerning geological survey, soil investigation, boring and material testing are shown in the attached references. Based on the previous data, the columnar sections and the locations of the previous bore holes totalling 44 holes are shown in Figures 2.4.1 and 2.4.2, respectively. The results of previous plate load tests were reported by "Report on Geotechnical Investigations on Indira Gandhi Memorial Hospital Project" and "Drilling Logs and Foundation Data on the Kalaafaanu Primary School", within the previous data.

(2) Geological Survey

The geological survey was obtained from geological mapping and air-photograph interpretation in Male' and Funadhoo Island.

a) Geology of Male' Island

Male' Island is located at the southeastern end of the North Male' Atoll. Male' Island is composed of a horseshoe shape coral reef, a lagoon enclosed with reef, and an island in the lagoon. The coral reef is made up of submarine outer edges, detrital outer ridges with coral detritus which are indicated by breakwater zone, and reef flats in the inside of outer ridges.

b) Geology of Funadhoo Island

Funadhoo Island is located about 700 m northeast of Male' Island. Funadhoo Island consists of a circular shaped coral reef with a diameter of about 400 m, an island having a diameter of about 200 m and lagoons between them. The coral reef is composed of submarine outer edges extended to southeast, and detrital outer ridges which are indicated by breaker zone resulting from the southeast monsoon winds.

(3) Core Drilling

Core drilling with standard penetration test (S.P.T.) was carried out at the east coast, the south coast and the west coast in Male' Island. The three bore holes (SDH1, SDH2 and SDH3) were drilled on the proposed seawall alignments at the above-mentioned coasts. Their columnar sections and locations are shown in Figure 2.4.1 and 2.4.2, respectively. The depth and the number of S.P.T. for each bore hole are shown in Table 2.8.1.

Table 2.4.1 The Depth and the Number of S.P.T.

Bore Hole No.	Location	Depth (m)	Number of S.P.T.
SDH 1	East coast	10.45	10
SDH 2	South coast	10.32	10
SDH 3	West coast	11.57	10
Total		32.34	30

The unconfined compression test and the unit weight test concerning the nine core samples taken from the bore holes, were carried out in accordance with JIS and test standards based thereon at a laboratory in Singapore.

(4) Geotechnical Analysis

The geological sections along the proposed seawall alignments were prepared on the basis of the columnar section of the previous bore holes and the present bore holes (SDH1, SDH2 and SDH3). The location of the geological section lines and the geological sections are shown in Figure 2.4.2 and 2.4.3, respectively.

The geotechnical analysis was carried out based on the geological sections, the columnar sections, the N-values (S.P.T.) and the results of laboratory tests of core samples. The results of the geotechnical analysis are summarized in the following items.

a) The Lagoon Sediments and the Loose Coral Rock

The foundation of the proposed seawall consists mainly of lagoon sediments (in the north side of the east coast), loose coral rock which forms reef flat (in the south side of the east coast an the south coast) and loose coral rock which forms the outer ridge (in the west coast).

The physical properties of the lagoon sediments and the loose coral rock are summarized in Table 2.4.2.

The ultimate bearing capacity of the lagoon sediments in Table 2.4.2 was taken on the basis of the previous plate load test for the Kalaafanu Primary School Project. Also, the ultimate bearing capacity of the loose coral rock in Table 2.4.2 was taken on the basis of the previous plate load test for the Indira Gandhi Memorial Hospital Project. Both plate load tests were performed on the lagoon sediments and on the loose coral rock, respectively.

Table 2.4.2 The Physical Properties of the Lagoon Sediments and the Loose Coral Rock

Name of Foundation Rock	Description	N-value (S.P.T.)	Unconfined Compressive Strength kgf/cm^2	Ultimate Bearing Capacity t/m^2
Lagoon Sediments	Coral Sand and gravel, median grain size: 0.4 ~ 0.6 mm	3 ~ 33	-	16 ~ 22
Loose Coral Rock	Reef building coral which grows in-situ, with many pores and cavities	2 ~ 50	5 ~ 135 (average 70) The test was performed on core samples only	45 ~ 60

b) Damage to Coral Reef on the West Coast

The proposed seawall alignment on the west coast is planned on the outer ridge of coral reef, and it is not the same as on the reef flat nor on the lagoon sediments in the case of the east and the south coast. The alignment is very near to the outer slope of coral reef and its distance ranges from 7 m to 3 m.

It is estimated that the coral reef on the west coast was probably damaged by wave erosion and surface erosion during the period of sea level change, because of the submarine notches found on the outer slope at a depth of 5 m to 10 m from D.L.

SDH 3 bore hole intersected sandy silt sediment, 1.4 m thick, at 7.3 m to 8.7 m depth from D.L. The sandy sediment which underlies the loose coral rock having 45 in N-value (S.P.T), shows the penetration advance of 67 cm at one blow by S.P.T. Therefore, the sandy silt sediment may be deposits in the cave.

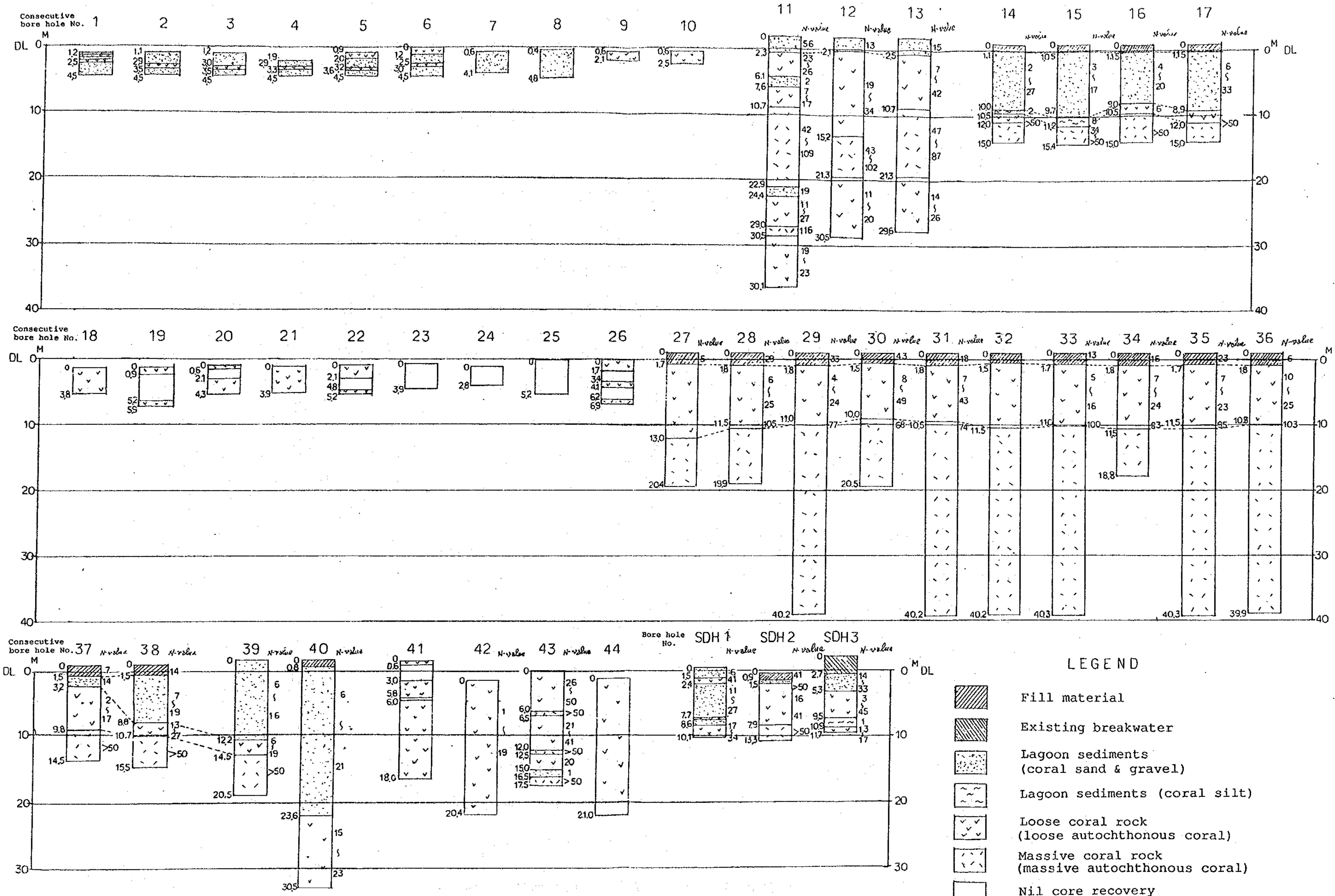


Figure 2.4.1 Columnar Sections of Bore Holes dilled for Foundation Investigation, Male'

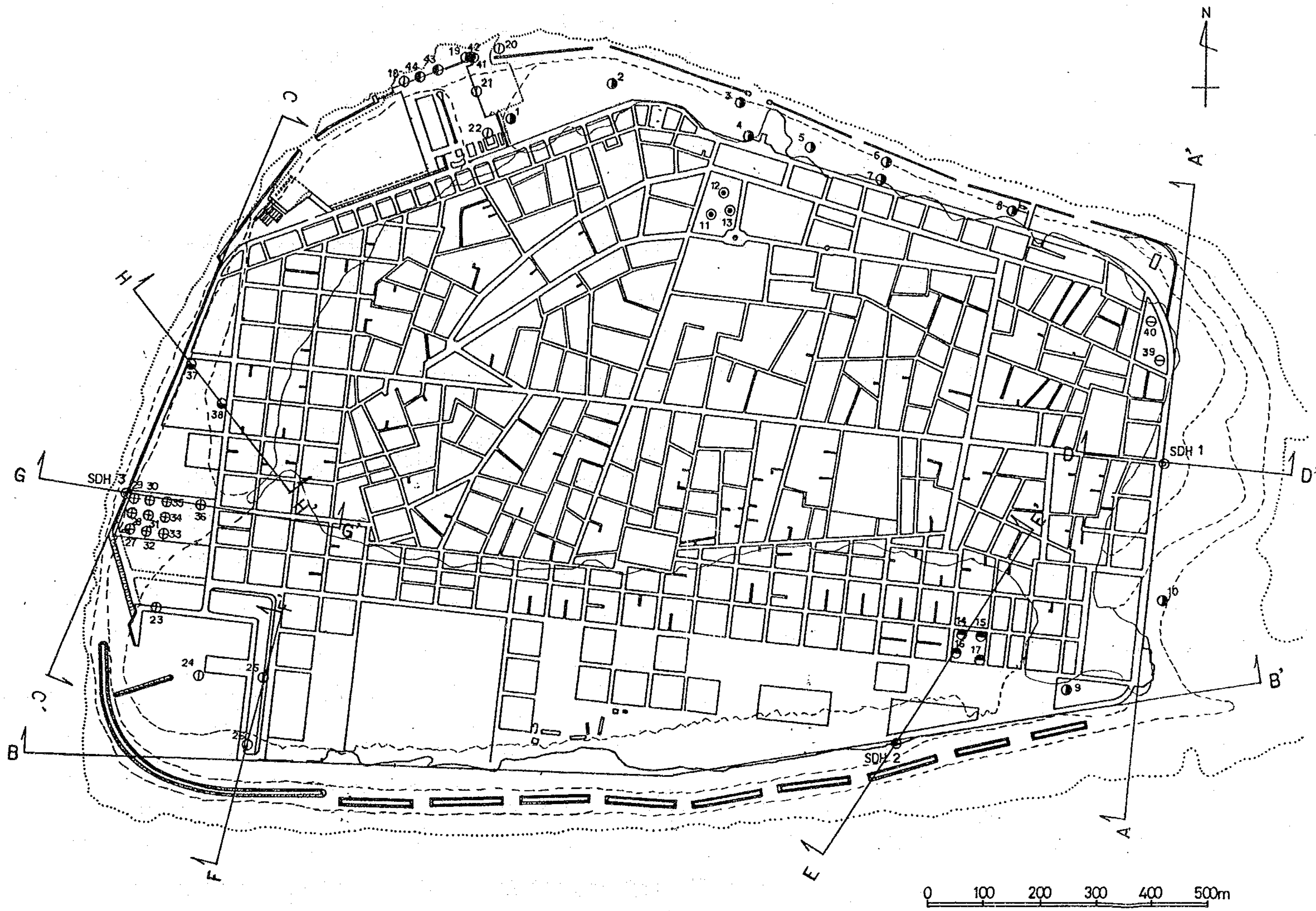


Figure 2.4.2 Location Map of Bore Holes drilled for Foundation Investigation and Geological Section Lines, Male'

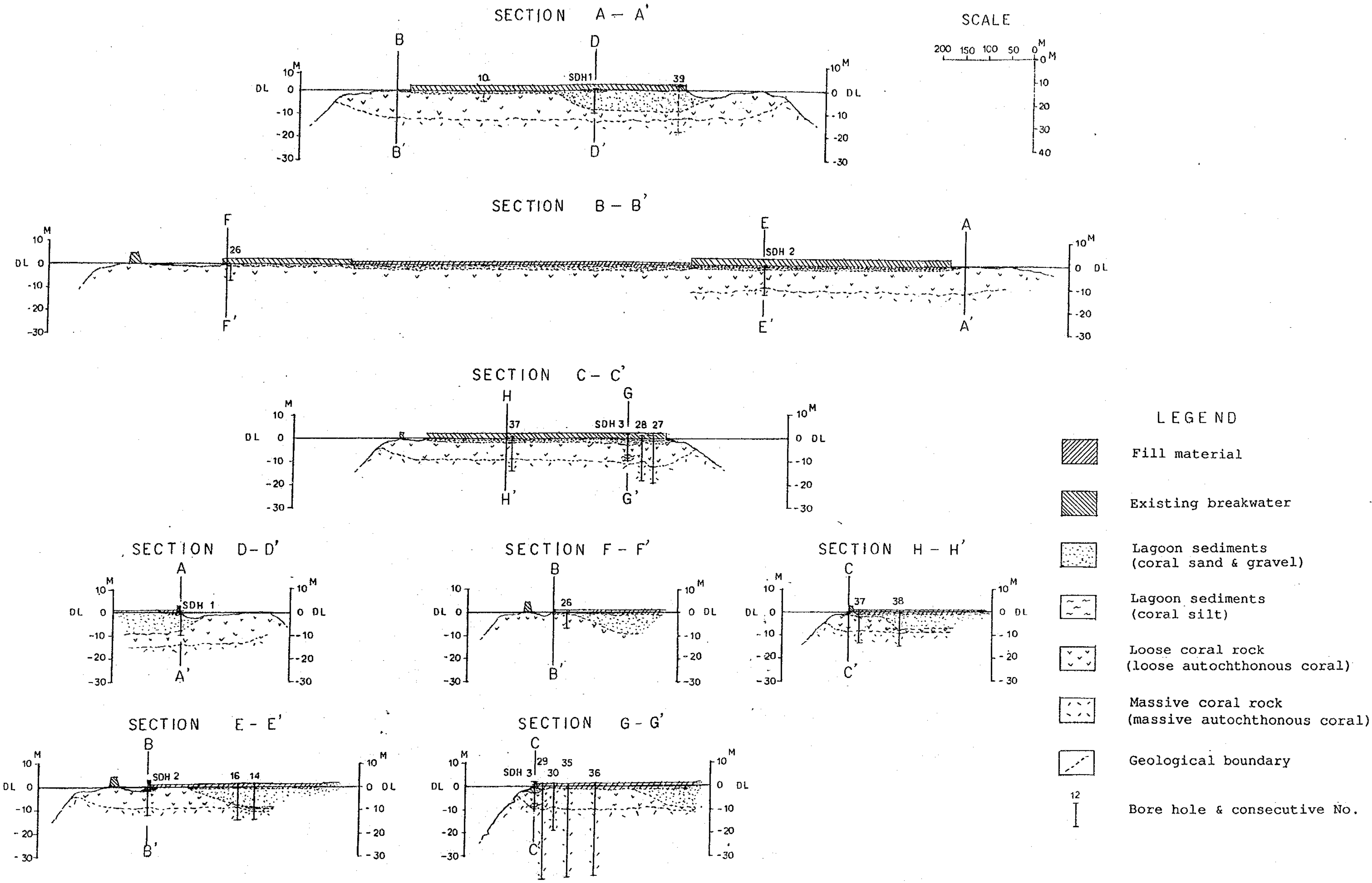


Figure 2.4.3 Geological Sections along the proposed Seawall Alignments and their Cross Sections

Table 2.8.5 The Results of Unconfined Compression Test and Unit Weight Test on the Coarse Aggregate Samples from the Existing Breakwaters and the Dredged Coral Samples

Sample No.	Sample		Locality	Unconfined Compressive Strength kgf/cm²	Strain at Failure %	Water Content in Percent of Dry Weight %	Unit Weight Paraffin Method g/cm³
E- 1	Coral Coarse aggregate from the existing breakwater	Bee hive-like coral	80m west from SDH2 position	6.4	2.50	17.3	1.08
E- 2		Massive porous coral	do	34.7	3.80	12.6	2.19
E- 3		Massive coral	SDH3, 0.88 ~1.00m depth in the existing breakwater body	56.1	5.00	31.9	1.93
E- 4		Bee hive-like coral	SDH3, 2.28 ~2.50m depth in the existing breakwater body	20.1	2.16	21.6	1.81
E- 5		Massive porous coral	10m south from SDH3 position	48.2	3.03	19.4	1.93
R- 1	Dredged coral Lump sample before screening	Bee hive-like coral	Taken by the domestic harbour dredging	9.5	1.11	1.9	1.85
R- 2		Massive coral	do	74.5	3.42	0.6	1.46
R- 3		Bar-like coral	do	135.5	4.93	1.2	2.25
R- 4		do	do	82.0	3.09	6.0	2.39
R- 5		Massive porous coral	do	31.2	3.62	6.5	1.98
R- 6	Dredged coral sample (40~100m/m in size) after screening	Bee hive-like coral	do	13.8	2.83	7.6	1.66
R- 7		Massive coral	do	46.6	3.79	0.6	1.74
R- 8		Bar-like coral	do	48.4	2.22	1.6	2.18
R- 9		do	do	57.6	3.13	1.8	2.35
R-10		Massive porous coral	do	47.3	4.42	2.0	2.10

(5) Material Tests

a) Sample

Five coarse aggregate samples were taken from the concrete body of the existing breakwaters. Ten dredged coral lump samples were collected at the pile area of the domestic harbour. The unconfined compression test and the unit weight test concerning the above-mentioned fifteen samples were carried out in accordance with JIS and test standards based thereon, at a laboratory in Singapore.

Seven dredged coral sand samples for fine aggregate were collected at the same stock pile area. Three river sand samples for fine aggregate imported from Lumut Port in Malaysia, were collected at the stock pile area of the tetrapod plant. The grading analysis and the specific gravity test for the above-mentioned ten samples were conducted in accordance with the test standards based on JIS at the same laboratory.

b) The Coral Coarse Aggregate Samples taken from the Existing Breakwaters

All the coral coarse aggregate samples taken from the existing breakwater are not suitable for structural coarse aggregates, because of "soft rock", lower unit weight and higher adsorption as compared with JIS A 5005 for "crushed stone for concrete". However, the coral coarse aggregate is suitable for use as fill material for the proposed seawall.

c) The Dredged Coral Lump Samples for Coarse Aggregate

All the dredged coral lump samples are not suitable for structural coarse aggregates, by reason of "soft rock" and lower unit weight as compared with JIS A 5005 for "crushed stone for concrete". However, the coral coarse aggregates are suitable for use as fill material for the proposed seawall.

d) The Dredged Coral Sand Samples for Fine Aggregate

All the dredged coral lump samples are not suitable for fine aggregate for concrete, because of "softer grain" and lower specific gravity in comparison with the river sand.

Table 2.8.6 The Results of Grading Analysis and Specific Gravity Test on the Dredged Coral Sand Samples and the River Sand Samples

Sample No.	Sample	Locality	Grading Analysis			Specific Gravity g/cm^3	Absorption %
			Median Grain size m/m	Coefficient of Uniformity	Coefficient of Curvature		
S- 1	Dredged coral sand (before screening)	taken by the domestic harbour dredging	0.64	4.3	0.93	2.51	0.3
S- 2	do	do	0.66	4.1	0.98	2.51	0.3
S- 3	do	do	0.54	3.9	0.70	2.55	0.3
S- 4	do	do	0.85	4.6	1.10	2.49	0.5
S- 5	Dredged coral sand (under 5m/m in size)	do	0.78	4.1	0.97	2.49	0.2
S- 6	do	do	0.76	4.1	0.94	2.47	0.5
S- 7	do	do	0.73	3.9	0.95	2.49	0.3
Average			0.71	4.1	0.94	2.50	0.3
S- 8	River sand (under 5m/m in size)	imported from Lumut Port, Malaysia	0.89	2.6	0.95	2.60	0.3
S- 9	do	do	0.90	3.1	0.85	2.61	0.3
S-10	do	do	0.80	2.6	1.04	2.61	0.2
Average			0.86	2.8	0.95	2.61	0.3

Note : Median grain size(m/m); 50% grain size(D_{50})
10% grain size(D_{10}), 30% grain size(D_{30}),
60% grain size(D_{60})

Coefficient of uniformity; D_{60}/D_{10}
Coefficient of curvature ;$(D_{30})^2/D_{10} \times D_{60}$

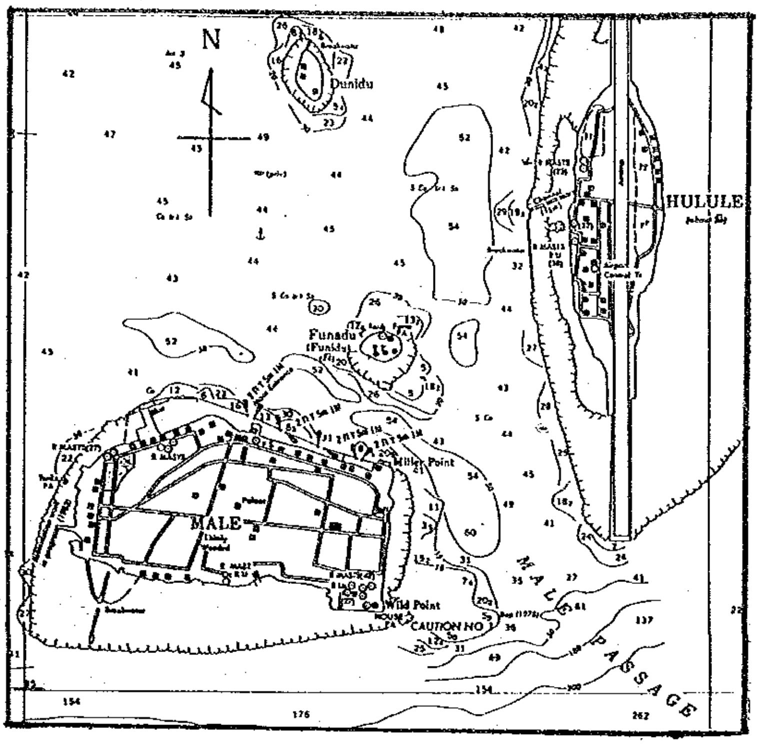
2.5 Meteorological Information

In order to understand the characteristics of meteorological conditions around Male' Island, the following items are summarized statistically using the data obtained from January 1986 to December 1990 at Hulule Island by the Weather Center in the Department of Meteorology;

(a) Frequency Distribution of Wind Speed and Wind Direction,
(b) Wind Rose,
(c) Frequency of Specific Strong Wind Speed,
(d) Frequency of Precipitation,
(e) Monthly Distribution of Maximum and Minimum Temperature.

