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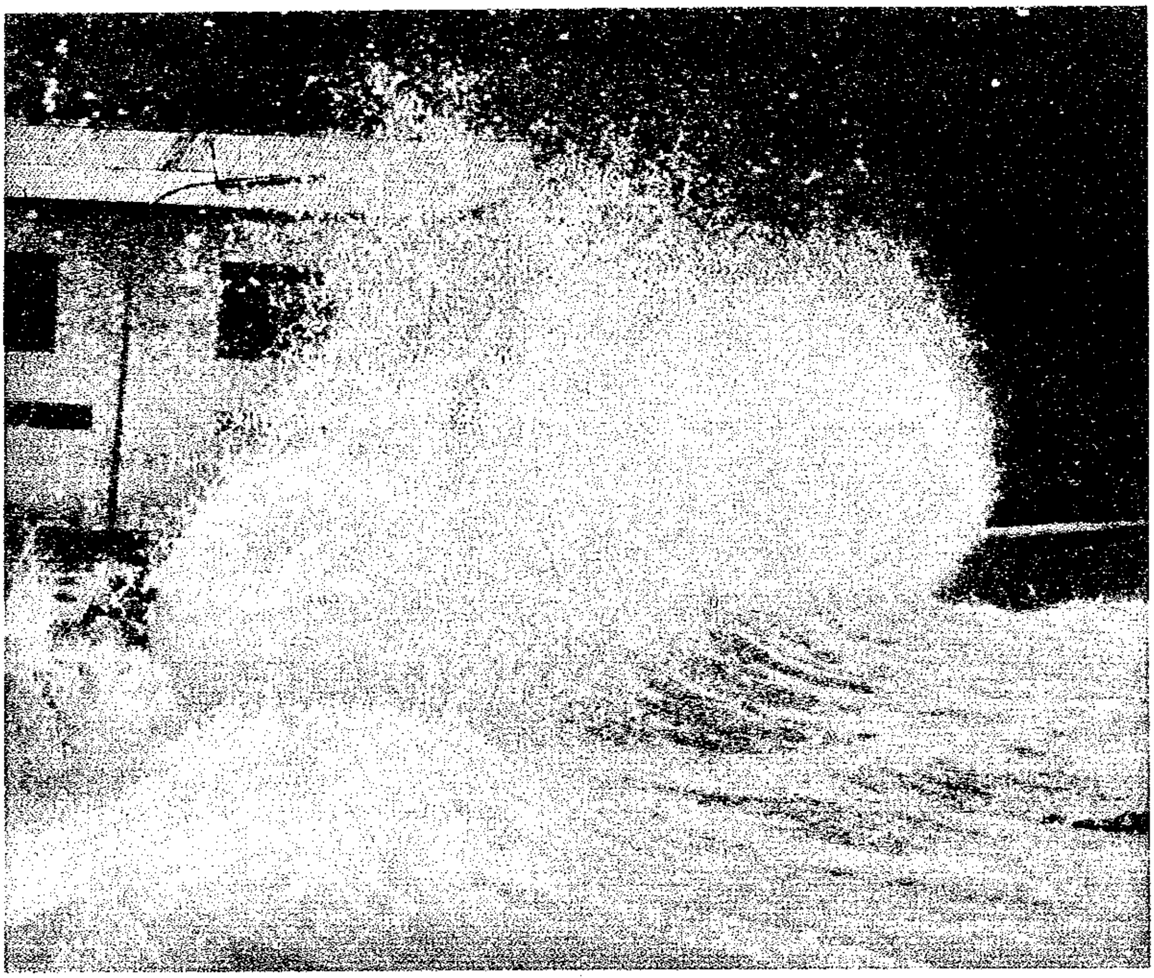
No. 52

THE DEVELOPMENT STUDY ON THE SEAWALL CONSTRUCTION PROJECT FOR MALE' ISLAND IN THE REPUBLIC OF MALDIVES

SUMMARY REPORT



DECEMBER 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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THE DEVELOPMENT STUDY
ON
THE SEAWALL CONSTRUCTION PROJECT
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PREFACE

In response to a request from the Government of the Republic of Maldives, the Government of Japan decided to conduct a development study on the Seawall Construction Project for Male' Island and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Maldives a study team headed by Mr. Hiroshi Sakuramoto, INA Cooperation, 3 times between September 1991 and October 1992.

The team held discussions with the officials concerned of the Government of Maldives, and conducted field Survey at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

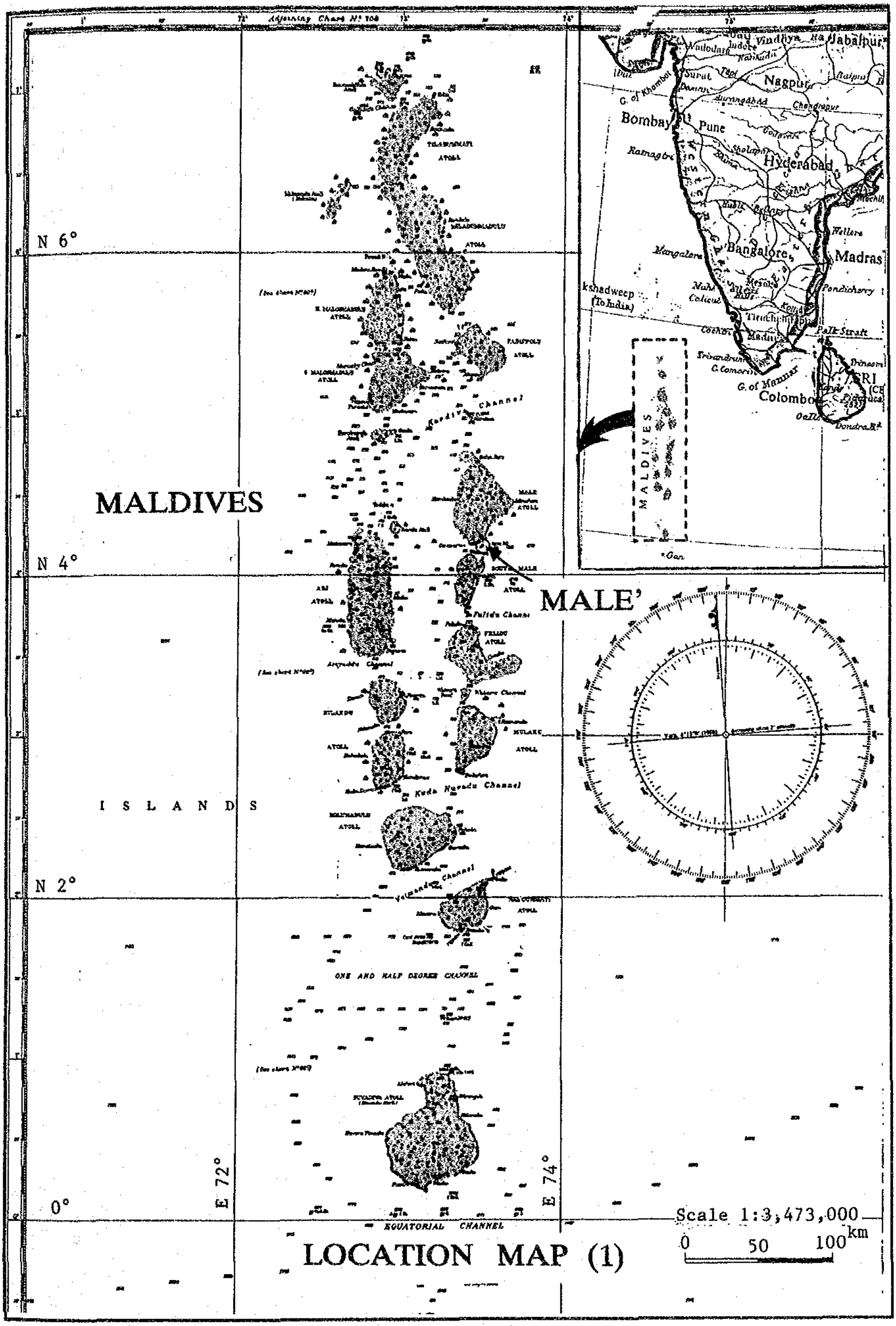
I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Maldives for their close cooperation extended to the team.

