Ministry of Foreign Affairs
Ministry of Construction and Public Works
Republic of Maldives

BASIC DESIGN STUDY REPORT ON THE PROJECT FOR THE SEAWALL CONSTRUCTION IN MALÉ ISLAND (PHASE IV) IN THE REPUBLIC OF MALDIVES

JULY 2000

JAPAN INTERNATIONAL COOPERATION AGENCY
PACIFIC CONSULTANTS INTERNATIONAL

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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 basic design study on the Project for the Seawall Construction in Malé Island (Phase IV) and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Maldives a study team from February 13th to March 13th, 2000.

The team held discussions with the officials concerned of the Government of Maldives, and conducted a field study at the study area. After the team returned to Japan, further studies were made. Then, a mission was sent to Maldives in order to discuss a draft basic design, and as this result, the present report was finalized.

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 teams.

July, 2000

Kimio Fujita
President
Japan International Cooperation Agency

July, 2000

LETTER OF TRANSMITTAL

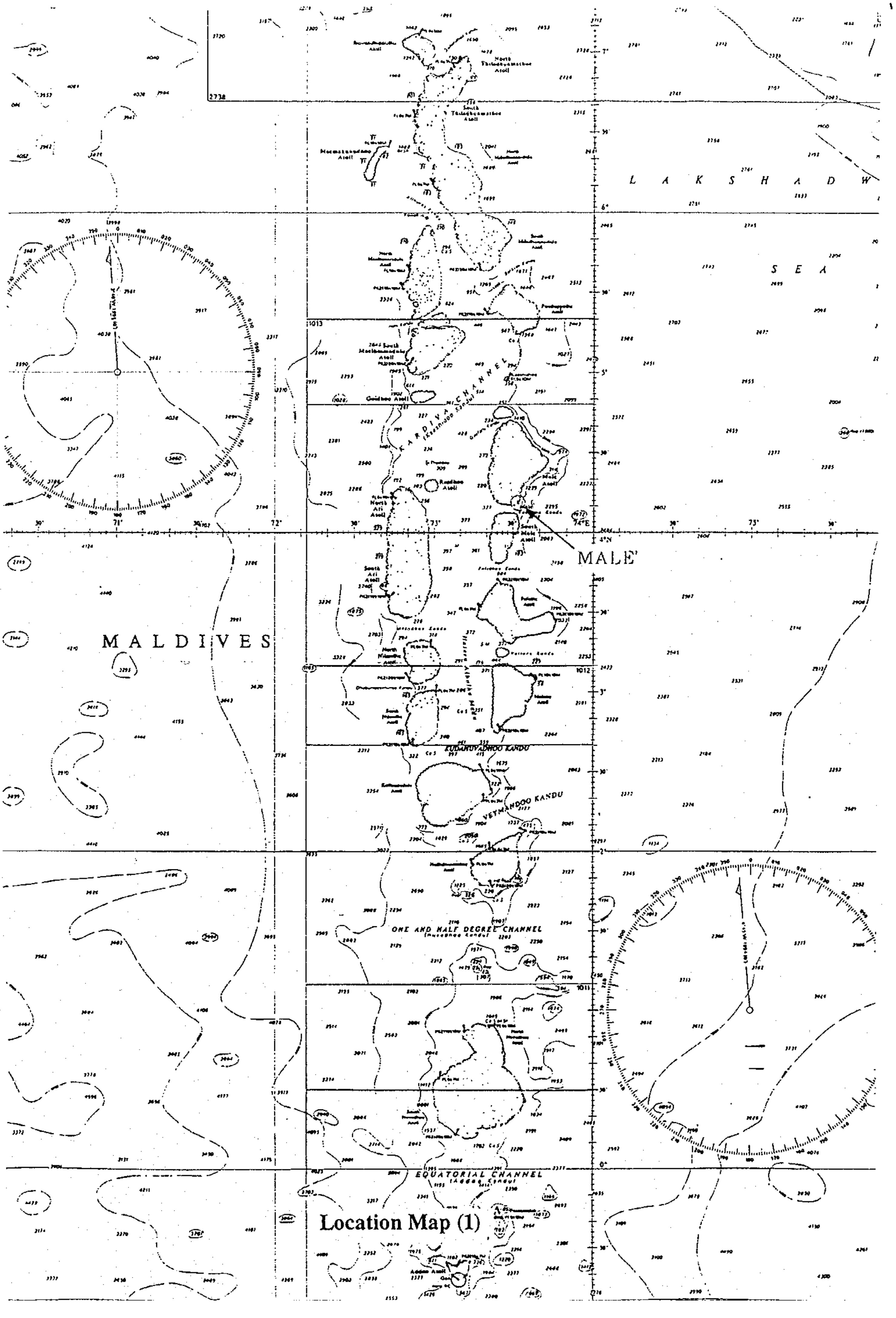
We are pleased to submit to you the basic design study report on the Project for the Seawall Construction in Male' Island (Phase IV) in the Republic of Maldives.

This study was conducted by Pacific Consultants International, under a contract to JICA, during the period from January 31st, 2000 to July 28th, 2000. In conducting the study, we have examined the feasibility and rationale of the project with due consideration to the present situation of Maldives and formulated the most appropriate basic design for the project under Japan's grant aid scheme.

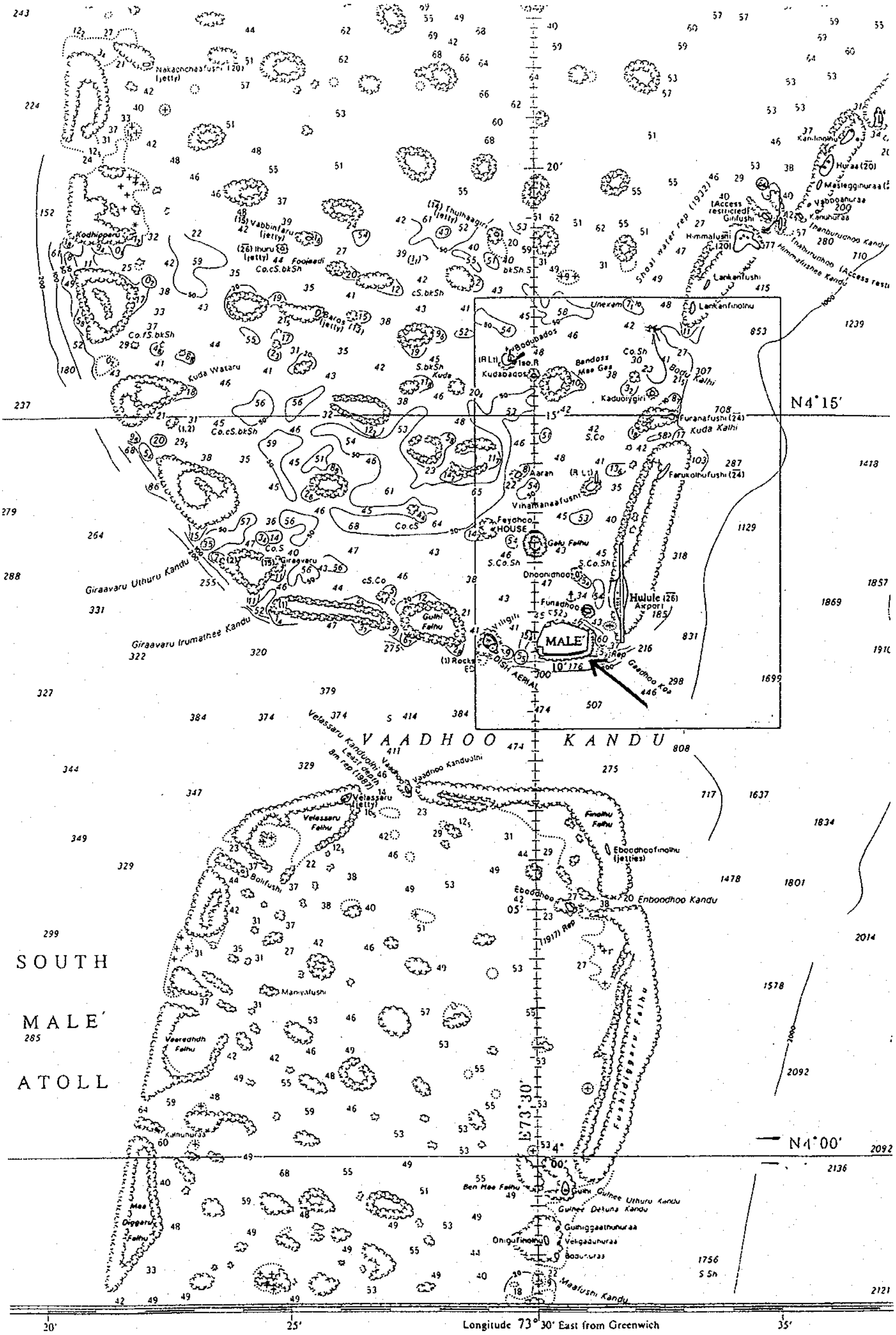
Finally, we hope that this report will contribute to further promotion of the project.

Very truly yours,

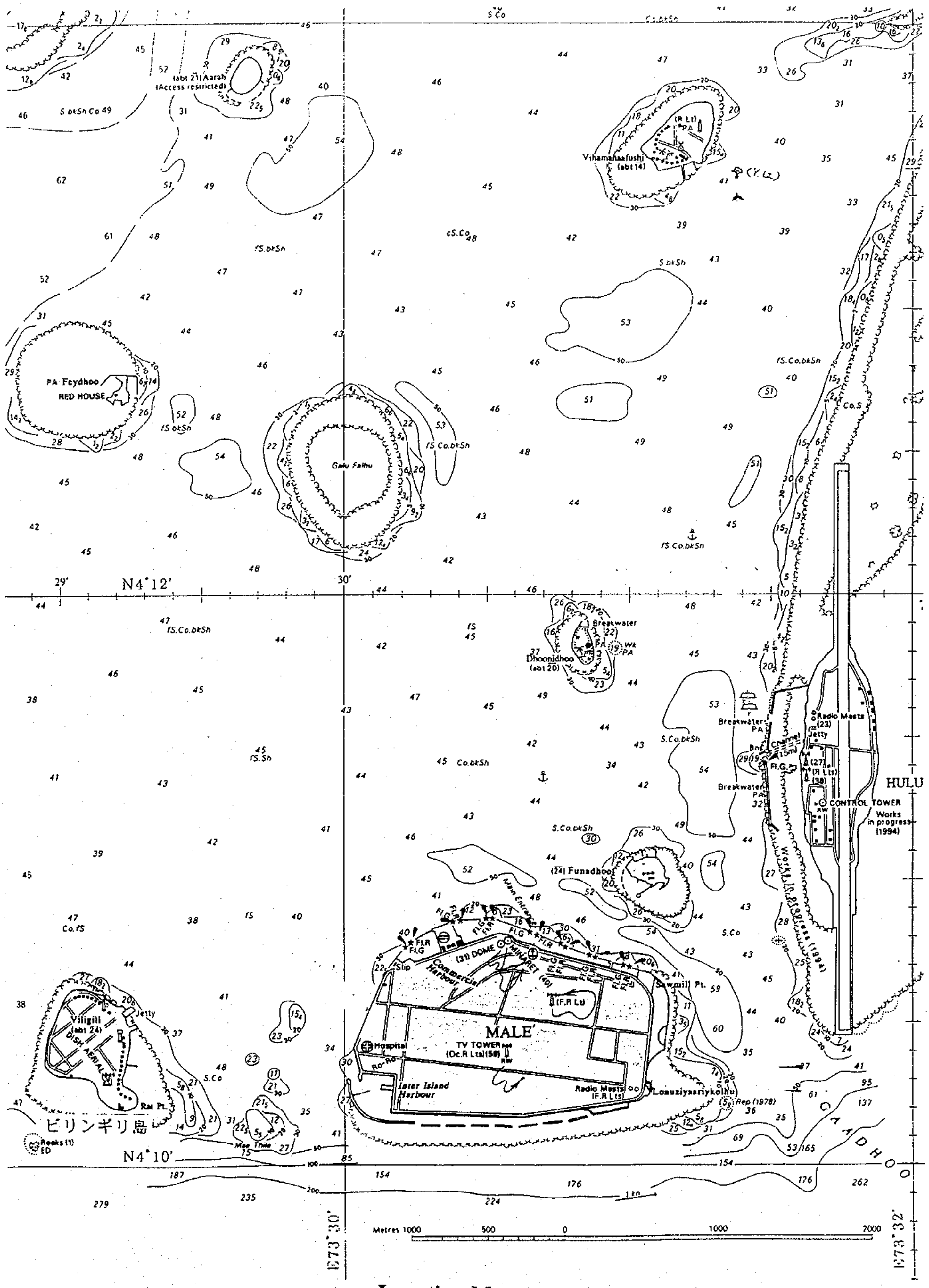
Hiromi Namiki
Project Manager,
Basic design study team on
the Project for the Seawall Construction
in Male' Island (Phase IV)
Pacific Consutatnts International



Location Map (1)



Location Map (2)