(1) Wind Condition

Figure 2.5.1 to 2.5.3 represent the directional distribution of all winds and strong winds. Winds from the west (W) and the north west (NW) and winds from the north east (NE) and the east north east (ENE) are predominant throughout the year. From the view point of seasonal changes, winds from the north east (NE) and the eastern north east (ENE) are predominant during December to February. Winds during March to April vary in their direction in a wide range. Winds from between the west south west (WSW) and the west north west (WNW) are predominant during May to June. During the period of July to October, winds from the north west (NW) increase and winds from between the west (W) and the north west (NW) dominate, whereas winds from the west south west (WSW) decrease. Winds from the west (W) blow frequently in November, but the direction begins to vary. According to the above characteristics, it is understood that the north-east monsoon appears during December to February and the south-west monsoon during May to October, and the remaining periods during March to April and November are the transient seasons.



YEAR

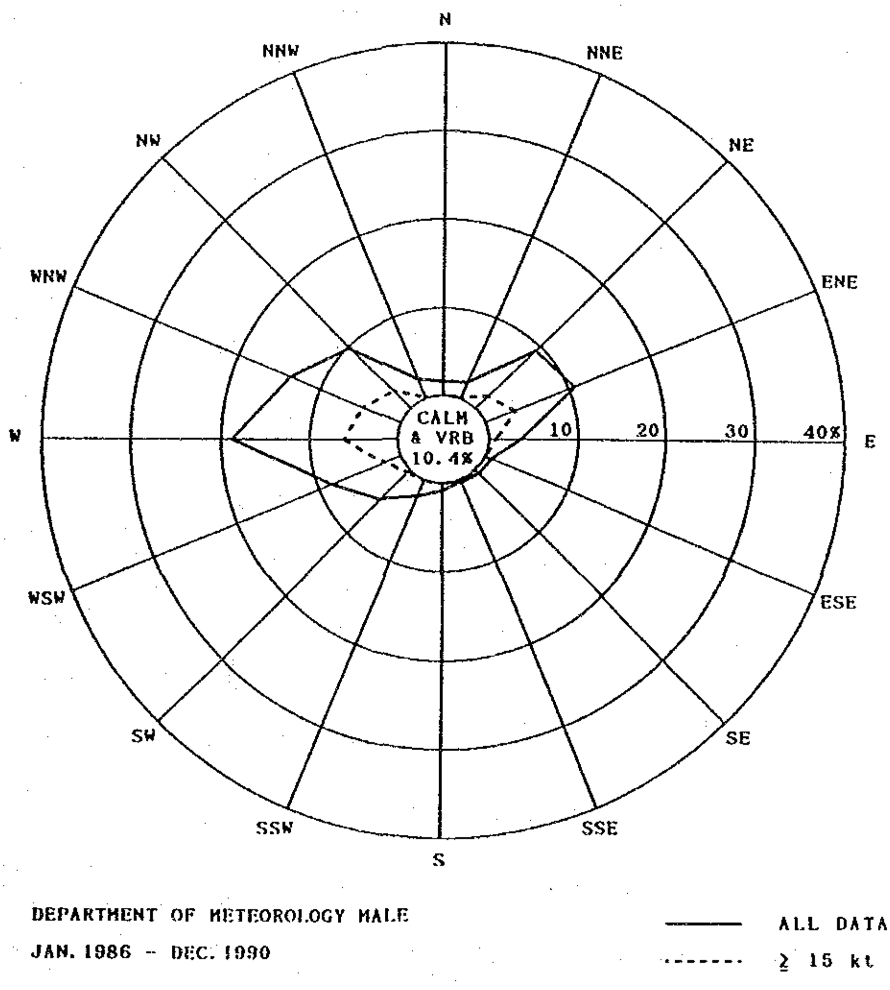


Figure 2.5.1 Wind Rose (all data from Jan. 1986 ~ Dec. 1990)

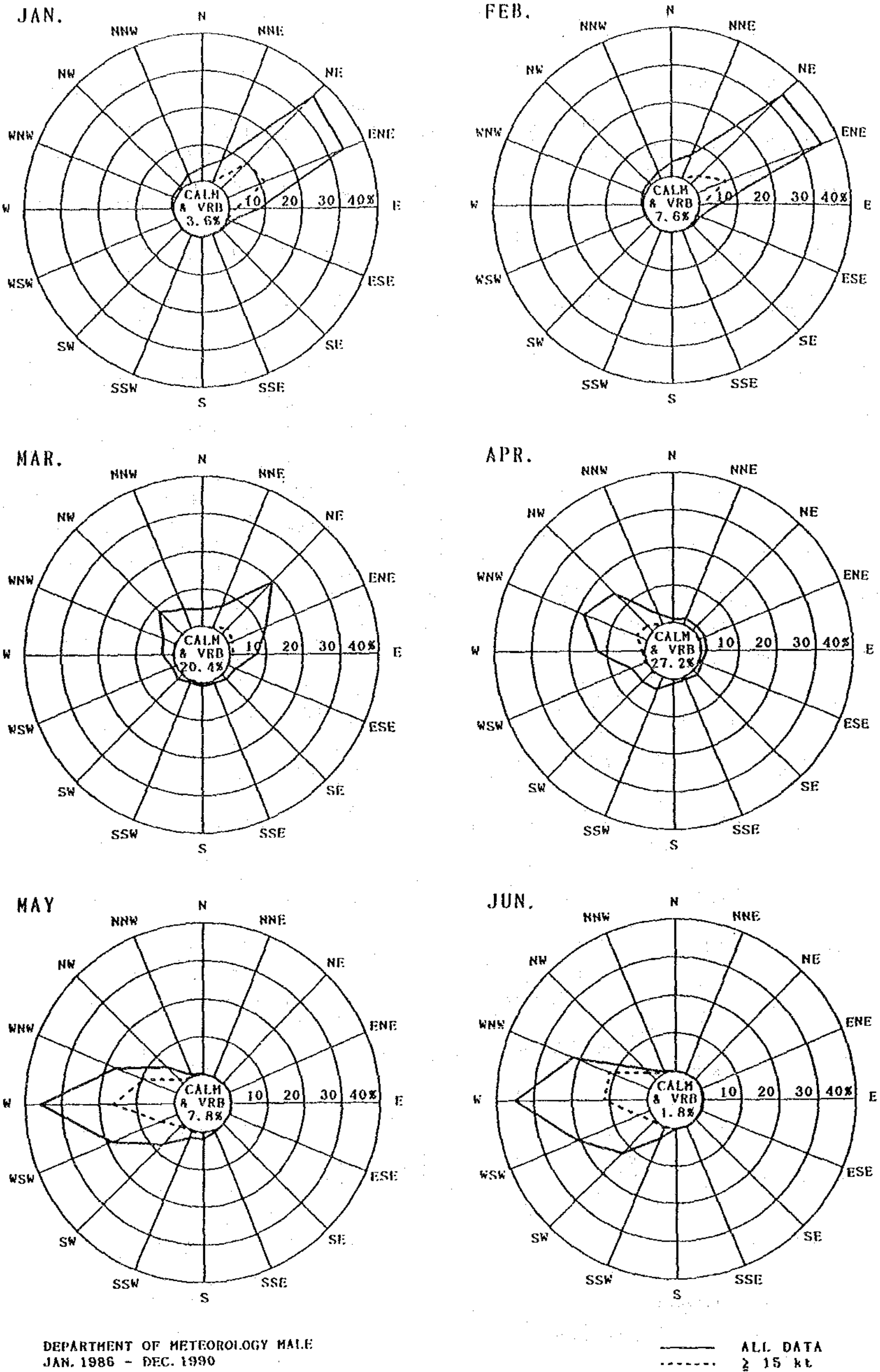


Figure 2.5.2 Monthly Wind Rose (Jan. ~ Jun.)

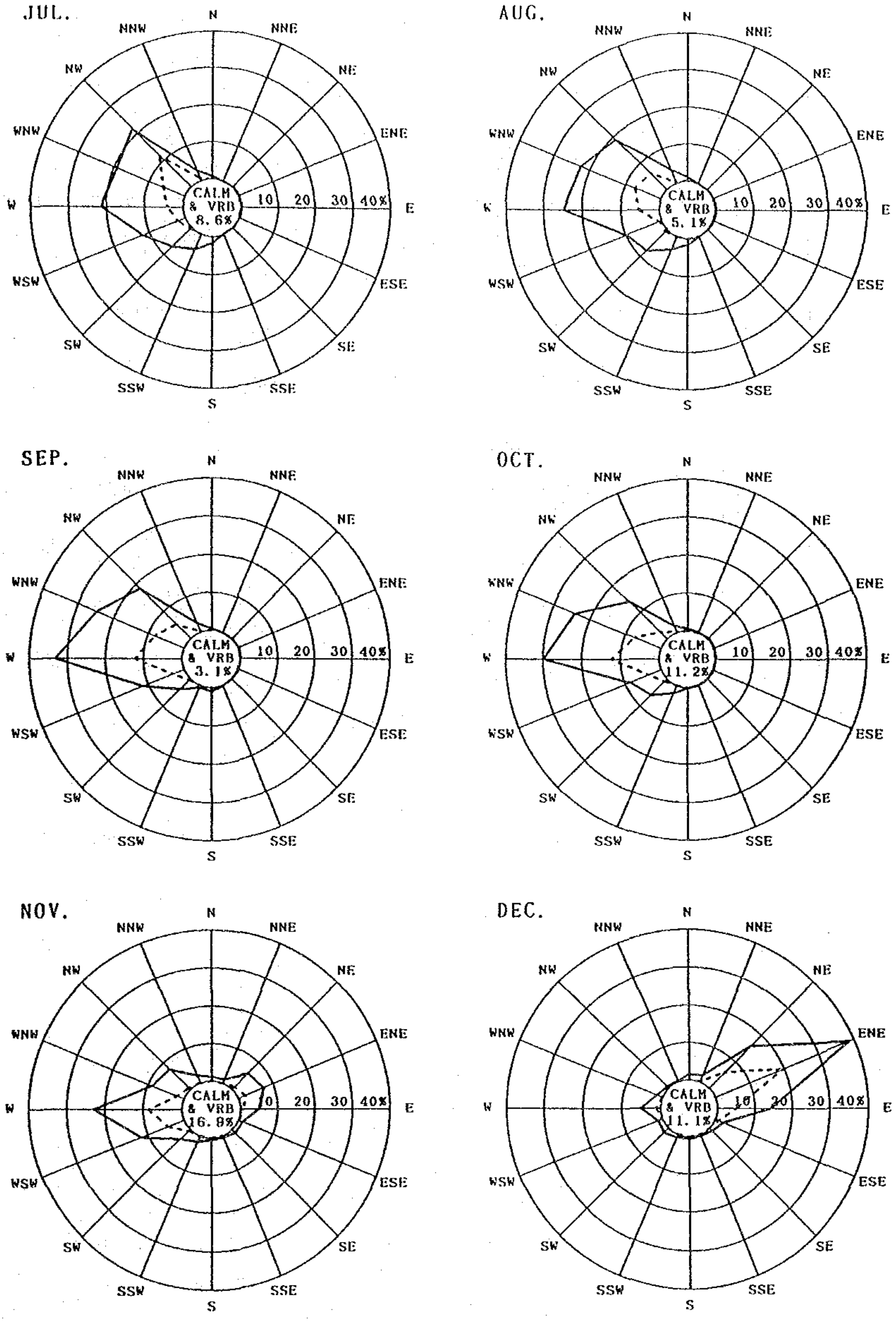


Figure 2.5.3 Monthly Wind Rose (Jul. ~ Dec.)

(2) Precipitation

Monthly average precipitation amount is presented in Table 2.5.1 and Figure 2.5.4 using the five year data from the Department of Meteorology. The amount of rainfall in February, March and July is relatively little, but the amount in December is the most predominant throughout the year.

(3) Temperature

Maximum and minimum temperatures from daily records during the five years from 1986 to 1990 are presented for each month in Table 2.5.2 and Figure 2.5.5. The maximum temperatures for each month are approximately 31 °C and do not vary so widely for each month. The difference between maximum and minimum is almost constant at about 5 °C throughout the year.

Table 2.5.1 Monthly Precipitation Amount

	1986	1987	1988	1989	1990	5 years
JAN	2.6	344.5	1.0	148.4	0.5	99.4
FEB	52.9	2.6	36.1	20.6	39.6	30.4
MAR	117.2	28.5	67.1	Tr.	87.9	60.1
APR	38.4	284.1	123.1	104.8	74.6	125.0
MAY	122.2	163.6	165.7	224.3	118.2	158.8
JUN	64.7	166.2	275.9	330.2	199.3	207.3
JUL	111.6	12.3	100.1	17.1	99.9	68.2
AUG	331.6	152.5	150.9	235.0	181.2	210.2
SEP	326.4	291.7	233.3	173.0	184.6	241.8
OCT	113.5	245.1	90.9	338.4	223.5	202.3
NOV	93.9	231.4	279.1	123.3	178.7	181.3
DEC	420.8	300.5	247.4	153.3	230.5	270.5
YEAR	1,795.8	2,223.0	1,770.6	1,868.4	1,618.5	1,855.3
MEAN	149.7	185.3	147.6	155.7	134.9	154.6

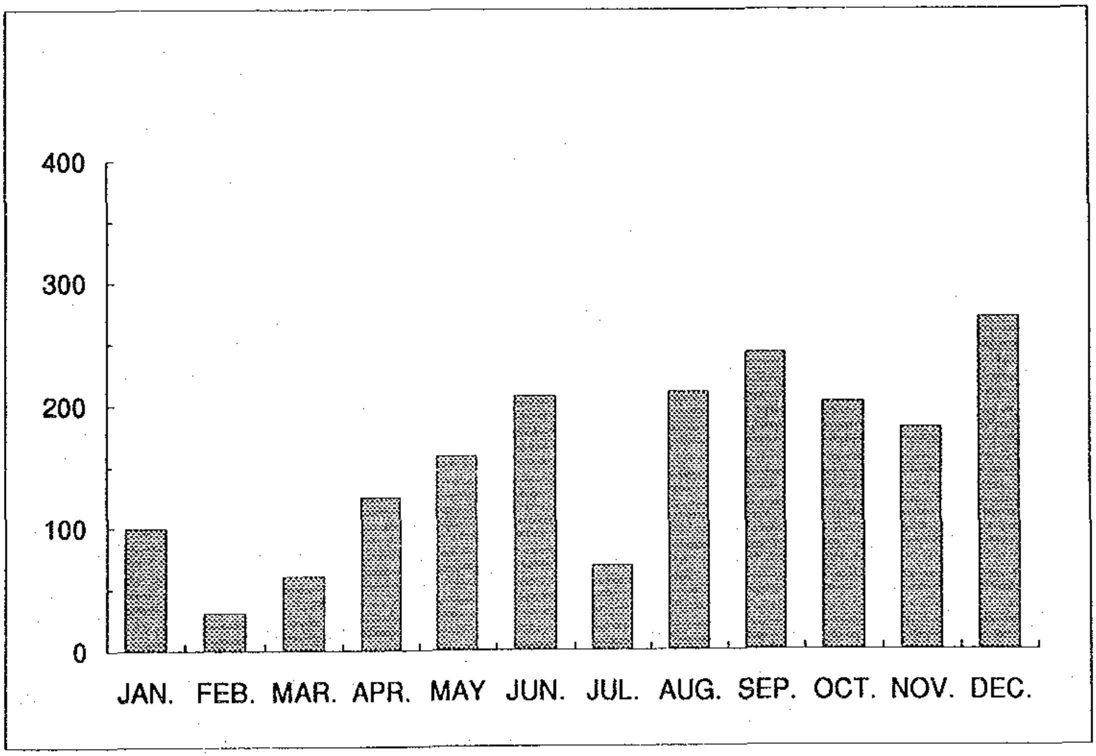


Figure 2.5.4 Monthly Distribution of Precipitation Amount

Table 2.5.2 Monthly Maximum and Minimum Temperature

unit: °C

	1986		1987		1988		1989		1990		5 Years	
Month	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
JAN	30.3	25.8	30.0	25.2	31.1	26.4	29.9	25.0	30.4	26.1	30.3	25.7
FEB	30.9	25.9	30.9	25.7	31.1	25.7	30.6	25.3	31.0	26.3	30.9	25.8
MAR	30.8	25.6	31.8	26.4	31.9	26.6	31.3	25.1	31.6	26.3	31.5	26.0
APR	31.3	26.8	31.6	26.2	32.0	26.6	31.6	26.2	31.8	27.3	31.7	26.6
MAY	31.0	25.8	32.4	26.6	31.4	26.6	30.5	25.6	31.5	26.9	31.4	26.3
JUN	30.6	26.1	31.3	26.6	30.9	25.9	30.1	24.7	30.8	25.8	30.7	25.8
JUL	30.3	26.0	31.6	26.8	30.9	26.2	30.2	26.2	30.6	25.7	30.7	26.2
AUG	30.0	25.3	30.9	25.2	30.8	25.5	30.0	25.0	30.3	26.0	30.4	25.4
SEP	29.2	24.1	31.0	25.5	30.4	25.4	30.0	25.3	30.2	25.4	30.2	25.1
OCT	30.1	25.5	30.5	25.2	30.8	25.9	30.3	25.3	29.9	25.4	30.3	25.5
NOV	30.7	25.9	30.6	25.7	30.2	24.9	30.5	25.8	30.3	25.6	30.5	25.6
DEC	30.1	25.2	30.7	25.6	30.3	25.3	30.2	26.1	30.0	25.0	30.3	25.4
MEAN	30.4	25.7	31.1	25.9	31.0	25.9	30.4	25.5	30.7	26.0	30.7	25.8

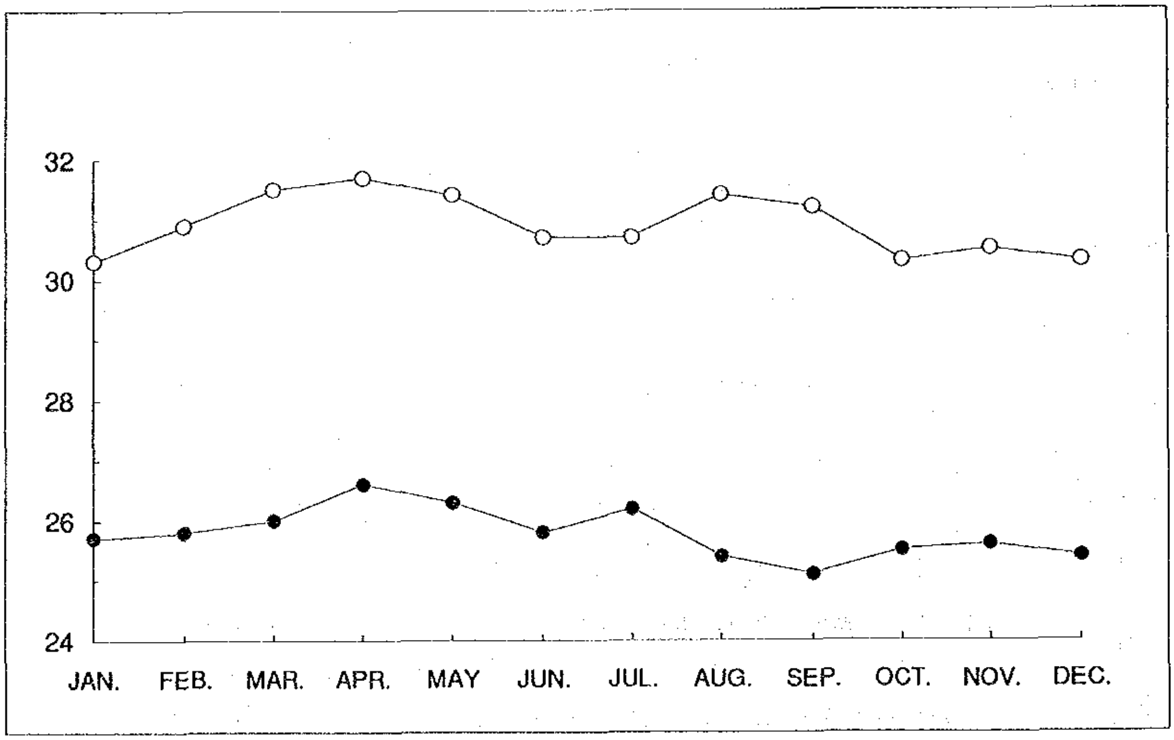


Figure 2.5.5 Monthly Distribution of Maximum and Minimum Temperature

2.6 Oceanographic Survey

(1) Observation Method

An oceanographic survey was carried out using instruments equipped with pressure type wave gage and electromagnetic current meter on the east, south and west coasts of Male' Island, respectively (Figure 2.6.1). The wave gage can measure a wave height and a wave period, and the current meter can measure the current speed and current direction. A wave direction can be calculated using the velocity of water particles induced by a wave.

The observation was conducted during the period from September 22nd to October 2nd on the east coast, from October 2nd to October 10th on the south coast and from October 10th to October 19th on the west coast, respectively. In addition, the instrument was installed at station No.0 which was located offshore in the southern part of the east coast in order to obtain the long term records for one year.

(2) Characteristics of Wave and Current

(a) South-East offshore Point (EAST No.0; Depth D.L. -20m)

Figure 2.6.2 and 2.6.4 represent the distribution of wave height and currents. Almost all data shows a wave height of 0.5 meter to 1 meter with a period of 10 seconds. It is understood that most waves propagating from the Indian Ocean come to Male' Island from the south east with a period of 10 seconds.

On the other hand, a maximum current speed of 96.7 cm/sec is recognized in January 1992. The direction of current is classified approximately into a west stream flowing in the west direction and a east stream flowing in the east direction. The west stream occurs at the time of the ebb stage (falling tide) and the east stream at the time of the flood stage (rising tide).

(b) East Coast (EAST No.1 ~ No.3)

Figures 2.6.3 and 2.6.4 represent the distribution of waves and currents based on the observed records on the reef flat of the east coast. Wave heights on the reef flat are considerably low compared with those of offshore waves due to the wave breaking close to the reef edge. The predominant wave direction changes counter-clockwise gradually from the south east (SE) at No.1 to the north (N) at

No.3. The change of wave direction is due to the refraction caused by the change of bottom topography in the nearshore region.

In regard to current, sea water flows uniformly in the north direction without any relationship to tide stage at all observation points. The water on the reef flat on the east coast is supposed to flow out of the reef flat into the offshore region throuth a reef gap at the north side. It is concluded that a predominant current on the reef flat on the east coast is a wave induced current, that is, "nearshore current" in the coastal engineering term.

(c) South Coast (SOUTH No.1 ~ No.3)

Figures 2.6.5 and 2.6.6 represent the distribution of wave and current based on the observed records on the south coast. The waves indicate low heights because the observation points are located inside the detached breakwaters. Station No.2 is located at the open area of two breakwaters and the wave heights are 30cm to 40cm higher than those of the other two stations which are sheltered from breakwaters.