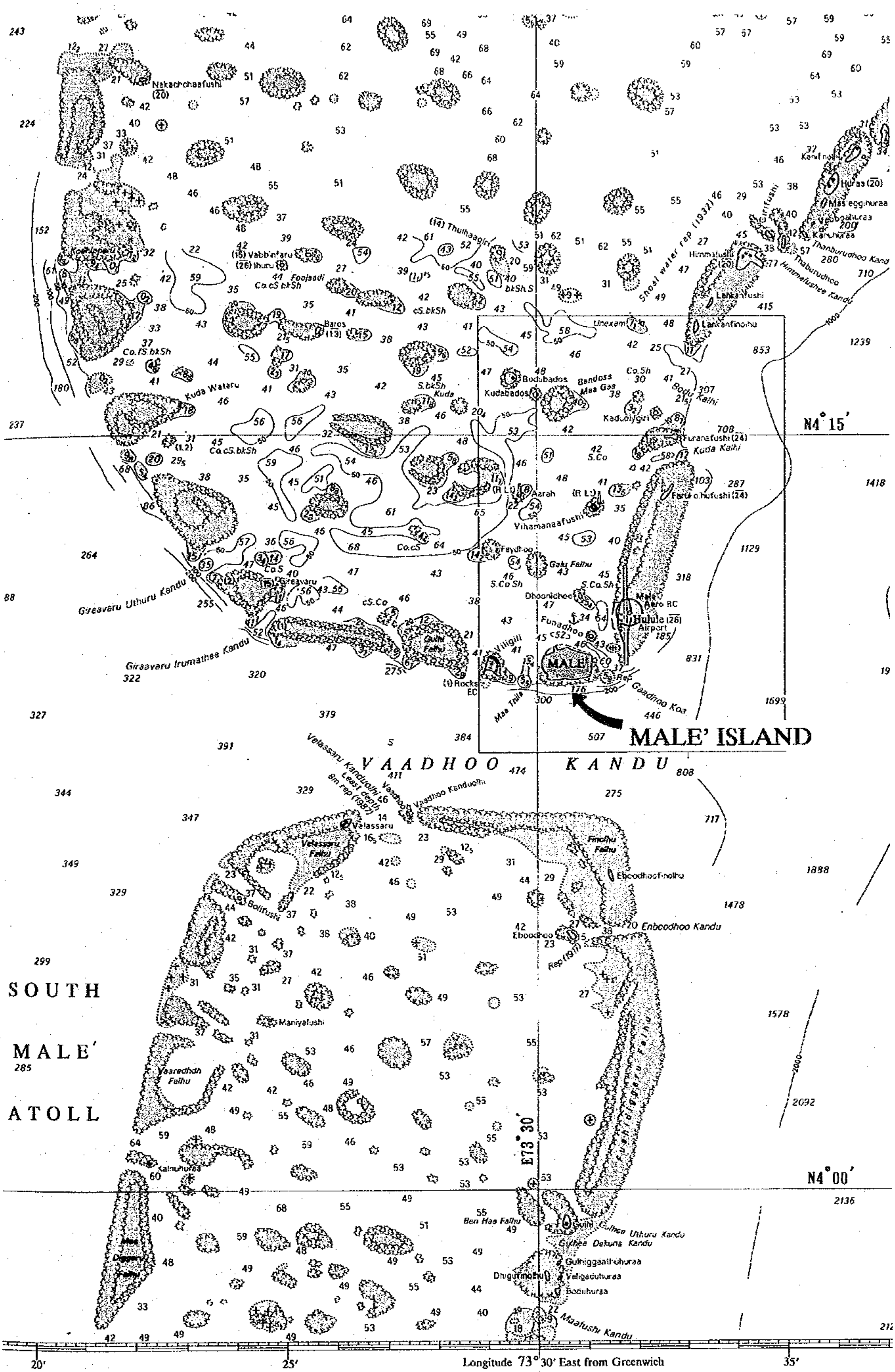
December 1992

Kensuke Yanagiya

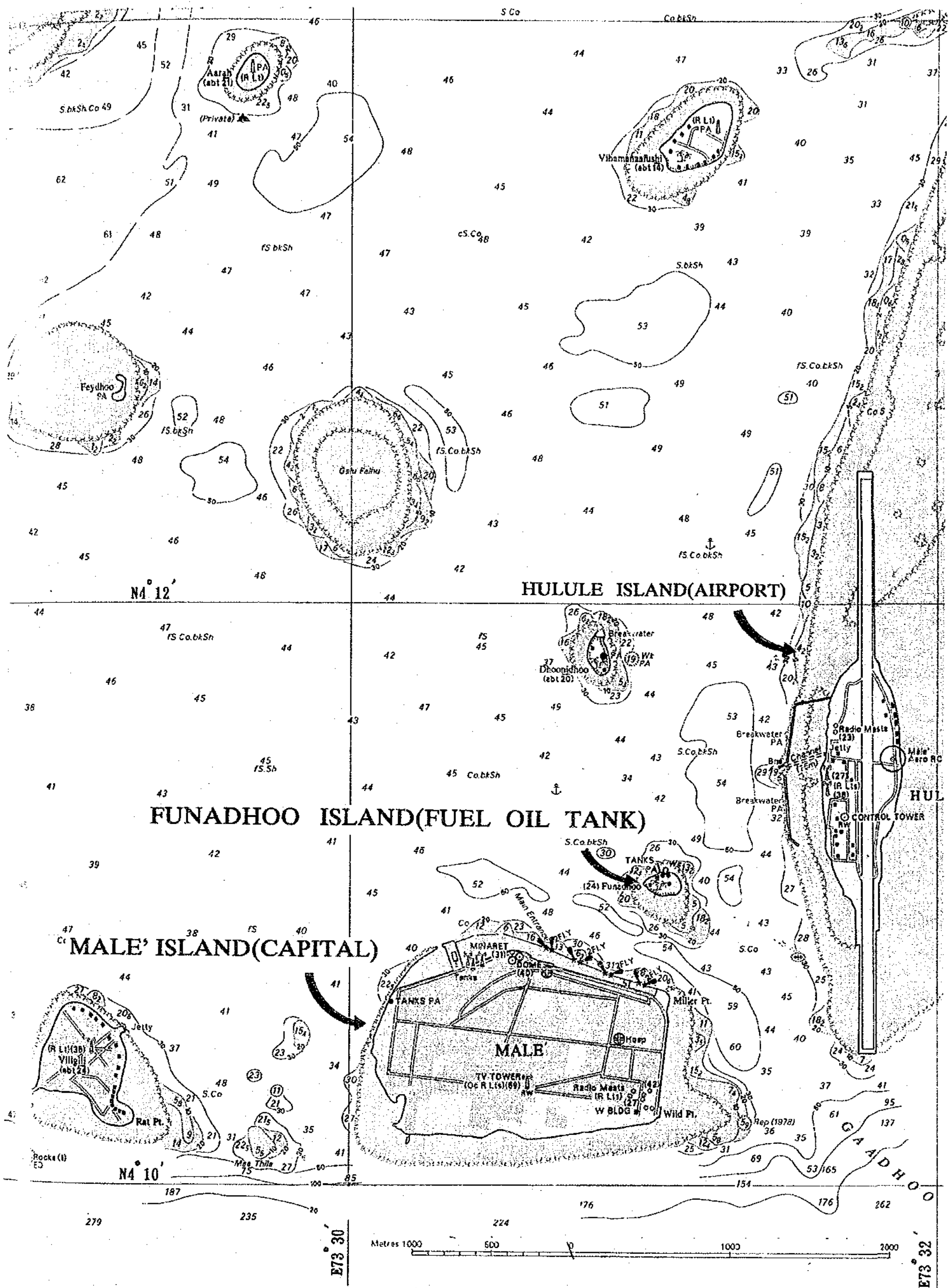
Kensuke Yanagiya
President
Japan International Cooperation Agency



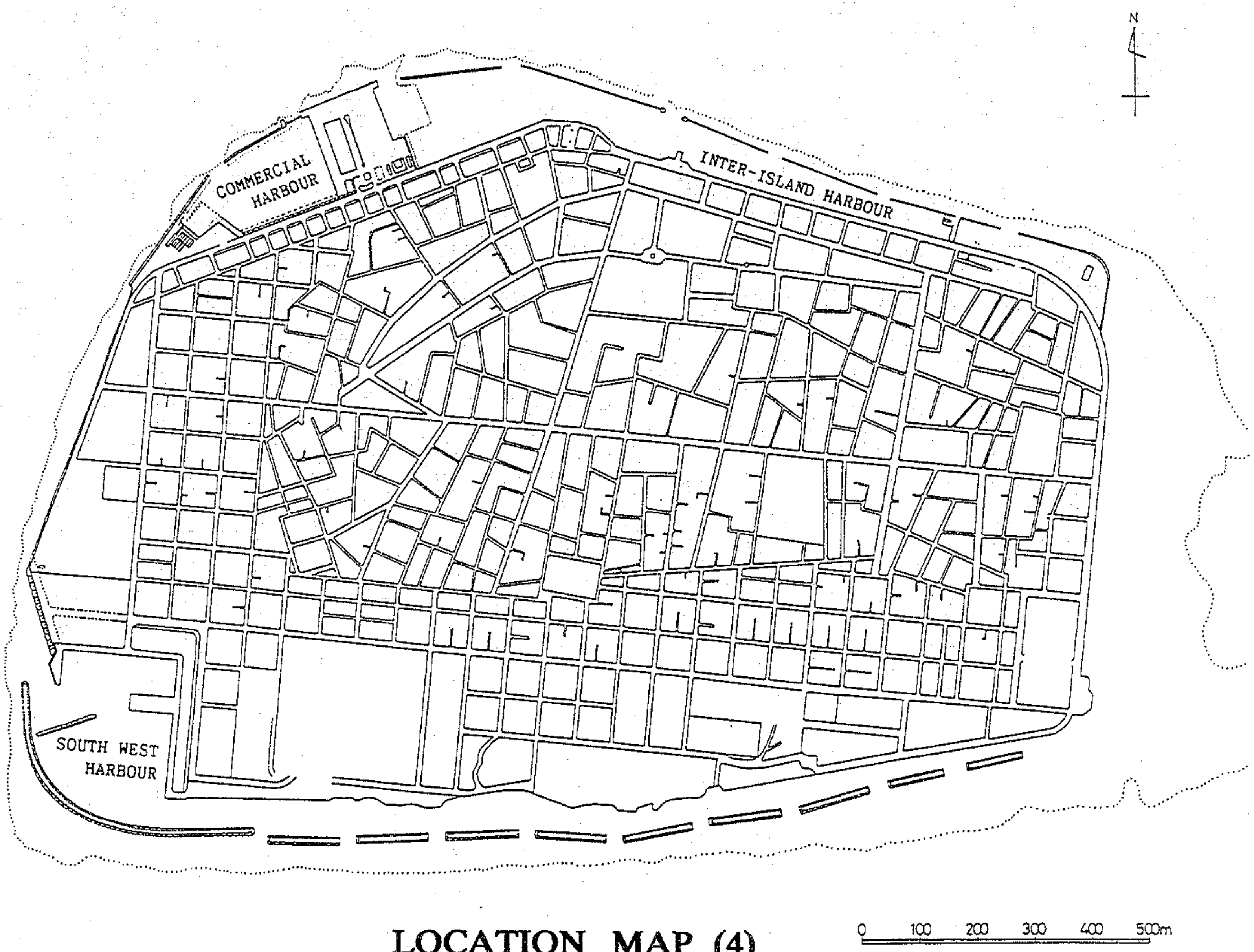
LOCATION MAP (1)



LOCATION MAP (2)



LOCATION MAP (3)



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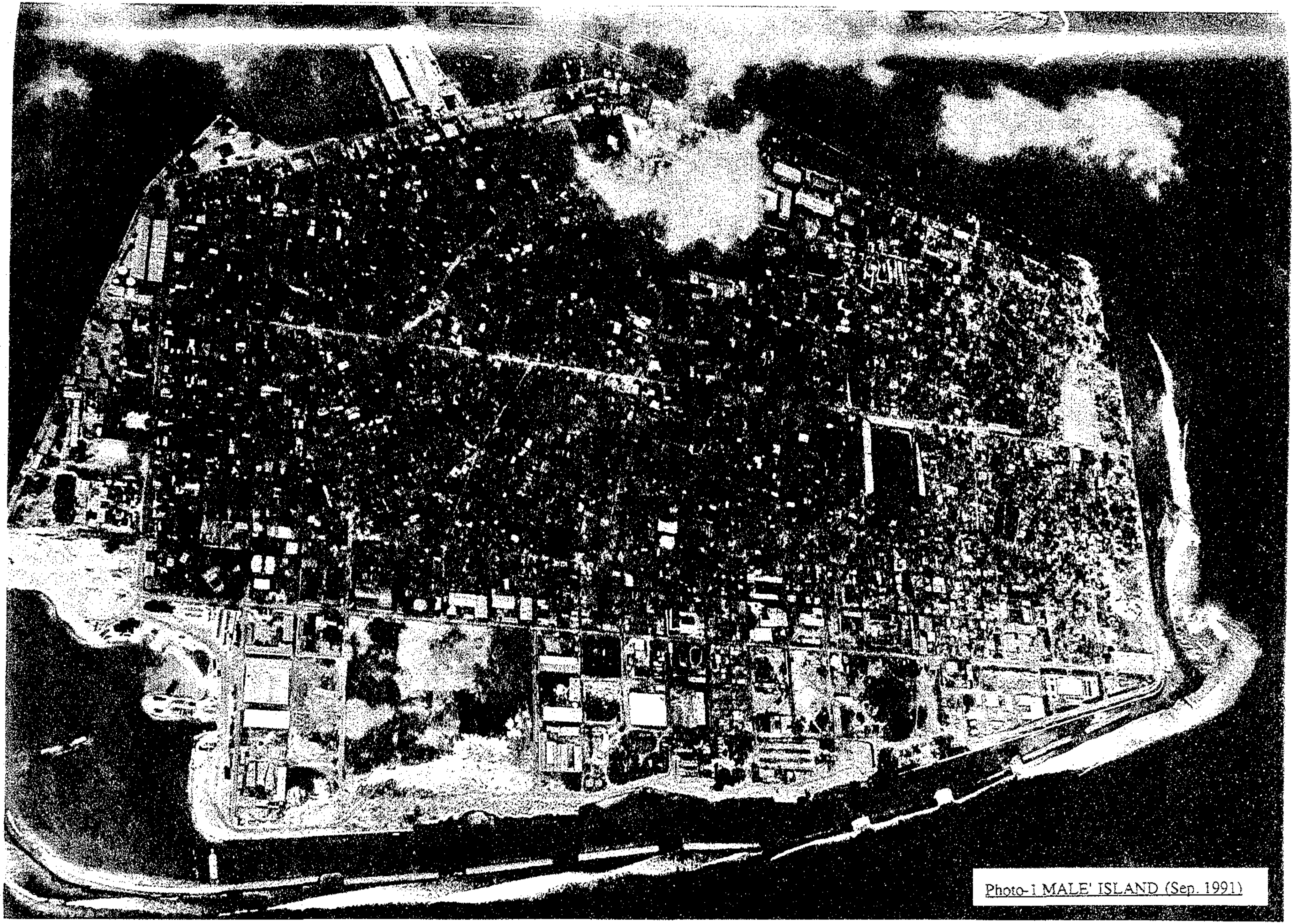
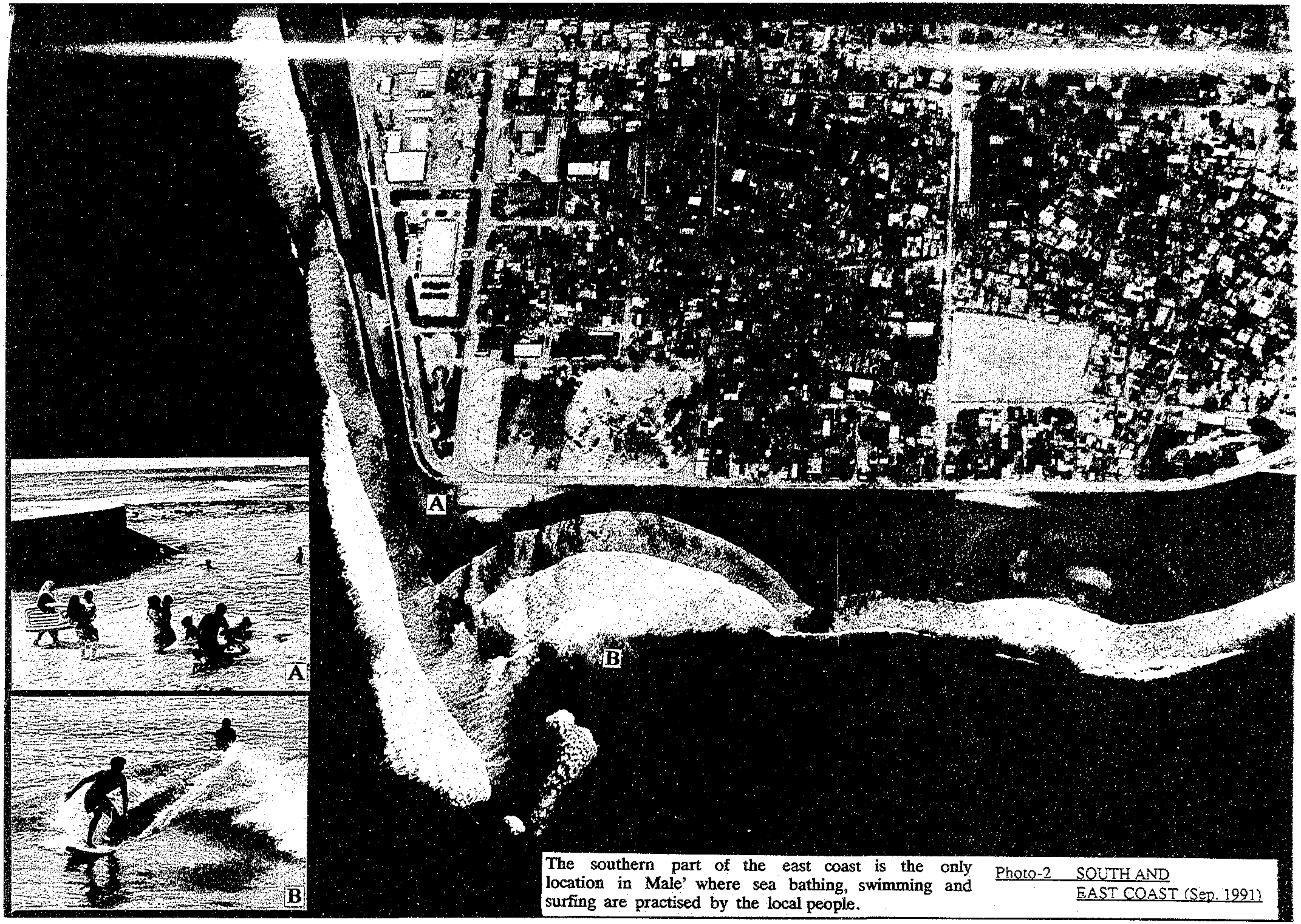