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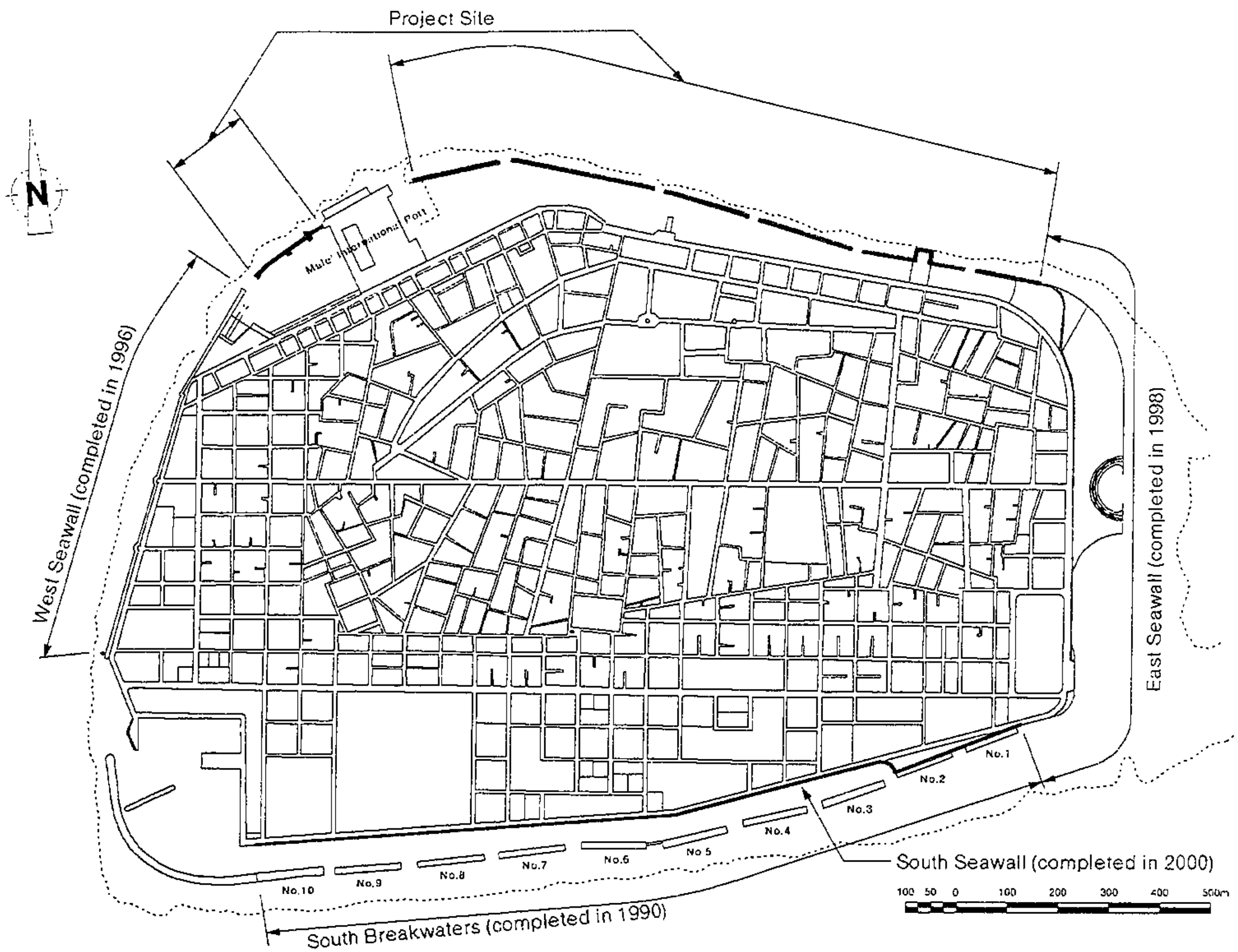
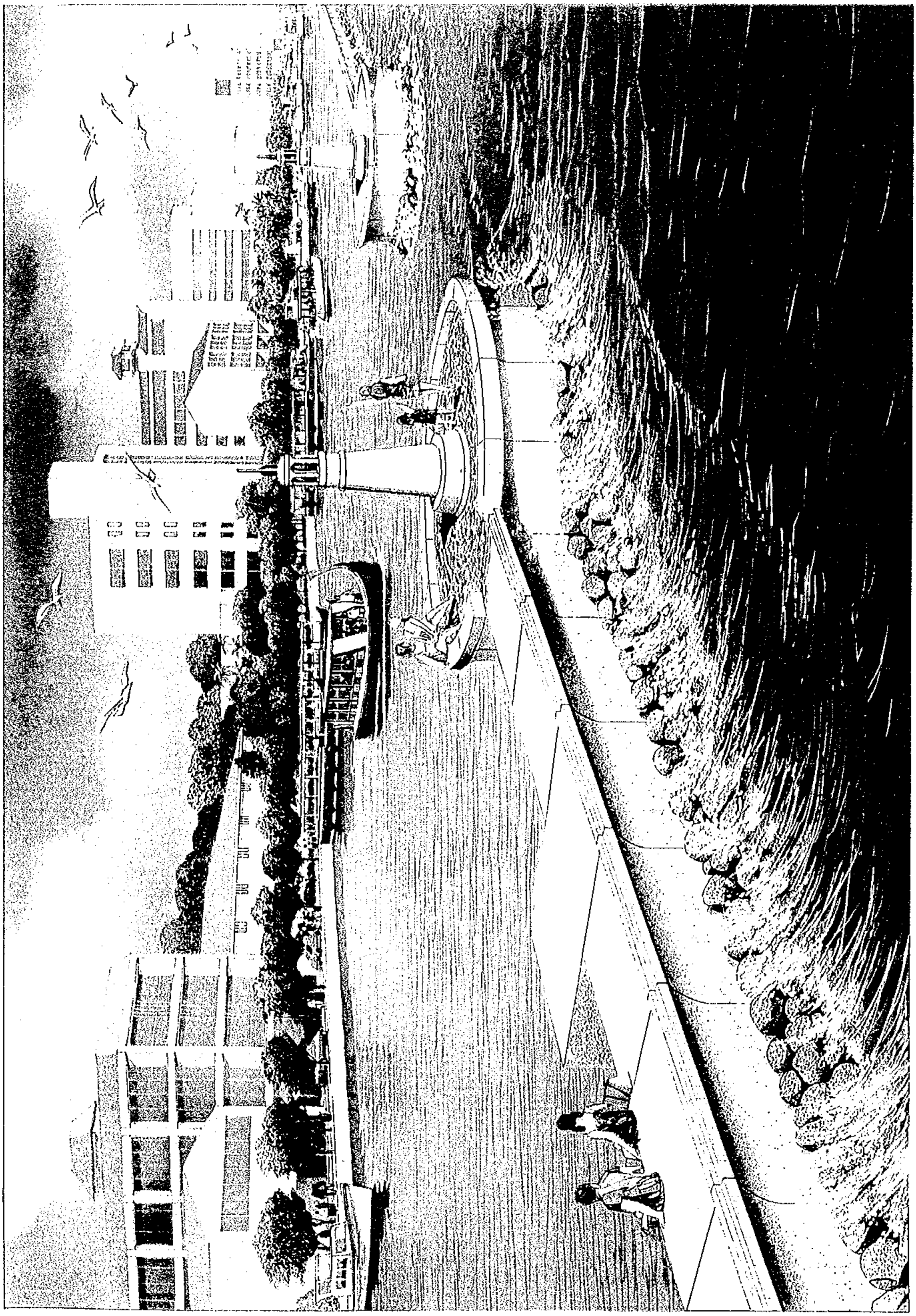
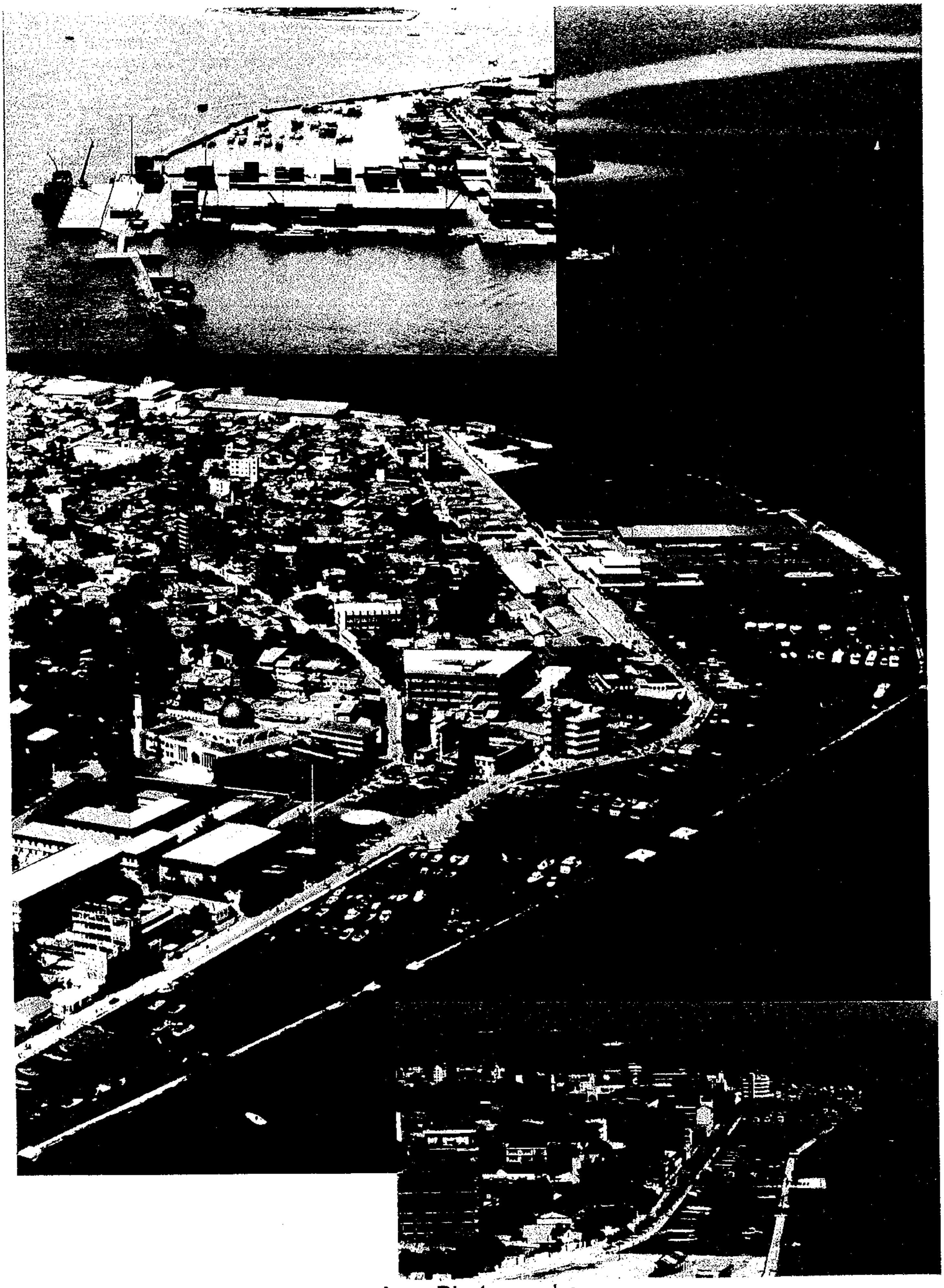
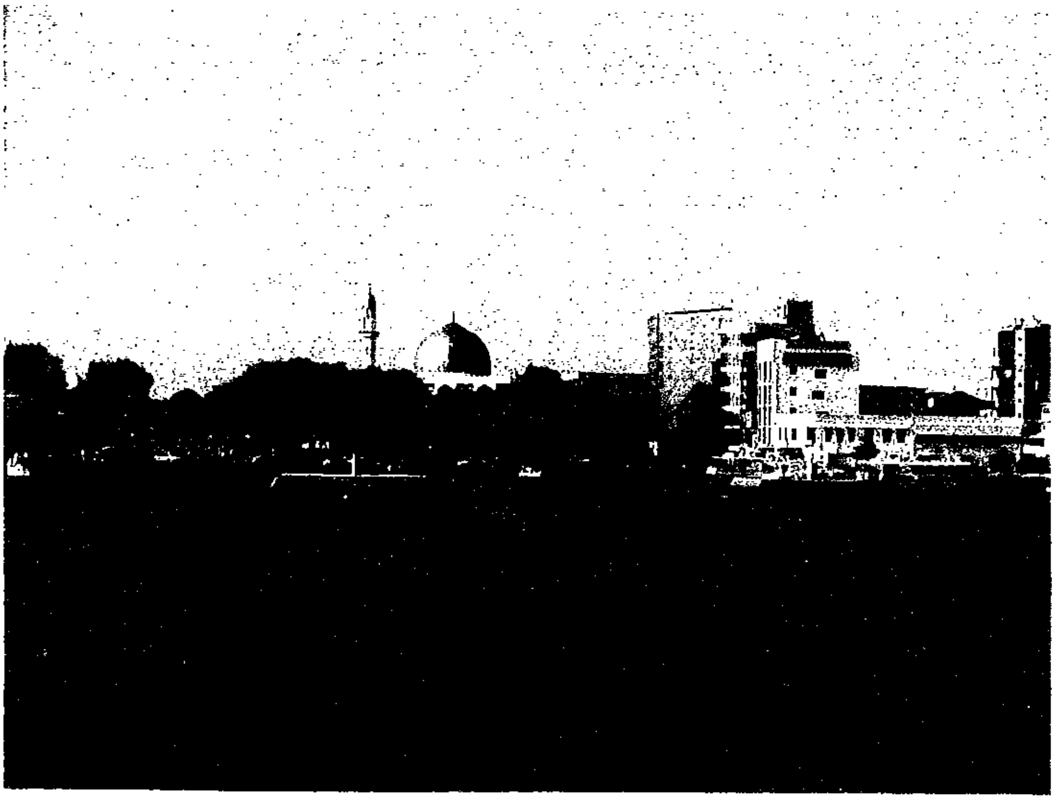