The currents observed inside the breakwater denote relatively weak currents, but the predominant currents flow in the west direction along the dredged channel behind detached breakwaters.

(d) West Coast (WEST No.1 ~ No.3)

Figures 2.6.7 and 2.6.8 represent the distribution of wave and current based on the observed records on the west coast. Due to the calm sea conditions during the observation term, the observed wave heights are 20 cm to 30 cm. Judging from the long wave period of about 10 seconds and the incident direction from the south at station No.3, the wave is thought to be a refracted and diffracted swell propagating from the Indian Ocean.

The offshore current on the west coast flows predominantly to the south west (SW). Judging from the vector of current, the significant current on the west coast is thought not to be a nearshore current but a tidal current.

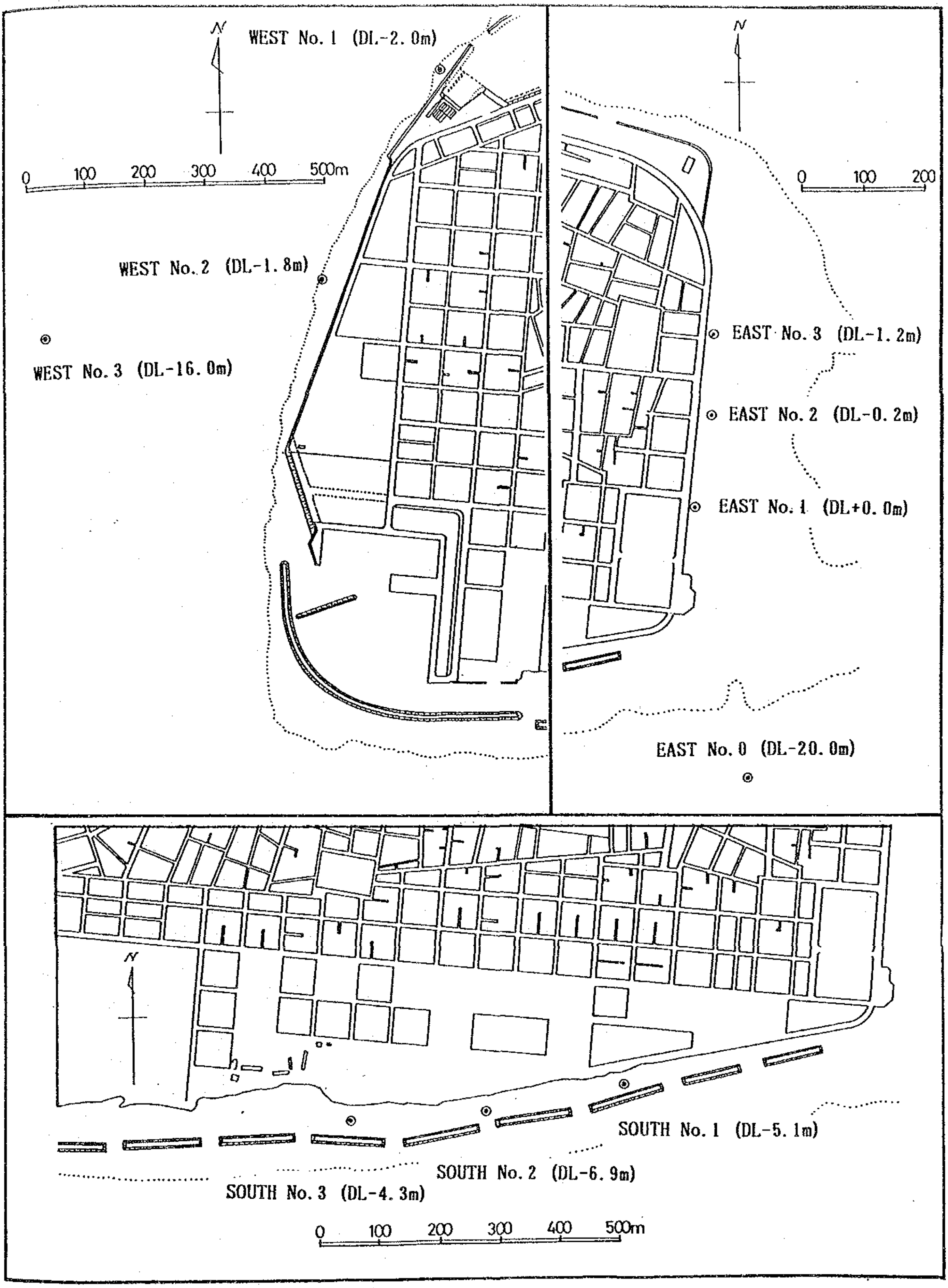
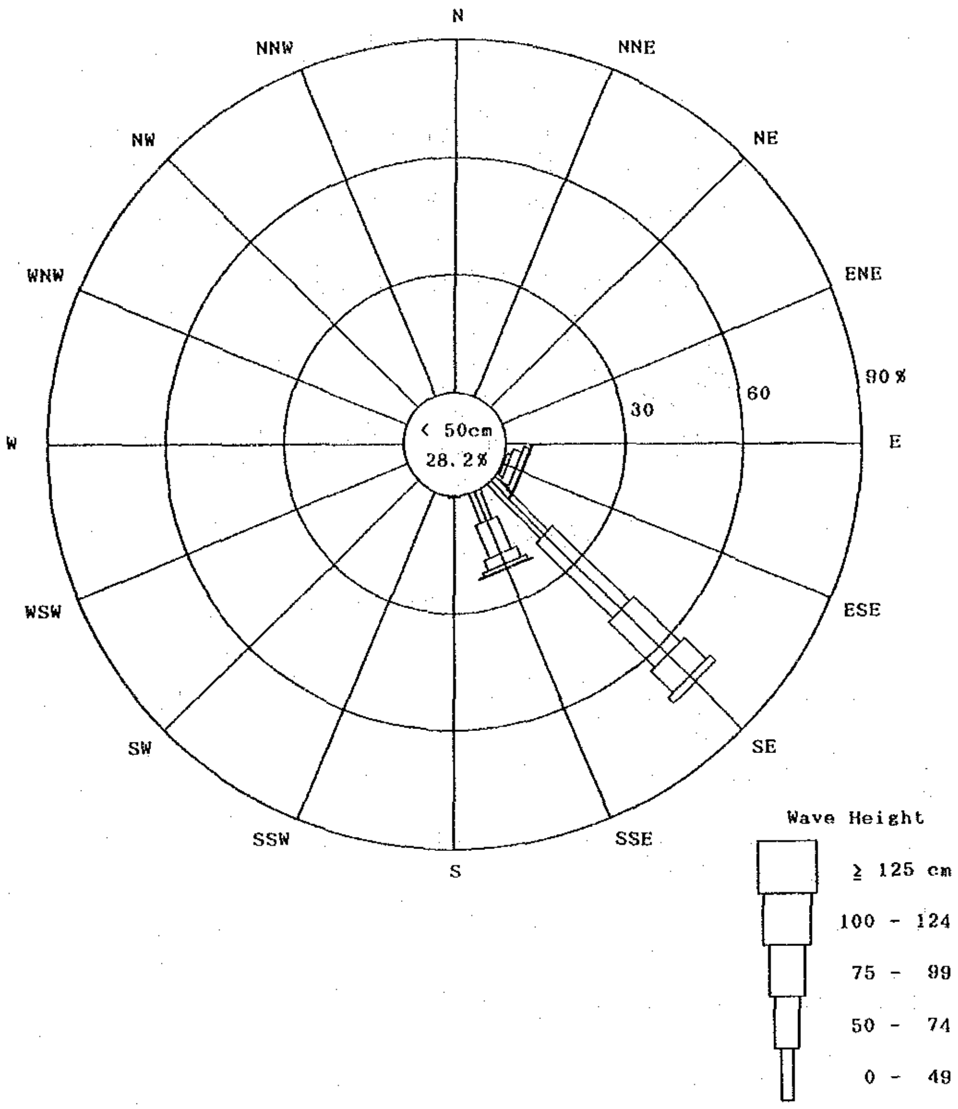


Figure 2.6.1 Location Map of Oceanographic Survey

All Terms (Oct. 1 1991 - Sep.30 1992)



Station : East No.0

Figure 2.6.2 Distribution of Wave Direction and Wave Height (EAST No.0)

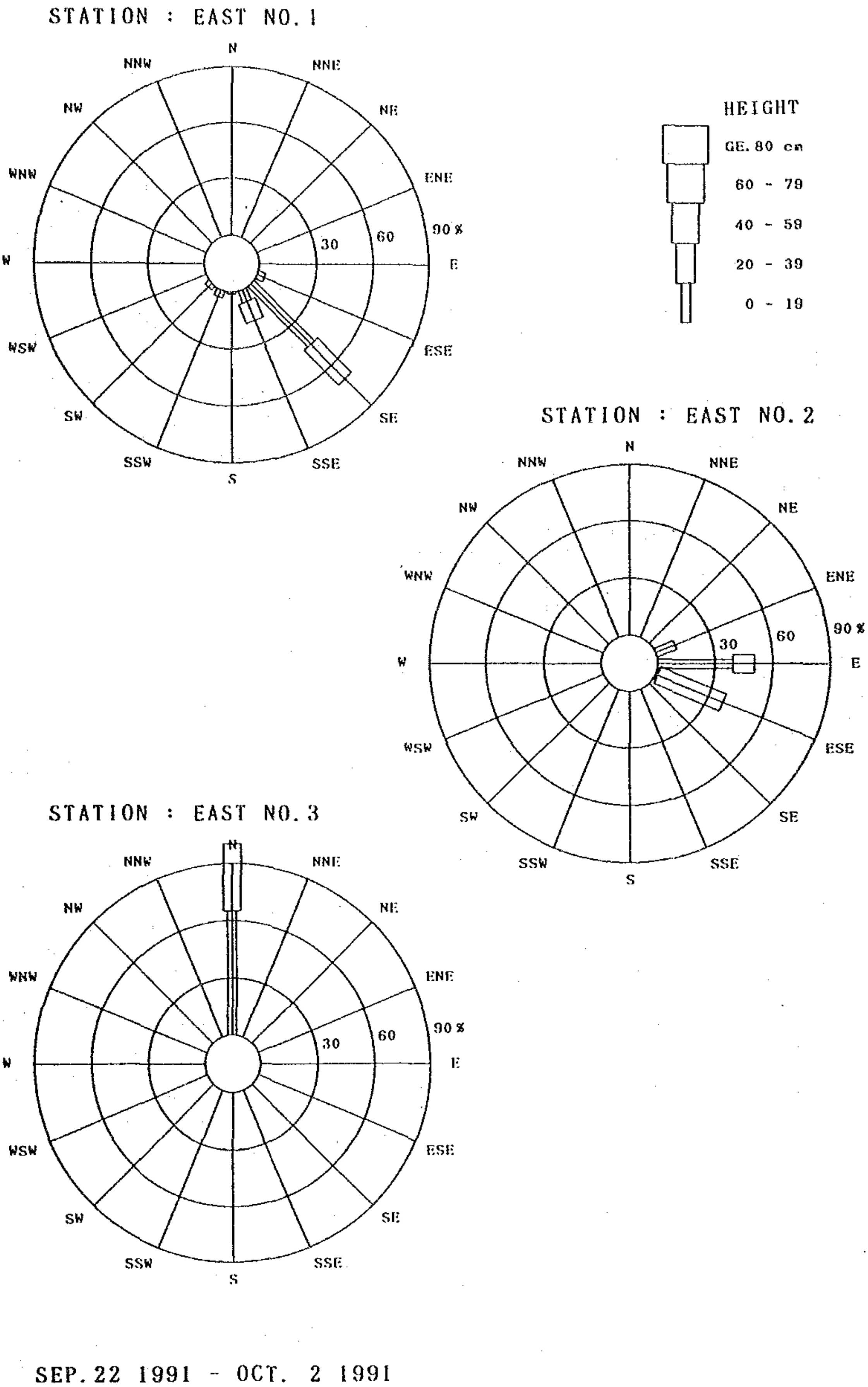


Figure 2.6.3 Distribution of Wave Direction and Wave Height (East Coast)

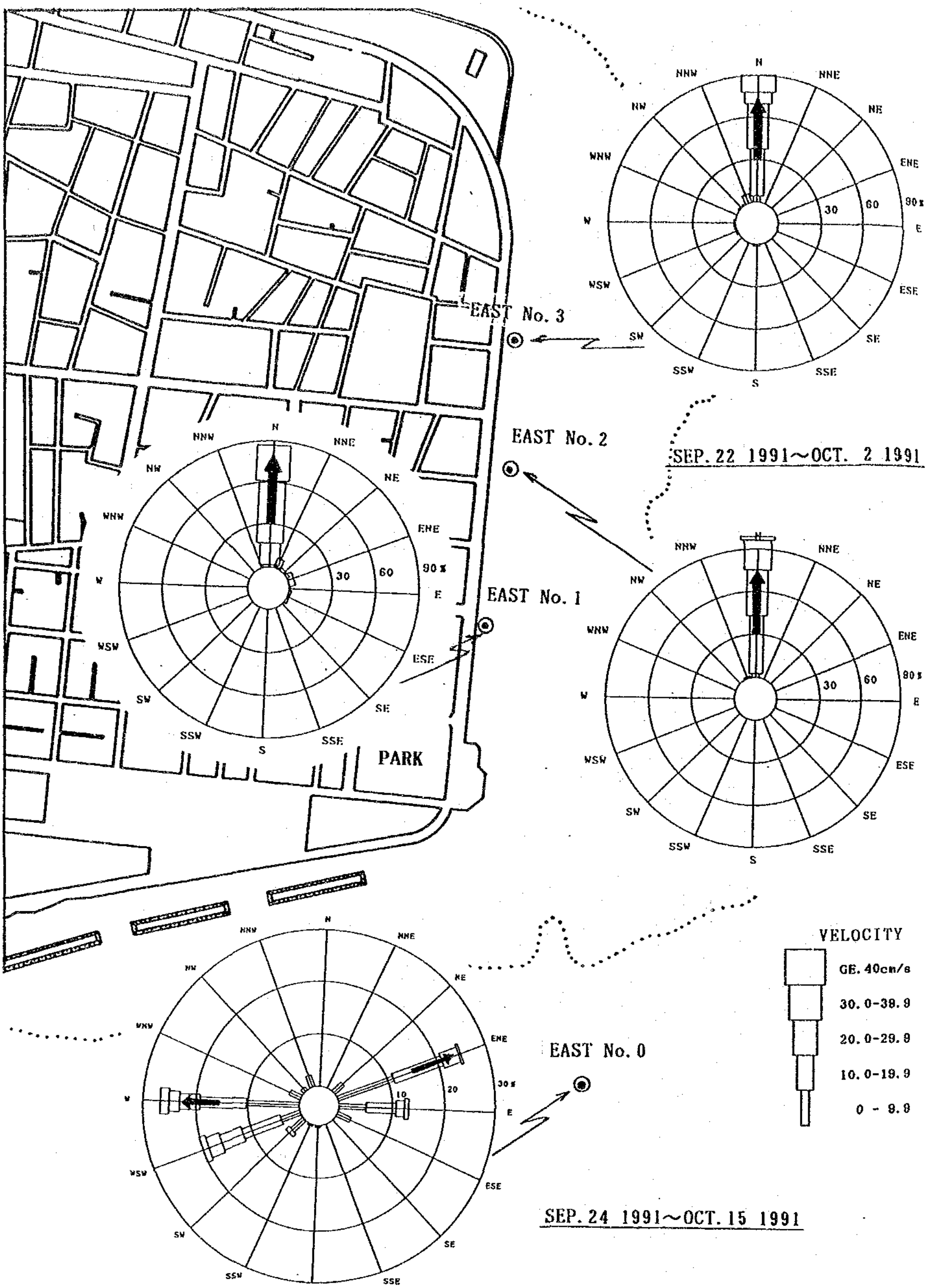


Figure 2.6.4 Distribution of Current (East Coast)

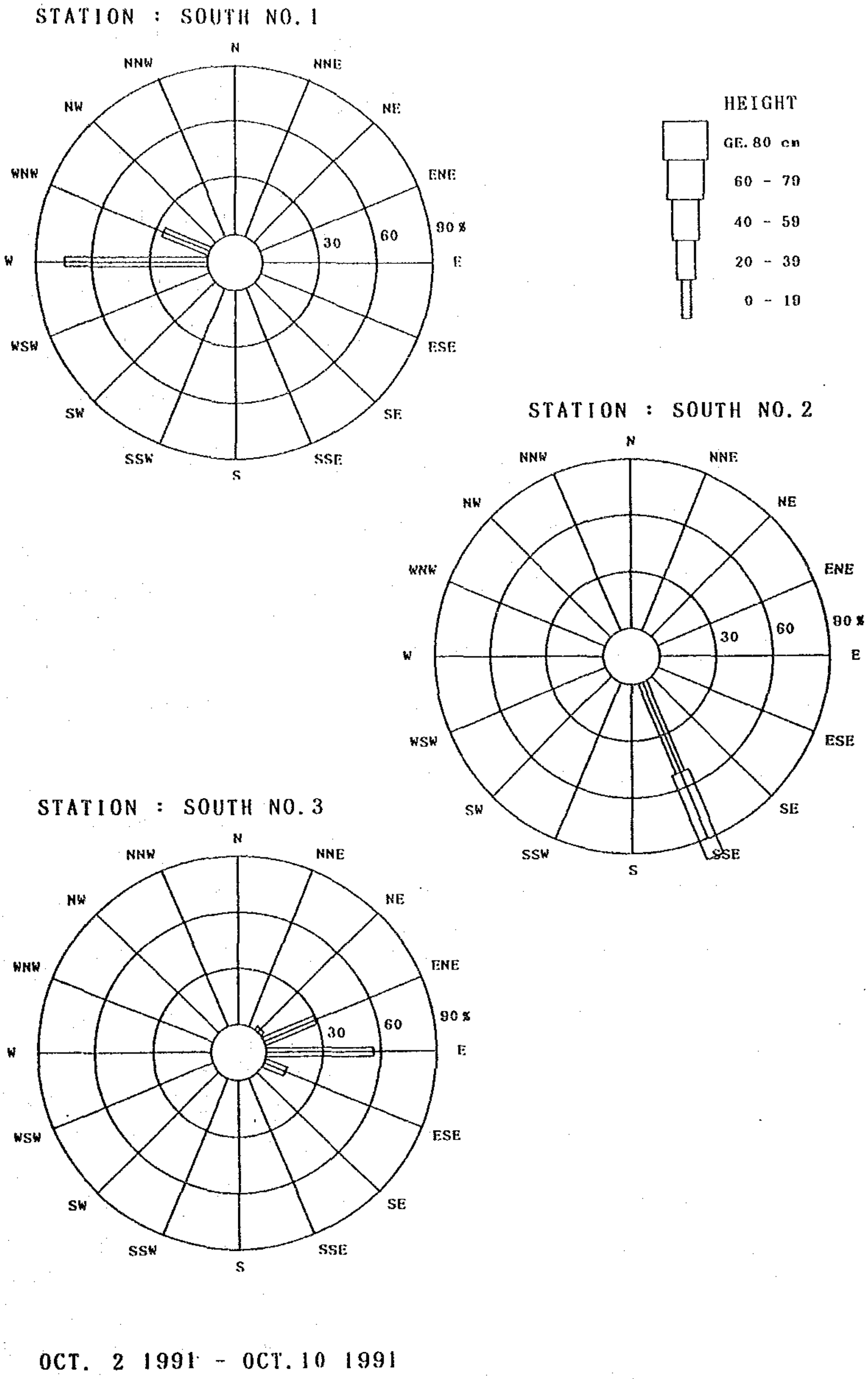


Figure 2.6.5 Distribution of Wave Direction and Wave Height (South Coast)