Photo-1 MALE' ISLAND (Sep. 1991)



The southern part of the east coast is the only location in Male' where sea bathing, swimming and surfing are practised by the local people.

Photo-2 SOUTH AND EAST COAST (Sep. 1991)

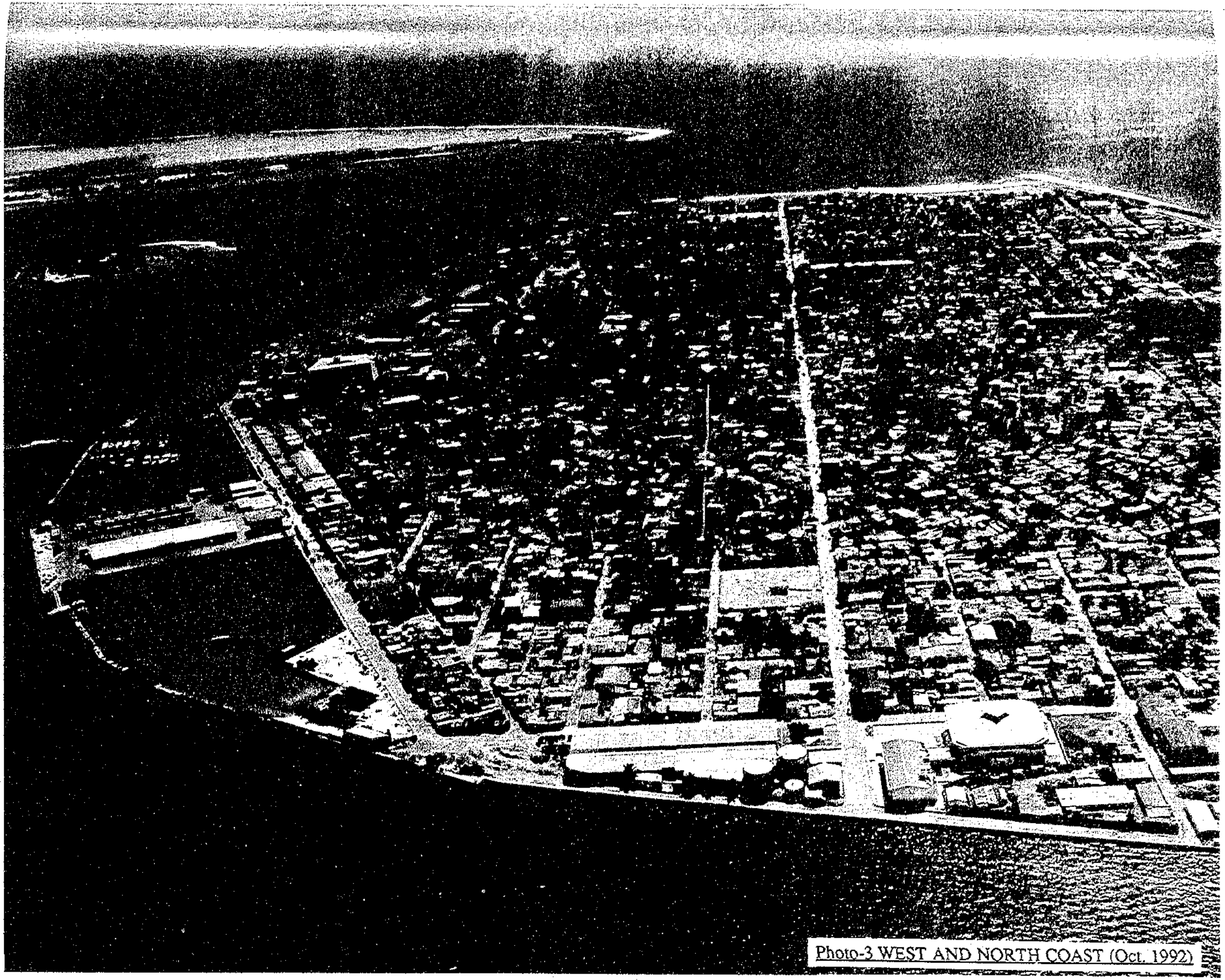


Photo-3 WEST AND NORTH COAST (Oct. 1992)

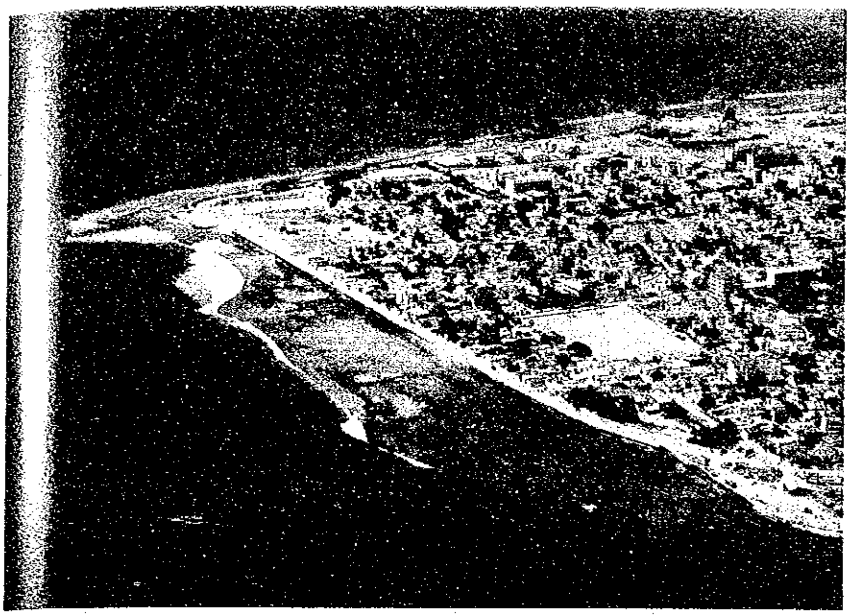


Photo-4 EAST COAST (Sep. 1991)

Although coral reef is the most ideal breakwaters, the Government plans to reclaim this coast to provide construction of swimming pool.

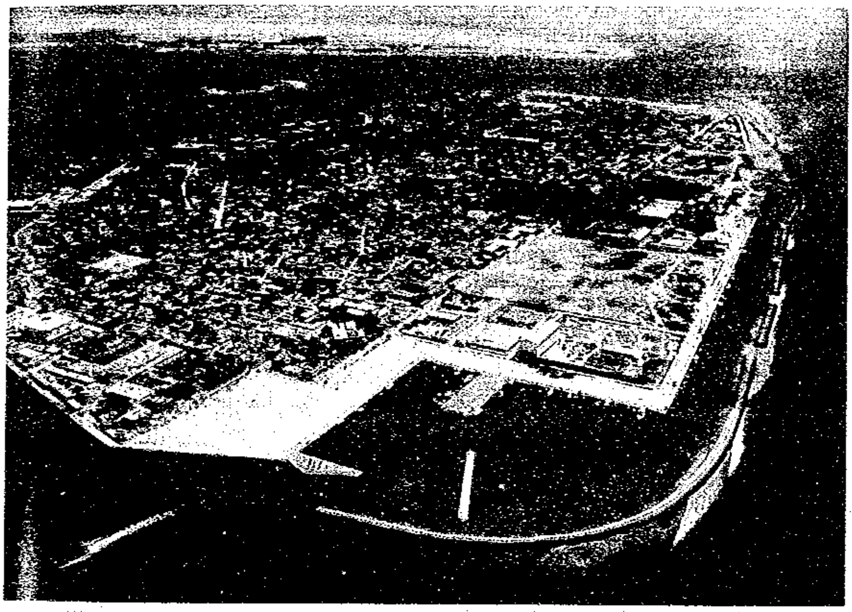


Photo-5 SOUTH COAST (Sep. 1992)

The detached breakwaters were completed in 1990. Along the coast, quaywalls for inter-island boats are planned.

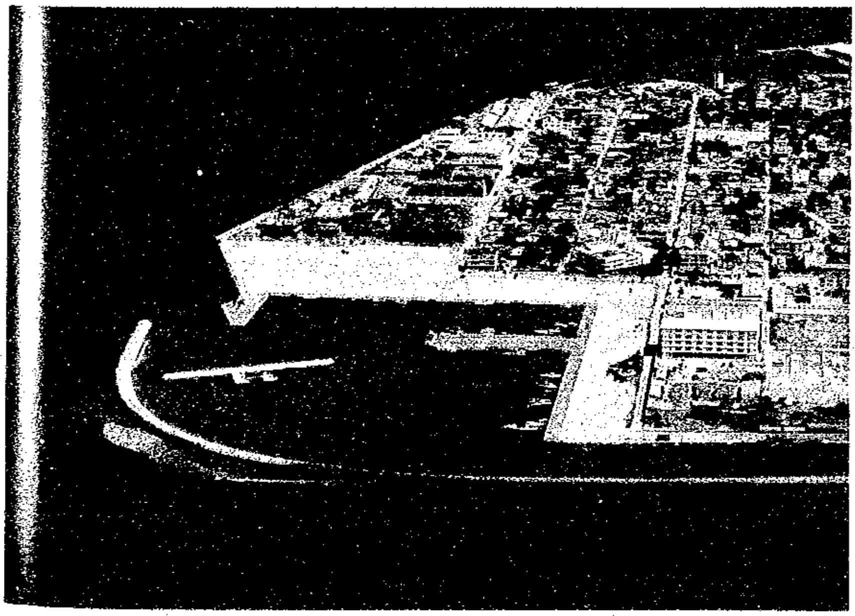


Photo-6 SOUTH-WEST HARBOUR(Oct. 1992)

Inter-island harbour was completed in November 1992.