Location Map

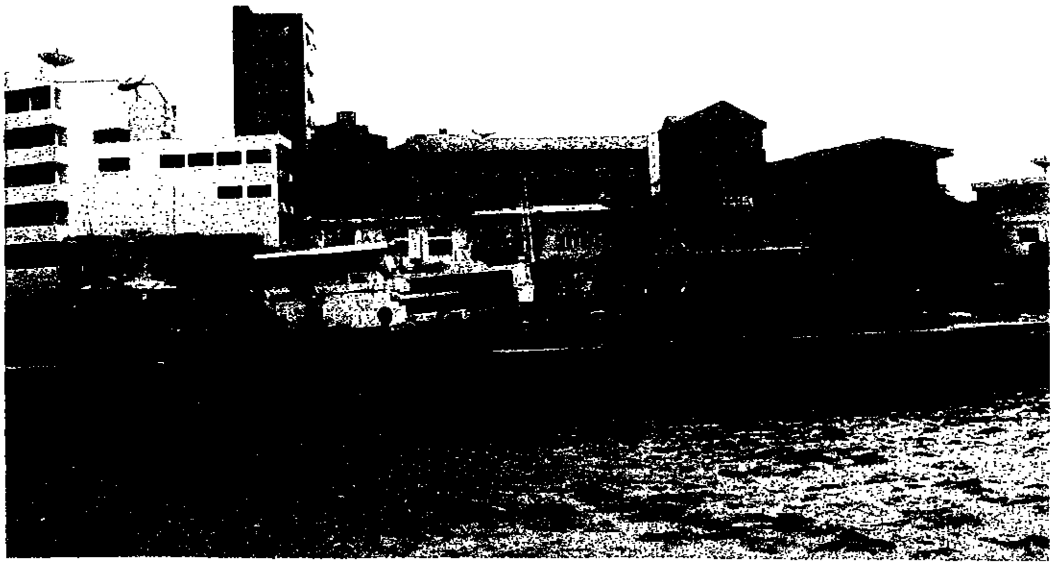




Aero Photographs

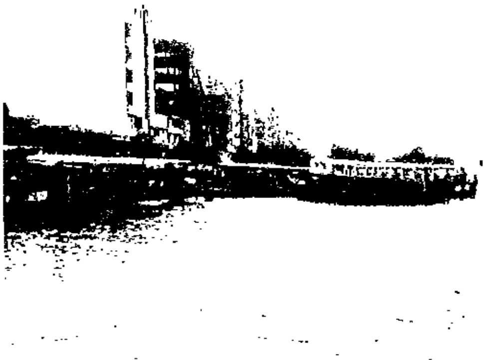


Landward view of the gateway of the capital Malé in front of the VIP jetty.

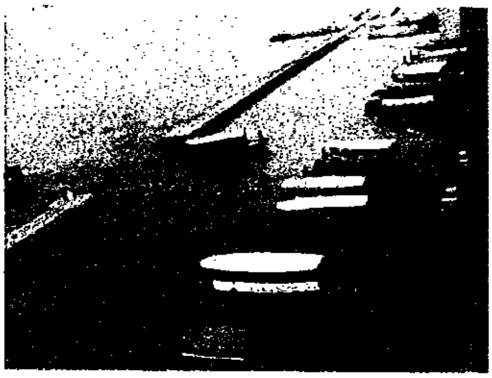


Congestion of the harbour basin in front of the Fish Market.

Water Area I: Berth area for shuttle service boats between Malé and Airport Island

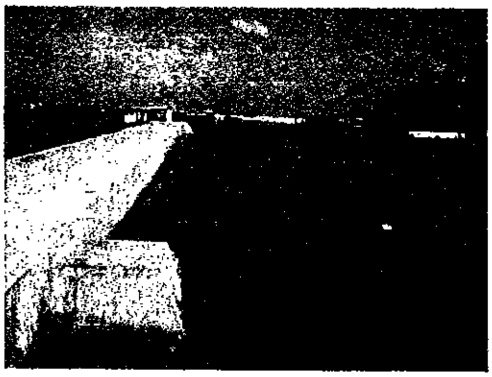


Berthing, arrival and departure of dhonis boats.



Expansion of water area for turning is required.

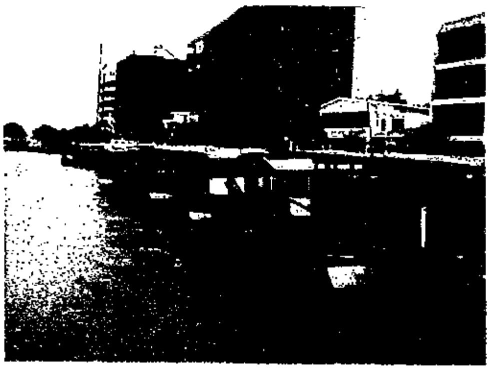
Collapse due to dredging of harbour basin behind breakwater (August 1999).



After repairing of breakwater (March 2000).

Water Area II: Berth area for fishing boats and passenger service boats of resort island

Fishing boats at berth.

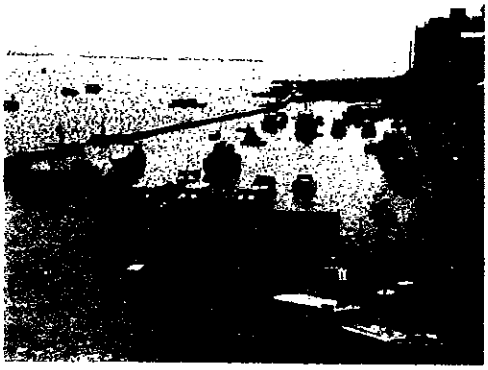


Dhonis boats at berth.

Many cracks and hole are seen on the crown.

A big hole on the crown; inside of the seawall is seen.

Water Area III: Berth area for Official/Coast Guard boats and pleasure boats



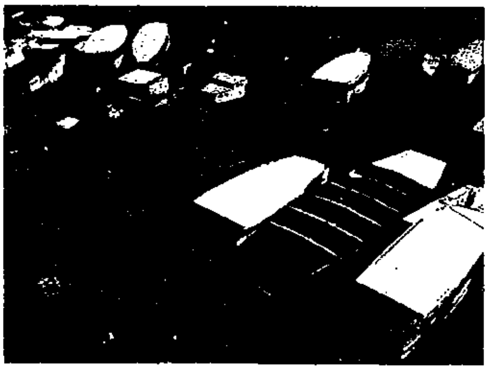
Entire view of Water Area III (1)。

Entire view of Water Area III (2)。

Pleasure boats at berth.

Back of breakwater; numbers of boats to berth are seen on the wall.

Water Area IV: Berth area for inter-island passenger boats and landing fishing boats



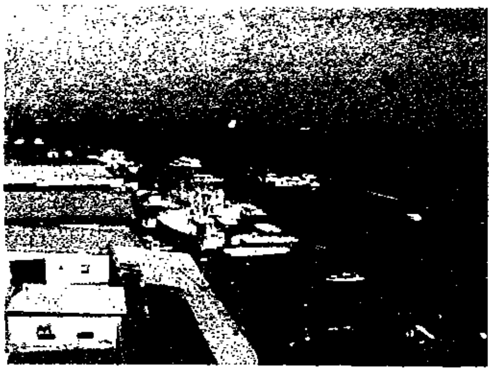
Congestion of the harbour basin by boats.

Landward view of the harbour basin in front of the Fish Market.

Fishing boats berthing and landing.

The body and opening of the breakwater.

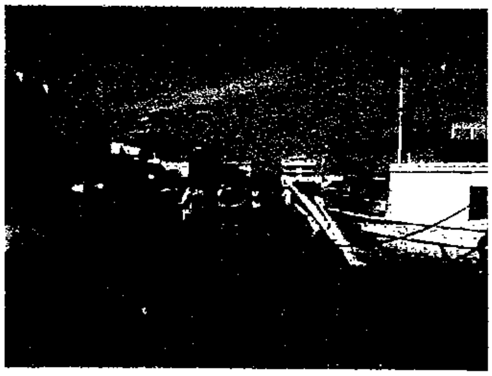
Water Area V: Berth area for inter-island commercial boats



Entire view of the water area V.

Congestion of the harbour basin and breakwater.

Cargo boats loading at berth.

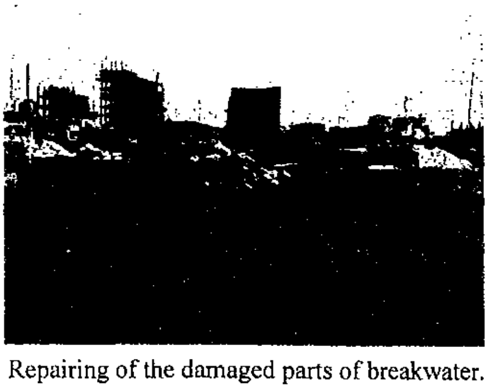


Bayside road is used as cargo wharf.

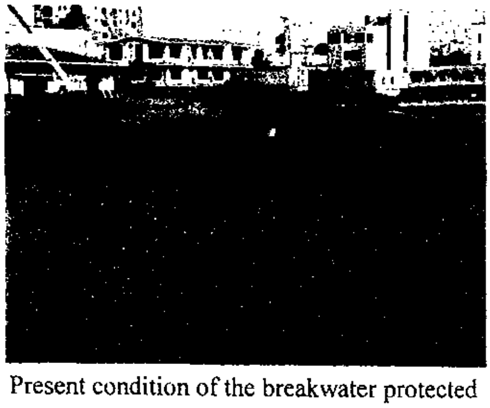
Water Area VI: Malé International Port area

Entire view of Malé International Port.

Dock yard in the Port area.



Repairing of the damaged parts of breakwater.

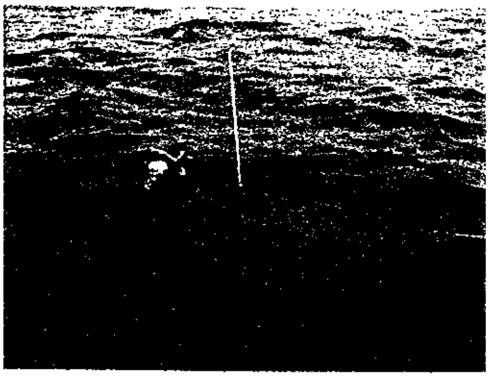


Present condition of the breakwater protected by concrete blocks.

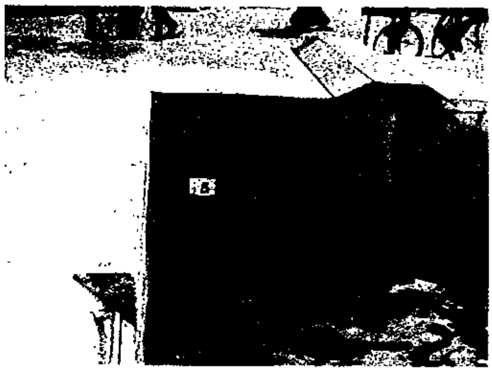
Bathymetric survey around the detached breakwaters (21 February - 2 March)

Survey in the harbour basin from breakwater.

Survey of outside the breakwater with lead.



Survey of outside the breakwater by diver.



Tide gauge in the harbour basin.

Tidal current observation (22 and 23 February)

Aandera self-recording current meter (RCM7) .

Marker Buoy at the point of current meter.

Current meter (RCM7) under the water surface.

Underwater cliff at reef edge.

ABBREVIATIONS

ADB	Asian Development Bank
B/D	Basic Design Study
D.L	Design Level
DER	Department of External Resources, Ministry of Foreign Affairs
E/N	Exchange of Notes
EIA	Environmental Impact Assessment
F/S	Feasibility Study
HWL	High Water Level
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standards
LAT	Lowest Astronomical Tide
MCPW	Ministry of Construction and Public Works
MHAHE	Ministry of Home Affairs, Housing and Environment
MHUDB	Maldives Housing and Urban Development Board
MHAHE	Ministry of Home Affairs, Housing and Environment
MOFA	Ministry of Fisheries, Agriculture and Marine Resources
MPA	Maldives Ports Authority
MRf	Maldivian Rufiyaa
MSL	Mean Sea Level
MTCC	Maldives Transport & Contracting Co.
MWSC	Maldives Water & Sewerage Company
NCPE	National Commission for the Protection of the Environment
M/D	Minutes of Discussions
ODA	Official Development Assistance
PVC	Poly-vinyl-chloride
STO	State Trading Organization
VAT	Value Added Tax

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CHAPTER 1

BACKGROUND OF THE PROJECT

CHAPTER 1 BACKGROUND OF THE PROJECT

The Republic of Maldives is an archipelago of tropical atolls in the north-central Indian Ocean located at about 750 km SW of Sri Lanka and roughly 600 km from the southern tip of India. The country consists of approximately 1,190 islands and 19 atolls. The islands straddle the equator and span an arc (between lat. 7° 9' N. to 0° 45' S. and long. 72° 31' E to 73° 48' E.), and is approximately 820 km wide from south to north and approximately 130 km from east to west.