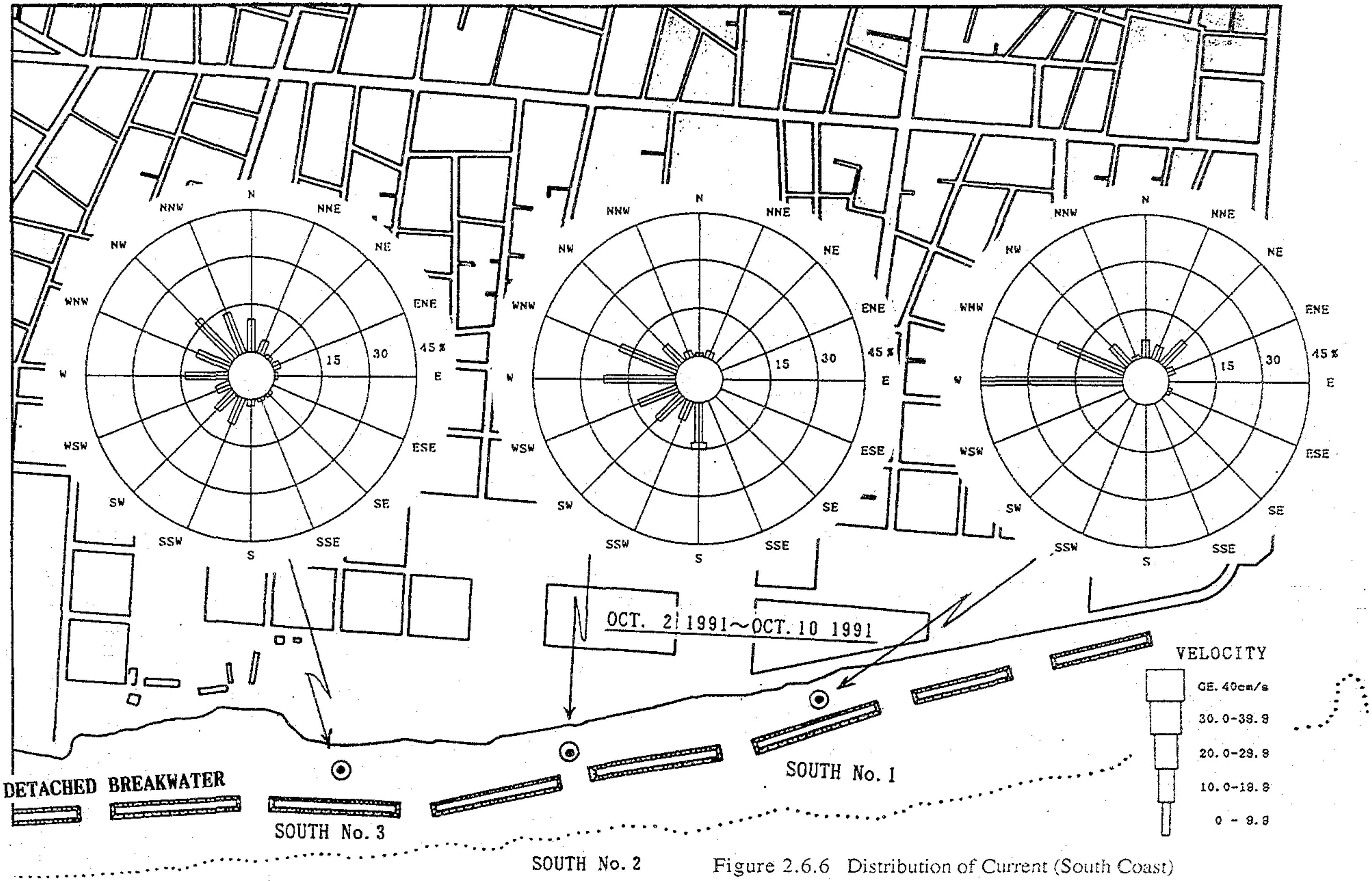
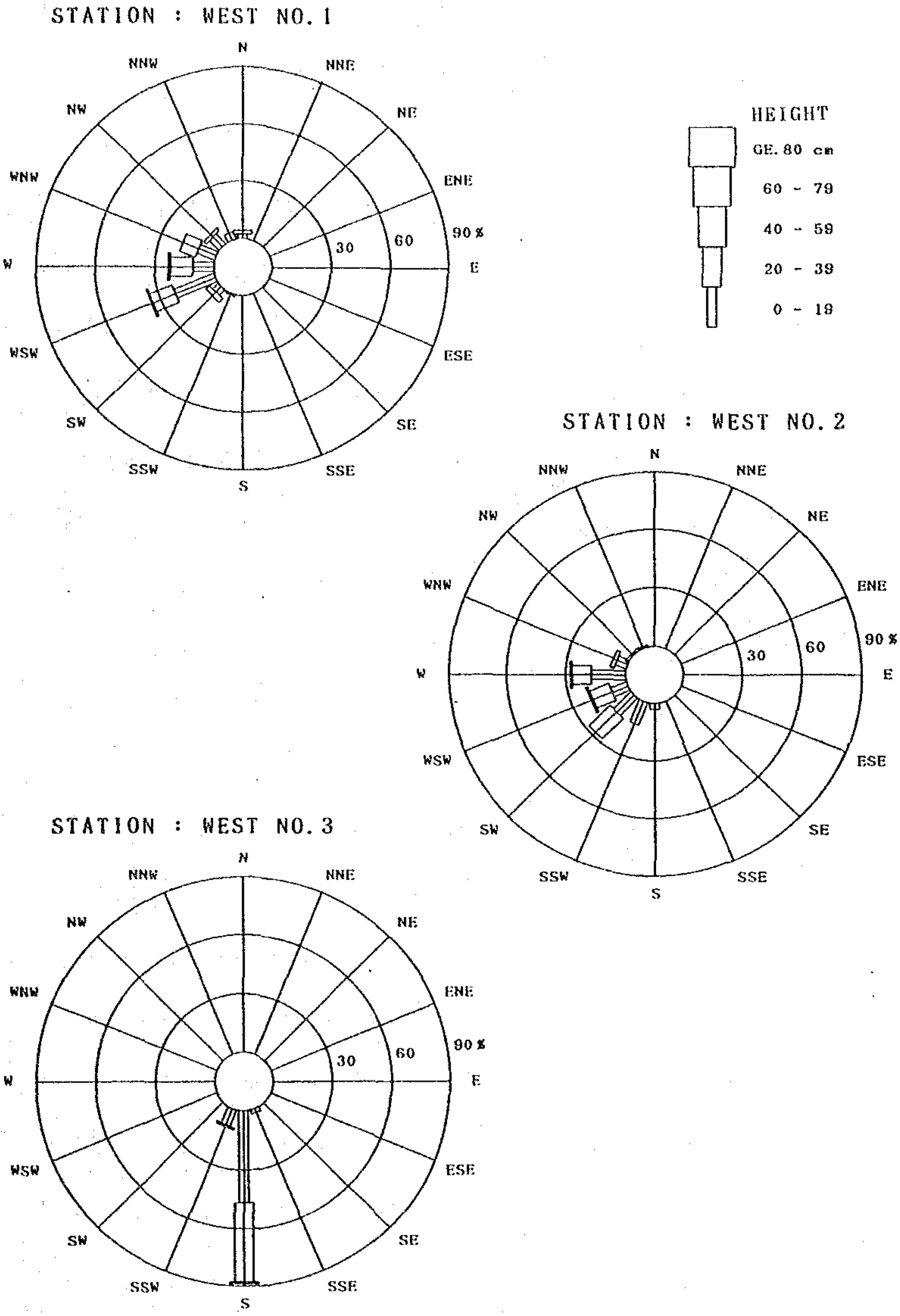


Figure 2.6.6 Distribution of Current (South Coast)



OCT. 10 1991 - OCT. 19 1991

Figure 2.6.7 Distribution of Wave Direction and Wave Height (West Coast)

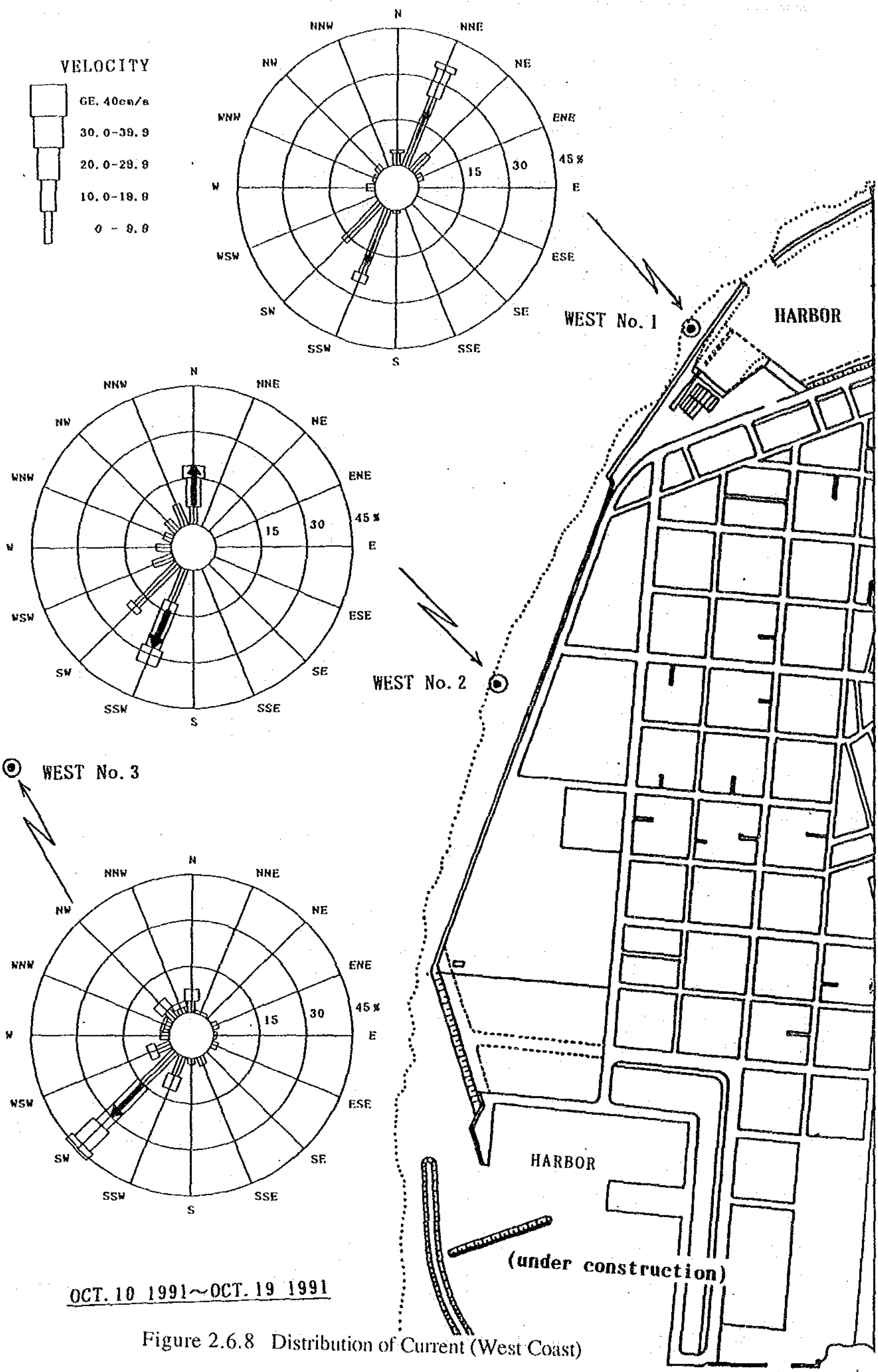


Figure 2.6.8 Distribution of Current (West Coast)

2.7 Existing Shore Protection Facilities

The existing shore protection facilities are shown schematically in Fig.2.7.1. The old seawalls were constructed on the east, west, north and south coasts and the structures are of coral rocks of 10 to 20 cm in diameter piled with its surface mortared or plastered as shown in Photo-13. They are generally obsolete having holes with the mortar deteriorated and the coral rocks dislodged, especially in the tidal zone. Along the back of the seawalls, the 5 m to 8 m wide road called the "Marine Drive" running around the island is provided.

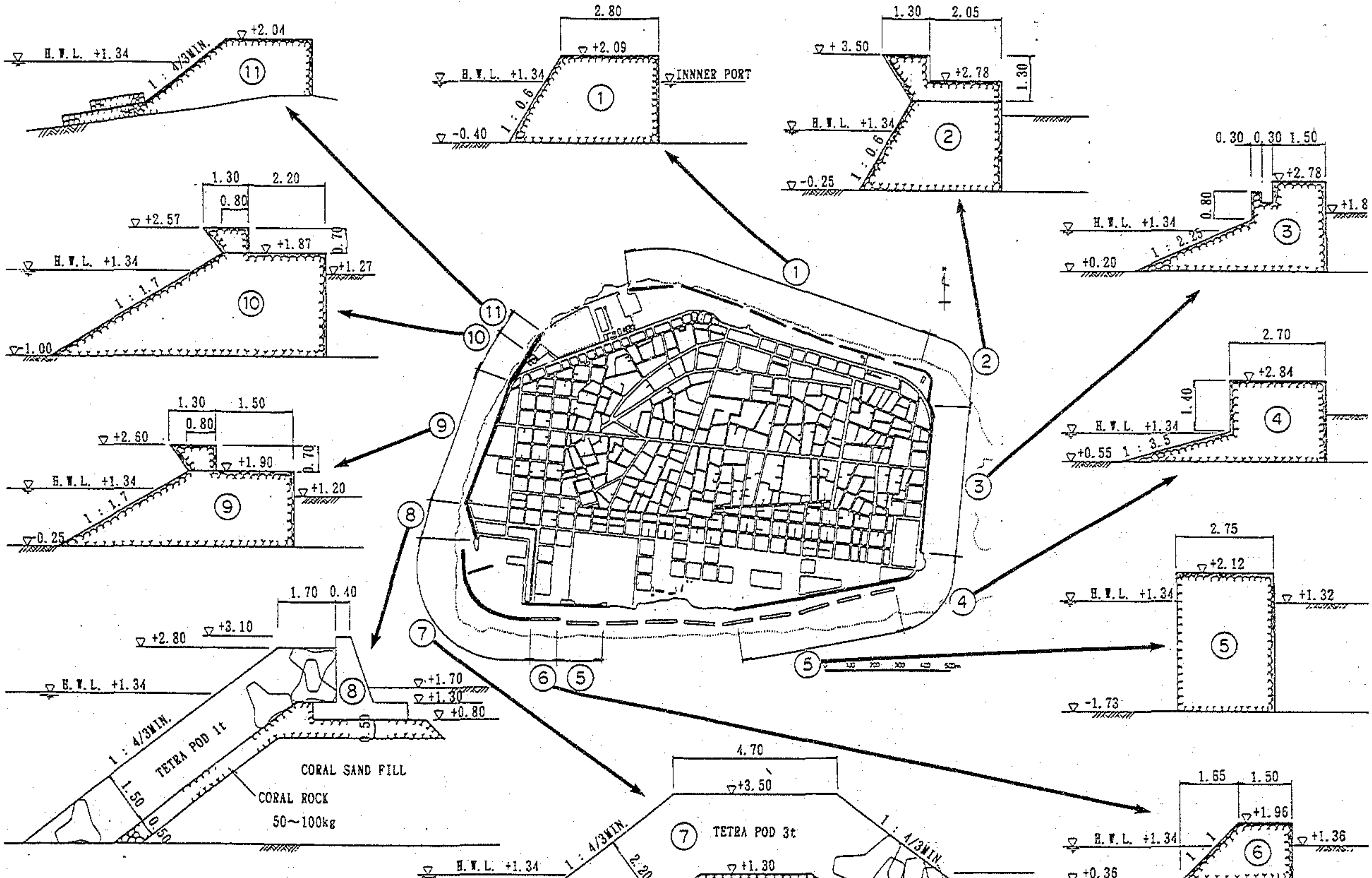
The commercial harbour and inter-island harbour are developed on the northern coast, sheltered by breakwaters and constructed along the coral reef edge. The breakwaters are the same type of structure as those of the seawalls on the northern coast. The seawalls on the northern coast are used for mooring and berthing small inter-island or pleasure boats. Those seawalls are now being reconstructed with a steel sheet pile wall.

The South-west harbour for inter-island boats is to be opened shortly. The harbour is protected by the breakwater and seawalls as shown in Fig.2.6.1.

Although no seawall is provided behind the Detached Breakwater in the southern coast, the Government is planning to provide new quaywalls enabling small boats to berth and load/unload their goods.

The approximate crown height of the seawalls and breakwaters is summarized as follows:

	Seawall (Quaywall)	Breakwater
East	+2.8	-
South	+2.1	+ 4.1
South-west	+3.1 (+1.8)	+ 3.5
West	+2.6	-
North	+2.0 (+1.8)	+ 2.1



Note : Existing seawalls except ⑦ and ⑧ are of coral rocks piled with its surface mortared or plastered.

Figure 2.7.1 Existing Shore Protection Facilities

Chapter 3. Shore Protection Planning

3.1 Basic Plan for Shore Protection

3.1.1 Approach

A flow chart of shore protection planning is presented in Figure 3.1.1. The determination of the shore protection plan requires an understanding of various kinds of coastal conditions, such as wave and tide characteristics, topographic configuration, coastal utilization, related development plans, demands from the local people and so on.

Waves approaching Male' Island were observed on the reef flat zone of the west, east and south coasts in the Seawall Project. On the other hand, long term observation of offshore waves around Male' Island was conducted by Lanka Hydraulic Institute and high waves incident from the south west, the north west and the south east directions were obtained by statistical analysis. Moreover, storm waves which caused severe disaster to Male' Island in April 1987 were investigated by Dr. Y. Goda and were made clear to be cyclone waves propagated from the western ocean of Australia.

Tidal level was examined by Hawaii University, Breakwater Project, Ministry of Public Works and Labor, and Port Project. A comparison between mutual tidal levels was made and a datum level the same as for Port Project was adopted in this Study.

A 50-year probability wave and a storm wave in 1987 coupled with a high tidal level was used in hydraulic model tests. Representative cross sections of shore protection facilities were introduced in hydraulic model tests taking into account design conditions such as requests from the Maldivian Government, related development plans and utilization of coastal area. A suitable crown height of a typical seawall was examined by physical model tests from view points of wave overtopping rate and wave runup heights. Influence of protection facilities by wave and currents to surrounding coasts was examined by numerical model tests. Finally, appropriate seawall plans for Male' Island were determined based on the results of model tests and empirical knowledge on coastal protection facilities.

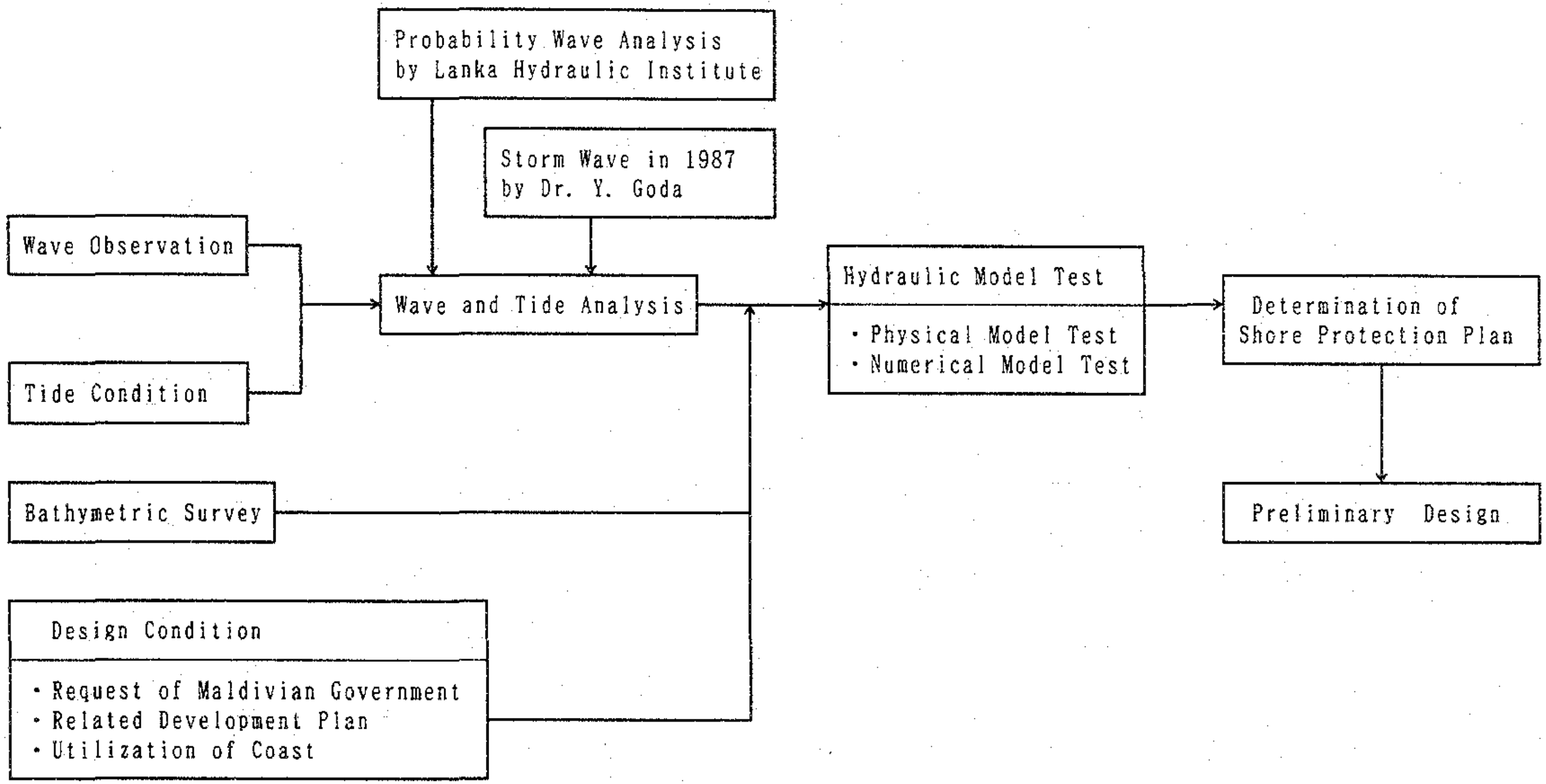
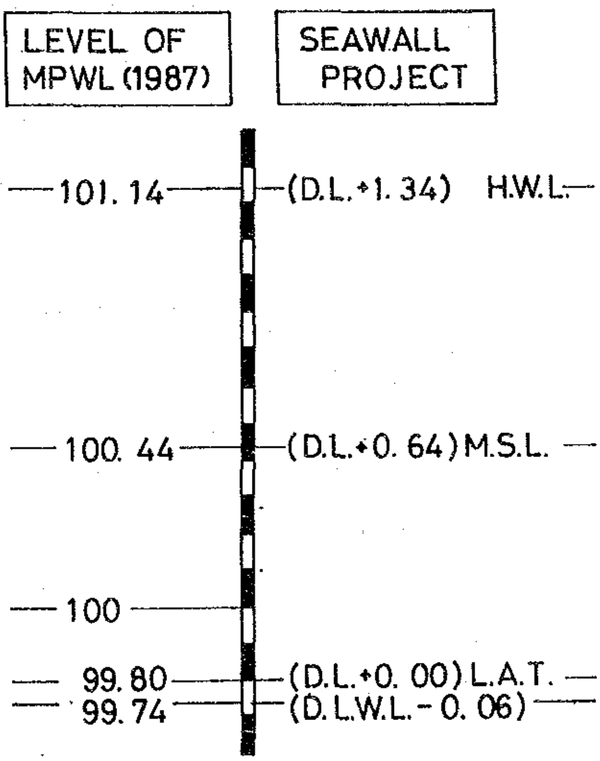


Figure 3.1.1 Flow Chart of Shore Protection Planning

Figure 3.1.2 Tidal Diagram



3.1.2 Design Criteria

The design criteria should be carefully determined because it affects the safety of coastal facilities, the security of its function and its economy. Taking into account the easy understanding of the underwater position or the on-land position and the connection of the port project, the seawall project will adopt the same datum line (D.L.) and tidal conditions as those of the port project. This datum line coincides with the level of 99.80 m in the Ministry of Public Works and Labor. Mean sea level (M.S.L.) is D.L. +0.64 m and an average high tide level at spring tide (H.W.L.) is D.L. +1.34 m as shown in Fig. 3.1.2.

Design High Water Level (D.H.W.L.) which is an important and fundamental criterion was determined by the results of hydraulic model tests on the south and east coasts. Furthermore, design offshore waves for each coast were determined based on the wave analysis by Lanka Hydraulic Institute and by Dr. Y. Goda (1988).

Final design wave coupled with the design high water level for each proposed facility on the west, east, south and north coasts were determined as follows:

(a) West Coast

- Offshore Design Wave: Ho = 1.2 m, T = 4.6 sec.
- D.H.W.L.: D.L. +1.34 m

(b) East Coast

- Offshore Design Wave: Ho = 3.0 m, T = 16 sec.
- D.H.W.L. in front of Proposed Facilities: D.L. +1.64 m
- Design Wave in front of Seawall: H = 1.3 m, T = 16 sec.

(c) South Coast

- Offshore Design Wave: Ho = 3.0 m, T = 16 sec.
- Design Wave in front of Quaywall: H = 0.7 m, T = 6 sec.
- D.H.W.L. in front of Quaywall: D.L. +1.63 m

(d) North Coast

- Offshore Design Wave: Ho = 0.6 m, T = 4.6 sec.
- D.H.W.L.: D.L. +1.34 m

3.1.3 Basic Policy for Shore Protection

For the convenience of shore protection planning, the coast of Male' Island is divided largely into four coasts. Moreover, each coast is divided into regions on the basis of geographical features as shown in Figure 3.1.3. From the view point of shore protection against storm waves, the east, south and west coasts have experienced high wave attacks several times accompanied by flooding in the hinterland area. Therefore, the above three coasts would have the priority for shore protection works.

Requests from the Government of Maldives should be taken into consideration for the convenience of local people's activities. The main requests concerned with shore protection planning are as follows:

(1) to reduce the crown elevation of the seawall to such an extent that the sea horizon is visible,

(2) to maintain a recreational function on the southern part of the east coast since this area is the only location in Male' where sea bathing, swimming and surfing are practised by the local people,

(3) to improve the existing seawall on the south coast as a quaywall for small boats because the Government has a plan to develop harbor facilities in this area,

(4) to provide enough space behind the seawall and the quaywall for a marine drive road of 10.5 meters width on the west, east and south coasts,

(5) to provide a drainage system behind the seawall,

(6) to make a plan of the seawall on the northern part of east coast under the condition of land reclamation which will be prepared and implemented by the Government of Maldives.