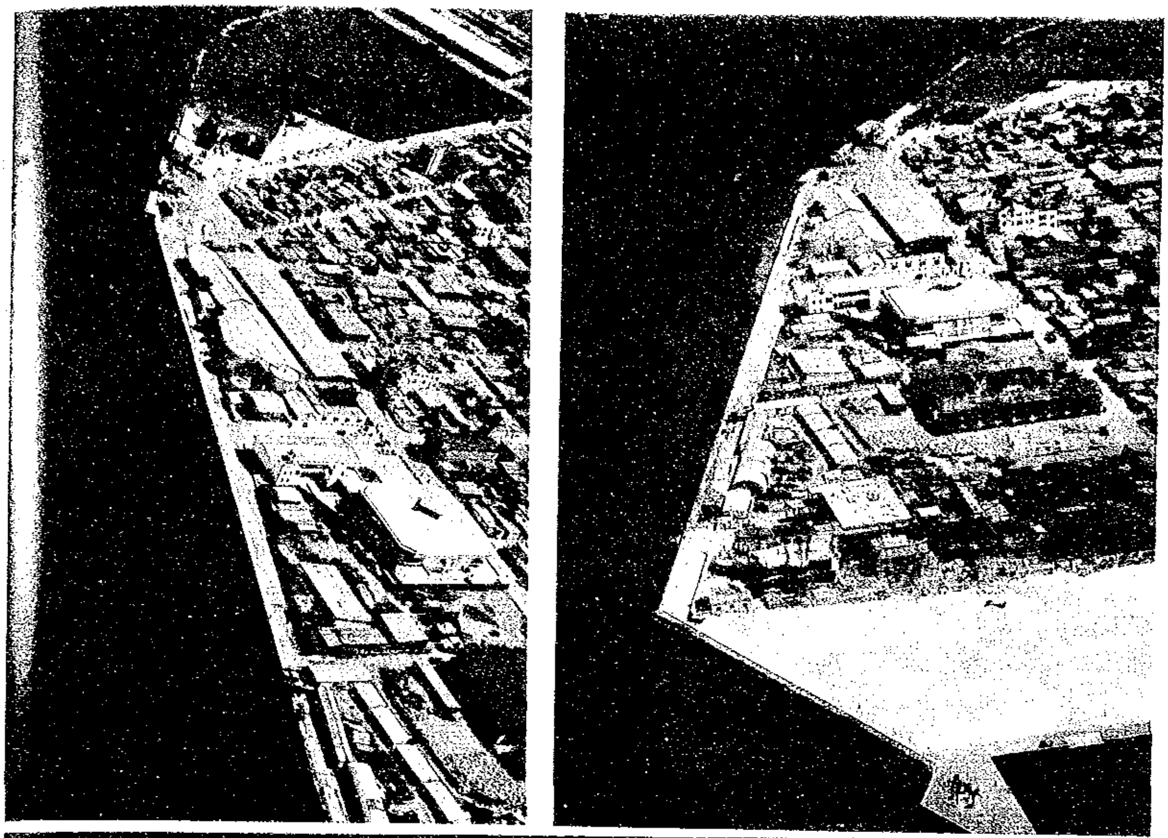


Photo-7 WEST COAST (Oct. 1992)

There are many important public facilities such as hospital, school and education center very close to the seawalls. The Government plans to expand Marine Drive to connect two harbours.

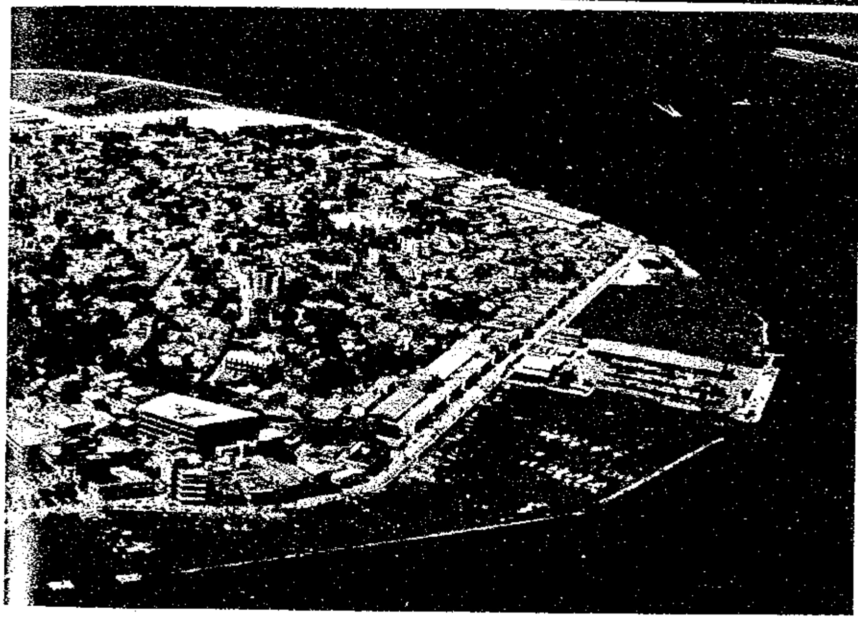


Photo-8 NORTH COAST (Oct. 1992)

Commercial harbour and Inter-island harbour are congested with dhonis, fishing boats and pleasure boats.

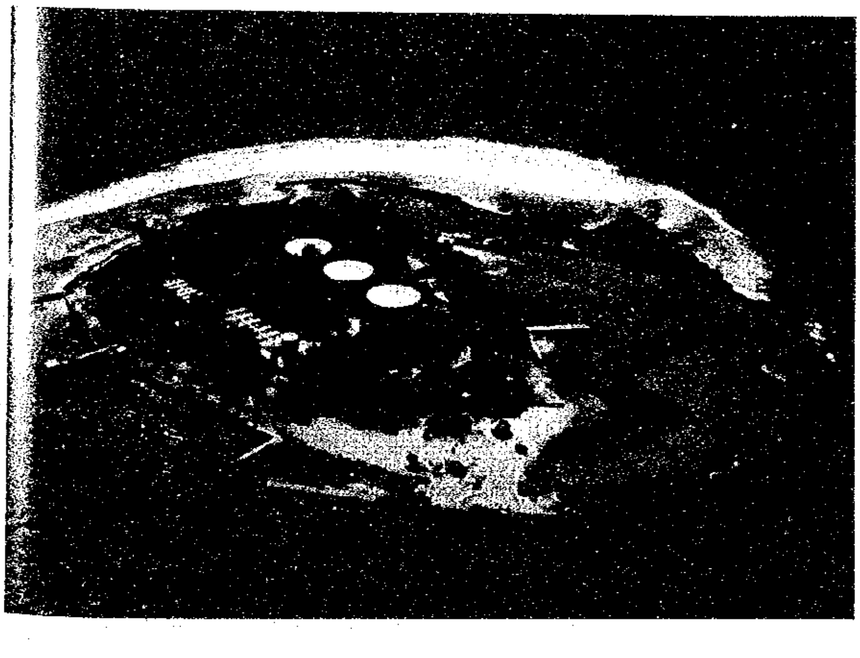


Photo-9 FUNADHOO ISLAND (Sep. 1991)

Three tanks of 1800 mt capacity are installed and utilized as fuel storage for Male' and other islands.
Fuel oil is transported to Male' everyday by small tankers.

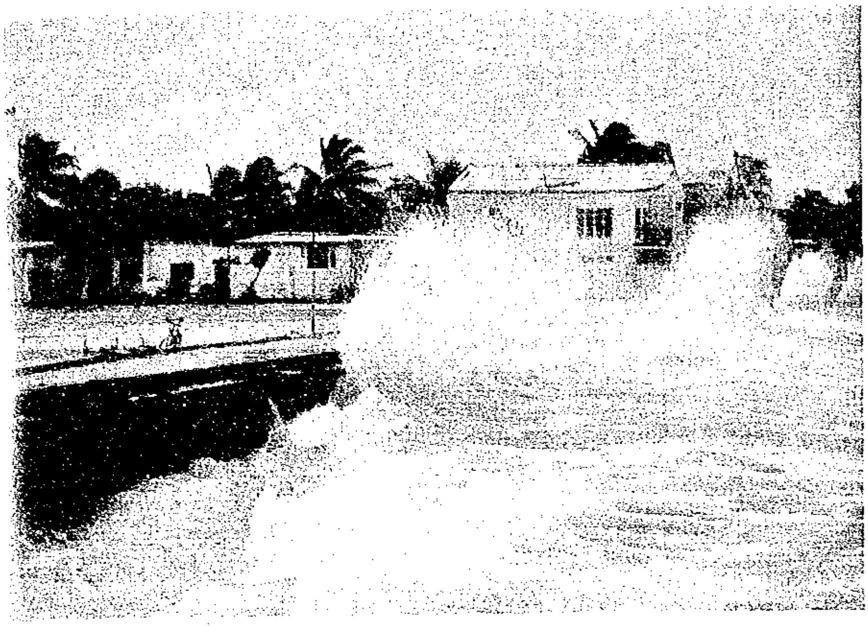


Photo-10 EAST COAST (Jul. 1992)

Wave overtopping occurs very often at the south part of east coast seawall.

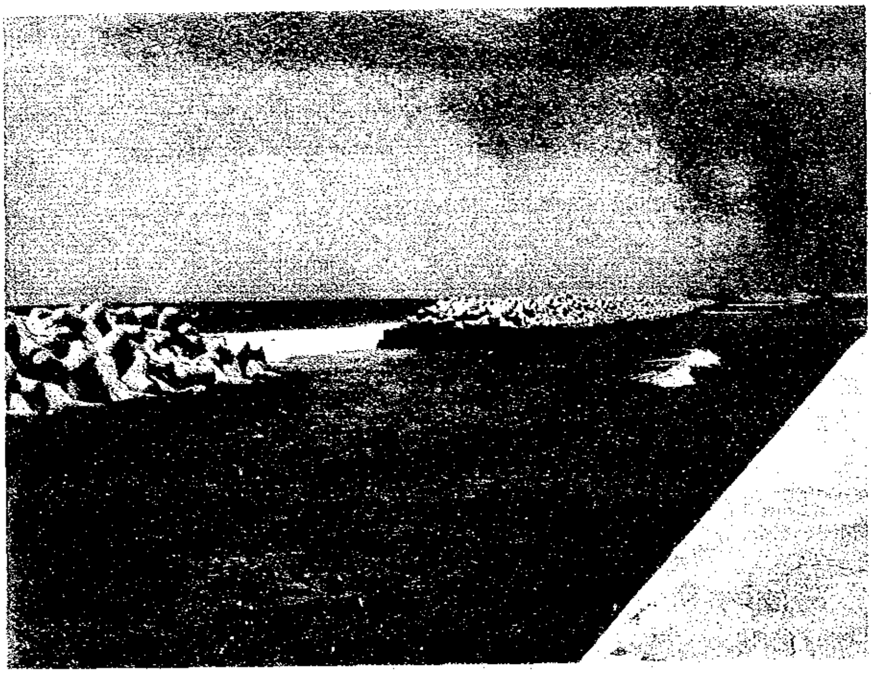


Photo-11 SOUTH COAST (Sep. 1991)

Detached breakwaters were constructed on the reef edge of the south coast after the 1987 high tide disaster.

Photo-12 WEST COAST (Sep. 1991)

The existing seawalls are constructed very close to reef edge. There is no room to expand the road seaward although the road is planned to be expanded.

Photo-13 EXISTING SEAWALL STRUCTURE (Sep. 1991)

The structure is of coral rocks of 10 to 20 cm in dia. piled with its surface mortared or plastered.

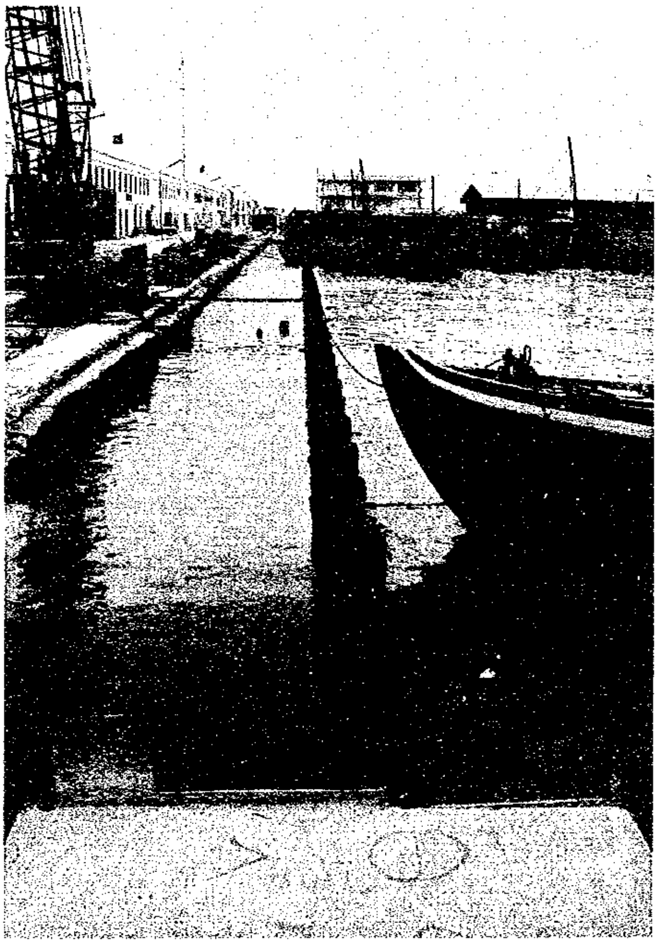


Photo-14 SHEET PILING SEAWALLS (Sep. 1991)

New sheet piling seawalls are being substituted for the old seawalls along north coast.