The population of Maldives is approximately 277,000 (1999 census), and the residential population of Malé is approximately 64,000 (1998 census) which is a quarter of the total population of the Republic of Maldives. Malé is the seat of commercial and economical activities and is the capital city of the Republic of Maldives where all the governmental agencies, most of the educational institutions and medical institutions concentrate.

To cope with the yearly growing population, the west and south portion of the shallow flat reef of the island was reclaimed to provide land for housing. And the island of Malé experienced unusual flooding by seawater in April 1987. The cause of the incidence was investigated and determined that the high waves must have been generated in the western-off Australia and the swell with its wave height about 3 meters traveled over the South Indian Ocean to the island of Malé. The seawater inundated the south coastal area where shore protection facilities were not constructed yet, and the total damages caused by this flood disaster was estimated at about US$ 6 million.

To meet the request of urgent construction of shore protection facilities from the Government of Maldives, the Government of Japan conducted a grant aid cooperation project to construct a group of detached breakwaters along the south coast of Malé Island in 1987 - 1989. In addition to the above cooperation, Japan International Cooperation Agency (JICA) dispatched a study team in 1991 - 92 (the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives). Consequently, a shore protection plan of seawall construction along the whole coastal area of Malé Island was formulated by the study team.

Following the study and its recommendations, the Government of Japan has provided grant aid three times since 1994 up to the present, and implemented cooperation projects to construct shore protection facilities on the west coast (B/D in 1993, Seawall Construction in 1994 - 96), the east coast (B/D in 1995, Seawall Construction in 1996 - 98), the south coast (B/D in 1997, Seawall Construction in 1998 - 2000) in Malé Island. Those constructed facilities have protected the hinterland area from inundation by high waves and also provided the inhabitant people of Malé Island with space of recreation.

The existing detached breakwaters on the north coast of Malé Island are built with the fragile structure of mortar masonry of coral stones and are noticeably damaged by waves. There is an urgent need to improve the detached breakwaters to a permanent facility and to make the disaster prevention of the north coast a reliable one.

The Government of Maldives has requested the Government of Japan to improve the detached breakwater at north coast of Malé as the final grant aid project of the seawall construction in Malé Island on November 1998. The terms of the request is for the construction of approximately 1.3 km of detached breakwaters and a part of seawall on the north coast of Malé Island. The Project will serve to secure the lives and property of the northern coastlines in case of calamities.

This project has been targeted as one of the most important project for the implementation of the City Disaster Mitigation of Malé in the fifth National Development Project (1997-2000). Also, the Project for the Seawall Construction in Malé Island has been evaluated as a good model for coastal protection against overtopping waves caused by the sea level rise due to the global warming of the earth. The Executing Agency for the project will be the Department of External Resources of the Ministry of Foreign Affairs, and the Implementation Agency will be the Ministry of Construction and Public Works.

With the foregoing background and enumerated importance of the Project for the Seawall Construction in Malé Island (Phase IV), the Government of Japan has decided to implement the Basic Design Study for this Project.

CHAPTER 2

CONTENTS OF THE PROJECT

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2-1 Objectives of the Project

The objective of this project is to secure the lives and property of the north coast area of Malé in case of calamities. This is the last project of the Seawall Construction Project for Malé Island, which has been conducted as the last (fourth time) of grant aid cooperation by Japan aimed to secure the safety of life of the people and stable infrastructure in Malé Island. This project aims to complete the Seawall Construction Project for Male Island with improvement of the detached breakwaters on the north coast.

2-2 Basic Concept of the Project

2-2-1 Requested and Accepted Project Component

In order to strengthen the coastal protection function in the capital Malé Island, the Government of Maldives has requested to the Government of Japan to improve the detached breakwaters (1,291-m in extent) on the north coast of the island. The contents of the grant aid cooperation programme to meet the request were studied in the Basic Design Study as follows.

(1) Most of the construction works in this project is to demolish and improve the existing detached breakwaters, and it is requested that some portions of the existing breakwaters should be shifted and newly constructed. The necessity and suitability of the request is studied.

The interior side of the detached breakwater located at the east end of the north coast is used as the harbour basin for the shuttle service boats between Malé Island and the airport island and other remote islands. The width of the basin is rather narrow in comparison with the other water areas behind the detached breakwaters on the north coast. Widening of the water area has been planned due to the congestion of boat operation in the harbour basin. Following the plan, the counterpart agency of the Government of Maldives requested that the location of newly constructed detached breakwater is to be shifted seaward and the harbour basin is to be widened as wide as possible.

Presently the harbour basin behind the east end of the breakwater is the water area of 150-m in length and about 40-m in width surrounded by the quay wall and breakwater. Boats are moored bow-to-pier and occupy 15-m of the basin width for their berthing space. The residual space for boat operation is limited to about 25-m in width and boats have to go ahead and astern repeatedly to turn their bows. It is judged therefore that adequate turning space for boat operation is not secured in the harbour basin.

The number of boats registered at the ferry harbour of the north coast is 135. The number of ferryboats that are berthing and standing-by constantly in the harbour is estimated as 25-30, and the number of ferryboats that are berthing and standing-by at the Airport Island side is assumed as same. It is also assumed that there are about 40 boats, 30 % of the registered boats, which are not berthing at Malé Island because of their repairs or sailing-out to remote islands. The residual 35 boats in the registered ferryboats are judged to be double registered also as cargo boats and berthed at the harbour area for cargo boats (source: MCPW).

The width of quay wall occupied by a ferryboat berthing bow-to-pier is about 5-m. The extent of quay wall required for the 30 boats constantly berthed at the harbour is estimated as 150-m in length and is fully occupied already at present. The ferry berth is to be hardly transferred to another harbour area considering the convenience of the hotels concentrated in the neighboring area of the harbour and also of visitors from abroad and/or remote islands.

It is confirmed by the bathymetric surveys that the newly constructed detached breakwater can be shifted by 10-12 meters seaward from the existing location and the change to oceanographic conditions and the increase in quantity and/or cost of construction are considered to be insignificant. Thus the necessity and suitability of the shift of the detached breakwater is confirmed in view of utility and security of the harbour basin behind the detached breakwater.

(2) The detached breakwater adjacent to the Malé International Port in the west end of the north coast should be designed to match the improvement plan of the Port in the future.

The expansion and improvement of the Malé International Port is at the stage of conceptual plan and is no yet budgeted at present. There is necessity to incorporate the improvement of the detached breakwater in the Port area into the scope of this project. The administrative agency of the Port (Maldives Port Authority; MPA) proposed that the crown height of the new detached breakwater should match the elevation of the existing pier (DL+2.3 m) considering expansion of the pier in future.

The design wave height in the Port area neighboring the west coast is considered to be higher than that of other portion of the north coast, and there is enough reason to design the detached breakwater of this area with the crown height DL+2.3 m higher than the existing breakwater (+2.0 m). The Study Team proposed to MPA that the detached breakwater of this project is to be taken into the future expansion plan of the Port and the basic function not to be affected.

(3) The previous projects for the construction of seawalls in Malé Island shall be reviewed and the Facility Planning in this Project shall reflect the study results.

The following four phases of projects to construct the shore protection facilities have been conducted on the coast of Malé Island since the flood disaster by the high waves in April 1987.

The Detached Breakwaters on the South Coast (1988 - 1990) dissipate the swells travel from Indian Ocean and reduce the height of waves directly approaching the shore to less than one third by the breakwaters piled up with 3-ton concrete blocks. This strong shore protection facility relieves the feelings of the people who live in the south coast area who experienced the flood in 1987, while the crown height of the breakwaters (+4.10 m) could not be lowered to increase the view seawards which give the feelings of oppression to the people.

The Seawalls on the West Coast (1994 - 1996) function satisfactorily as the shore protection facility with no problem. The crown height of the seawalls (+2.60 - 3.00 m) were designed rather low employing wave dissipating works. The design of seawalls avoiding the oppressive impressions from high walls of concrete and considering the view seawards is highly reputed. The picture tiles inlaid in the seawalls as part of the public relations activities of ODA are favorably accepted by the Maldivian side and the seawalls has been close to the hearts of the people in Malé Island.

The Seawalls on the East Coast (1996 - 1998) maintain the expected shore protection functions though spray of waves overtop a part of the seawall and wet the sidewalk in the case of high waters in spring tide. The artificial recreation beach that was reclaimed to recover the only beach in Malé Island is highly reputed by the people, and many people enjoy swimming in the beach during holidays.

The Seawalls on the South Coast (1998 - 2000) could be designed under the condition of the reduced design wave height by 30 % and an economic structure was realized by employing lowered crown height (+2.10 - 2.50 m). This was due to the effect of the wave dissipating concrete blocks relocated to the openings between detached breakwaters on the south coast.

Previously constructed seawalls and detached breakwaters in Malé Island mentioned above are functioning not only as shore protection as expected without any particular problem but also as public-access facilities considering the unique living conditions in Malé Island. Based on these experiences, lessons to be reflected in the plan and design of this project are as follows.

1) To design the crown height of seawall considering the seaward view from land side,

2) To consider installation of pipes through breakwater bodies to expedite exchange of sea water of harbour basin behind the detached breakwaters not to cause water pollution. This is based on the experience that, after construction of the detached breakwaters on the south coast, the seawater in the channel got turbid behind the breakwaters.

3) To pay enough attention to the design of breakwaters as marine concrete structure and also to the quality control and working method of concrete in the construction works of this project.

4) To consider the structure and appearance of breakwaters to match to the landscape of Malé Island where many travellers visit from abroad.

2-2-2 Basic Concept

The design wave condition of the return period of the 50-year probability is employed for the plan and design of coastal structures following the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives (1991 - 92, JICA). This condition of design wave is similar to the previous three cooperation projects. Also the location, type and structure of facilities are determined taking into account the land use plan and/or development plan of the north coast area, natural and social environment of Malé Island.

2-3 Basic Design

2-3-1 Design Concept

Based on the study on the existing conditions of the detached breakwaters on the north coast of Malé Island and the discussions with the Governmental Agencies of Maldives, the Basic Design of the detached breakwaters of the north coast is conducted based on the following Design Concept.

(1) Consideration for facilities planning

1-1) Design objective is to improve the detached breakwaters and a part of seawall on the north coast of Malé Island; the existing detached breakwaters and a part of seawall are to be demolished and replaced with newly constructed breakwaters. The length of the detached breakwaters and a part of seawall were 1,327 m in total as a result of detailed site survey in this study.

1-2) For the facilities planning, the detached breakwaters are divided into 6 areas on the basis of the present utilization and future utilization behind the breakwaters.

1-3) Basically the detached breakwaters are to be planned and improved at the original location except for the eastern end portion of the north coast. The detached breakwater of the east end, where the water area behind the breakwater is used as the harbour basin for shuttle service boats between Malé and Airport Island, is planned to be shifted 11m seawards in order to alleviate the congestion and secure the turning space for the boats.

1-4) The structure of the detached breakwater is to be planned as maintenance-free, basically. The coral materials of the existing breakwaters to be demolished are planned to be recycled in the newly constructed detached breakwaters.

1-5) Type and structure of the detached breakwater are to be determined considering the present utilization of the breakwaters as the mooring wall for the ferryboats, cargo and fishing boats. Also future utilization of the breakwater as the walkway connected with land at inter-island commercial harbour and fish landing area, is taken into account

1-6) The structure of the detached breakwater is to be planned satisfying the allowable rate of wave overtopping so as to secure the safety of the activities in accordance with the present utilization and future utilization of the detached breakwaters.

1-7) As the water areas behind the detached breakwater is utilized for a variety of activities, consideration to maintain good water quality of the basin is necessary. Installation of pipes through breakwater bodies to expedite exchange of seawater of the basin is planned.

1-8) The north coast of Malé Island is the main gateway for the visitors to Maldives. Hence the breakwater is to be designed considering the structure and appearance of breakwaters to match to the landscape as well as a variety of utilization and recreation activities.

(2) Consideration for natural conditions

2-1) Design wave

Design wave conditions for the shore protection facilities were given as mentioned below in the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives (1991 - 92, JICA)

(a) Estimation of extreme high waves

Based on the wave survey data by Lanka Hydraulic Institute (June 1988 - May 1989), an estimation of extreme high waves was conducted in the JICA Study (Table 2.3.1). Fundamentally, a significant wave corresponding to a 50 year return period was taken as the offshore design wave for shore protection facilities like breakwater, seawall and quay wall in the JICA Study.

Table 2.3.1 Estimation of Extreme Waves and Return Periods

Return Period (year)	Significant Wave Height H_s (m)		
	Wave incidence; NW T = 4.6 sec	Wave incidence; SW T = 6.7 sec	Wave incidence; SE T = 14.5 sec
1	0.95	1.00	1.85
2	1.00	1.10	1.95
5	1.05	1.25	2.15
10	1.10	1.35	2.25
20	1.15	1.60	2.60
50	1.20	1.60	2.60

(b) West coast of Malé Island

Following Table 2.3.1, the conditions of H_o = 1.20 m, T = 4.6 sec, wave incidence NW was taken as the offshore design wave (return period: 50-year) for the west coast of Malé Island.

(c) North coast of Malé Island

The predominant wave condition on the north coast was analyzed, in the JICA Study, as coming from north west because of a wind wave generated in the north sea area of Malé Island (inside the North Malé Atoll). Its approaches from the north direction is obstructed to propagate by many islands located in the north area.