The following is the basic consideration for shore protection plans on the east, south and west coasts.

(a) West Coast

A little high wind wave from the west direction causes wave over-topping on the existing seawall. Taking into consideration that important structures such as the social education center, the school and a hospital located nearby the existing seawall, shore protection facilities with armor blocks in front of a reinforced seawall could be proposed on the west coast. Furthermore, the extension plan of the road along the seaside is desirable to be included in the west seawall plan. As the above seawall would be influenced largely by the restriction of the reef flat width, an examination by a physical model is vital in order to propose an appropriate plan. According to the results of the physical model, the reef flat width could be too narrow to set enough armor blocks in front of the seawall in Region B. The existing seawall in Region B could be obliged to retreat in the inland direction several meters from the present position. In addition, as several notches on the bottom slope in the west coast were discovered by the survey, the retreating of the seawall in Region B would be preferable for the safety of the proposed facilities.

The fundamental plans in the west coast are as follows:

Region A :	Seawall with armor blocks,
Region B :	Retreated seawall with armor blocks.

(b) East Coast

Wind waves from the north west and refracted swells from the south east travel to Region A on the east coast. Due to the existence of Funadhoo and Hulule islands, and the direction of coast line, the sea condition in Region A is generally assumed to be calm. On the other hand, a relatively high swell reduces in height rapidly due to breaking on the reef edge in Region B and C. As the wave crest on the reef flat is almost parallel to the distribution of reef edge in these regions, the longshore faceline of the proposed seawall should be parallel to the distribution of reef edge in order to avoid the convergence of wave energy or the stagnation of currents. The separation of Region C from Region B is judged from the difference of incident wave crests in both regions.

The government of Maldives has a plan for athletic facilities such as a swimming pool on the east coast. Considering the importance and the realization of the plan, the seawall on the east coast will be proposed allowing for the athletic plan at present. It is preferable to locate reclamation for the athletic area in Region B because of the severity of incident waves.

There is no natural shoreline in Male' for recreation like sea bathing and so on because of the reclamation year by year. Region C is the only remaining area of marine recreation for the local people in Male'. Recreation facilities such as an artificial beach could be proposed in Region C.
The fundamental plan on the east coast are as follows:

Region A: seawall,
Region B: seawall with armour blocks at the foot of the wall,
Region C: artificial beach with accessible seawall.

(c) South Coast

The south coast is sufficiently protected by the detached breakwaters against storm high waves. It would be enough to construct a strong seawall in the same position as the existing one in Region A. Based on the harbour plan of the government on the south coast, a quaywall could be proposed in Region B taking into account the wave condition for loading or unloading as a small boat harbor.

The fundamental plans in the south coast are as follows:

Region A: seawall,
Region B: quaywall.

(d) Priority of Shore Protection Facilities

From the urgency of establishing shore protection facilities against high wave attacks, the high priority for construction works would be given to the west, east, south and north coast in this order.

3.1.4 Possible Alternative Plan

(1) Faceline of Shore Protection Facility

Based on the characteristics of coastal conditions, the future plans and demands of the Government of Maldives, the plan layout of shore protection facilities on the east, south and west coasts will be proposed in this section. The layout of facilities on the north coast, however, is omitted because the existing breakwaters are to be reinforced at the same location on this coast.

(a) West Coast

The plan layout of facilities is illustrated in Figure 3.1.4. As the reef flat extends in the southern part of this coast, the seawall is thought to be effective even if the position of the new seawall is several meters offshore from the present seawall position. As there is no reef flat adequate for seawall facilities in the northern part of this coast, the block mound type of seawall is necessary to be established at a position 7 to 8 meters inland from the present location.

(b) East Coast

The layout of facilities is shown in Figure 3.1.5. In the northern part of this coast, the proposed seawall is set up in front of the reclaimed land which will be filled by the Government of Maldives. The continuous seawall is allocated to be parallel to the distribution of the reef edge. In the southern part, the sandy beach coupled with a step type of seawall and two groins is allocated to prevent refracted incident waves from running up directly to the seawall and flushing the filled sand out of this region. Moreover, in the southern part adjacent to the proposed sandy beach a block mound type of seawall is allocated because relatively high waves always attack and run up to the present seawall.

(c) South Coast

The layout of facilities on the south coast is shown in Figure 3.1.6. This plan consists of a continuous quaywall for small boats in the same position as the existing seawall.

(2) Typical Cross Section of Possible Plan

Taking into account the wave and tide characteristics, sea bottom topography, coastal utilization, related development plans and requests from the Government of Maldives, tentative seawall plans for the west, east, south and north coasts are summarized in Table 3.1.1.

On the west coast, a block mound type of seawall is proposed to protect its hinterland from wave attacks. This type of seawall dissipates wave energy most effectively and is very popular all over the world.

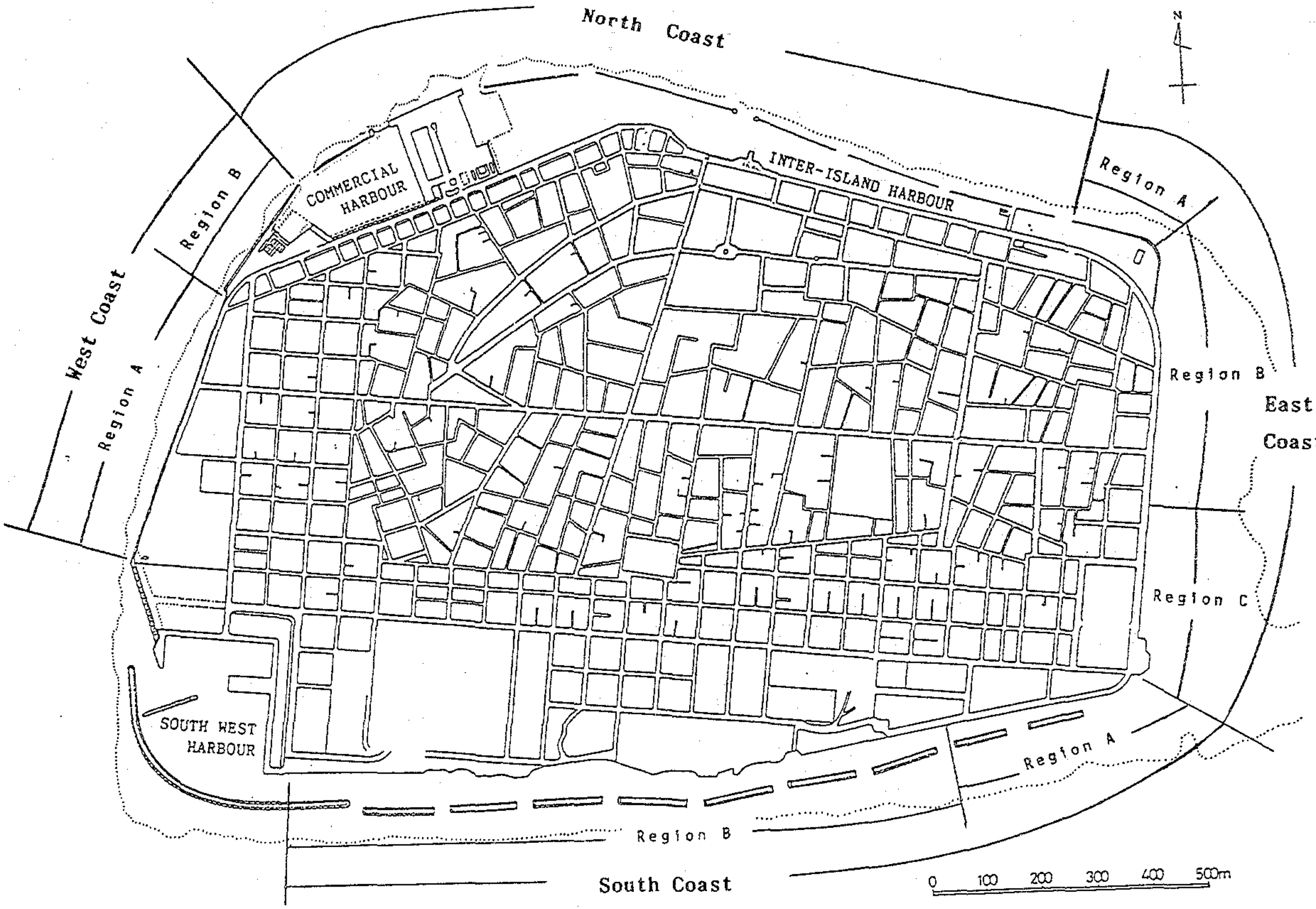


Figure 3.1.3 Project Site for Shore Protection

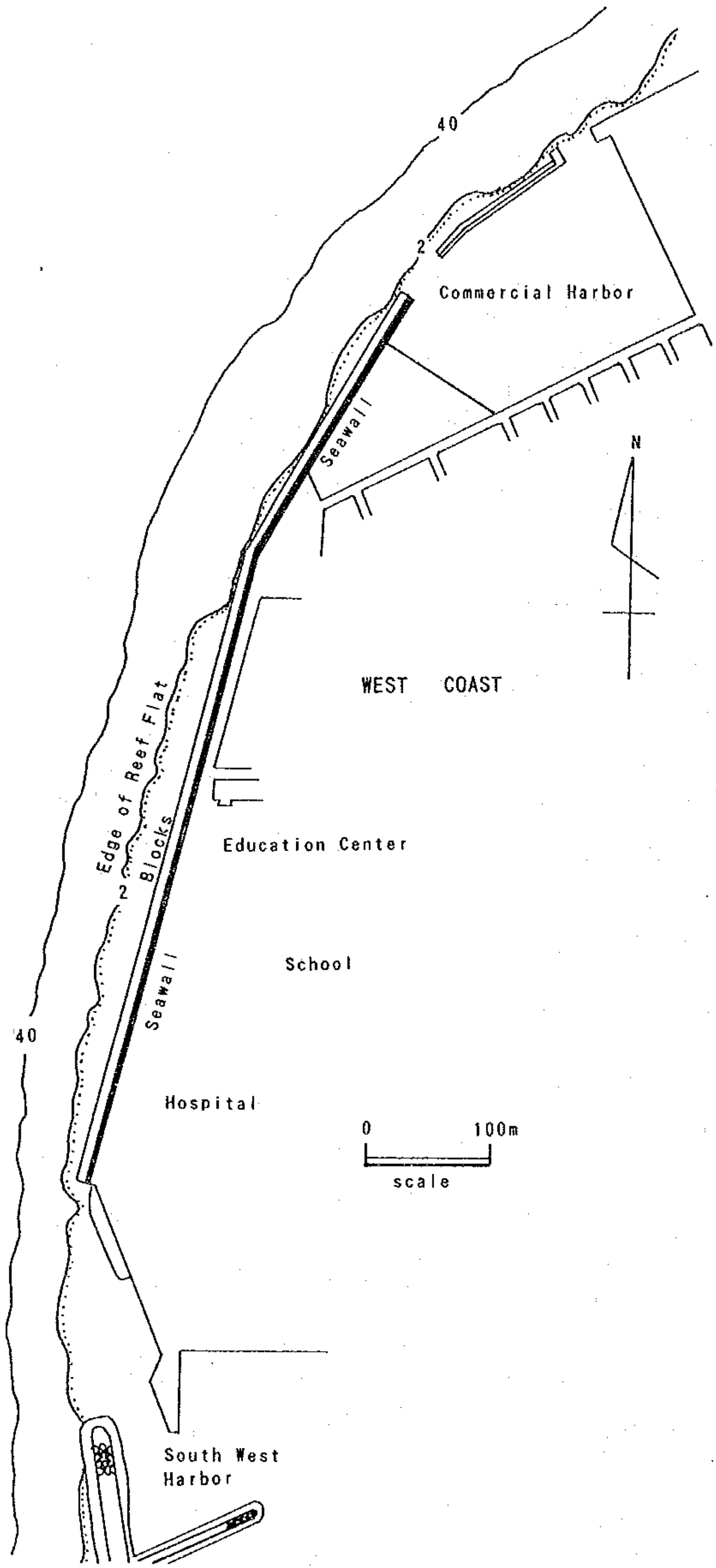


Figure 3.1.4 Layout of Facilities on the West Coast

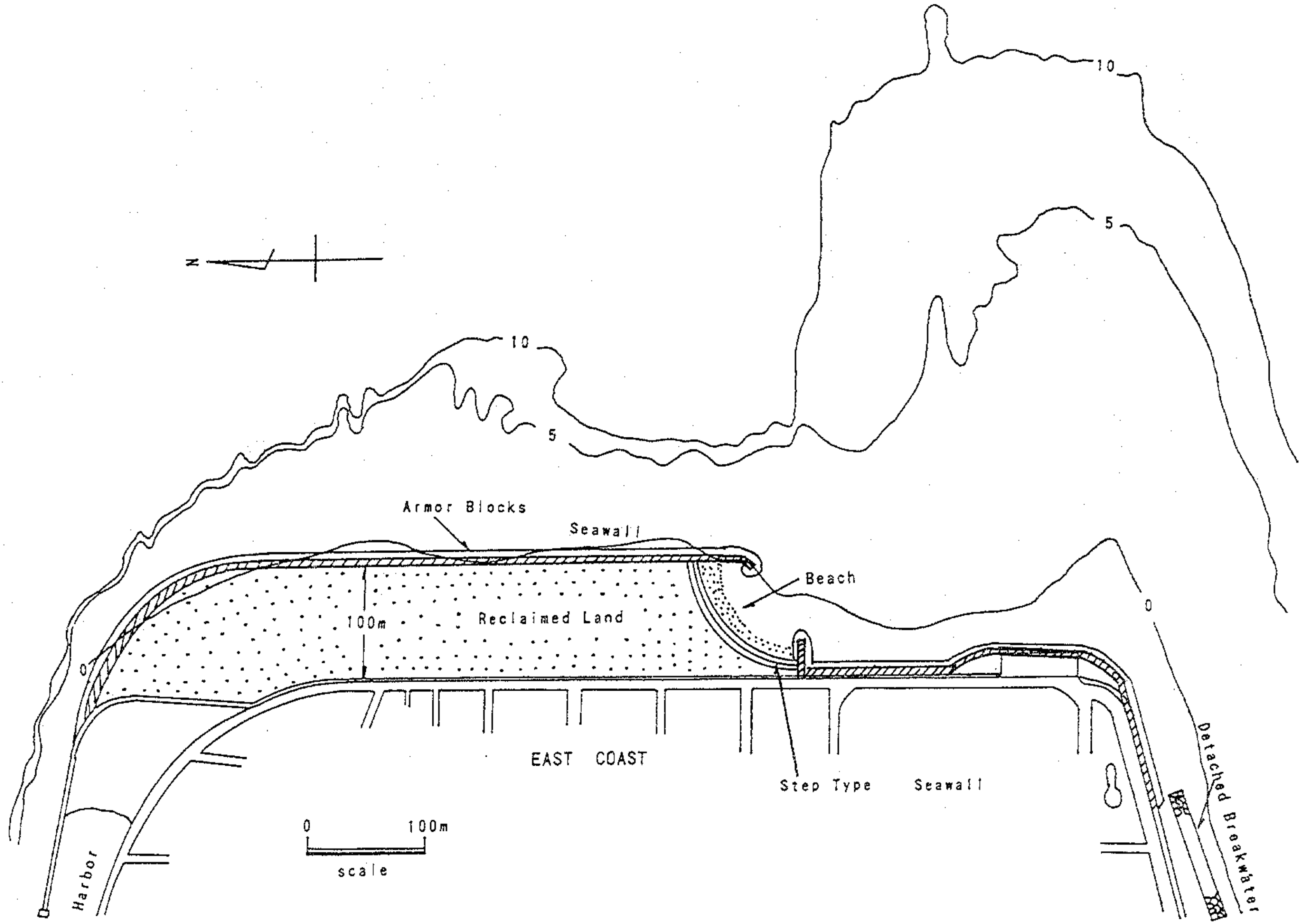


Figure 3.1.5 Layout of Facilities on the East Coast

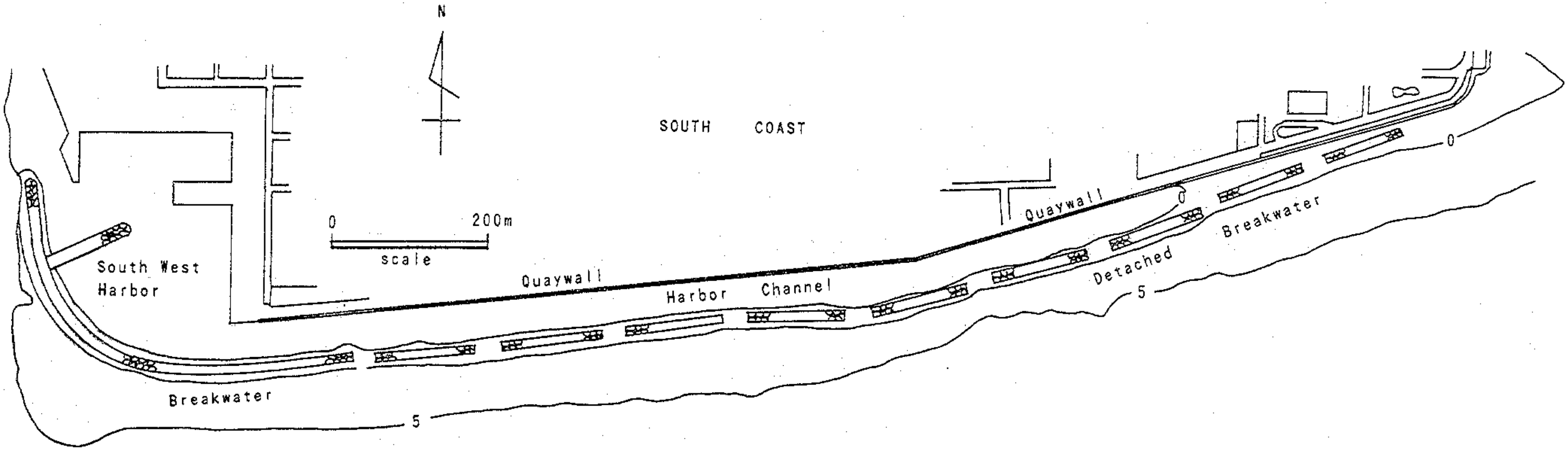


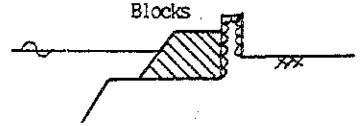
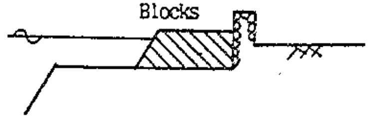
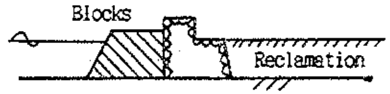
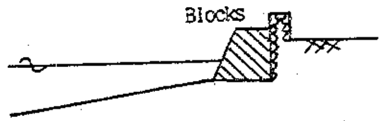
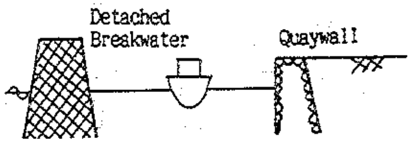
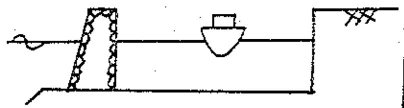
Figure 3.1.6 Layout of Facilities on the South Coast

On the east coast, a step type of seawall is proposed for the local people to enjoy sea bathing on the sandy beach. On the other part of east coast, a block mound type of seawall is proposed in order to prevent high waves from overtopping into its hinterland area.

On the south coast, a vertical wall type of quaywall with low crown elevation is proposed for small boat activities because the channel is protected from rough sea conditions by the existing detached breakwaters.

On the north coast, a reinforced breakwater in the same position as the present one is proposed. However the proposed breakwater could be extended outwards as far as possible based on the results of the detailed survey and design. A concrete block type is preferable to a tetrapod type because the required cross section of tetrapod breakwater is too wide to give enough space for its anchorage area of the north harbor.

Table 3.1.1 Summary of Basic for Shore Protection

Coast Name	Offshore Design Wave	Wave & Tide in front of Seawall	Utilization Condition	Crown Height Condition	Water Depth of Seawall	Possible Plan
West	H_0 = 1.2m T = 4.6sec	H = 1.2m T = 4.6sec D.H.W.L.: D.L.+1.34m	Commercial Harbor	Almost Same as Present Height	D.L.-0.5m	
			Marine Drive Extension, Public Facilities	The lower height is desirable	D.L.-0.5m	
East	H_0 = 3.0m T = 16sec	H = 1.3m T = 16sec D.H.W.L.: D.L.+1.64m	Reclamation	The lower height is desirable	D.L.+0.0m	
			Sea Bathing	The lower height is desirable	D.L.+0.0m	
			Surfing	The lower height is desirable	D.L.+0.0m	
South	H_0 = 3.0m T = 16sec	H = 0.7m T = 6sec D.H.W.L.: D.L.+1.63m	Small Boat Harbor	Suitable Height as Quaywall	D.L.-2.5m ~ D.L.-1.5m	
North	H_0 = 0.6m T = 4.6sec	H = 0.6m T = 4.6sec D.H.W.L.: D.L.+1.34m	Harbor	Present Height	D.L.-0.4m	

3.2 Hydraulic Model Test

3.2.1 Physical Model Test

Based on the results of site investigations concerning wave, tide, topography and the historical storm disaster, physical model tests have been conducted using a 2-dimensional wave flume. These tests aim to provide technical assurance for proposed facilities on the east, south and west coasts of Male' Island.

(a) West Coast

Experimental results are summarized in Table 3.2.1. Under the present condition, waves after striking the seawall run up to a considerable height producing a large amount of sea water overtopping into its hinterland. As the hinter area along the west coast is too extensively utilized to allow a wide flood, a countermeasure work like Plan-(3) or Plan-(4) or Plan-(5) would be appropriate as a shore protection facility because little or no overtopping rate is recognized in these plans.

All experiments for countermeasure works were conducted under the condition of crown elevation at D.L. +3.0 m. This crown elevation, however, is a little high for a person to see the sea horizon sufficiently. Figure 3.2.1 shows the relation between the ratio of crest height and the crown width of blocks by Y. Goda and Y. Kishira (1976). According to the results, the crest height of seawall covered with a mound of artificial concrete blocks can be reduced with the increase in crest width. If two rows of blocks at crest in our experiment are changed to three rows, the crest elevation of seawall at D.L. +2.60 m is almost sufficient to secure the same overtopping rate as in our experiment.

Therefore, the block mound type of seawall with three rows of blocks at crest would be preferable from view points of both technical aspects and requests from the Government of Maldives.