Composition of the Report

This report consists of six volumes as follows;

①	Summary Report	:	Summary
②	Main Report I	:	Report for Male'
③	Main Report II	:	Report for Funadhoo
④	Supporting Report	:	Supplementary Study Report
⑤	Supporting Data I	:	Topo/Hydrographic Maps
⑥	Supporing Data II	:	Oceanographic Survey Data

Table of Contents

Chapter 1. Background of the Study

1.1 History and Purpose of the Study

1.1.1 History

Any serious damage caused by extremely high tides may not have been recorded before 1986 in the Republic of Maldives, but thereafter high tides occurred three times and caused considerable damage in April 1987 and in June and September 1988.

From 10th to 15th April 1987, extremely high tides occurred in Male' and its surrounding islands and caused damage to seawalls, private houses, airport facilities, etc. The total loss caused by this high tide was estimated at about US$ 5 million concentrated along the heavily populated south coast area of Male' Island and at the international airport in Hulule Island. When high tides occur in Male' Island, flood waters continue to remain for considerably long periods, mainly because the island is flat and low lying and has no adequate drainage system. In 1987, due to flooding for a long period of time coupled with high temperatures, an epidemic of diarrhea broke out.

Immediately after the flood disaster in 1987, the Government of the Republic of Maldives requested the Japanese Government for an investigation on damages caused by the extremely high tides. The Japanese Government dispatched an urgent mission to study the flood disaster for 9 days from 24th April, 1987. The mission surveyed the damaged sites and recommended an urgent construction plan of a detached breakwater in order to protect the southern coast of Male' Island from intrusion of big swells. Following the recommendation, the Government of the Republic of Maldives requested the Government of Japan for grant aid to implement this Project, and the Japan International Cooperation Agency (JICA) had a basic design study mission to work in the field for 23 days from 30th July 1987. Based on the plan studied by JICA, the detached breakwaters were constructed and completed in 1990 along the southern coast as an urgent means against extremely high tides.

During the construction of the detached breakwaters in 1988, high tides, which were smaller in scale than the ones in April 1987, occurred and flooded the area along the southern coast of Male'. However, the damage by high tides were minimized by preventing flood water intrusion by constructing a temporary stop water sand bag mound of approximately 0.5 m high and 4 m wide across the road in the southern area of the island. Furthermore, the sand bag mound was moved to the shoreline of a reclamation area to prevent wave overtopping. These emergency works were carried out by bulldozers owned by a Japanese construction company working on the detached breakwater project.

Although the urgent construction of the detached breakwaters has been completed, a further development study on the Seawall Construction Project is required in order to protect the Male' Island from any extremely high tides. In response to the request of the Government of Maldives, JICA dispatched a preliminary study team headed by Dr. Takaaki Uda, Head of Coastal Engineering Division, Public Works Research Institute of the Ministry of Construction, to Maldives from January 22 to February 2, 1991 and the Scope of Works for the Study was concluded.

1.1.2. Purpose

The southern and western areas of Male' Island comprise reclaimed land with its ground level almost the same as the spring high water level. Along the west and east coasts, seawalls were constructed, but they do not properly meet technical requirements against high tides and wave overtopping. The north seawall, generally used as berthing facilities for dhoni and pleasure boats, is sheltered from wind waves generated in the atoll by breakwaters, but the crown height of the seawall is not high enough and was overflowed in the 1988 high tide.

The land area of Male' is less than 2 km^2 and accommodates about 26 % of the nation's total population of 213,215 (in 1990). In recent years, the population has shown a large migration into the capital forming an extremely high population density in Male'. Therefore, in order to ensure a safe livelihood for the residents of Male' Island, the development study of the improvement of the seawall in Male' Island is urgently required.

The Study objectives are to make topographic/hydrographic survey, oceanographic survey, soil investigations and other necessary investigations and formulate the construction plan of the seawall, and to perform technology transfer to the Maldivian counterpart personnel.

1.2 Description of the Project Site

1.2.1 Project Site

(1) Maldives

The Republic of Maldives is an archipelago of 1,190 small coral islands, out of which 200 are inhabited. The islands are formed into 26 natural atolls but for easy administration, they are divided into 19 administrative units or "atoll". The islands are very small and low-lying with many being no more than two meters above sea level.

The 1990 census puts the population at 213,215. It is expected that the figure would rise to 288,800 by the year 2000.

The economy is based on three principal activities, fishing, tourism and shipping. Poor soil and limited availability of cultivable land limit agriculture. Traditional industry consists of local boat-building, handicraft such as mat-weaving, jewellery-making and lacquer work. Export-oriented industries include tuna fish canning, and manufacture of garments.

(2) Male', the Capital of the Maldives

Male' is just one island in a multitude of islands making up the Male' Atoll. Throughout its known history, Male' (Pronounced Maaley) has been the political, business as well as cultural center of the country.

Situated north of the center of the island chain that makes up the Maldives, the island of Male' is approximately one and a half square kilometers in area and houses a population of 55,130 (census in 1990). In addition to its permanent population, Male' also has a floating population of several thousands who arrive from other atolls to sell their products, do their shopping and to receive medical treatment. People from other islands send their children to either Government or private schools in Male' for education.

The climate of Male' is warm and humid. The average daily temperature varies between 30.4 °C and 25.7 °C. The monthly rainfall averages 162.3 mm. Light cotton clothing is preferred. Visitors are expected to respect the local practice of propriety in dress while in Male'.

A reclamation project carried out recently in the shallow waters within the western and southern reefs has added almost half of its original size to the island.

Male', being quite a small island, there is no place one cannot walk. In fact, it takes about 20 minutes to walk the length of the island. However, bicycle is the commonly favoured mode of transport. Other vehicles including motor cycles, vans, lorries and cars are rapidly increasing too.

Going out of Male', whether to the International Airport or any other place, means using sea transportation; generally by a local ferry boats known as Dhoni. Most of these are anchored in the Male' inner harbour-the breakwater enclosed area lying to the North of the island. Sections of the water front are allocated for various purposes such as ferrying outbound passengers, unloading local products, and fish landings.

All ocean-going vessels are anchored in the outer harbour and the cargo is ferried by towed lighters to the newly built wharf in Male' Viyafaari Ban'dharu which also houses Male' Customs.

1.2.2 Related Development Plans

(1) National Development Plan (1991-1993)

The Government accepts that the ultimate goal of all development must be to achieve a sustained improvement in the human condition. This improvement must encompass advances in both the material and non-material status of the Maldivian people and find expression in increased incomes with reduced disparities better housing, improved access to quality health and education services, and more and diverse opportunities for recreation. No less important, progress must result in improvements in the less quantifiable aspects of improved levels of well-being, rooted in respect for social and cultural values, conservation of the environment and the existence of a stable and harmonious society.

The main objectives have been formulated for the period 1991-93. These objectives are to:

(i) secure improvements in the living standards and quality of life of all Maldives;
(ii) ensure that the benefits of development are shared more equitably among the population; and
(iii) achieve greater self-reliance, which is essential for future growth.

While these objectives will serve to guide the nation's development over the next three years, the formulation of strategies require their translation into specific priorities. In formulating these priorities, the Government has made a detailed review of the performance of past policies and plans, and identified some 30 priorities for the Plan period. While some of these priorities are multisectoral in character, they can be approximately grouped under five main headings:

- economic management and development;
- infrastructure development;
- social development;
- institutional development; and
- the environment.

(2) Related Regional Development Plan

i) Male' Land Reclamation Projects

The Project was launched in April 1979 and was completed in July 1986. This project aimed at creating 59.7 ha of land area in the shallow flat reef over the southern and western sides of Male' Island to provide land for housing, schools, a new hospital, a power plant, a harbour for inter-island transport, a sports complex and other public facilities. The total land area of Male' Island before this project was measured at about 108 ha. By 1979, a land area of 14.9 ha was reclaimed. Out of this reclaimed land, 22 % has already been handed over to new home-owners and the concerned governmental departments. The total volume of soil required for this project amounts at about 850,000 m^3 and was to be met by dredged material mainly from the port development site on the northern side of the island. The construction equipment for this project included two cutter suction dredgers of 12 inch suction pipe each, 4 excavators and 5 tipper lorries. The land area reclaimed and yearly project costs incurred are shown in Tables 1.2.1.

Table 1.2.1 Land Reclamation Project

Year	Area Reclaimed (ha.)	Cost (000 Rf.)
1979	0.2	2,212
1980	13.6	4,464
1981	8.4	6,941
1982	8.4	5,259
1983	12.5	8,754
1984	1.3	6,643
1985	7.4	7,429
1986	7.9	n.a.
	59.7	41,702

Source: DPWL (1985)

ii) Port Development for Inter-island Transport and Fishing Boats

The northern shore of the island is bounded by a series of harbour basins serving inter-island diesel boats, open dhonis, Government and private launches, tourist boats and cargo lighters. The latter are operated from the Commercial Basin situated in the north-west corner of the island and are used to unload cargo from ships anchored in the roadsteads just north of the island. One of the Project objectives is to alleviate the congested conditions in these various harbour basins by the construction of a new harbour serving inter-island boats and fishing boats in the south-west corner of the island. The construction works of the project, financed by ADB, UNCDF and OPEC, were started in March 1991 and scheduled to be completed in October 1992.

iii) Expansion of Marine Drive

In order to meet increasing traffic volume after the completion of new south-west inter-island harbour, the Government plans to widen the existing Marine Drive road along the western coast from 25 feet to 35 feet. Since a part of the existing western seawall is constructed on the extreme edge of the coral reef and there is no space to extend the road, careful attention should be paid when new seawalls are planned.

iv) Swimming Pool

The Government is desirous of promoting swimming amongst the public because of the maritime nature of the country. It is for this reason and also to train swimmers to participate in both national and international events that a swimming pool is planned for Male'. The site for the swimming pool is planned to be provided on new-reclaimed land on the east coast.

v) Others

The other related plans are as follows:

a) Garbage Collection and Sanitary Fill,
b) Power Plant Project,
c) Water Supply and Sewage Development Project,
d) Desalination Plant Project,
e) Center for Social Education,
f) Indira Gandhi Memorial Hospital.

Chapter 2. Results of Site Investigations

2.1 General

In order to collect data and information on environmental conditions, topography, geology, meteorology, oceanography and shore protection facilities, the Study Team conducted site investigations in Male' and Funadhoo Islands.

2.2 Environmental Conditions

2.2.1 Socio-economic Environment

(1) Population

The total population of the Maldives in 1990 was 213,215 and the annual exponential population growth has been over 3 % since 1965 (Ministry of Planning and Environment). The population of Male' island accounts for 26 % of the total of the Maldives, or 55,130. The population of Male' is increasing 1 - 17 % in the annual exponential population growth rate since 1965. The population density in Male' is 30,627 people/km^2.

(2) Land Use

Land use on Male' island is shown in Table 2.2.1 and Fig. 2.2.1. Male' island has an area of approximately 1.8 km^2. Residential and small shop areas account for 57 % of total area of Male'. Most government warehouse and project sites are distributed in the south of Male'. There are commercial areas in the northwest and in the center of Male'.

Table 2.2.1 Land Use in Male', 1991

Area Category	*Area (km^2)	(%)
Residential/Small Shops	1.000	57.0
Commercial Area	0.142	8.1
Government Office	0.059	3.4
Government Warehouse/Project Sites	0.284	16.2
Public Utilities	0.095	5.4
Educational Area	0.046	2.6
Recreation/Park	0.128	7.3
Total	1.754	100

* Area includes roads.

(3) Coastal Use

The protective structures of coastal disaster and coastal use map in Male' at present are shown in Fig. 2.2.2.

Male' is surrounded by Seawalls and detached breakwaters. The Commercial Harbour (under construction) and the Inter-Island Harbour are in the north of Male'. The Inter-Island Harbour is used by many dhonis for anchorage. Southwest Harbour in the south is completed in November 1992.