A northwest wave with the height of design wave (H_0 = 1.20 m, T = 4.6 sec) comes obliquely to the shoreline of north coast and is refracted following the Snell's Law. The wave height on the north coast becomes 0.60 m and these wave approach the detached breakwaters without any transformation due to shoaling and/or breaking.

The Study Team confirmed on the wave conditions of the north coast as follows by hearing survey to the relevant officers of the MCPW and MPA during the Field Study (February - March 2000):

(i) There is no extra information or data newly observed for the north coast,

(ii) There has been no extra wind or wave climate accompanied by extreme high waves in recent years,

(iii) Wave height around 0.5 m can be assessed as maximum on the north coast.

Based on the above-mentioned studies, it is judged to be adequate to follow the design wave conditions determined in the previous JICA Study (1991 - 92). The design wave for the north coast of Malé Island is as follows.

North Coast (the East and Central portion)
Offshore Wave Height: Ho = 0.60 m, Wave Period: T = 4.6 sec

Concerning the west end portion of the north coast (Malé International Port), the following condition is given as the design wave considering the consistency with the condition on the west coast. The condition is similar to the design wave condition given in the Second Malé Port Project (1993).

North Coast (Malé International Port portion)
Offshore Wave Height: Ho = 1.20 m, Wave Period: T = 4.6 sec

2-2) Base foundation of Malé Island

Base foundation conditions of the Malé Island and properties of coral rocks were given based on the bore-hole drilling and investigations in the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives (1991 - 92, JICA). Figures 2.3.1 and 2.3.2 are location map of bore holes and columnar sections of bore holes drilled for foundation investigations. Table 2.3.3 shows the physical properties of coral materials of Malé Island.

(a) Property of base foundation

Figures 2.3.1 and 2.3.2 denote that there is a group of geological data with 16 point bore-holes drilling on the north coast of Malé Island.

Boreholes No.1 - No.8 are the points in the harbour basins behind the detached breakwaters, and the foundation materials are the lagoon sediments (coral sand and gravel) in those points. Thin layers of coral rock are seen between sand layers. Boreholes No. 18, 19, 20, 21, 22 and 42, 43, 44 are the points around the Malé International Port and the columnar sections of those points show the deep layer of coral rock. The foundation of the existing detached breakwaters of the north coast is formed mainly with coral rock similar to those drilled points. The Study Team confirmed the foundation of coral rock by underwater observation in the Field Study of this time.

Table 2.3.2 shows the mechanical properties of lagoon sediments and coral rock of Malé Island. Unconfined compression tests were carried out on core samples only. The ultimate bearing capacity of the lagoon sediments and loose coral rock were determined based on the plate load test. It is known from those properties that the foundation has sufficient bearing strength against the load by the planned detached breakwaters.

Table 2.3.2 Mechanical Properties of Lagoon Sediments and Loose Coral Rock

Name of Foundation Rock	Description	N-value (S. P. T.)	Unconfined Compression Strength (kg/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	45 ~ 60

Source: Main Report I, The development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives

Based on the previous study results, the bearing capacity of the lagoon sediments and the coral rock foundation is given in this Study by the strength of lower limit of both materials shown in Table 2.3.2 (16 t/m^2 for Lagoon Sediments; 45 t/m^2 for Loose Coral Rock).

(b) Coral rock as construction material

The refuse coral lumps produced from the demolition of the existing breakwaters on the north coast are planned to be recycled as filling material of the caisson of the planned detached breakwaters (type A and type C). The unit weight of coral rocks used as filling material is studied here.

The unit weights of coral rock samples that form the existing seawalls and/or breakwaters are shown as 1.80 - 2.19 t/m^3 in Table 1.3.3. Also unit weights of dredged coral sample range from 1.46 to 2.39 t/m^3. The scattering of the values is due to the difference properties among beehive-like porous coral and/or massive coral.

The unit weight of rocks (2.6 t/m^3) is given as 1.8 t/m^3 considering the pore among rocks when it is used as filling material. The unit weight of coral rocks (1.80 - 2.19 t/m^3) as filling material can be set as 1.26 - 1.53 t/m^3 considering the same ratio (1.8/2.6). To eliminate the inconvenience of scattering of the value, the unit weight of coral rock as filling material is given as 1.4 t/m^3 as an average value.

2-3) Tide

Conditions of tide level are given as follows by the previous JICA Study (1991 - 92).

HWL (High Water Level)	DL+1.34 m
MSL (Mean Sea Level)	DL+0.64 m
LAT (Lowest Astronomical Tide)	DL+0.00 m

In the previous studies and plan/design of the shore protection facilities, the above-mentioned LAT was employed as the datum level of works and HWL above was employed as design high water level. This setting is also followed in this Study.

2-4) Seismic force

No records of earthquake and/or earthquake-origin disaster are seen in the history of Maldives. Seismic force is not taken into account in plan/design of the facilities.

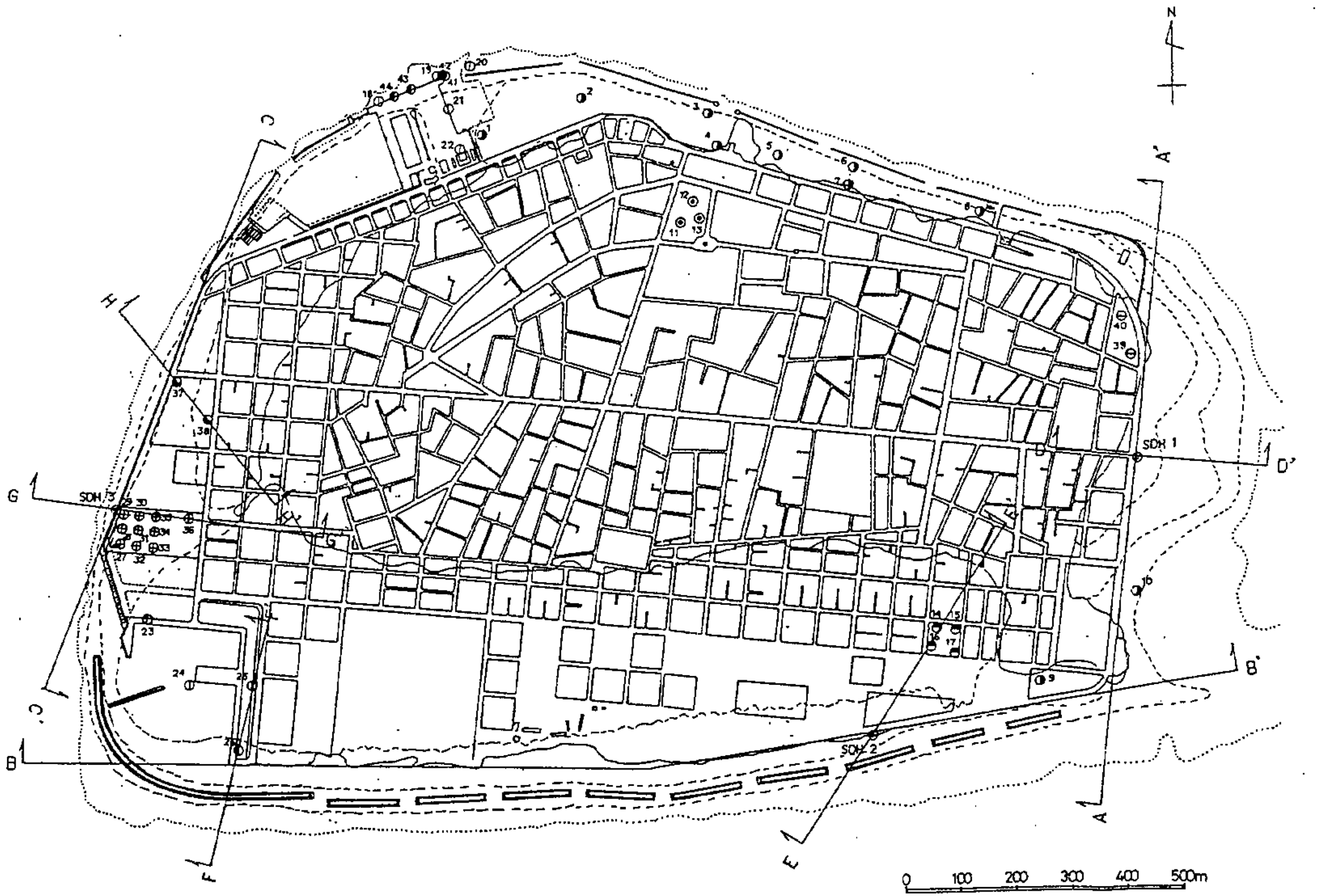


Figure 2.3.1 Location Map of Bore Holes Drilled for Foundation Investigation

Source: Main Report I; the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives (1991 - 92, JICA)

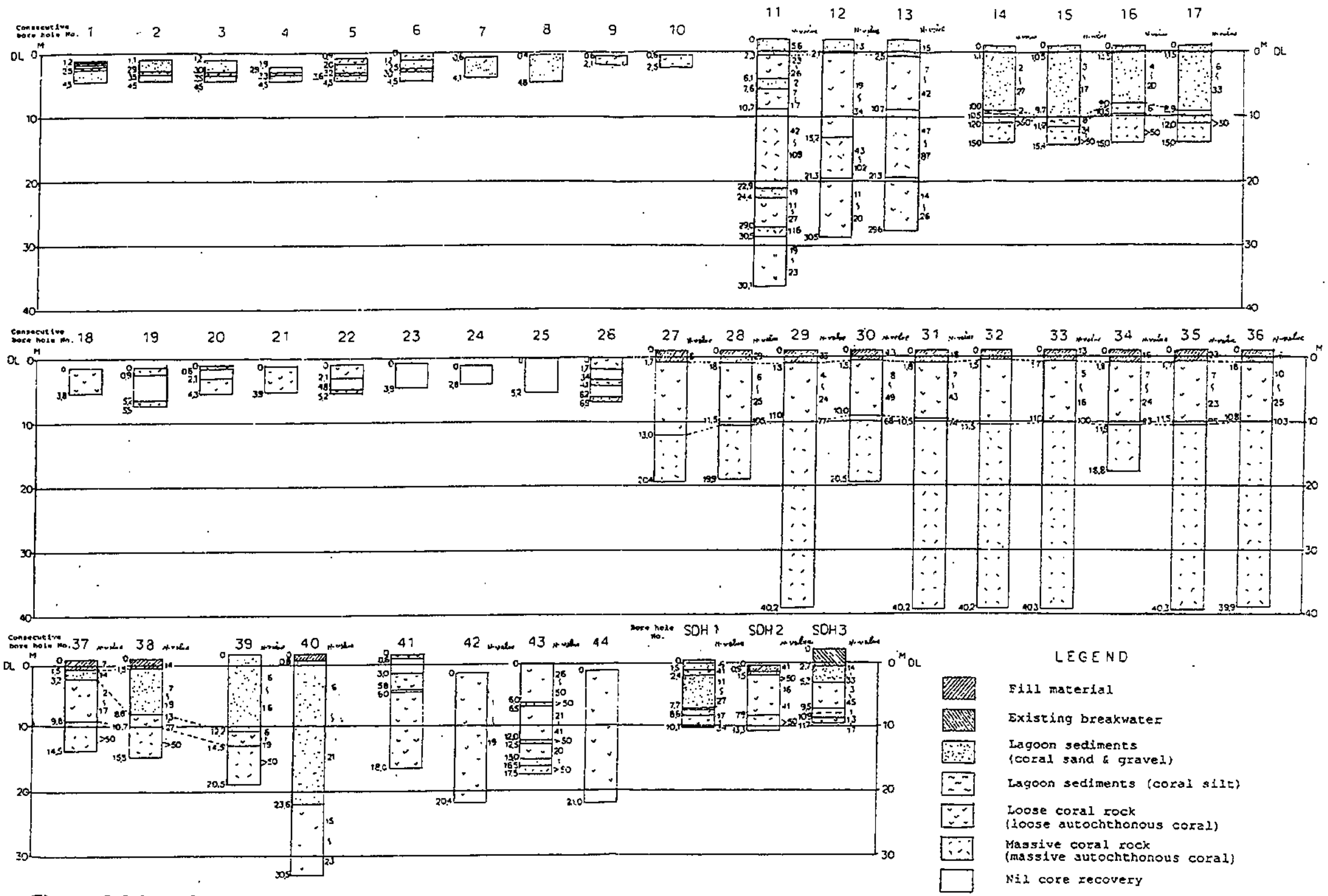


Figure 2.3.2 Columnar Sections of Bore Holes Drilled for Foundation Investigation

Source: Main Report I; the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives (1991 - 92, JICA)

Table 2.3.3 Physical Properties of Coral Materials of Malé Island

No.	Sample		Locality	Unconfined Compressive Strength (kg/cm²)	Strain at Failure (%)	Water Content in Percent of Dry Weight (%)	Unit Weight (g/cm³)
E-1	Coral Coarse Aggregate from the existing Breakwater	Beehive-like Coral	80 m west from SDH2 position	6.4	2.50	17.3	1.80
E-2		Massive porous Coral		34.7	3.80	12.6	2.19
E-3		Massive Coral	SDH3, 0.88 ~ 1.0 m depth in the existing breakwater body	56.1	5.00	31.9	1.93
E-4		Beehive-like Coral	SDH3, 2.28 ~ 2.5 m depth in the existing breakwater body	20.1	2.16	21.6	1.81
E-5		Massive porous Coral	10 m south from SDH3 position	48.2	3.03	19.4	1.93
R-1	Dredged Coral Lump Sample before Screening	Beehive-like Coral	Taken by the dredging in the domestic harbour.	9.5	1.11	1.9	1.85
R-2		Massive Coral		74.5	3.42	0.6	1.46
R-3		Bar-like Coral		135.5	4.93	1.2	2.25
R-4		ditto		82.0	3.09	6.0	2.39
R-5		Massive porous Coral		31.2	3.62	6.5	1.98
R-6	Dredged Coral Sample (40 ~ 100 mm in Size) after Screening	Beehive-like Coral		13.8	2.83	7.6	1.66
R-7		Massive Coral		46.6	3.79	0.6	1.74
R-8		Bar-like Coral		48.4	2.22	1.6	2.18
R-9		ditto		57.6	3.13	1.8	2.10
R-10		Massive porous Coral		47.3	4.42	2.0	

Source: Main Report I: the Development Study on the Seawall Construction Project for Malé Island in the Republic of Maldives (1991 - 92, JICA)

(3) Consideration for construction and procurement

3-1) Background of construction industry

There are a number of local construction companies in Maldives and are seen that those companies in the region have experience with equipment and key staff to carry out the general building works to an acceptable level. However, there is no contractor except for the state-owned construction company MTCC (Maldives Transport & Contracting Co.; it has experience in dredging works) that have sufficient experience in specialized fields such as port and harbour.