(b) East Coast

Experimental results are listed in Table 3.2.2. For the protection of a relatively densely populated coastal area, an overtopping rate of 0.01 $m^3/m.s$ is currently adopted as a guideline in Japan. If the safe passage of cars is to be secured at all times along a coastal road protected by a continuous seawall, the tolerable limit seems to be on the order of 10^{-4} $m^3/m.s$ (Y.Goda, 1985). Especially in a low lying and densely populated area like Male', lower runup height than the elevation of seawall and no overtopping rate would be desirable as countermeasure works. Therefore, Plan-(1), Plan-(3), Plan-(4) and Plan-(5) would be acceptable works from a technical point of view.

In these plans, Plan-(3), Plan-(4) and Plan-(5) are the plans in which shallow reef flat zone similar to natural reef topography extends artificially towards the offshore. They have, however, some problems in terms of difficulty of construction works. On the other hand, Plan-(1) is examined under the condition of storm waves which occurred in 1987 and the tidal level is set at D.L. +0.9 m lower than D.L. +1.34 of H.W.L. Considering the situation of storm wave attack at the time of high tidal level, the same phenomena as in the case of Present Condition-(2) are thought to be possible. Therefore, the seawall of block mound installed in front of a vertical wall would be desirable for the safety of the hinterland area.

(c) South Coast

Experimental results are summarized in Table 3.2.3. Compared with the results of the present condition, wave runup heights in both Plan-(1) and Plan-(2) are almost the same, but overtopping rates in both plans are larger than in the present condition due to the reduction of seawall elevation. Both plans, however, would be acceptable if the background behind the quaywall is paved sufficiently. In addition, judging from technical aspects Plan-(2) including a submerged breakwater is preferable to Plan-(1) because of a smaller overtopping rate and a calmer sea condition in the channel.

Table 3.2.1 Experiment for the West Coast

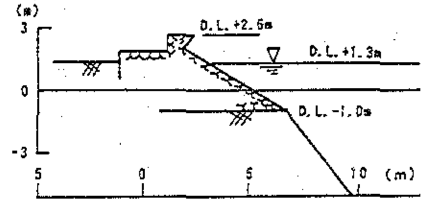
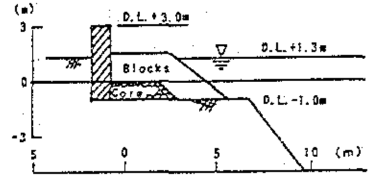
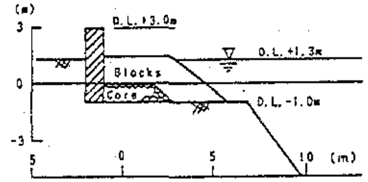
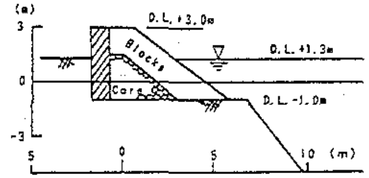
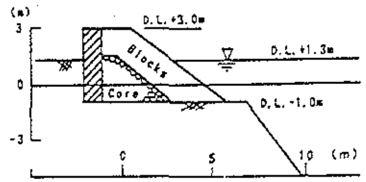
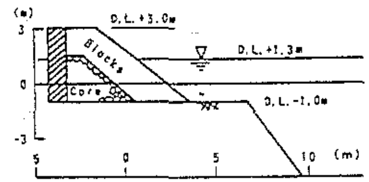
TYPE	ELEVATION OF SEAWALL (D.L.+m)	BLOCK MOUND Num. of Row	BLOCK MOUND Num. of Layer	CROWN HEIGHT OF BLOCKS (D.L.+m)	INCIDENT WAVE Ho(m)	INCIDENT WAVE T(sec)	TIDE LEVEL (D.L.+m)	OVERTOPPING RATE (m^3/m s)	RUNUP HEIGHT (D.L.+m)	REMARKS
PRESENT CONDITION	2.6	—	—	—	1.2	4.6	1.34	0.034	6.5	
PLAN-(1)	3.0	4	2	1.5				0.005	4.4	
PLAN-(2)	3.0	4	3	1.5				0.004	4.1	
PLAN-(3)	3.0	5	2	3.0				0.002	2.7	
PLAN-(4)	3.0	5	3	3.0				0.0	—	
PLAN-(5)	3.0	5	3	3.0				0.0	—	

Table 3.2.2 Experiment for East Coast

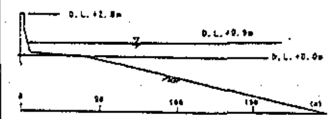
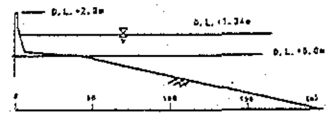
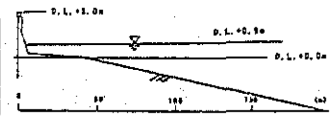
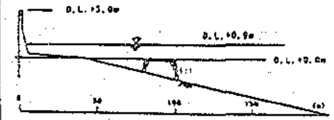
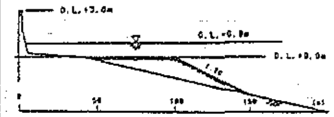
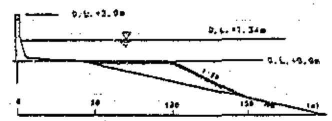
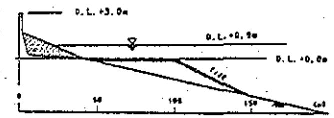
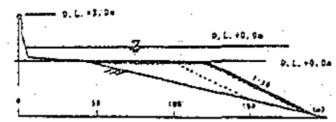
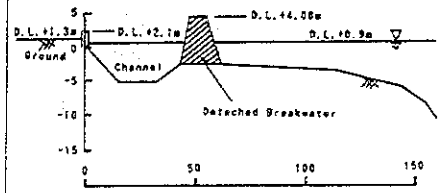
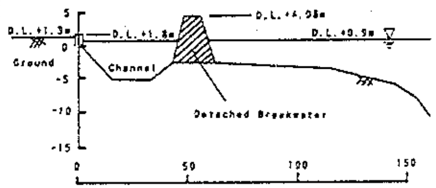
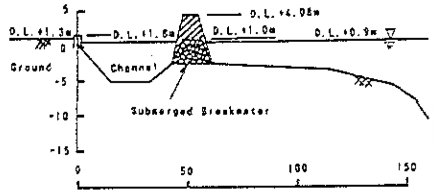
TYPE	ELEVATION OF SEAWALL (D.L. +m)	ADDITIONAL FACILITY	INCIDENT WAVE Ho (m)	INCIDENT WAVE T (sec)	TIDE LEVEL (D.L. +m)	MEASURING POINT FROM SEAWALL (m)	WAVE HEIGHT (m)	WAVE PERIOD (sec)	MEAN SEA LEVEL (D.L. +m)	OVERTOPPING RATE ($m^3/m/s$)	RUNUP HEIGHT (D.L. +m)	REMARKS
PRESENT CONDITION - (1)	2.8	non	3.0	16	0.90	481 330 300 200 40	3.21 4.40 4.07 2.65 0.88	15.9 15.9 15.8 15.6 18.2	0.87 0.92 0.96 1.16 1.26	0.0008	2.4	
PRESENT CONDITION - (2)	2.8	non			1.34	481 330 300 200 40	3.15 4.75 4.62 2.93 1.20	15.8 15.8 15.8 15.8 17.1	1.32 1.33 1.39 1.57 1.69	0.0045	3.3	
PLAN- (1)	3.0	non			0.90	481 330 300 200 40	3.15 4.44 4.18 2.74 0.88	16.0 16.0 16.0 15.7 20.1	0.87 0.92 0.94 1.13 1.26	0	2.3	
PLAN- (2)	3.0	submerged breakwater			0.90	481 330 300 200 40	3.14 4.48 3.89 2.71 0.86	16.0 16.0 15.9 15.8 18.0	0.86 0.92 1.01 1.10 1.29	0.0003	2.4	
PLAN- (3)	3.0	artificial reef			0.90	481 330 300 200 40	3.11 4.72 4.03 2.68 0.62	16.0 16.0 16.0 15.7 21.6	0.86 1.00 1.00 1.15 1.34	0	2.1	
PLAN- (3)'	3.0	artificial reef			1.34	481 330 300 200 40	3.13 4.79 4.92 3.04 0.99	15.9 15.9 15.9 15.6 17.8	1.30 1.37 1.39 1.53 1.72	0.0036	3.2	
PLAN- (4)	3.0	artificial reef and sand nourishment			0.90	481 330 300 200 40	3.07 4.61 4.20 2.53 0.56	16.2 16.1 16.1 15.9 21.7	0.87 0.93 0.99 1.11 1.35	0	1.5	
PLAN- (5)	3.0	artificial reef			0.90	481 330 300 200 40	3.18 4.76 4.07 2.62 0.61	15.9 15.9 15.8 15.7 24.1	0.85 0.83 1.03 1.14 1.43	0	2.2	

Table 3.2.3 Experiment for South Coast

TYPE	ELEVATION OF QUAYWALL (D. L. + m)	ELEVATION OF SUBMERGED BREAKWATER*) (D. L. +m)	INCIDENT WAVE Ho (m)	INCIDENT WAVE T (sec)	TIDE LEVEL (D. L. +m)	MEASURING POINT FROM QUAYWALL (m)	WAVE HEIGHT (m)	WAVE PERIOD (sec)	MEAN SEA LEVEL (D. L. +m)	OVERTOPPING RATE (m³/m·s)	RUNUP HEIGHT (D. L. +m)	REMARKS
PRESENT CONDITION	2.1	—	3.0	16	0.9	200	2.27	15.9	0.88	0.030	2.4	
						125	2.86	13.9	0.76			
						40	1.00	8.7	1.65			
						(40)*)	(0.53)	(7.3)	(1.73)			
						15	0.70	6.6	1.71			
PLAN－(1)	1.8	—				200	2.05	15.3	0.87	0.085	2.3	
						125	2.76	12.0	0.77			
						40	1.01	9.8	1.61			
						(40)*)	(0.51)	(8.0)	1.55			
						15	0.65	5.9	1.63			
PLAN－(2)	1.8	1.0				200	2.11	16.0	0.88	0.072	2.2	
						125	2.94	14.8	0.92			
						40	0.67	7.8	1.86			
						(40)*)	(0.28)	(9.3)	(1.80)			
						15	0.40	5.0	1.83			

*) ( ) denotes the position behind the existing breakwater.

*) Submerged breakwater is set between the existing breakwaters.

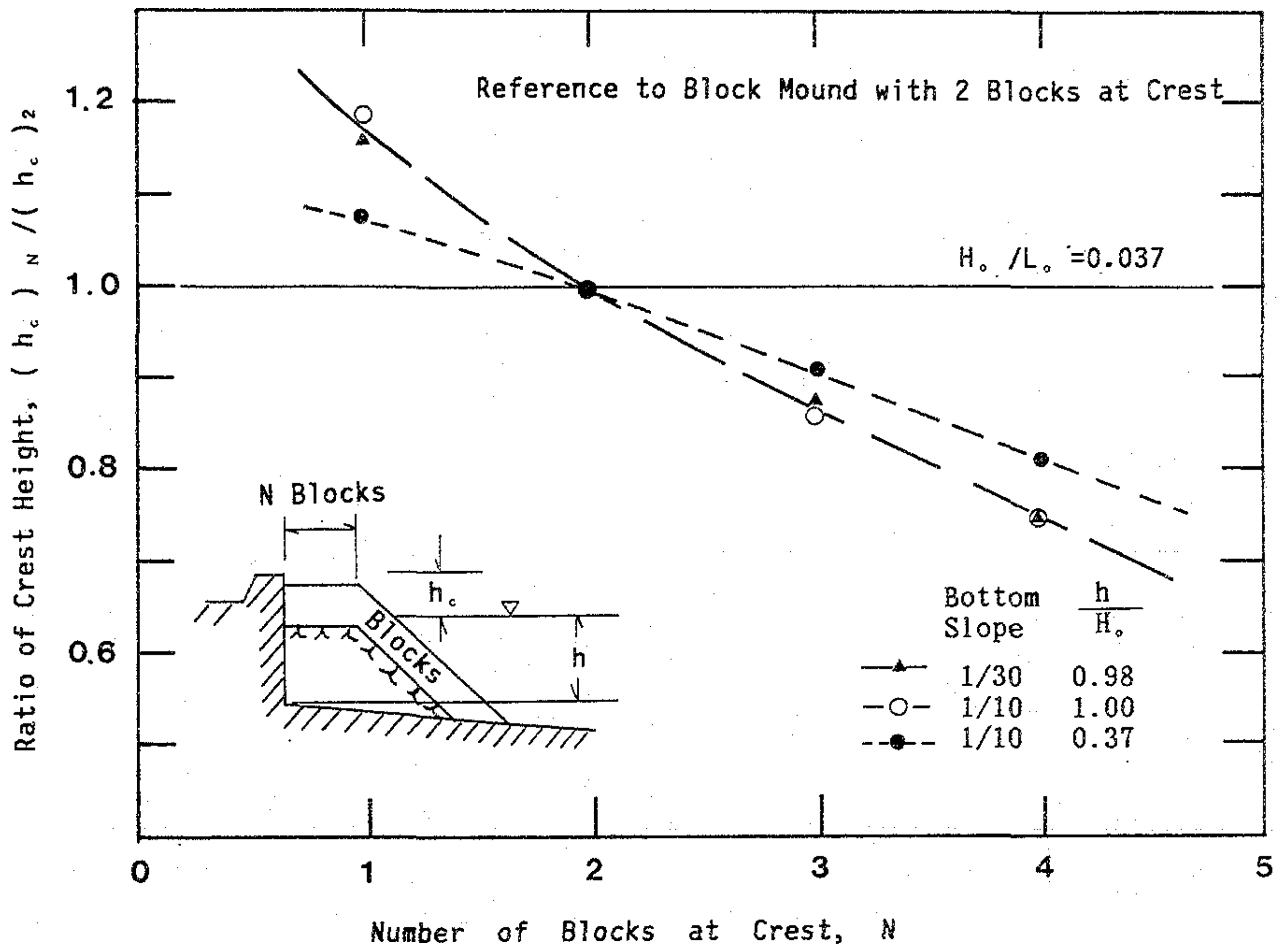


Figure 3.2.1 Relation between the Ratio of Crest Height and the Crown Width of Blocks

3.2.2 Numerical Model Test

A numerical model test is composed of a wave and current computer model. As the computer model has several unknown factors, a verifying calculation using actual field data is essential for a precise prediction. The verifying calculation has been applied to the east coast of natural reef and to the south coast protected by artificial facilities of breakwaters. The results of the verification tests are summarized in Table 3.2.4. Though a little discrepancy is recognized, the results of calculations agree well with those of field observations as a whole.

Using this numerical model, predictions for shore protection plans have been conducted. The current distribution on the east coast is presented in Figure 3.2.2 for a storm wave of 3 meters in height and of 16 seconds period under the present facility condition. Predominant currents on the reef flat flowing to the north direction were the same as the results of field measurements on September to October 1991. On the other hand, the current distribution in Figure 3.2.3 is obtained for the shore protection plan. From this prediction, a proposed beach surrounded by L shaped groins is well protected from strong nearshore currents. Therefore, sand filled into this region is thought to be stable by this protection works. The speed of current which appears in front of the reclaimed land is almost the same as those in the present condition. Therefore, no significant influences are thought to occur on the east coast.

The longshore distribution of wave height in the channel on the south coast is shown in Figure 3.2.4 for both cases "with" and "without" submerged breakwaters between detached breakwaters. From this result, the highest wave occurs just behind the gaps between the fourth and fifth detached breakwaters from the east side. This high wave is due to the offshore bottom topography where the deep region reaches the gap most closely.

An example of calculation results on the west coast is shown in Figure 3.2.5. Though swell waves having a long period come from the south direction, a wave does not break in almost all areas of this coast, and a small wave approaches the seawall due to the wave refraction. According to the results of calculations, a nearshore current due to waves does not occur on the west coast.

Table 3.2.4 Verification of Numerical Model

		East Coast		South Coast	
Observation Date		1st, Oct (6 o'clock)		9th, Oct (4 o'clock)	
Station	Item	Observation	Calculation	Observation	Calcultaion
Offshore Wave	Tide Level	D.L. +0.86 m		D.L. +0.87 m	
	Wave Height (m)	0.78	-	1.24	-
	Wave Period (sec)	12.8	-	11.8	-
	Wave Direction	SSE	-	SE	-
No.1	Wave Height (m)	0.24	0.32	0.13	0.14
	Wave Direction	SE	ESE	W	SSE
	Velocity (m/sec)	0.465	0.14	0.023	0.011
	Current Direction	NNW	N	SSW	SSE
No.2	Wave Height (m)	0.26	0.39	0.39	0.40
	Wave Direction	ESE	ESE	SSE	SSE
	Velocity (m/sec)	0.297	0.26	0.071	0.033
	Current Direction	N	N	SW	NW
No.3	Wave Height (m)	0.27	0.36	0.10	0.16
	Wave Direction	N	ESE	ESE	SE
	Velocity (m/sec)	0.272	0.050	0.086	0.063
	Current Direction	N	N	W	W

