CHAPTER 5 MULTI-PURPOSE BUILDING AND ISLAND OFFICE

5.1 Introduction

In community reconstruction terms, the serious damage brought about by the tsunami on 26th December, 2004 was sustained in the social facilities and administrative facilities. The damage to facilities and the activities therein will translate into several social and economic distresses, however, rapid public action to provide assistance to the affected communities may solve some of such distress.

The reconstruction work for local public administration facilities would provide significant effectiveness for smooth execution of tsunami recovery projects, which is crucial for regenerating the local economies and the stability of people's livelihood.

Therefore, urgent implementation of reconstruction of community facilities and recovering damaged government facilities was requested. In response to this pressing need, community facilities and key local administration facilities should be newly constructed focusing on the followings.

- Construction of Island Office with Community Facilities in Fonadhoo Island, Laamu Atoll
- Construction of Multi-purpose Building in Thundi, Gan Island, Laamu Atoll

  Facility including;
  - Island office
  - Island court
  - Police office
  - Post office
  - Banking booth
  - Community hall and multi-use space

Service areas of those facilities are shown in the following table.

Service Area	Island Office	Island Court	Police Office	Post Office	Banking Booth	Community Facilities
Thundi including Resettlement Community	●					
Whole Gan Island (Thundi, Mathimaradhoo, Mukurimagu)		●				
4 Islands (Gan, Maandhoo, Kaddhoo, Fonadhoo)			●	●	●	●

Taking advantage of the construction, it is recommended to add a safe shelter function for the islanders to evacuate in case of a natural disaster. This is of vital importance for the communities who live on low-lying islands. Thus the building must be a double-storey structure with:

- Ground Floor: minimum utility space / mostly vacant for avoiding tsunami or high water flooding
- 1st Floor: community and local government administrative office spaces and safe shelter

It should be considered that the facility is equipped with emergency utility support systems such as solar power generator and back-up accumulator.
Corresponding with the on-going demonstration project in the Fonadhoo Island, debris of the destroyed/demolished houses can be recycled and used as building materials to inspire the tsunami recovery, initialize people's participation as well as economising the costs.

5.2 Present Conditions of the Construction Site

The construction site for the island office is in front of the Fonadhoo Harbour. The tsunami evacuation Platform is going to build in the next site of this. It is considerably conveniently located to serve the whole residents in Fonadhoo. The site is flat and already cleared for the construction work.

The site for the multi-purpose building is in Thundi, Gan Island. The settlement of Thundi is planned for relocating houses the tsunami-hit island communities from Mundhoo and Kalhaidhoo. The island of Mundhoo has a population of 504 (registered population 742). The number of houses on the island is estimated at 96. The island of Kalhaidhoo is home to a population of 456 (registered population 635). The number of houses is estimated to be 118.

Relocation of these communities is planned on Thundi, Gan Island. Gan, having a land area of 516.6 hectares, is the largest island in the Maldives, and has a potential of functioning effectively as a regional growth center. Gan is part of the strategic chain of islands in the Laamu Atoll.

A neighbourhood development plan is being developed for around 3,000 people in the vicinity of the Thundi settlement. The plan has been developed taking into account the existing infrastructure in Thundi at the neighbourhood level and also the facilities such as hospital and secondary school located in the Mathimaradhoo settlement. The multi-purpose building is located in the central part of the new settlement. With these movements in mind, the multi-purpose building could be encouraged to accommodate a regional growth center in the largest island.

The construction site for the multipurpose building in Thundi, is situated middle of resettlement areas and south part of existing Thundi community as shown in Figure 5.1.