As for the public works, almost all the civil construction works are carried out under the direct management of MCPW, and capability of the local private contractors is considered to be low. The contracts of large-scale construction works have been depended upon foreign companies and contractors from Japan, Kuwait, Denmark and New Zealand.

3-2) Procurement of construction equipment and materials

It is expected that the construction equipment and vessels for this project can be procured by leasing contract with MTCC or the contractor who under took the previous projects of the seawall construction in Malé Island.

Though there is no Maldivian provisions in design standards and/or specifications of civil construction works, the usage of coral sand and coral stones as concrete aggregates is formally accepted.

Procurement of construction materials in Maldives depends totally on importation except for coral sand and aggregates. Rocks for concrete aggregate, stones and steel materials can be procured from local trading companies for a limited volume. Usually, construction materials are directly procured by contractor from the neighboring countries (such as Malaysia, Singapore and Indonesia) in the case those are needed in large volume and in short term.

Some defects in quality are pointed out about the concrete aggregate that is imported and provided by local trading companies. A cement bag-packing factory was established as the joint venture of a state's organization of Maldives and a cement manufacturing company of Switzerland and started its operation in 1999, and the procurement of cement in large volume and in short term became available from its factory.

3-3) Transportation

Special attention should be paid to the transportation of construction materials and equipment because of the site is on a remote island. The means of transportation is (i) to transport the materials from exporting country to Malé Island directly by barges or (ii) to transport the materials up to Singapore by barges and transfer to Malé Island by a regular service vessel. In the case the materials in bulk, chartering of a bulk cargo vessel or barge must be considered. In the case of (ii), there is a limit to the size or weight of cargoes handled by the regular service vessel. Transportation should be precisely planned after checking the property of materials and cargoes in detail.

Except alongside berth in the Malé International Commercial Harbour, there is no other suitable pier where a large-scale barge can berth in Malé Island. The alongside berth has been always occupied by the normal port operation as the only available berth to unload all imported goods in the Maldives. With consideration of the condition for the import materials in this project, which would need 4 occupying days of the berth for unloading of the construction materials from the barge, the Maldives Port Authority (MPA) requested other means to unload the materials for the project. Therefore, the temporary jetty constructed in the South Coast Seawall Project (Phase 3) on the north coast will be used for the transportation of construction materials from abroad for this Project. Also the temporary yard for the contractor of the South Coast Seawall Project will be used for this project as well.

(4) Consideration for manageability of implementing agency

4-1) Maintenance of the seawalls constructed by the previous grant aids

Seawall is not a structure that requires maintenance and no particular repair or maintenance is conducted to maintain the basic function of the seawalls. But concerning the peripheral facilities, it was seen that the coverings of a drain pit and/or drainage gate are broken or lost and are left open. Also graffiti on the seawalls were seen everywhere. To cope with the situation, repair and changing of coverings of drainage facilities, cleaning of seawalls, caution and warning are to be enforced routinely by the administrative agency.

Following considerations should be given to plan/design of this Project from the viewpoint of maintenance.

(a) The detached breakwaters should be designed as structures free of any particular maintenance,

(b) Drainage should be designed basically with natural gravity drainage by the slope of land surface,

(c) To avoid graffiti on seawalls, seawalls should be designed to have surface of vertical walls as small as possible employing, for example, step-type body.

4-2) Manageability of implementing agency - MCPW

Design and Project Management Unit (Construction and Physical Planning Section, MCPW) is in charge of making the maintenance program and Ports and Harbours Unit (Public Works Section, MCPW) is in charge of implementation of the maintenance works. As the structure of seawalls in this Project is designed basically as maintenance-free, the budgetary measures to maintain the function and utility of seawalls (cleaning, observation, drainage, mooring, etc.) is judged as not significant.

As the agency has implemented and administrated a number of projects by Japan's grant aid cooperation, port and harbour construction and dredging, the technical level of the implementing agency (MCPW) is judged as sufficient. Judging from the experiences in the previous projects undertaking of the implementing agency of the Maldivian side will be executed satisfactorily.

(5) Consideration for construction period

The construction period for this Project is planned to be divided into two terms considering the following conditions.

1) The temporary jetty for the landing facility of construction materials is located at the east end of the north coast and is planned to be used throughout the construction period. Therefore, the eastern part of the construction is incorporated in the second term.

2) The central part of the construction area, where congestion of boats is not heavy, is planned to be implemented in the first term in order to shift the berthing boats out of the construction area smoothly at the beginning of construction.

2-3-2 Design Conditions and Criteria

(1) Design standards for civil structures

As Maldives' own technical design code of practice or materials standards is currently unavailable, basic design for the shore protection facilities is carried out on the basis of the Japanese standards for design as follows.

- Design Standards and Commentaries for Shore Protection Facilities, Revised edition (Editing Committee of Design Standards for Shore Protection Facilities; 1987)
- Technical Standards for Port Facilities, Revised edition (The Japan Port and Harbour Association; 1999)
- Japanese Industrial Standards (Japanese Standards Association)
- Standard Specification for Concrete (Japan Society of Civil Engineers; 1996)
- Shore Protection Manual (US Army Corps of Engineers; 1984)

(2) Tides

HWL; High Water Level	DL+1.34 m
MSL; Mean Sea Level	DL+0.64 m
LAT; Lowest Astronomical Tide	DL+0.00 m

(3) Design waves

- North Coast (the East and Central portion)

  Offshore Wave Height: H_0 = 0.60 m, Wave Period: T = 4.6 sec

- North Coast (Malé International Port portion)

  Offshore Wave Height: H_0 = 1.20 m, Wave Period: T = 4.6 sec

(4) Seismic force

Seismic force is not taken into account in plan/design of the facilities.

(5) Design condition for use of seawalls

- Mooring of boats (Dhonis with engine)

Length overall:	10 - 15 m
Maximum draught:	1 - 1.5 m

- Surcharge load: w = 0.2 t/m^2

(6) Materials

- Unit weight

Concrete:	2.30 t/m^3 (in air),	1.30 t/m^3 (underwater)
Reinforced concrete:	2.45 t/m^3 (in air),	1.45 t/m^3 (underwater)
Filling material, foundation stone	1.80 t/m^3 (in air),	1.00 t/m^3 (underwater)
Coral lump (Filling material of caisson):	1.40 t/m^3 (in air)	

- Filling material: angle of internal friction $\phi = 30°$,
  angle of wall surface friction $\delta = 15°$
- Foundation stones: angle of internal friction $\phi = 40°$

(7) Coefficient of bottom friction

- Concrete to concrete: $\mu = 0.5$
- Concrete to foundation stone: $\mu = 0.6$

(8) Safety factor

- Sliding: 1.2
- Downfall: 1.2
- Bearing: 2.5
- Bearing capacity: 45 t/m^2 for Loose Coral Rock, 16 t/m^2 for Lagoon Sediments

(9) Strength of materials

- Concrete	Standard design strength:	180 kg/cm^2
- Reinforced concrete	Standard design strength:	240 kg/cm^2
	Allowable bending strength:	90 kg/cm^2
	Allowable shearing strength:	9 kg/cm^2
- Reinforcement steel bar	SD30:	1,800 kg/cm^2
	SD35:	2,000 kg/cm^2

2-3-3 Basic Design

(1) Division of water area of design objective

The water area behind the detached breakwaters on the north coast is divided into the following 6 areas in accordance with their current usage. The division of water area based on the Field Study of this time is shown in Figure 2.3.3.

I: Berth area for shuttle service boats between Malé Island and Airport Island
II: Land area for fisherman's park
III: Berth area for fishing boats and resort island boats
IV: Berth area for Official/Coast Guard Boats, company boats and tourist entrance
V: Berth area for inter-island commercial boats and unloading fishing boats
VI: Malé International Port area

(2) Types of Seawall

Five types of seawalls (detached breakwaters; from Type A to Type E) are designed considering the usage of water areas as shown in Figure 2.3.3.

2-1) Type A (Figure 2.3.4)

Area I and III; Breakwaters are connected with land and also to neighboring Fishermen's Wharf in this division, and the crown of breakwater is used as the space for lading and unloading of cargoes and/or recreation of the town people. Consideration to enable dhonis (boats) to moor and berth in the water area behind the breakwater is necessary in basic design of this division.

Caisson type body is employed to secure sufficient width for use of the crown and deep water for mooring of boats behind the breakwater. The coarse aggregate (coral lumps) of the existing breakwaters is planned to be recycled as the filling materials of caissons of the new detached breakwaters.

Walking space of 1.5 meters in width and mild-slope steps are designed to give the convenience for the use of the crown and loading/unloading from the mooring boats.

2-2) Type B (Figure 2.3.5)

Area IV; Detached breakwaters in this division are disconnected from land. Though the water areas behind the breakwaters are used as berthing area for dhonis (boats) and other motor boats, use of the crown for approaching boats are not considered particularly in the design. Therefore, the Type B is designed to have the shape maintaining the continuity of landscape with the division of Type A.

2-3) Type C (Figure 2.3.6)

The divisions of V are the most congested portions of water area on the north coast with densely berthed dhonis and fishing boats. Fish market, warehouses and trading companies are located in the land area facing the divisions V, and the waterfront road is occupied as quay wall for loading/unloading of cargoes. The part of slash referred in Figure 1.3.3 has a plan that the fish market is expanded and moved onto the artificial platform constructed in future. Also an access road to connect the detached breakwater with land area is planned at the border of the division V and Malé International Port Area. The landing of fish catches of fishing boats and loading/unloading of cargoes of boats moored in the water area V will be done using the crowns of the detached breakwaters, in future.

Sufficient width of the crown for cargo handling activity and deep water behind the breakwater for mooring of boats are taken into account in the design of this division. Also caisson type body is employed similar to the Type A and coral lumps of the existing breakwaters are recycled as the filling materials of caisson. Steel rings for mooring are designed to be installed at 5-m intervals at the inner shoulder of the breakwater.

2-4) Type D (Figure 2.3.7)

The division of Malé International Port Area is located at the western end of the north coast and belongs to the portion of higher design wave. Detached breakwater is designed with higher crown height (DL+2.30 m) same as the height of the pier where cargo vessels are moored. The existing breakwater (the crown height: around DL+2.1 m) has experienced overtopping of waves under the stormy weather, and wave dissipating work is designed up to around the crown height considering stability of breakwater against waves and wave overtopping.

Breakwater of this division is connected with the mooring dolphin of Malé International Port, and the walking space on the crown is provided for the convenience of port activity. Steel rings for mooring are designed to be installed at 5-m intervals at the inner shoulder of the breakwater.

2-5) Type E (Figure 2.3.8)

Area II; This seawall is the portion of the Fishermen's Wharf reconstructed in accordance with the plan of detached breakwaters on the north coast. The crown height is designed to agree with the elevation of land to be connected. Steel rings for mooring are designed to be installed at 5-m intervals at the outer shoulder of the breakwater

(3) Allowable wave overtopping

Allowable wave overtopping in the plan of each portion of the seawall (detached breakwater) is designed so as to secure the safety of human activities considering the usage of the crown of seawalls and the water area behind the breakwaters.

Type of Seawall	Usage of the crown of seawalls and the water area behind the breakwaters	Allowable rate of wave overtopping ($m^3/s/m$)
A	Walking on the crown; berthing in the water area	2×10^{-4}
B	Berthing in the water area	around 0.01
C	Walking on the crown; berthing in the water area	2×10^{-4}
D	Berthing in the water area (partly, walking on the crown)	around 0.01
E	Recreational use on the crown of the seawall	2×10^{-4}

【References】 Standards of Allowable Rate of Wave Overtopping

(Damaging limit of shore protection facility)

Facility	Type of armoring works	Rate of wave overtopping ($m^3/s/m$)
Sea-dike	No armoring coat both on crown surface and on back slope	less than 0.005
	Armoring coat on crown surface and without coat on back slope	0.02
	Three surfaces armoring	0.05
Seawall	No armoring coat on crown surface	0.05
	Armoring coat on crown surface	0.2

Source: Random Seas and Design of Maritime Structures, Goda, Y., 1990.