The shoreline of Male' is used as recreation area for residents. The southeast of Male' is also popular with young people, as this area is the only place on Male' island where surfing is possible.

Maldives government has some development plans for the future on Male'. These development plans are shown in Fig. 2.2.3.

(4) Transportation

The Maldives has a variety of vessels such as dhonis, mechanized yacht dhonis, baththeli and launches. However, the most popular sea transportation is the dhonis. The dhonis are also used for inter-island transport. Many dhonis anchor in the Inter-island Harbour in the north of Male'.

Fig. 2.2.1 Land Use Map

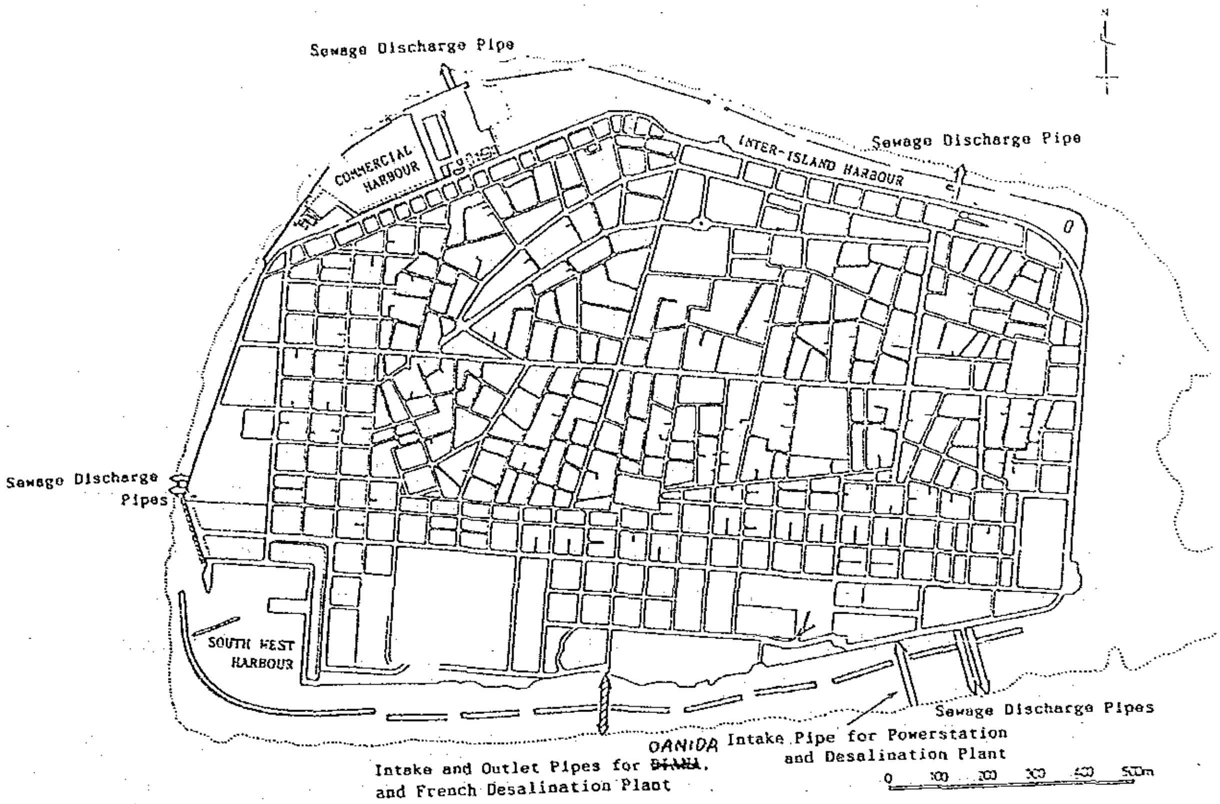


Fig. 2.2.2 Coastal Use Map at Present

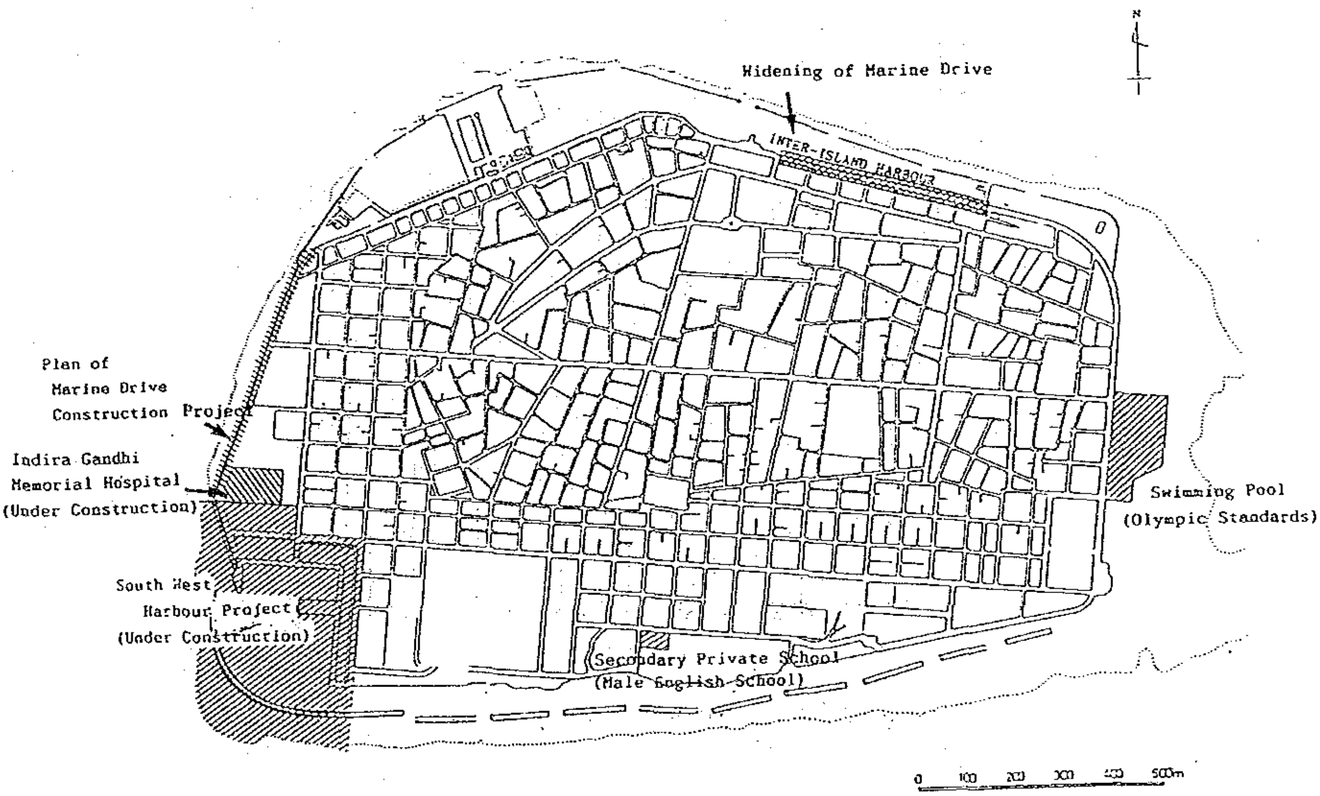


Fig. 2.2.3 Coastal Use Map in Future

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. 2.2.4.
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.
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'.

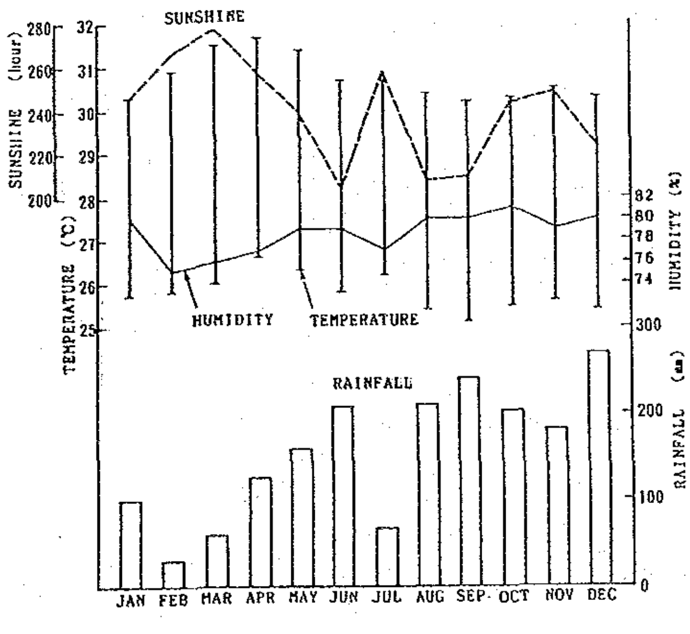


Fig. 2.2.4 Monthly Average Climate

(2) Ground Water

The conditions of ground water depends on the characteristics of porous coral rock, sea level and rainfall. According to Alasdair J.Edwards (1981), 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.

Male' Water Sanitation Project has surveyed the quality of ground water by monitoring wells. As a result, concentration level of chlorides in ground water results from rainfall and sea level. Low concentration of chlorides is distributed in the center of Male'.

(3) *Marine Hydrology*

a) Currents

A general view of the seasonal current patterns in the Indian Ocean is shown in Fig. 2.2.5. The currents flow westward during the northeast monsoon period, and they flow eastward during the southwest monsoon period.

Generally, the tidal currents are eastward in flood, and westward in ebb. The velocity, however, varies by island areas.

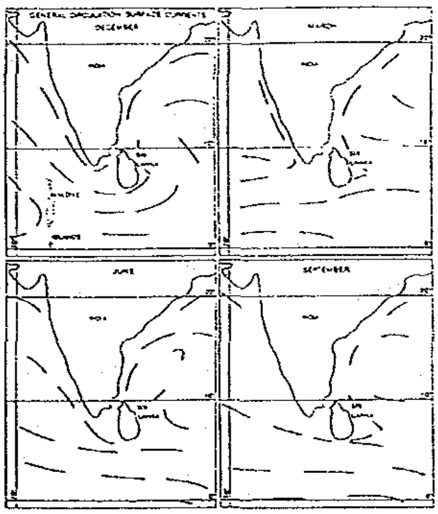


Fig. 2.2.5 Surface Currents around Maldives (by Bernard Swan)

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

(4) Marine Water Quality

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 shores

(5) 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.

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. 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. Live coral of all sorts on top was 1 % or less.

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. In general, the Acropora and Pocillopora seemed to be surviving well, while the massive corals seemed to be in worse condition.

d) North Side

There are 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.

2.3 Topographic/Bathymetric Surveys

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.

Bathymetric Survey was conducted by using a boat. The 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.

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

2.4 Soil Conditions

Soil conditions were examined based on geotechnical information as well as sub-surface soil data of the proposed seawall alignments on the east, south and west coasts of Male' Island.

(1) Geological Survey

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.

(2) Soil Characteristics

The core drilling with standard penetration test (S.P.T.) was done at the east coast, the south coast and the west coast in Male' Island. The three bore holes were drilled on the proposed seawall alignments at the above-mentioned coasts. The results of the geotechnical analysis are summarized in the following items.

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 and the south coast) and loose coral rock which forms the outer ridge (on the west coast).

The physical properties of the lagoon sediments and the loose coral rock are summarized in Table 2.4.1.

Table 2.4.1 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

(3) Material Tests

a) 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.

b) 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.

c) The Dredged Coral Sand Samples for Fine Aggregate

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

2.5 Meteorological Information

In order to understand the characteristics of meteorological conditions around Male' Island, the data obtained from January 1986 to December 1990 at Hulule Island by the Weather Center in the Department of Meteorology were examined statistically as to wind, precipitation and temperature.

(1) Wind Condition

Winds from the west and the north west and winds from the north east and the east north east are predominant throughout the year. From the view point of seasonal changes, winds from the north east and the east north east 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 and the west north west are predominant during May to June. During the period of July to October, winds from the north west increase and winds from between the west and the north west dominate, whereas winds from the west south west decrease. Winds from the west 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.

(2) Precipitation

Monthly average precipitation amount is presented in Figure 2.2.3 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 Figure 2.2.3. 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.

2.6 Oceanographic Survey

Oceanographic survey has been carried out by using instruments equipped with pressure type wave gage and electromagnetic current meter on the east, south and west coasts of Male' Island, respectively.

(1) South-East offshore Point

Almost all data showed 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 was 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).

(2) On the Reef Flat of 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 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 through 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.