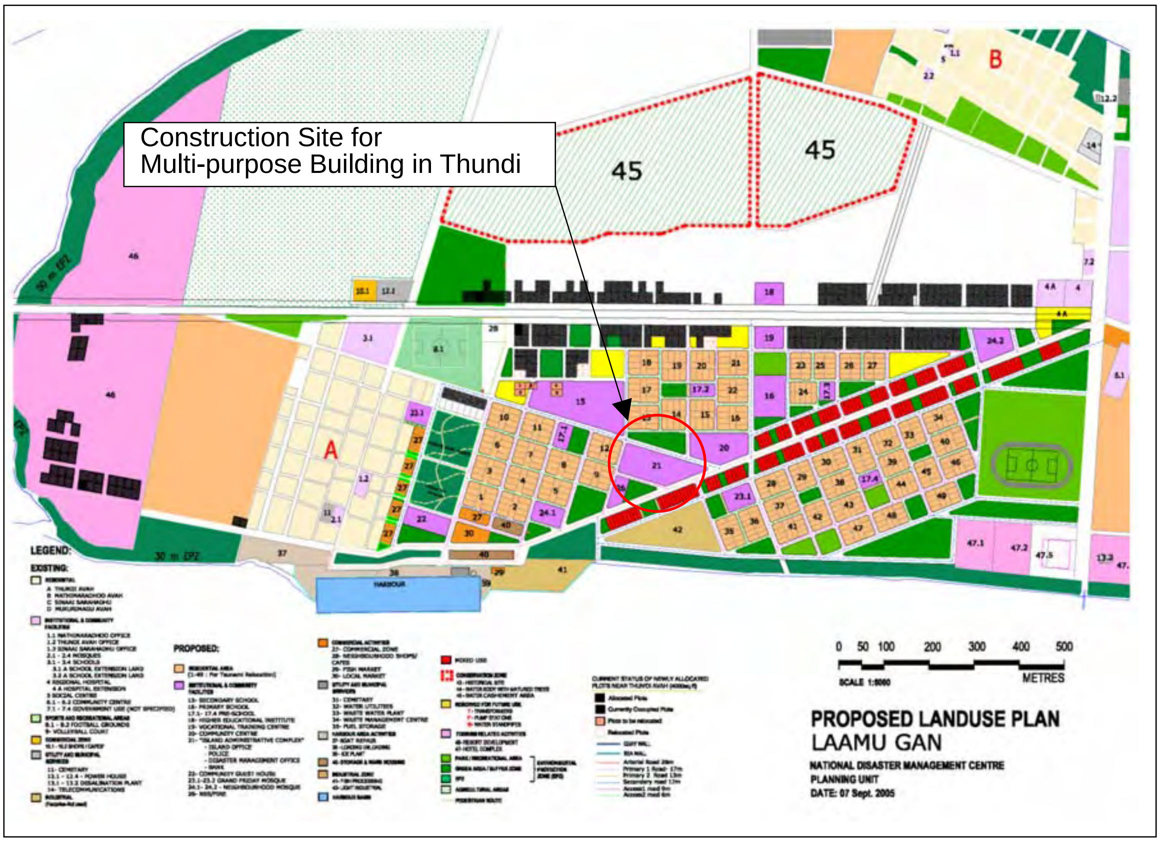


Figure 5.1 Construction Site for the Multi-purpose Building in Thundi, Laamu Gan

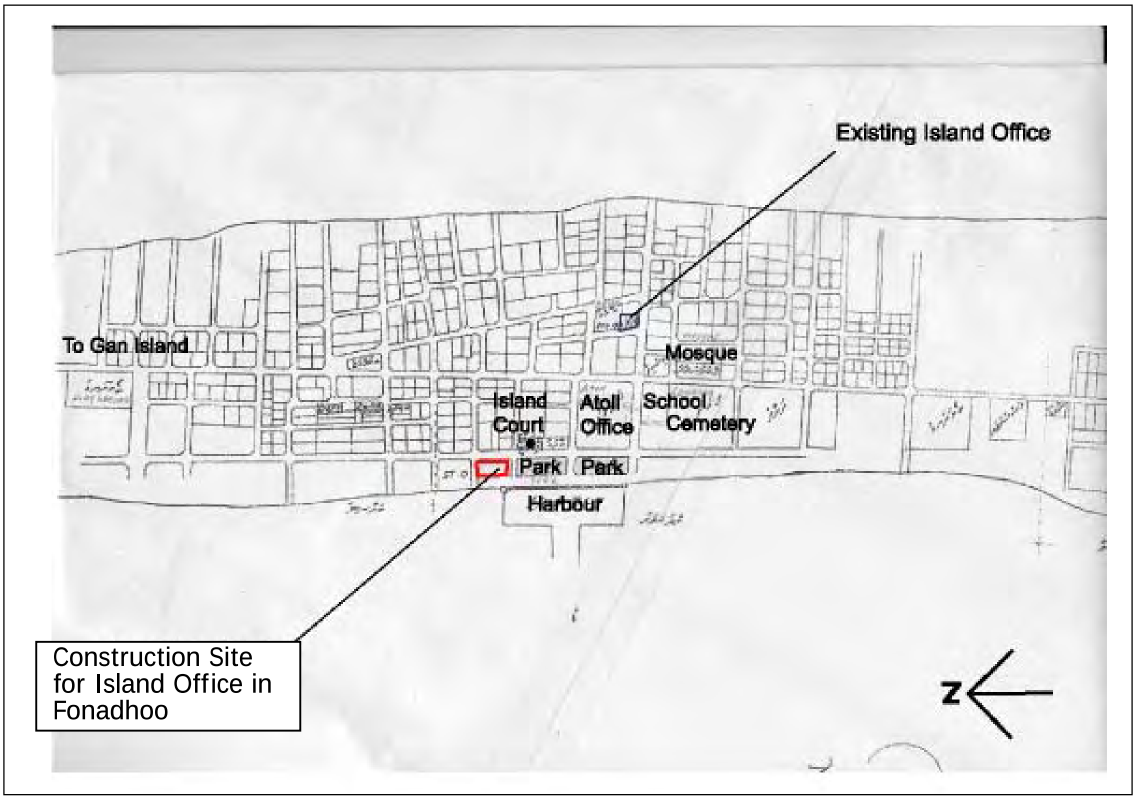
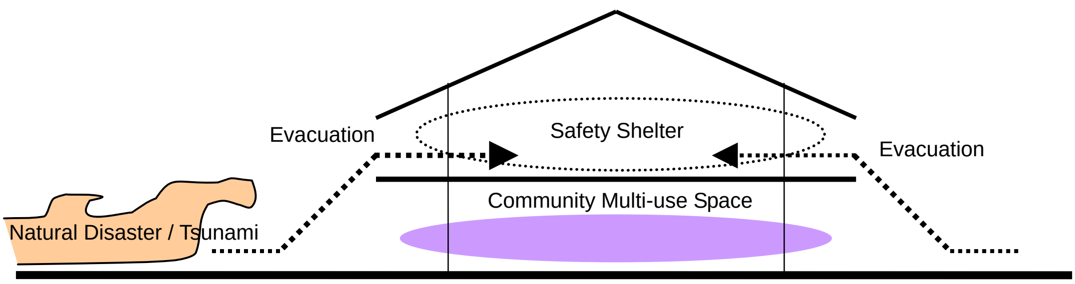