(Allowable rate of wave overtopping by the usage of hinterland)

Usage	Level of safety		Rate of wave overtopping ($m^3/s/m$)
Walking	Direct rear of dike	(50 % safety)	2×10^{-4}
	ditto	(90 % safety)	3×10^{-5}
Bicycle	Direct rear of dike	(50 % safety)	2×10^{-5}
	ditto	(90 % safety)	1×10^{-6}
Houses	Direct rear of dike	(50 % safety)	7×10^{-5}
	ditto	(90 % safety)	1×10^{-6}

Source: Technical Standards for Port Facilities, Revised edition, 1999.

(Allowable rate of wave overtopping by the importance of hinterland)

Description	Rate of wave overtopping ($m^3/s/m$)
An area behind sea-dike where houses and public institutions are concentrated and particularly a serious damage is predicted by inflow of wave overtopping and/or sprays.	around 0.01
Other important area	around 0.02
Other area	0.02 - 0.06

Source: Technical Standards for Port Facilities, Revised edition, 1999.

(4) Peripheral facilities

The following peripheral facilities are considered to be installed as parts of planned detached breakwaters.

4-1) Conduit for seawater interchange

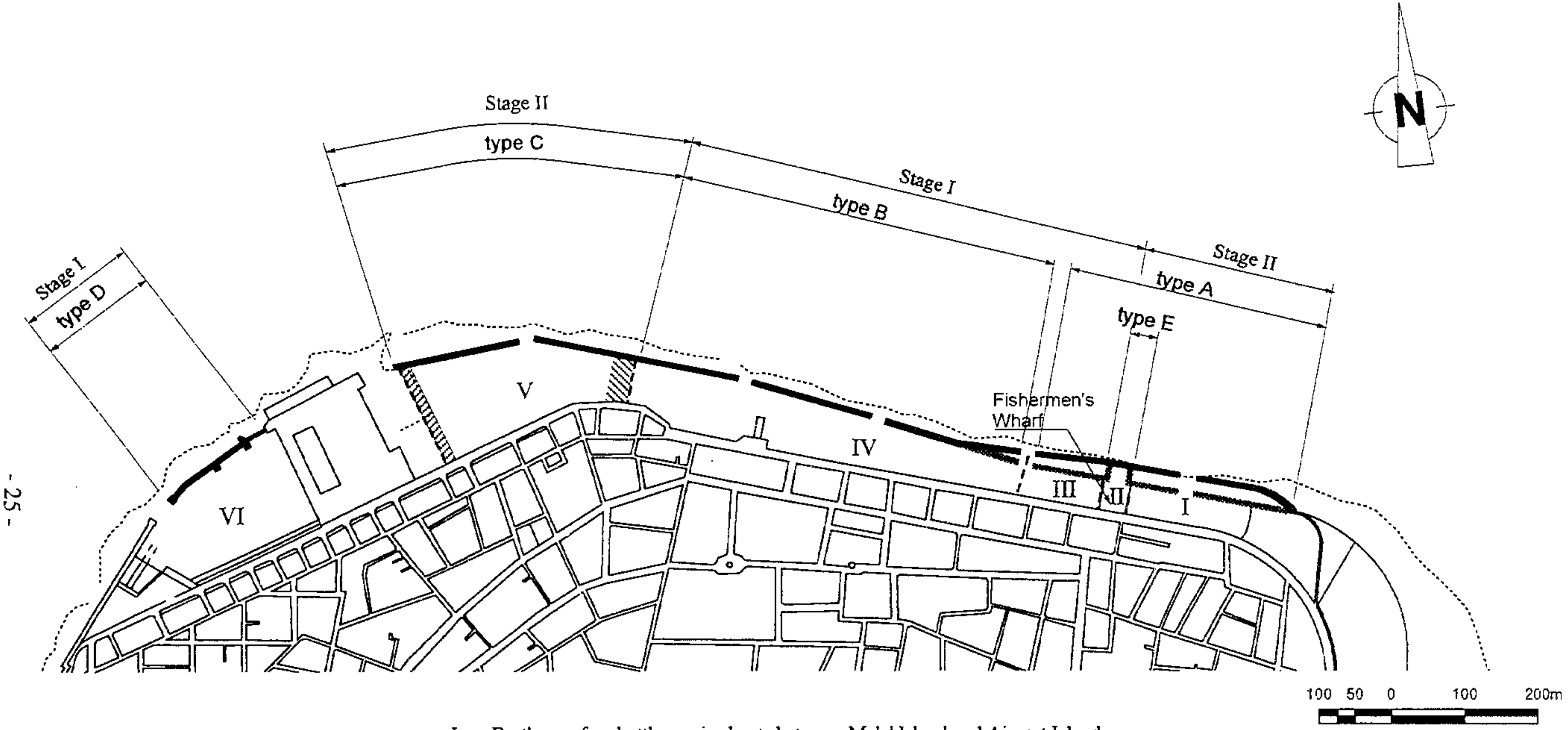
In order to maintain good water quality in the water areas behind the breakwaters, installation of conduits (pipe or culvert) through breakwater bodies to expedite exchange of seawater of the basin is planned.

In the case of seawalls with direct foundation, Type A and Type C, a PVC pipe of 500-mm in diameter is installed through the body of breakwater below LWL.

In the case of Type B and Type D with mound-type foundation, a box culvert of similar size is installed through the mound foundation below LWL. The interval between conduits is planned as 50-m.

4-2) Beacon light

Existing beacon lights at the openings of detached breakwaters are to be reused for the new breakwaters. As the construction site of this project is the main gateway of the capital of Maldives, the foundation of beacon light employed would match the landscape (Figure 2.3.9).



I : Berth area for shuttle service boats between Male' Island and Airport Island

II : Land area for fisherman's park

III : Berth area for fishing boats and resort island boats

IV : Berth area Official/ Coast Guard Boats, company boats and tourist entrance

V : Berth area for inter-island commercial boats and unloading fishing boats

VI : Male' International Port area

▨ : Access Road to connect the Breawater with Land was planned by GOM

Figure 2.3.3 Division of Water Area and Types of New Seawalls

Seawall - type A

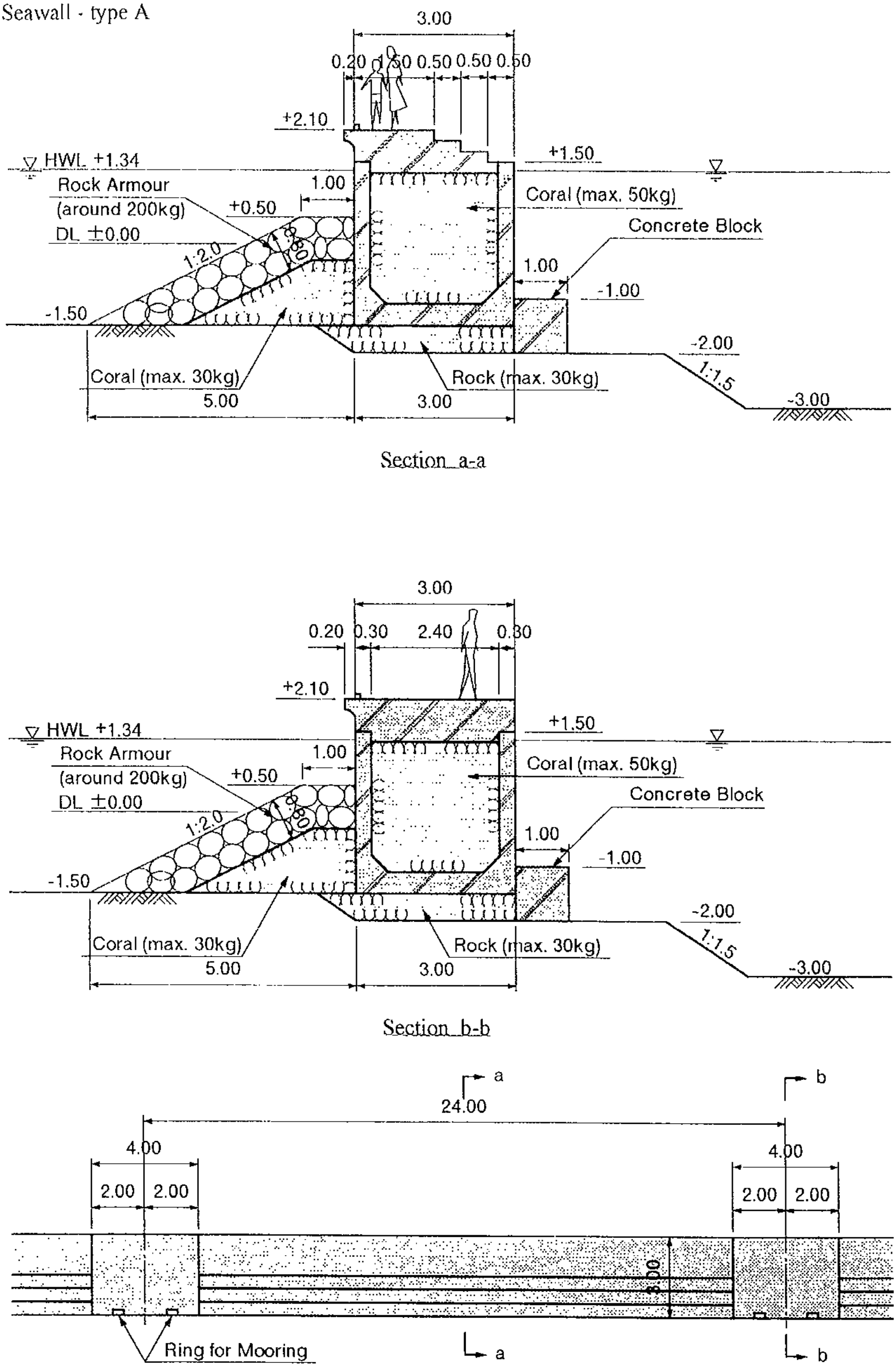
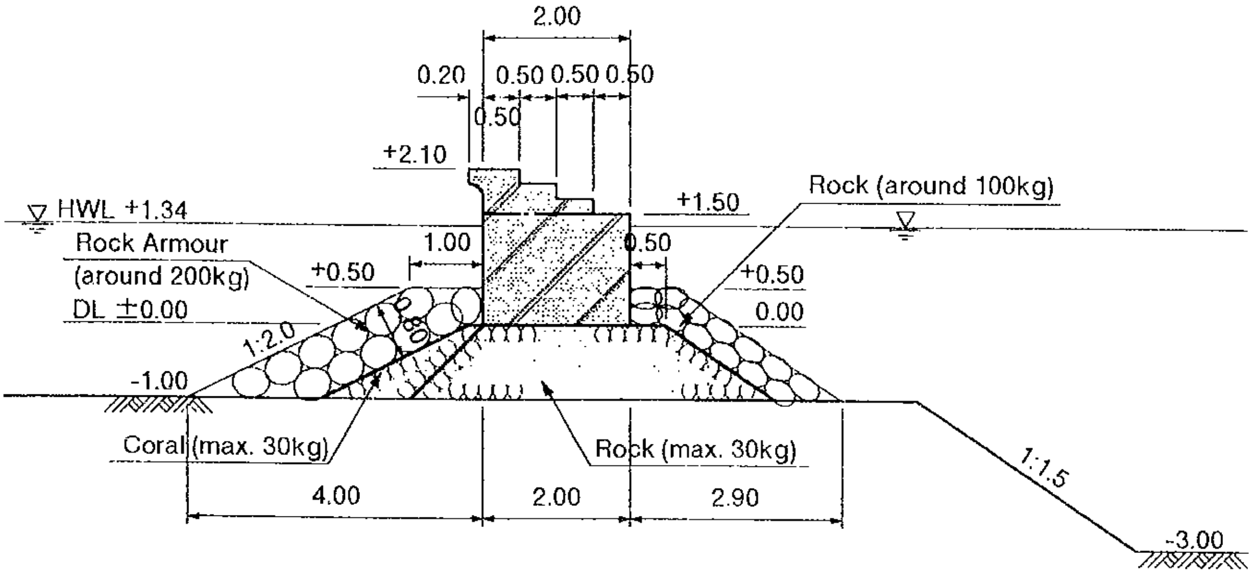
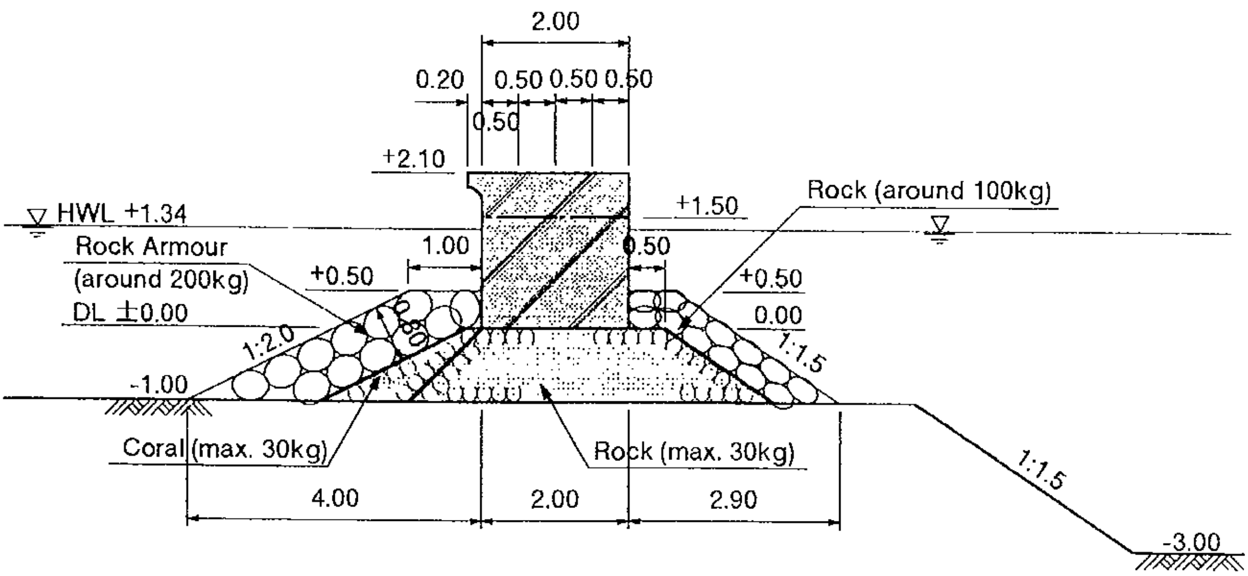