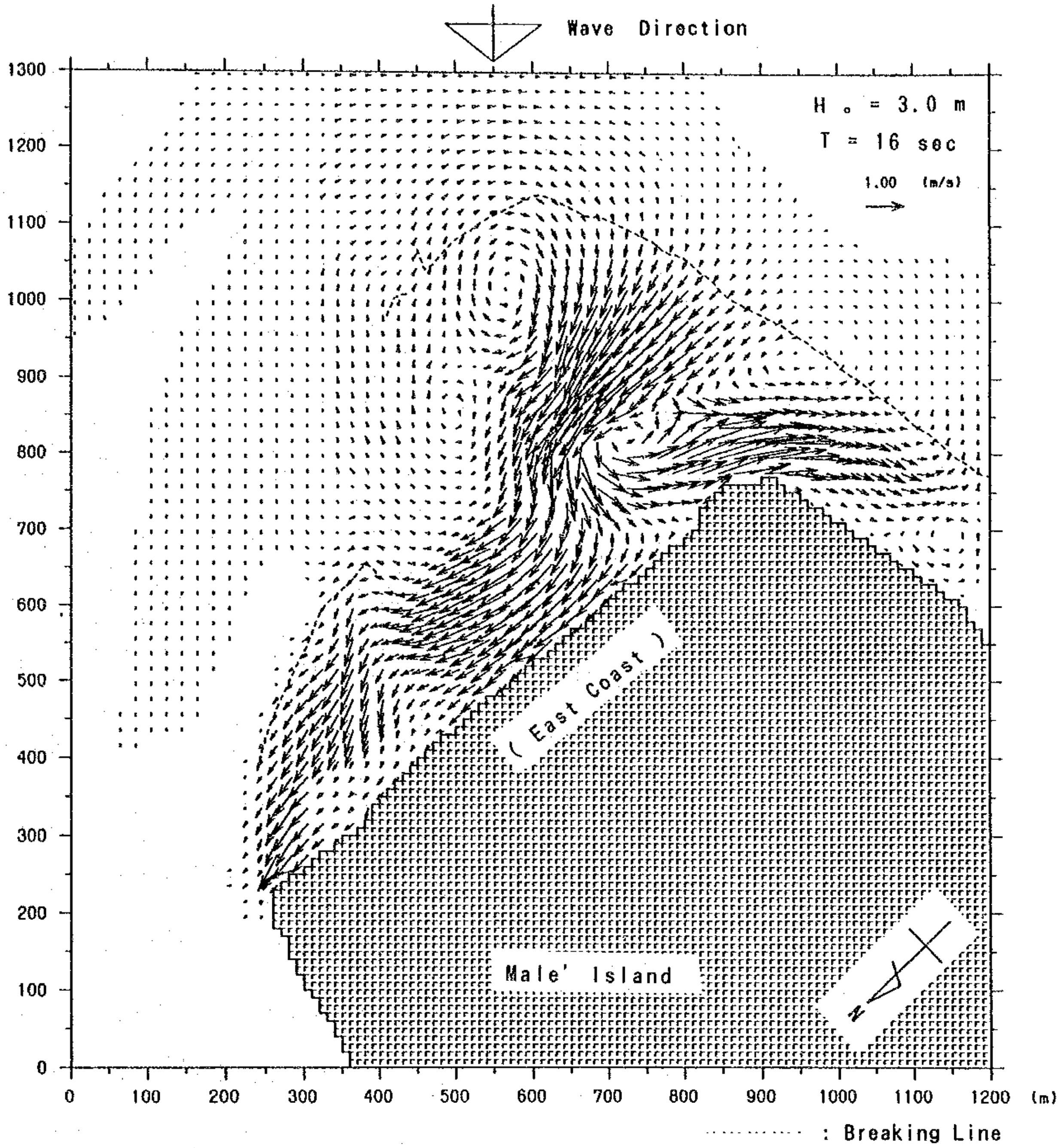


Figure 3.2.2 Nearshore Current Distribution

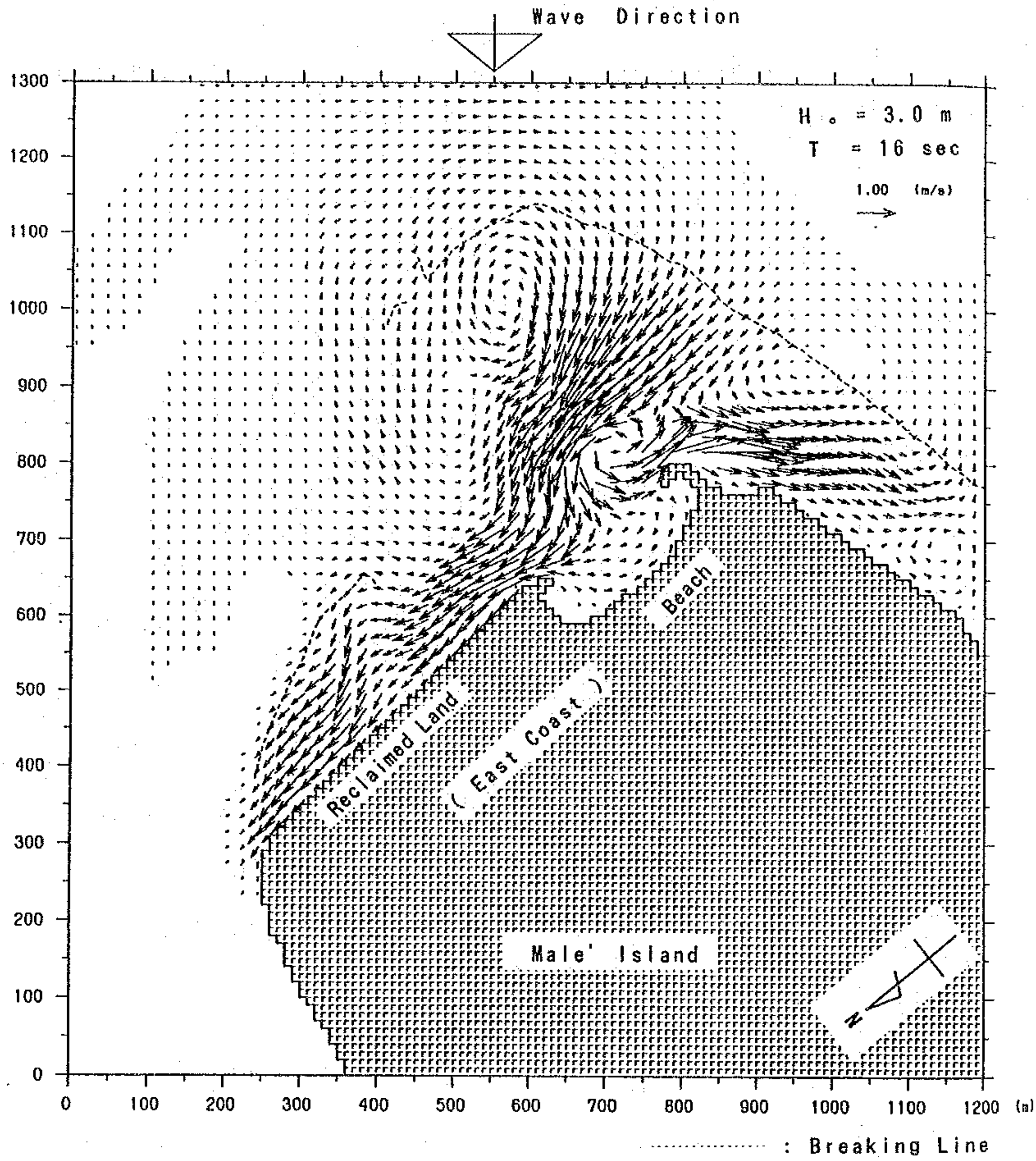


Figure 3.2.3 Nearshore Current Distribution

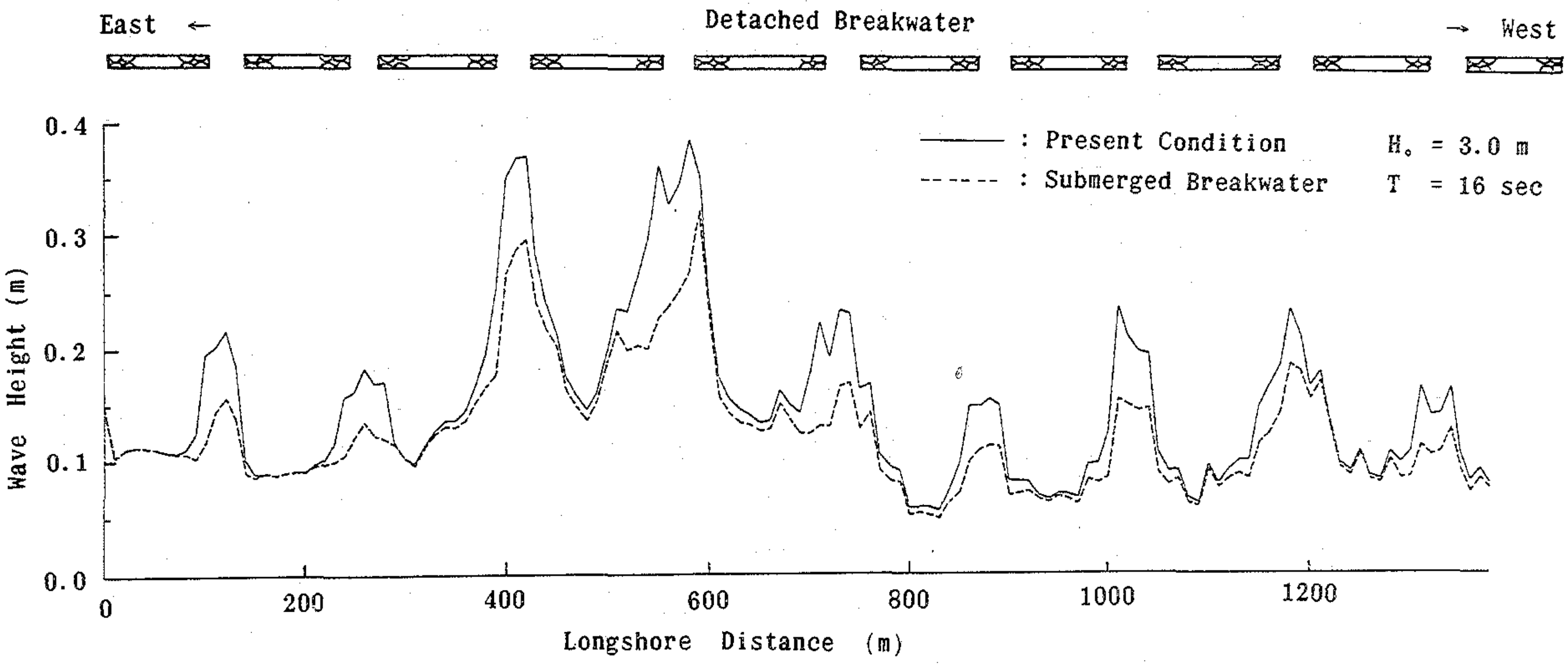


Figure 3.2.4 Distribution of Wave Height in Front of the Seawall (South Coast)

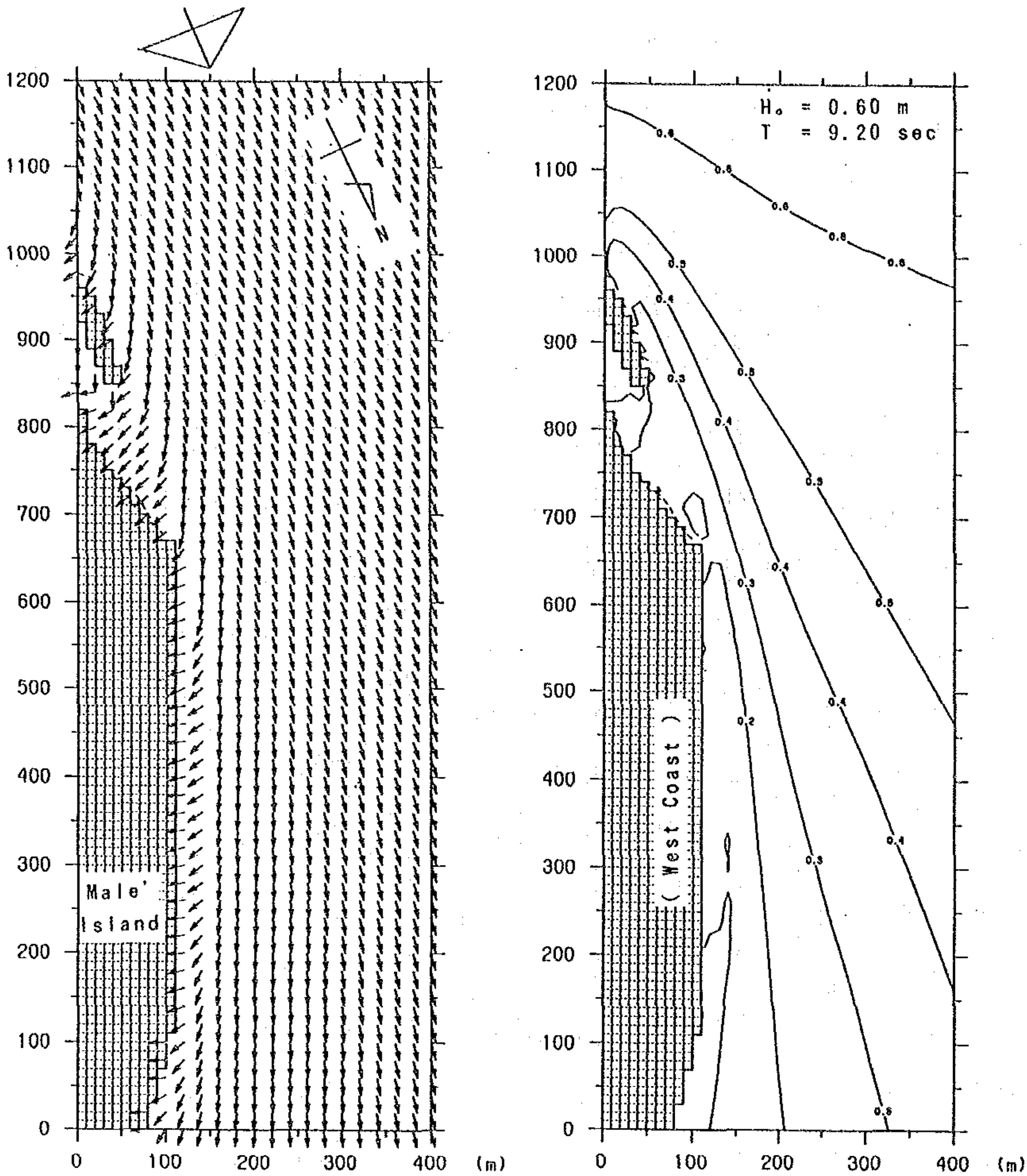


Figure 3.2.5 Wave Rays and Wave Height Distribution (West Coast)

3.3 Preliminary Design

3.3.1 Basic Plan

Based on the examinations of hydraulic model test and the requests from the Government of Maldives, the following basic plans could be proposed as countermeasure works on each coast of Male' Island:

(1) West Coast

According to the results of physical model tests, it was found that the present crown height of D.L. +2.60 m without any armor blocks is not high enough to prevent wave overtopping. In addition, as there is no space for an armor block type seawall on the northern part of this coast, a proposed seawall is desirable to be moved landward several meters in the area in front of the commercial harbor. Finally the following seawall is proposed on the west coast:

a) Northern Area

Type	:	Armor Blocks with Vertical Wall
Crown Elevation	:	D.L. +3.00 m
Number of Blocks at Crest	:	Two Rows

b) Other Area

Type	:	Armor Blocks with Vertical Wall
Number of Blocks at Crest	:	Three Rows

(2) East Coast

According to the experimental results, storm waves run up to the height of D.L. +3.3 m under the present condition at high water level. Storm waves propagating from Indian Ocean are estimated to come in directly to this coast by numerical model tests as for wave refraction analysis. Fundamentally any facility of wave energy absorption such as block mound type seawall is essential for a countermeasure work on this coast.

An artificial beach, which is necessary to maintain a recreational function for the local people, requires to be protected by some facility like a groin from a rough sea condition due to high ocean waves and to prevent the waves from washing away approaching the beach and in resisting wave run-up than an uniformly sloping seawall like the present one.

Considering the above situations and the reclamation plan by the Government of Maldives, the following seawalls are proposed:

a) Artificial Beach

Seawall Type	:	Step type Seawall
Groin Type	:	Block Mound with Vertical Wall
Crown Elevation	:	D.L. +3.00 m

b) Reclaimed Land and Other Area

Type	:	Block Mound with Vertical Wall
Crown Elevation	:	D.L. +3.00 m

(3) South Coast

According to the results of the experiment, a little amount of wave overtopping into the land area behind a proposed quaywall is expected to occur at the time of storms. Therefore, its hinterland area is necessary to be paved well and to have a slope as a drainage system.

On the other hand, though a quaywall with a submerged breakwater is desirable judging from the results of the model test, the submerged breakwater is beyond the scope of this seawall project. But a little high vertical wall on a quaywall behind the open area of detached breakwater is thought to prevent overtopping sea water from entering the land area in case of storm attacks. The following quaywall is fundamentally proposed:

a) Harbor Site

Quaywall Type	:	Concrete Block Type Vertical Wall
Crown Elevation	:	D.L. +1.80 m
Apron Slope	:	2 %

b) East Site

Seawall Type	:	Concrete Block Type Vertical Wall
Crown Elevation	:	D.L. +2.40 m

(4) North Coast

Though a permeable breakwater with a tetrapod units can be expected to improve water quality in the harbor, but it can not afford enough space for small boat activities. Considering a narrow zone of shallow reef flat at the offshore side of present breakwater and a relatively low wave attack to this coast, a strong breakwater made of concrete block with the same elevation as the present could be proposed as a countermeasure work:

Seawall Type	:	Concrete Block Type Breakwater
Crown Elevation	:	D.L. +2.10 m
Location	:	Same Position of Present Breakwater or outward if technically possible

3.3.2 Design Policy

The preliminary design for the Project will be based on the following:

(1) Natural conditions at the Project Site shall be carefully considered so that:

1) The terrain, geology and consideration of weather and marine phenomena be reflected in the design.
2) The littoral drift from currents occurring within the coral reef be considered.
3) The effects of high tides, abnormal weather and high waves be considered, and the ground levels will be considered on this basis.
4) Protection of the environment be considered.

(2) The structures, materials and construction methods for the Project should meet the site conditions.

1) The structures should be as simple as possible, and the highest priority will be given to the materials being easily obtainable and the facility easy to maintain and repair.
2) The construction methods and schemes should consider the natural conditions of the Site.

(3) The construction codes and technical standards of the Maldives are not developed as yet and the design of the facilities will be based on the Japanese codes and standards.

3.3.3 Design Conditions

Based on the field survey, data collected and results of model tests, design conditions for the Project are established as follows:

1) Oceanographic Conditions

- Tide	:	H.W.L.	=	D.L. +	1.34 m
		M.S.L.	=	D.L. +	0.64 m
		L.W.L.	=	D.L. -	0.06 m
- Design Waves		See Fig. 3.3.1.			

2) Seismic Forces

Earthquakes are non-existent in the Maldives, and there are no records of earthquakes in the past records. Hence, earthquake factors will not be considered.

3) Soil Conditions

See paragraph 2.4, Chapter 2.

4) Quaywall Use Conditions

Objective Vessel	:	Diesel Boats
Overall Length	:	13.5 m
Maximum Beam	:	3.6 m
Full Load Draft	:	0.9 m
Bulwark Height	:	0.2 m
Berthing Speed	:	0.3 m/sec.
Surcharge	:	$q=1$ t/m^2
Width of Apron	:	3.0 m

5) Construction Materials

Filling Materials	:	Angle of Internal Friction :		$\varnothing = 30°$, $\delta = 15°$
Rubble Mound	:	Angle of Internal Friction :		$\varnothing = 40°$
Unit Weight	:	Reinforced Concrete	:	2.45 t/m^3 (in air)
				1.45 t/m^3 (in water)
	:	Plain Concrete	:	2.30 t/m^3 (in air)
				1.30 t/m^3 (in water)
	:	Filling Materials	:	1.80 t/m^3 (in air)
				1.00 t/m^3 (in water)

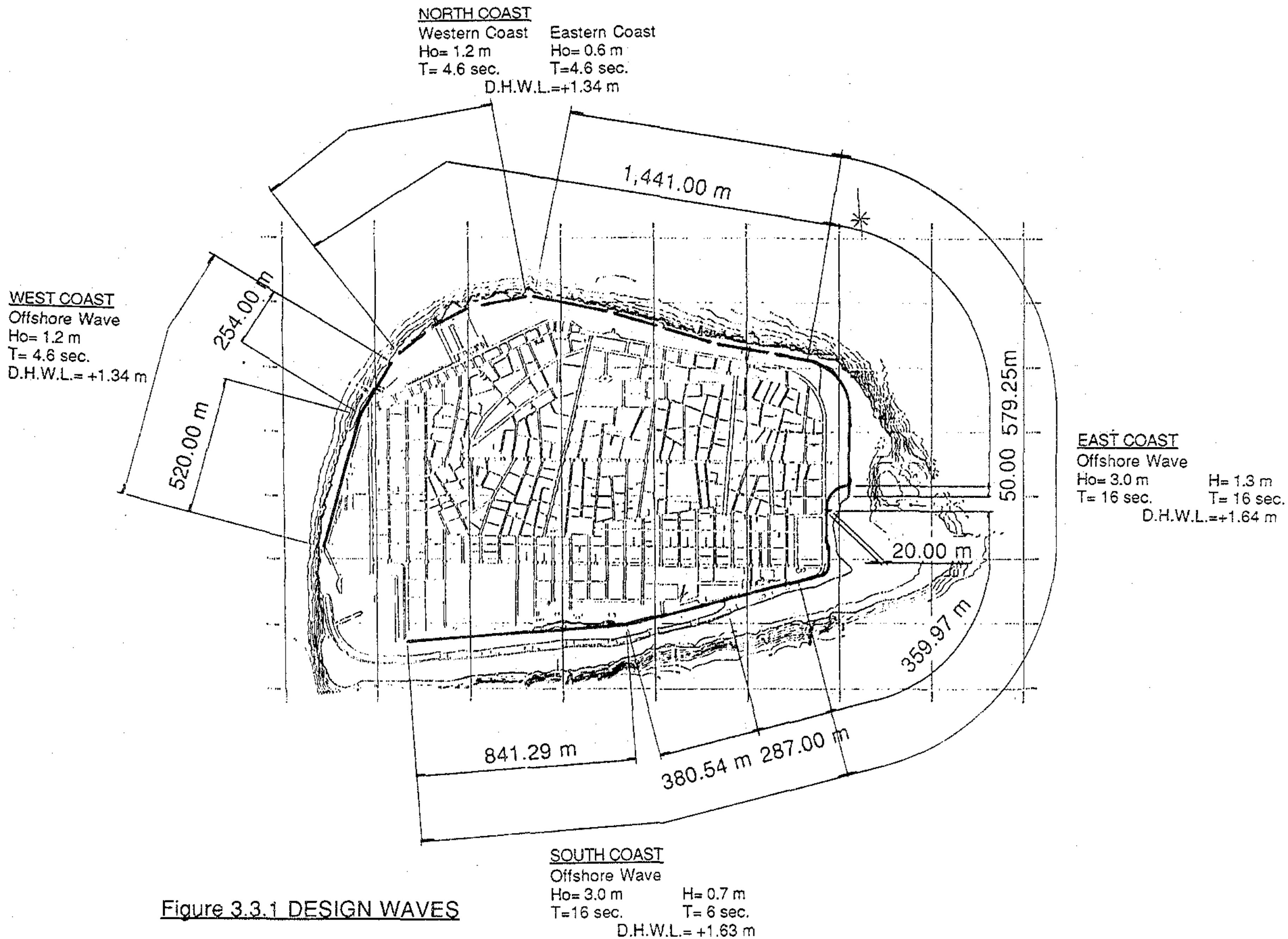


Figure 3.3.1 DESIGN WAVES

6) Static Friction Coefficient

Between precast concrete and precast concrete : 0.5

Between precast concrete and rubble mound : 0.6

7) Safety Factors

Sliding	:	1.2 (under normal conditions)
Overturning	:	1.2 (under normal conditions)
Bearing Capacity	:	2.5

8) Allowable Strength of Materials

Steel Sheet Pile	:	1,800 kgf/cm² (SY295A)
Deformed Reinforcing Steel Bar	:	1,800 kgf/cm² (SD295A)
Reinforced Concrete	:	240 kgf/cm² (standard design strength)
		90 kgf/cm² (allowable flexural compressive strength)
		9 kgf/cm² (allowable shearing strength)
Plain Concrete	:	180 kgf/cm² (standard design strength)

9) Reference Standards

Japanese Industrial Standard : JIS (Japanese Standards Association)

Technical Standards for Shore Protection Facilities (Japan Association of Coastal Engineering)

Shore Protection Manual (US Army Corps of Engineers)

Technical Standards for Port Facilities (Japan Port Association)

Standard Concrete Specifications (Japan Association of Civil Engineers)

3.3.4 Preliminary Design

(1) Layout Plan

Shore protection facilities to be designed in this study are as indicated in Fig. 3.3.2 and 3.3.3. The shore protection facilities in the area for South-West harbour, which was recently constructed, is excluded from this study. The approximate length of the shore protection facilities planned is tabulated in Table 3.3.1.

Table 3.3.1 Total Length of Shore Protection Facilities

Coast	Sector	Length (m)	Length by Coast
West	North	254.00	774
	South	520.00	
East	North	579.25	1,088.45
	Step	149.23	
	Groin	(71.00)*	
	South	359.97	
South	West	841.29	1,508.83
	Center	380.54	
	East	287.00	
North		(1,291.00)**	1,291.00
Total*		4,812.28	4,812.28

* Groin is not included.

** Seawall in front of the 150 m wide mole is not included because a development study for this area is being conducted under an ADB assistance.

(2) Preliminary Design of the Facilities

Based on the results described in paragraph 3.3.1, preliminary design of the structures is presented as indicated in Fig. 3.3.4. Alternative studies including cost comparison are included in the Supporting Report.