(3) On the Channel of South Coast

The waves denote low heights because the observation points are located inside the detached breakwaters. The wave heights at the open area of two breakwaters are 30 cm to 40 cm larger than those at the sheltered area 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.

(4) West Coast

Due to the calm sea conditions during the observation term, the observed wave heights were 20 cm to 30 cm. Judging from the long wave period of about 10 seconds and the incident direction from the south, 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 in the south west. Judging from the vector of current, the significant current on the west coast is thought to be not a nearshore current but a tidal current.

2.7 Existing Shore Protection Facilities

The existing shore protection facilities are schematized as shown 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. 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.2.7.1.

Although no seawall is provided behind the Detached Breakwater on 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

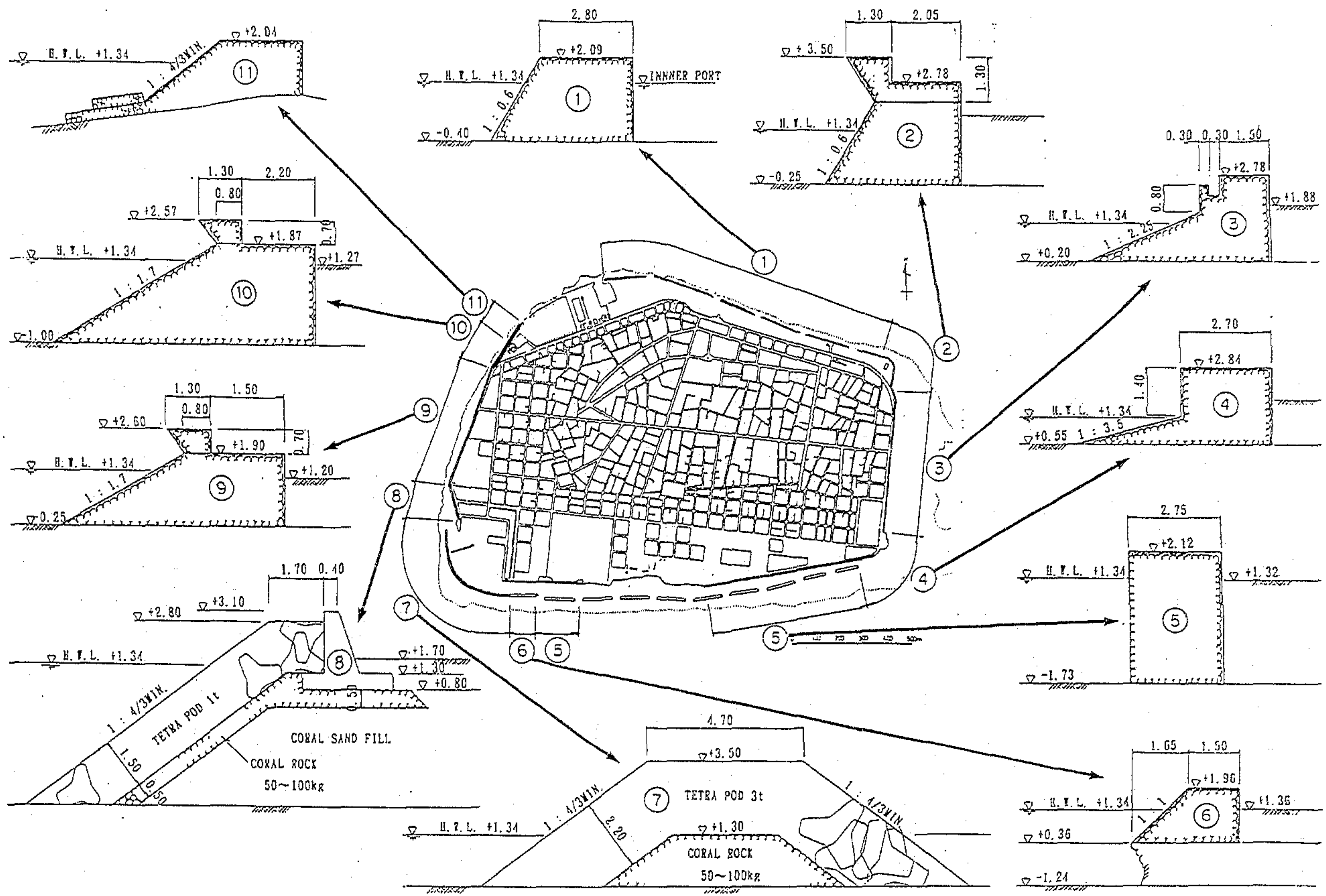


Figure 2.7.1 Existing Shore Protection Facilities

Chapter 3. Shore Protection Planning

3.1 Basic Plan for Shore Protection

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.

(1) Design Criteria

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.

Final design waves 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

(2) Basic Policy for Shore Protection

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:

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

(b) 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,

(c) 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,

(d) 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,

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

(f) 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.

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) 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.

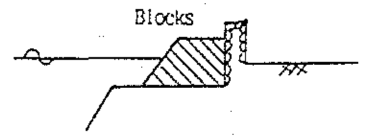
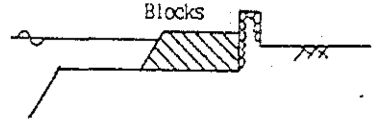
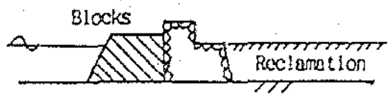
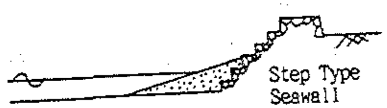
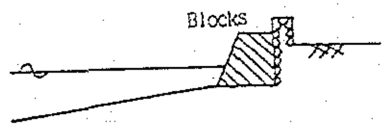
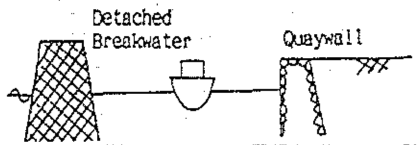
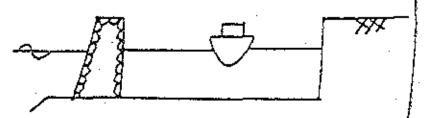
On the west coast, a block mound type of seawall is proposed to protect its hinterland from wave attacks. This type of seawall dissipates wave energy most effectively and is very popular all over the world.

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 surrey 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	H₀ = 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	H₀ = 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	H₀ = 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	H₀ = 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

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, the block mound type of seawall with three rows of blocks at crest, the elevation of which is at D.L. +2.60 m, would be preferable from view points of both technical aspects and requests from the Government of Maldives.

(b) East Coast

Considering the situation of storm wave attack at the time of high tidal level, the same overtopping phenomena as in the case of present condition are thought to be possible. Therefore, the seawall of block mound installed in front of a vertical wall with the height of D.L. +3.0 m would be desirable for the safety of the hinterland area.

(c) South Coast

Overtopping rates in quaywall plans with the elevation of D.L +1.8 m are larger than in the present condition due to the reduction of seawall elevation. Quaywall plans, however, would be acceptable if the background behind the quaywall is paved sufficiently. In addition, judging from technical aspects the quaywall plan including a submerged breakwater is preferable to the plan of only quaywall because of a smaller overtopping rate and a calmer sea condition in the channel.

3.2.2 Numerical Model Test

The verifying calculation was applied to the east coast of natural reef and to the south coast protected by artificial facilities of breakwaters. 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 speed of current which appears in front of the reclaimed land on the east coast is almost the same as those in the present condition. Therefore, no significant influences are thought to occur on the east coast.

According to the results of the longshore distribution of wave height in the channel on the south coast, 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.

It was found by the calculation that a nearshore current due to waves does not occur on the 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

a) Northern Area

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

b) Other Area

Seawall Type	:	Armor Blocks with Vertical Wall
Crown Elevation	:	D.L. +2.60 m
Number of Blocks at Crest	:	Three Rows

(2) East Coast

a) Artificial Beach

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

b) Reclaimed Land and Other Area

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

(3) South Coast

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

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.

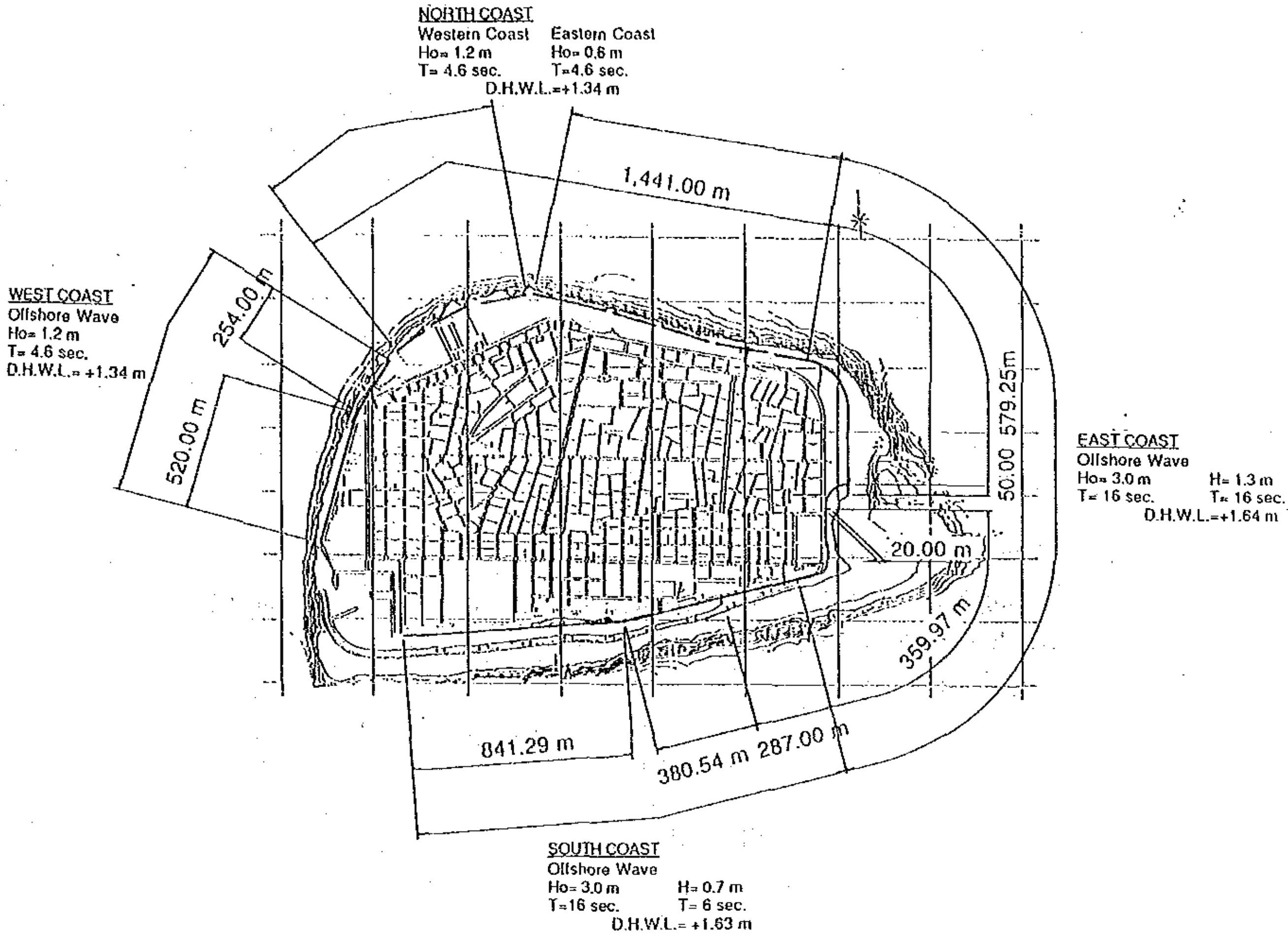
3.3.3 Design Conditions

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.				

Figure 3.3.1 Design Waves



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)

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/cm^2 (SY295A)
Deformed Reinforcing Steel Bar	:	1,800 kgf/cm^2(SD295A)
Reinforced Concrete	:	240 kgf/cm^2 (standard design strength) 90 kgf/cm^2 (allowable flexural compressive strength) 9 kgf/cm^2 (allowable shearing strength)
Plain Concrete	:	180 kgf/cm^2 (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.