Figure 2.3.4 Standard Cross Section of Seawall - Type A

Seawall - type B



Section a-a



Section b-b

Figure 2.3.5 Standard Cross Section of Seawall - Type B

Seawall - type C

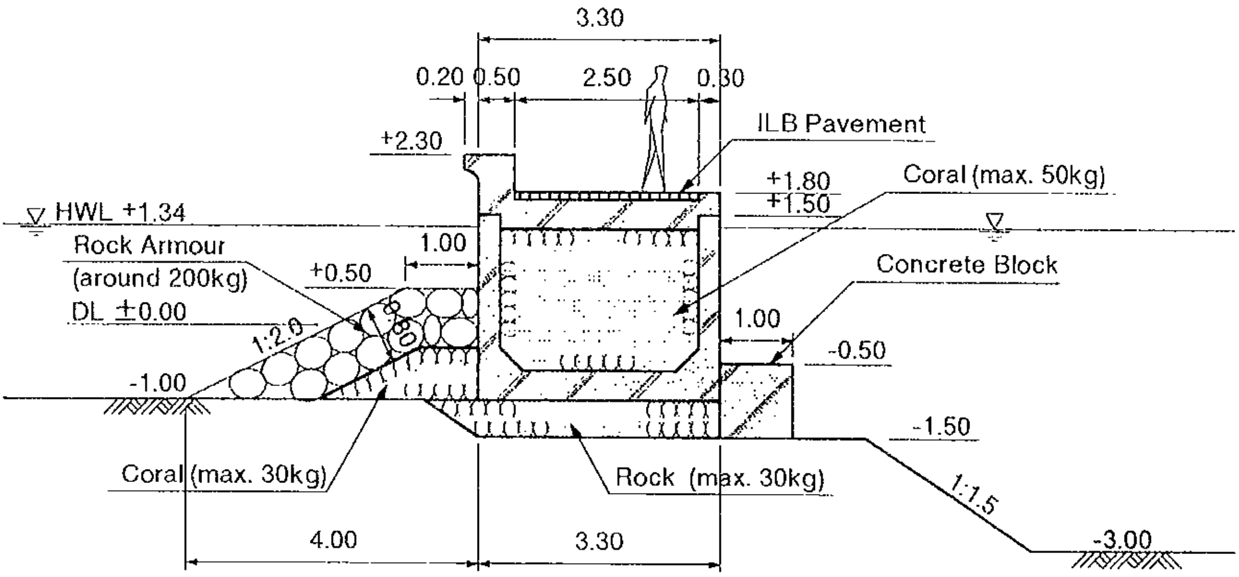


Figure 2.3.6 Standard Cross Section of Seawall - Type C

Seawall - type D

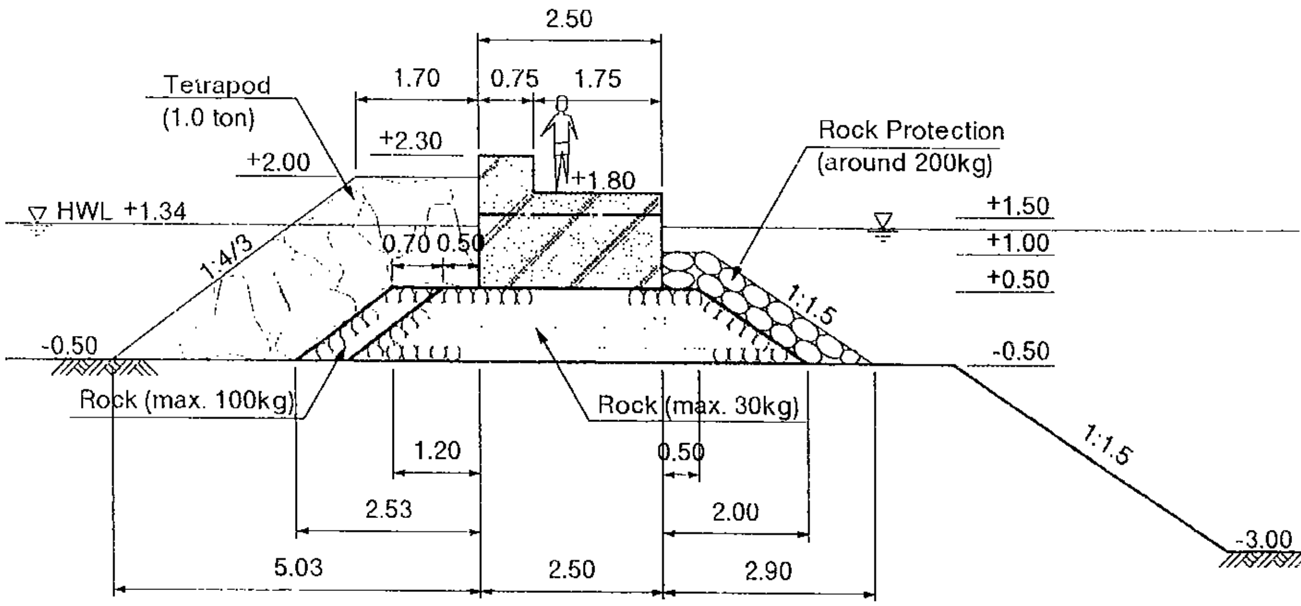


Figure 2.3.7 Standard Cross Section of Seawall - Type D

Seawall - type E

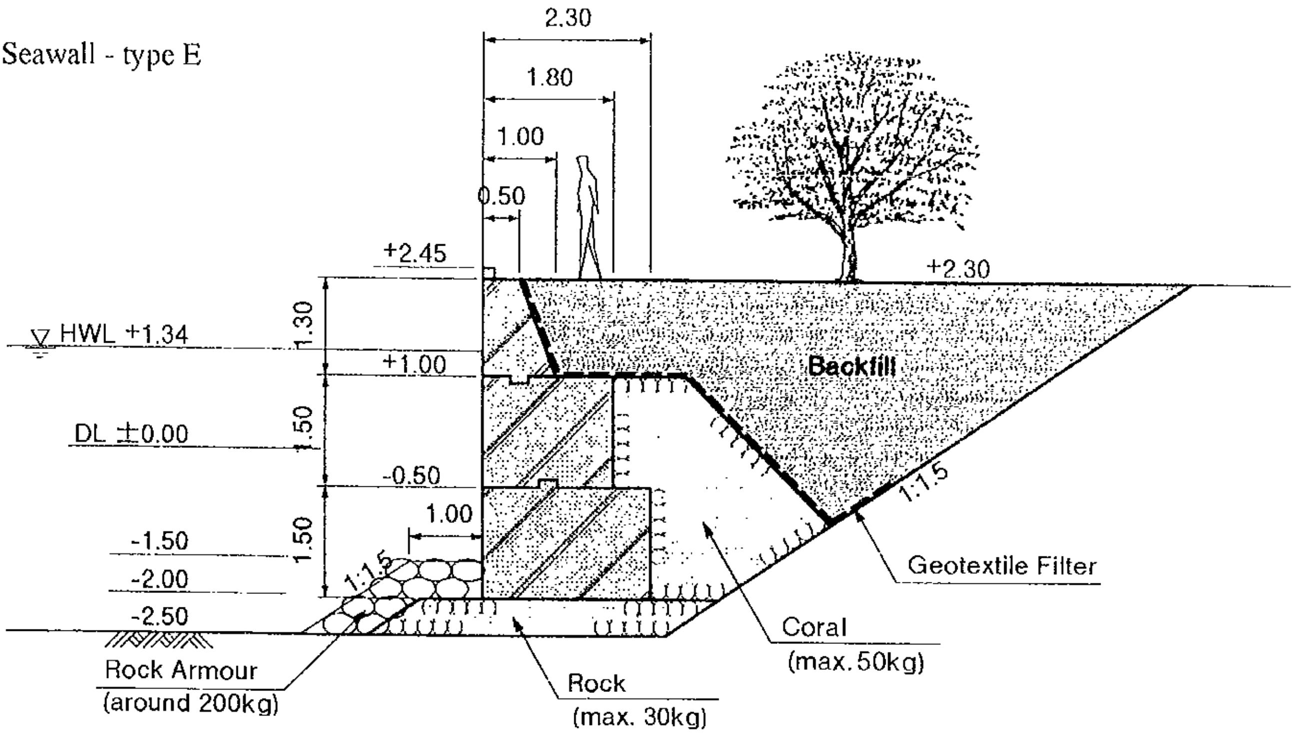


Figure 2.3.8 Standard Cross Section of Seawall - type E

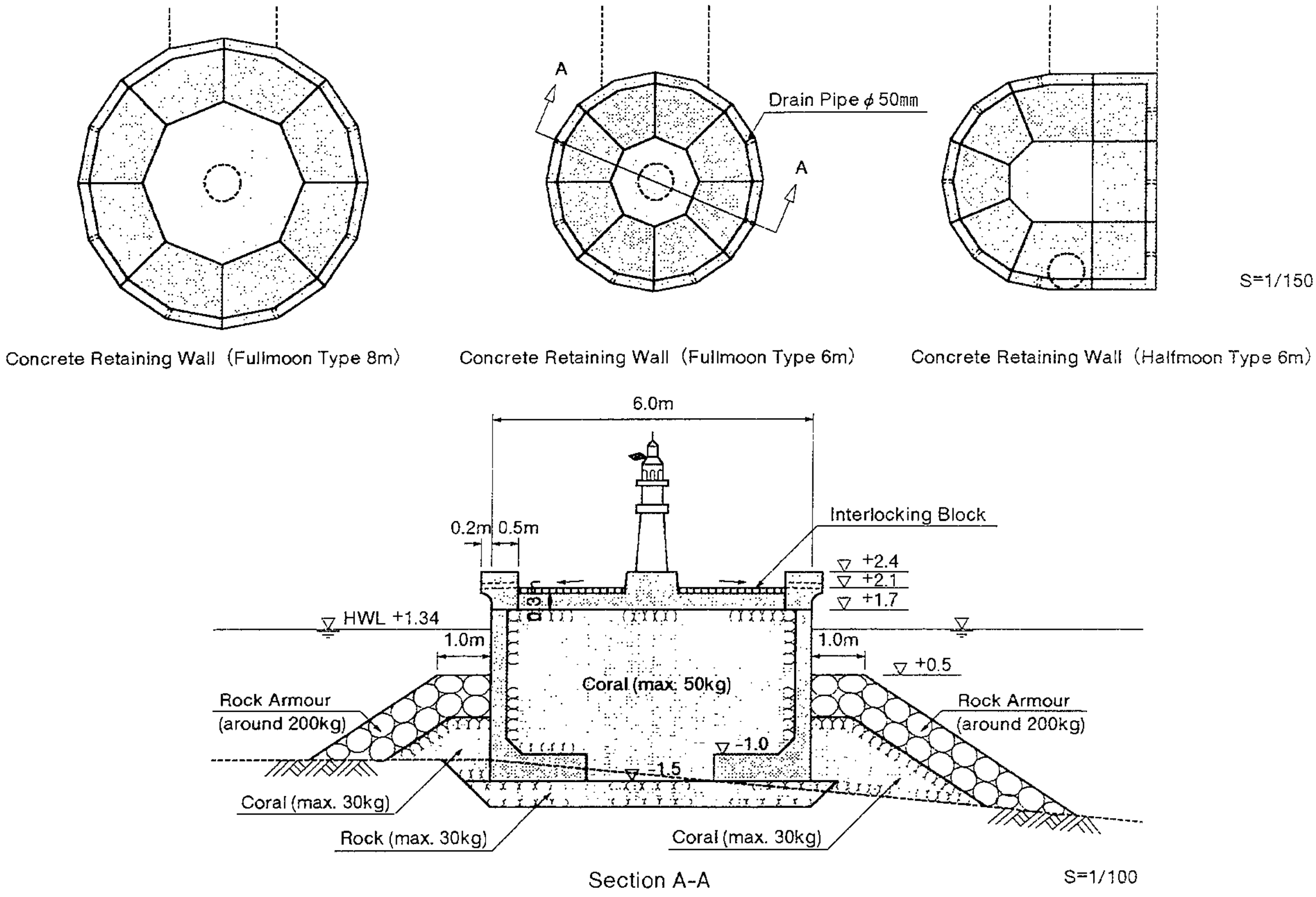


Figure 2.3.9 Standard Cross Section at the End of Breakwater