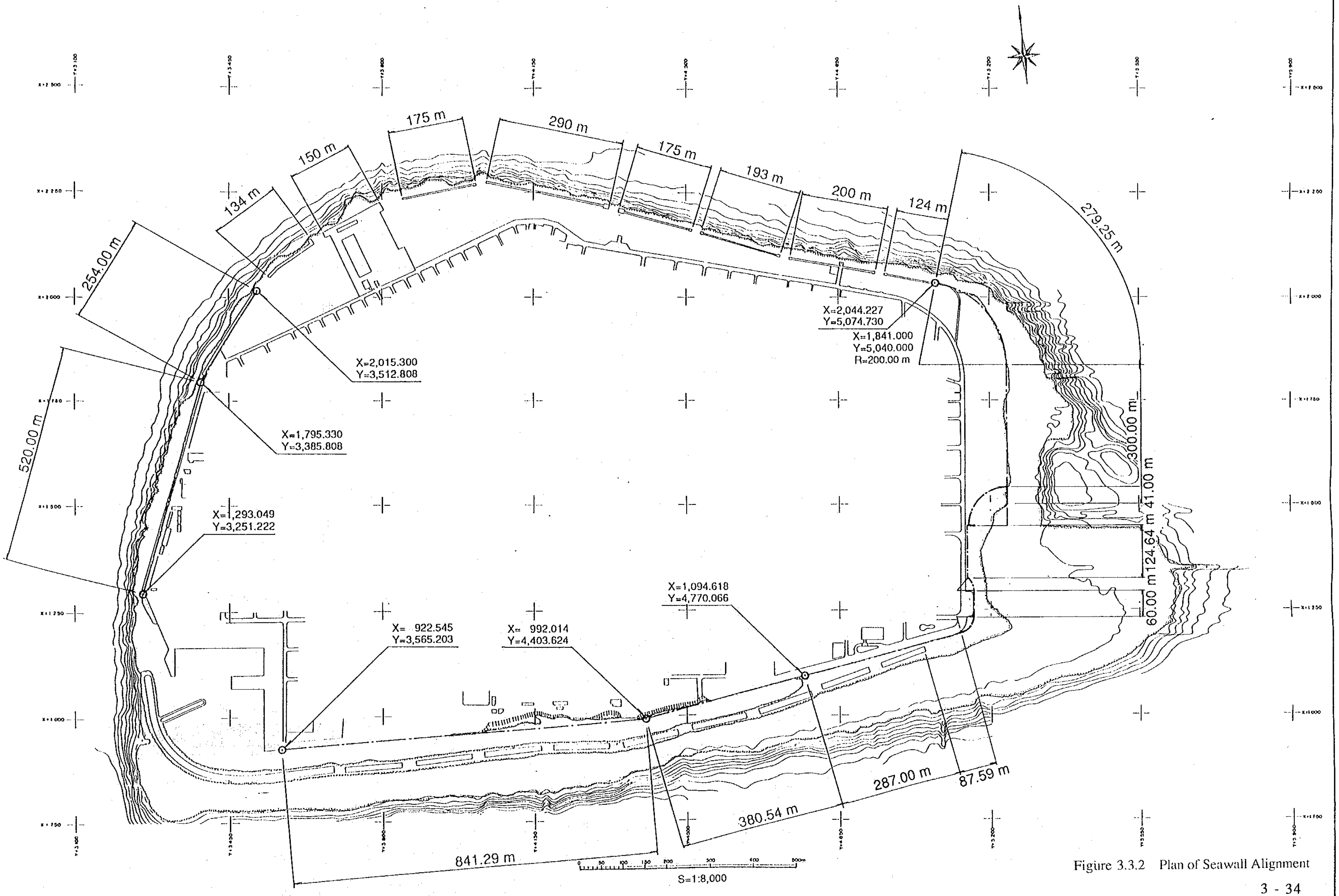


Figure 3.3.2 Plan of Seawall Alignment

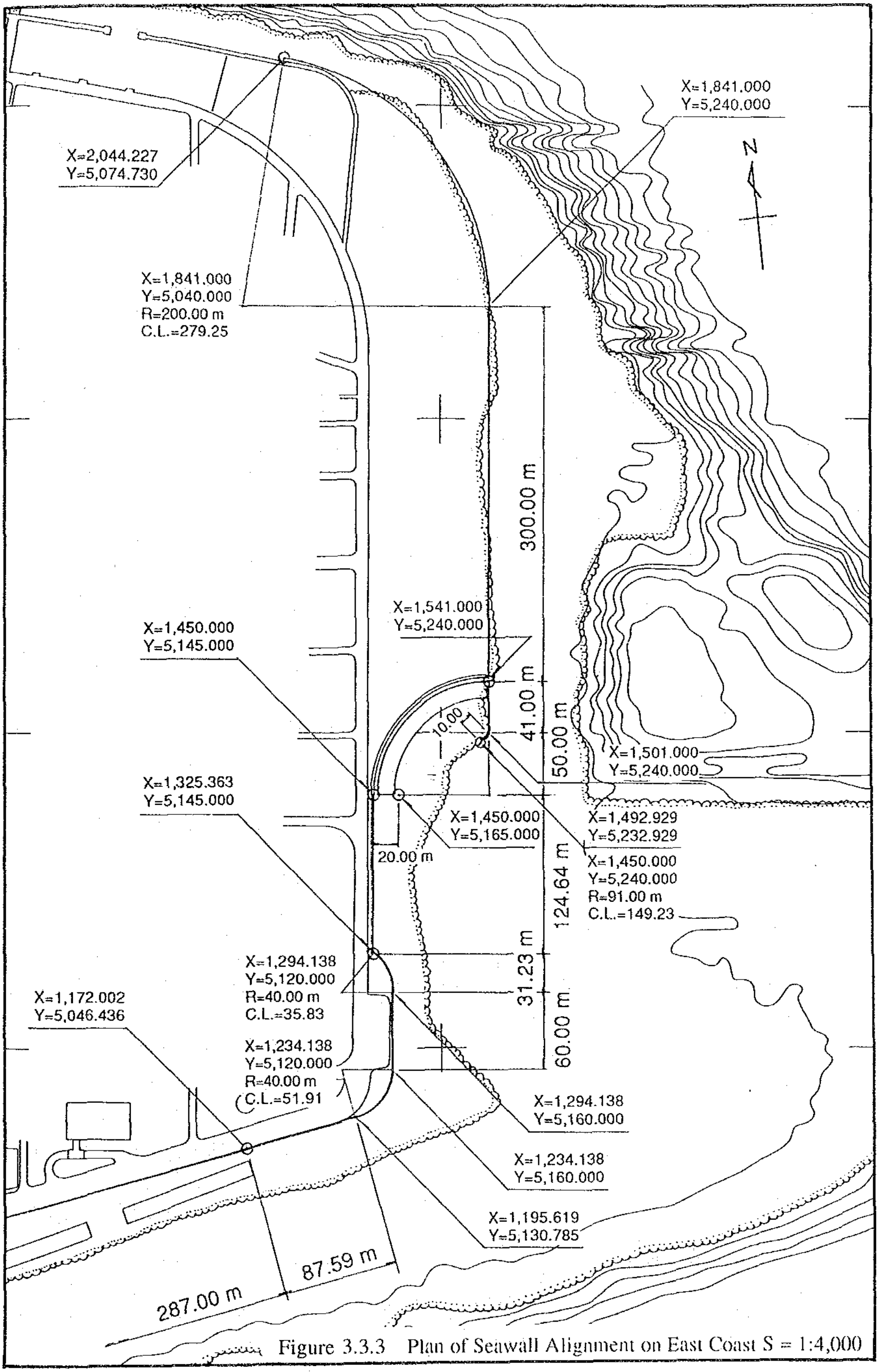
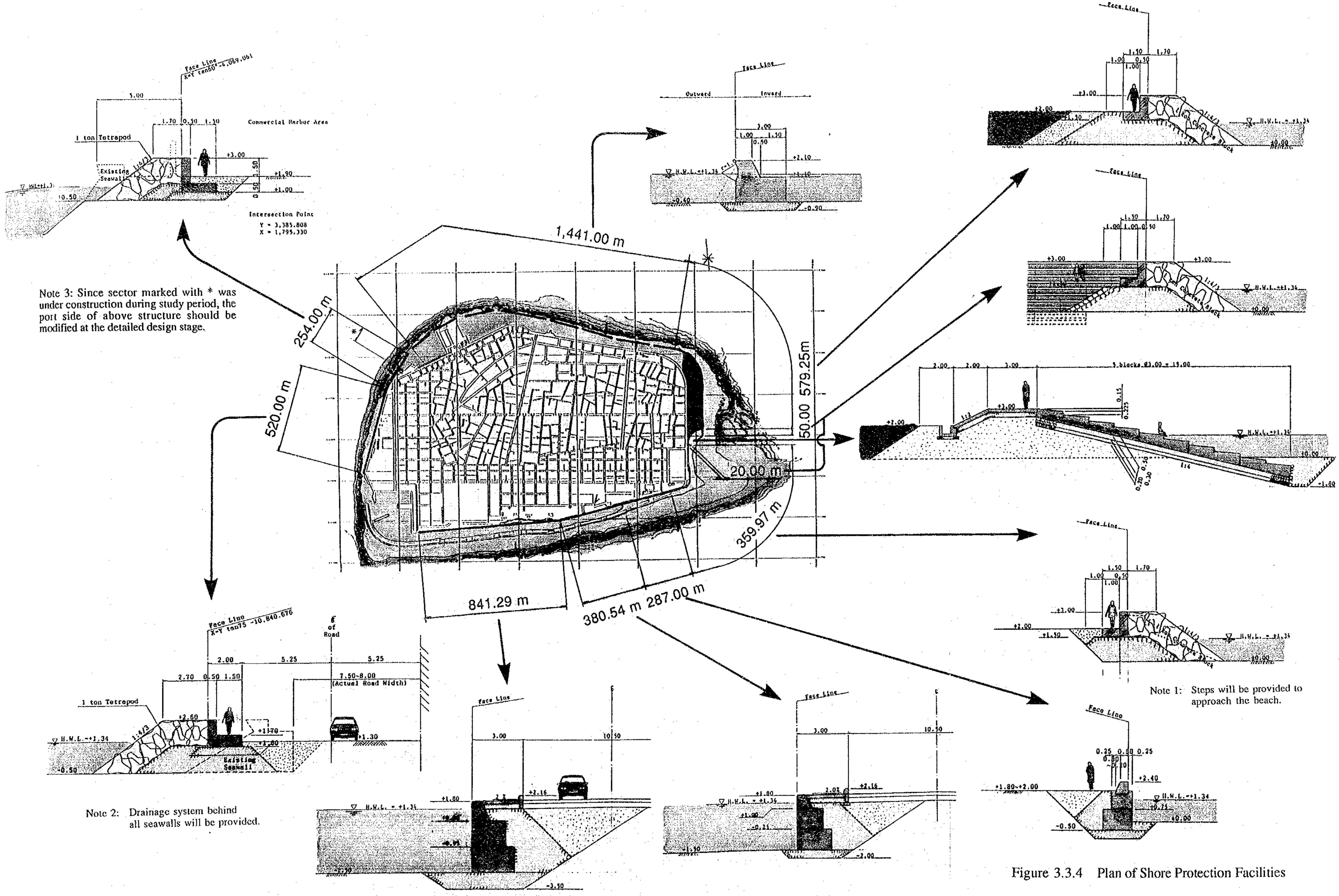


Figure 3.3.3 Plan of Seawall Alignment on East Coast S = 1:4,000



Note 3: Since sector marked with * was under construction during study period, the port side of above structure should be modified at the detailed design stage.

Note 2: Drainage system behind all seawalls will be provided.

Note 1: Steps will be provided to approach the beach.

Figure 3.3.4 Plan of Shore Protection Facilities

3.4 Cost Estimates

Project cost for each coast in Male' Island is summarized in Table 3.4.1 based on the shore protection facilities explained in the previous paragraph 3.3. The project cost is estimated by dividing into the following items.

(1) Direct Construction Cost	:	based on the unit prices as of December 1991, direct construction cost was calculated with the share of foreign currency and local currency portions.
(2) Indirect Construction Cost	:	Indirect cost is estimated including transportation cost, overhead and company's profit.
(3) Engineering Services	:	Cost for engineering services is divided into two stages, namely detailed design and construction supervision. The cost for each stage is estimated at 2 % and 7 % of (1) + (2) above respectively.
(4) Physical Contingency	:	Physical contingency is divided into two parts; one is for construction, 10 % of (1) + (2) above, and the other is for Engineering services, 5 % of (3) above.
(5) Price Escalation	:	Price escalation is excluded.

The esimate was based on the following conditions:

(1) Exemption from taxation and duties

(2) Exchange Rate

The exchange rate for cost estimation is computed at an average of daily TTS rate during six months from March 16 to September 15, 1992.

1 US$ = ¥129.53
1 MRf = ¥11.99

Table 3.4.1 COST ESTIMATE

Phase 1 West Coast 92.10.6

Work Item	Unit	Quantity	1 MRf=¥ 11.99 Maldivian Rufiyaa (M		1 US $=¥ 129.53 US Dollar (US$)		Jpn (¥ 1,000)		Jpn (¥ 1,000)	Unit Price
			Unit Price	Amount	Unit Price	Amount	Unit Price	Amount	Total Amount	
CONSTRUCTION COST										
1. Direct Construction Cost				2,313,006		3,806,598		109,190	629,991	
West Coast North	l.m.	254.00		781,464		975,595		34,164	169,902	669
-do- South	l.m.	520.00		1,531,543		2,831,004		75,026	460,089	885
2. Indirect Cost				2,722,593		1,707,918		240,345	494,216	78%
3. Total Construction Cost									1,124,207	
ENGINEERING SERVICES									101,179	
1. Detailed Design		2%							22,484	
2. Supervision		7%							78,694	
CONTINGENCY Construction		10%							112,421	
Engineering Services		5%							5,059	
TOTAL PROJECT COST									1,337,806	

Phse 2 Easth Coast

Work Item	Unit	Quantity	1 MRf=¥ 11.99 Maldivian Rufiyaa (M		1 US $=¥ 129.53 US Dollar (US$)		Jpn (¥ 1,000)		Jpn (¥ 1,000)	Unit Price
			Unit Price	Amount	Unit Price	Amount	Unit Price	Amount	Total Amount	
CONSTRUCTION COST										
1. Direct Construction Cost				3,165,141		5,608,355		127,284	891,685	
East Coast N/S/G	l.m.	1,010.22		2,539,035		4,562,954		111,022	732,504	725
-do- Step	l.m.	149.23		626,106		1,045,401		16,263	159,181	1,067
2. Indirect Cost				3,663,954		1,885,775		303,999	592,194	66%
3. Total Construction Cost									1,483,879	
ENGINEERING SERVICES									133,549	
1. Detailed Design		2%							29,678	
2. Supervision		7%							103,872	
CONTINGENCY Construction		10%							148,388	
Engineering Services		5%							6,677	
TOTAL PROJECT COST									1,765,816	

Phase 3 South Coast 92.10.6

Work Item	Unit	Quantity	1 MRf=¥ 11.99 Maldivian Rufiyaa (M		1 US $=¥ 129.53 US Dollar (US$)		Jpn (¥ 1,000)		Jpn (¥ 1,000)	Unit Price
			Unit Price	Amount	Unit Price	Amount	Unit Price	Amount	Total Amount	
CONSTRUCTION COST										
1. Direct Construction Cost				3,324,896		8,154,188		116,235	1,212,312	
South Coast West	l.m.	841.29		2,426,782		5,603,358		77,233	832,133	989
-do- Center	l.m.	380.54		420,836		1,579,863		23,146	232,831	612
-do- East	l.m.	287.00		477,278		970,967		15,856	147,348	513
2. Indirect Cost				4,063,041		1,881,233		352,033	644,425	53%
3. Total Construction Cost									1,856,737	
ENGINEERING SERVICES									167,106	
1. Detailed Design		2%							37,135	
2. Supervision		7%							129,972	
CONTINGENCY Construction		10%							185,674	
Engineering Services		5%							8,355	
TOTAL PROJECT COST									2,209,518	

Phase 4 North Coast

Work Item	Unit	Quantity	1 MRf=¥ 11.99 Maldivian Rufiyaa (M		1 US $=¥ 129.53 US Dollar (US$)		Jpn (¥ 1,000)		Jpn (¥ 1,000)	Unit Price
			Unit Price	Amount	Unit Price	Amount	Unit Price	Amount	Total Amount	
CONSTRUCTION COST										
1. Direct Construction Cost				2,520,573		4,069,816		91,915	649,300	
North Coast	l.m.	1,291.00		2,520,573		4,069,816		91,915	649,300	503
2. Indirect Cost				2,566,015		1,678,657		234,912	483,115	74%
3. Total Construction Cost									1,132,415	
ENGINEERING SERVICES									101,917	
1. Detailed Design		2%							22,648	
2. Supervision		7%							79,269	
CONTINGENCY Construction		10%							113,242	
Engineering Services		5%							5,096	
TOTAL PROJECT COST									1,347,574	

Chapter 4 Environmental Impact Assessment

4.1 *Sources of Environmental Impact*

The seawall project has positive impacts as well as negative ones on the environment. Sources of environmental impact of the seawall project are described in two stages: during and after construction.

4.1.1 During Construction

Sources of environmental impact which could be caused by the proposed plan can be divided into four components as follows:

- Operation of heavy equipment
- Dredging
- Construction of structures
- Transportation of construction materials

Construction of structures, in which the operation of heavy equipment and vehicles is involved, may cause air pollution, and raise noise and vibration levels. An increase in traffic volume on the roads may be caused by the construction vehicles. Water pollution may be caused by the generation of turbid water, which will give rise to deterioration of the marine biology.

4.1.2 After Construction

After construction there may be impacts caused by the erection of structures as protection against high tides and wave overtopping. Setting up such structures on the shorelines may cause changes in the environment including changes in coastal use, currents and aesthetics. These changed environment factors may give rise to deterioration of ecosystems and human life. Their impacts depend on type, size and location of the structures.

4.1.3 Identification of Environmental Impact

A project impact matrix that covers the possible impacts on environmental elements during and after construction is shown in Table 4.1.1.

Table 4.1.1 Environmental Impact Matrix for the Proposed Project

Project Component and Project Area		Socio-economic Environment												Physical and Natural Environment									
	Environmental Element	Land Use	Coastal Use	Traffic	Infrastructure	Community stability	Migrant population	Fishery	Employment	Public health	Cultural values	Recreation	Aesthetics	Slope stability	Coastal hydrology	Sea water quality	Ground water use	Ground water quality	Air quality	Noise	Vibration	Terrestrial biota	Marine biota
During Construction	Operation of heavy equipment			-2									-1						-1	-3	-3		-1
During Construction	Demolition of existing structures		-2	-1				-1		-1		-1	-2			-2			-1				-1
During Construction	Dredging/Excavation		-2					-2								-2							-3
During Construction	Construction of structures		-2	-1				-1				-2	-2			-1							-1
During Construction	Transportation of construction materials			-1															-1	-2	-1		
After Construction	West coast	+2		+1	+3	+2				+1			+1	+2									-1
After Construction	East coast – Reclaimed area	+3	-2		+2					+1		-2* / +2	+1		-2								-3
After Construction	East coast – Artificial beach	+2	+2									+2	+1										-2
After Construction	South coast	+1	+2	+2																			
After Construction	North coast																						

* Upper figure in column : Aquatic Sports
Lower figure in column : Outdoor sports, Football etc.

Environmental Impact Rate

-3 Significant negative impact
-2 Moderately negative impact
-1 Negligible negative impact

+3 Significant positive impact
+2 Moderately positive impact
+1 Negligible positive impact

4.2 Forecast and Evaluation of Environmental Impact of the Proposed Plan

Environmental negative impacts which may be caused by the proposed plan were observed in Table 4.2.1 of the preceding section. These impacts are examined in more detail in this section.

4.2.1 During Construction

(1) Coastal Use

Coastal use includes fishing, recreational activities, and residents along the coast. Transportation is not included in this section.

Residents of Male' island enjoy recreational fishing and walking on the shoreline. In particular, the east coast is popular for surfing and swimming among young people. The commercial fishing ground is located in the atoll rim channel and further away from the atoll so that the area around Male' island is not used for commercial fishing.

Demolition of existing structures and construction of new structures will have an impact on coastal use along the shoreline such as access to shoreline for recreation and living. Residents will not have access to the shoreline during the construction period. Construction activities in the coastal area such as dredging and excavation also obstruct coastal use in front of the seawall.

These impacts will last only for the period of construction, and furthermore the project area will be divided into several work sections. Therefore, environmental impact is predicted to be low.

(2) Traffic

Demolition of existing structures and construction of new structures will require heavy equipment as follows:

- dump trucks
- mobile cranes
- back-hoes
- rock breakers
- rock drills
- floating cranes, etc.

The erection of structures and operation of heavy equipment will occupy considerable space on the coastal roads. Consequently, construction of the seawall will obstruct land transportation. Furthermore, the traffic volume will increase on account of conveyance of transport materials. However, the period of transportation will not be long and some detours will be provided, so environmental impact caused by the construction is predicted to be low.

(3) Fishing

Fishing is very important to the economic industrial sector in the Maldives. Fishing accounts for approximately 15 % of the GDP, and 70 % of the export product value in 1990.

Main fish caught for commercial purposes such as skipjack and yellowfin tuna, are large in size, and their fishing grounds are far away from the reef. Therefore, construction on Male' island will not cause a great impact on the fishing resources.

However, small reef fish may be influenced by turbid water from the construction sites. Deterioration of the water quality will be discussed in "(7) Sea Water Quality"

(4) Public Health

Assuming that coral dust will be generated by demolition of existing structures, the generated dust may influence conditions of residents health. However, the volume of generated dust is expected to be limited, so that its impact will not be serious.

Construction waste such as concrete blocks and coral rock will be generated due to demolition of existing structures. The construction waste can be disposed in the reclaimed area on the east coast and parts of the construction waste can be used as construction material, therefore the solid waste system in Male' will not suffer from an overload of waste.

(5) Recreation

It may be possible that recreational activities of residents on the coast will be influenced to some extent for the following aspects:

- access to the shoreline
- walking, fishing, swimming, and other recreational activities

During construction, however, the period of obstruction will not be long. The construction of the structures in the whole project area will not be carried out at the same time, but will be carried out section by section, therefore, the impact will not cover a large area at once. Consequently, environmental impact of construction operations is predicted to be low.

(6) Aesthetics

When the structures are demolished or built, aesthetics of construction sites may be worse than existing conditions. Heavy equipment, construction materials and waste concrete blocks may be left at the site near the residential area. However, the period of construction is expected to be short and the construction will take place in divided sections. Therefore, negative aesthetical impact is not expected to be serious.

(7) Sea Water Quality

a) Demolition of Existing Structures/Dredging and Excavation

Demolition of existing structures will generate some turbid water. The generated turbid water consists of coral sand and pieces of concrete blocks from the existing structures. Small size substances will be diffused by currents. However, it seems reasonable to suppose that most of the substances are not small in size so that these substances may sink in front of the shoreline and may not generate turbid water. Therefore, impact on the sea water quality is not expected to be serious.

b) Construction of Structures

Concrete blocks may generate lye during the construction stage. The pH will increase if there is much lye in the sea. As a result, there will be some impact on aquatic life. Actually, however, generated lye will be small in volume and is expected to be diluted with diffusion by the sea currents. Sea water also has a buffer action. Therefore, generated concrete lye is not expected to cause deterioration of sea water.

(8) Air Quality

It may be possible that the ambient air quality will be influenced and that the following activities will generate air pollutants:

- Operation of heavy equipment and vehicles for transportation of construction materials will generate emission gas as CO_2 and NO_x
- Demolition of existing structures will generate dust

The dispersion of emission gas and dust are influenced by a number of conditions such as wind direction and speed, stability of the atmosphere and conditions of operations.

Dust may be generated by the demolition of existing structures. Provided that the following activities will be taken up as a countermeasure for air quality in the construction stage, dust will not be generated to any high concentration level.

- Demolition of structures will not be carried out on windy days
- Water will be sprinkled at the site where demolition work takes place.

Heavy equipment will generate CO_2 and NO_x. However, generated air pollutants such as CO_2 and NO_x are not expected to influence the ambient air quality, because operation of heavy equipment will last only for a short period of time and emission gas is easily dispersed by the winds (average wind speed between 1967 and 1990 : 4.7 m/s).

(9) Noise

For the construction of seawall operations the use of some heavy equipment such as back hoes, concrete breakers, and concrete mixers will be needed. Some heavy equipment generates noise. It is estimated that the noise level will be raised by heavy equipment as follows:

Noise levels are calculated by the following formula which represents a hemisphere for sound.

$$L_r = L_w - 8 - 20 \log r$$

where :

L_r	:	noise level at r meters away from the source of the noise	(dB(A))
L_w	:	average power level of the source of noise	(dB(A))
r	:	distance between the noise source and receiver	(m).

Conditions for calculation of the noise level by heavy equipment are set in Table 4.2.1:

Table 4.2.1 Condition of Noise Calculation

Items	Conditions	
Power Level	Back hoe	L_W = 118 dB
	Concrete breaker	L_W = 113 dB
	Concrete mixer	L_W = 108 dB

The Background noise level around the coastal area is set at 55 dB.

The predicted noise level caused by heavy equipment is shown in Table 4.2.2. As a result, during demolition of existing structures, noise of a back hoe is similar to the background noise level at 500 m from the source of the noise, and the noise of a concrete breaker at 300 m distance reaches a noise similar to the background level. These noises will be emitted intermittently. The noise of a concrete mixer is similar to the background noise level at 150 m from the source. It can be recognized from the above results that there will be some influence in the area near the work site. However, the period of impact will be short. Therefore, the impact of noise is not expected to be serious for the residents.

Table 4.2.2 Predicted Noise Level caused by the Heavy Equipment

unit: dB(A)

Equipment	Distance from source of the noise (m)										
	5	10	20	50	100	150	200	250	300	400	500
Back hoe	96	90	84	76	70	67	64	62	60	58	56
Concrete breaker	91	85	79	71	65	62	59	57	55	53	51
Concrete mixer	86	80	74	66	60	57	54	52	50	48	46

(10) Vibration

For the construction of the seawall operations the use of some heavy equipment will be needed. The following activities will possibly generate vibration:

- Operation of heavy equipment for demolition of existing structures
- Transportation of vehicles for construction materials