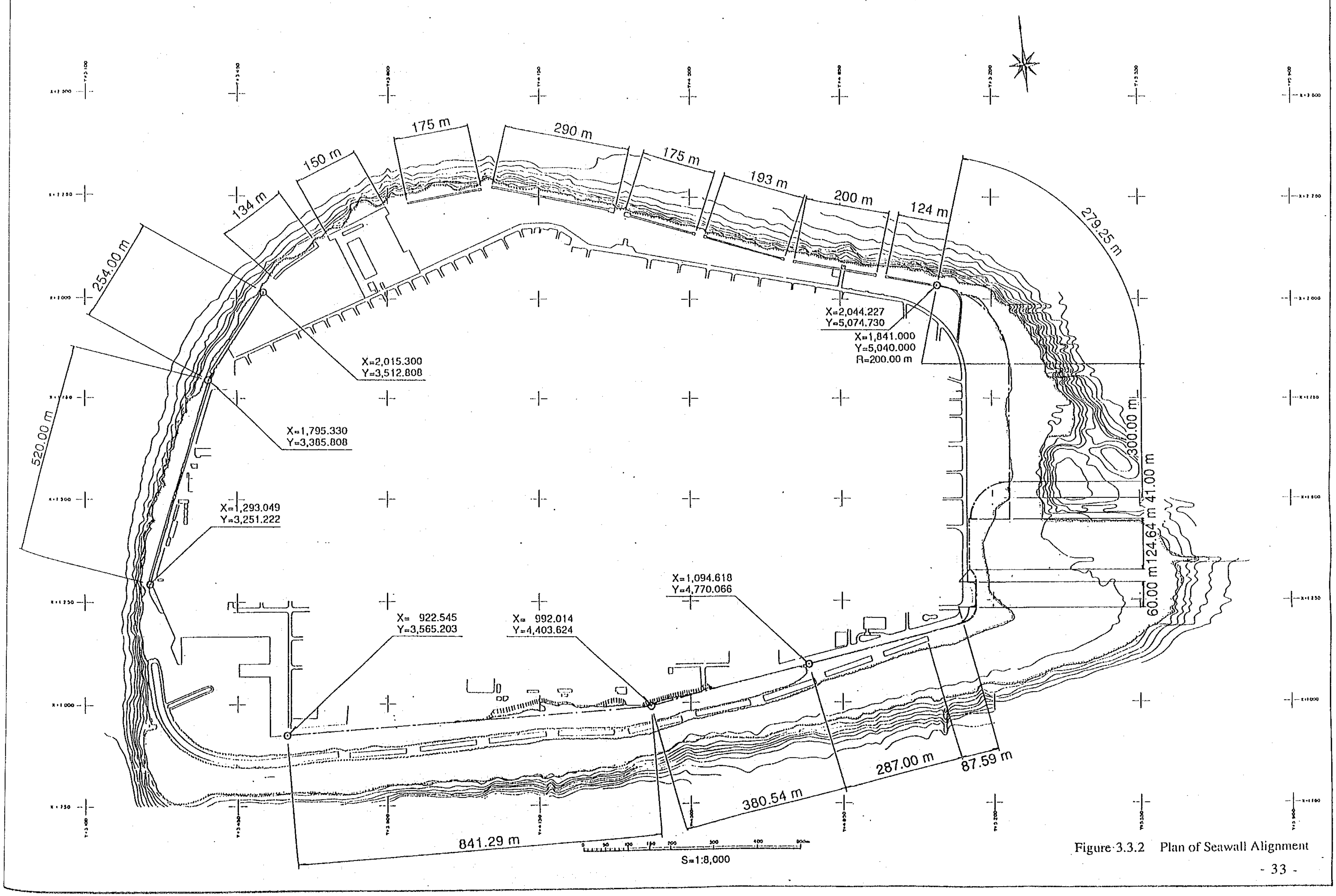


Figure 3.3.2 Plan of Seawall Alignment

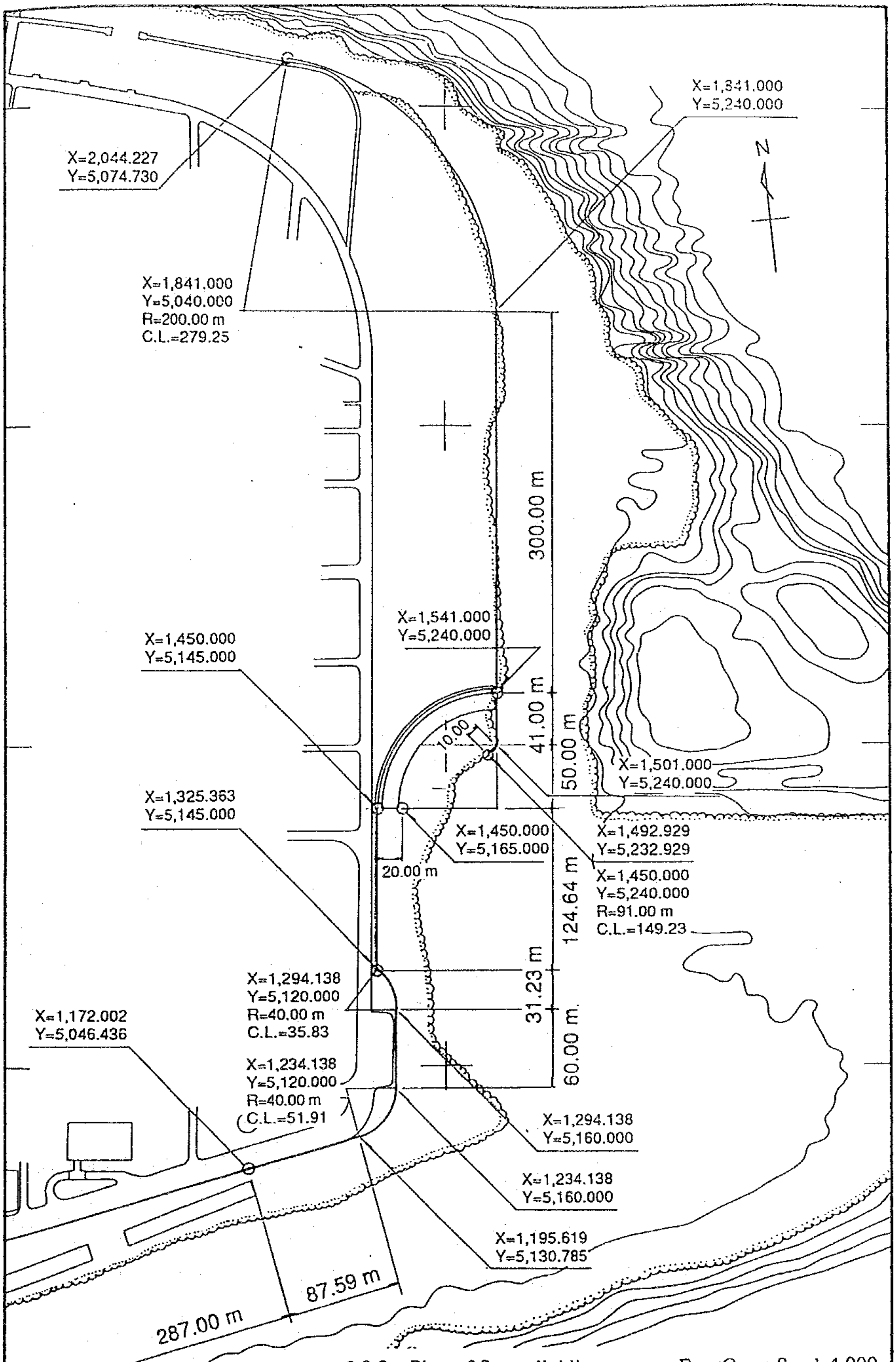
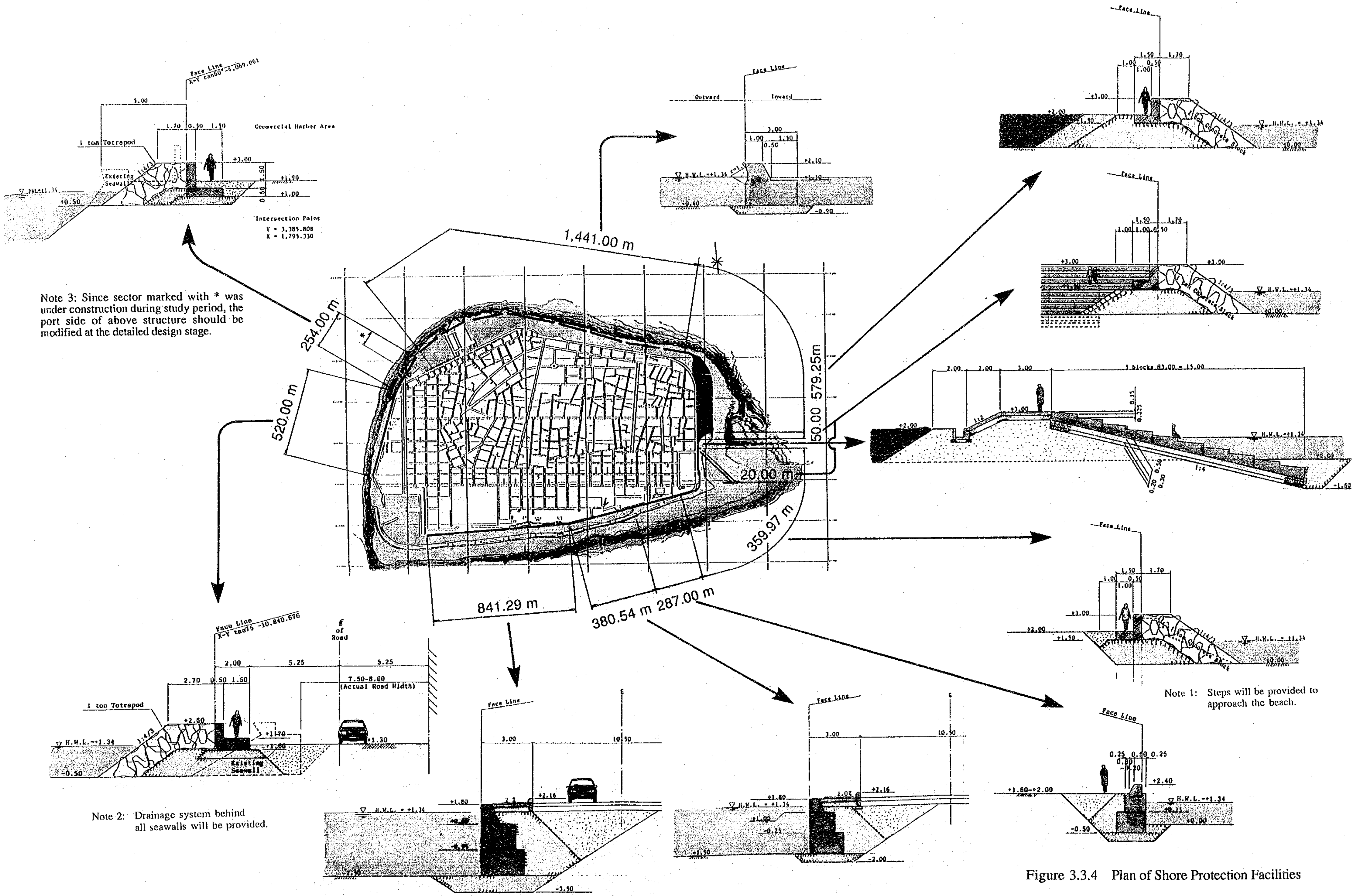


Figure 3.3.3 Plan of Seawall Alignment on East Coast S = 1:4,000



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 1: Steps will be provided to approach the beach.

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

Figure 3.3.4 Plan of Shore Protection Facilities

(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.

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 estimate 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 — 92.10.14

Work Item	Unit	Quantity	1 MRf=¥ 11.99 Maldivian Rufiyaa (M Unit Price	Amount	1 US $=¥ 129.53 US Dollar (US$) Unit Price	Amount	Jpn (¥ 1,000) Unit Price	Amount	Jpn (¥ 1,000) Total Amount	Unit Price
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 Unit Price	Amount	1 US $=¥ 129.53 US Dollar (US$) Unit Price	Amount	Jpn (¥ 1,000) Unit Price	Amount	Jpn (¥ 1,000) Total Amount	Unit Price
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 — 92.10.14

Work Item	Unit	Quantity	1 MRf=¥ 11.99 Maldivian Rufiyaa (M Unit Price	Amount	1 US $=¥ 129.53 US Dollar (US$) Unit Price	Amount	Jpn (¥ 1,000) Unit Price	Amount	Jpn (¥ 1,000) Total Amount	Unit Price
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 Unit Price	Amount	1 US $=¥ 129.53 US Dollar (US$) Unit Price	Amount	Jpn (¥ 1,000) Unit Price	Amount	Jpn (¥ 1,000) Total Amount	Unit Price
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	