Figure 5.2 Construction Site for the Island Office in Laamu Fonadhoo

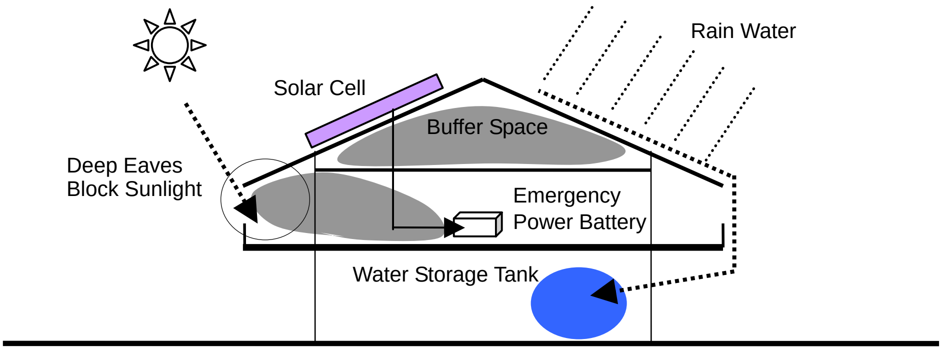
5.3 Planning and Design Policies

1) Double-storey structure
   - To avoid tsunami / high tide water flooding
   - To provide a safety shelter for the surrounding residents
   - To provide universal / multi-use space on the ground floor under the shade



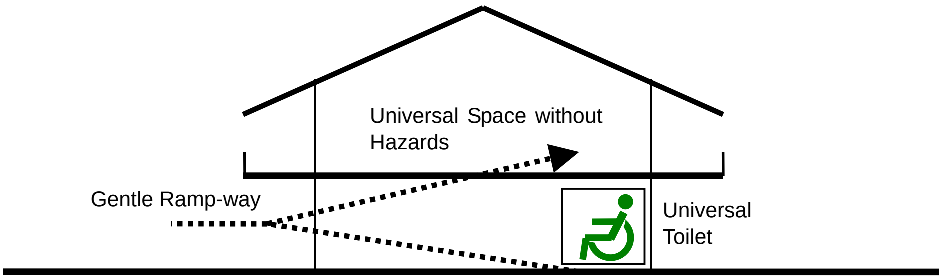
2) Sloping roof and deep eaves

- To collect storm water on the roof and storage in the reservoir tank.
- To install solar panels with sufficient angle to the sun
- To provide a cool condition in the room by cutting off the direct sunlight into the windows
- To provide triangle air buffer space as heat insulation in between the roof and the ceiling



3) Consideration for disabled persons

- To provide ramp way and universal toilet for disabled persons such as the handicapped, the aged, pregnant women and so on.
- To function as a smooth evacuation route in case of emergencies



5.4 Room Requirements

Room requirements for both facilities are prepared by the MPND in cooperation with the MOAD. The Study Team has carried out minor adjustments to floor area in order to designate the floor layout in each building. The results of room requirements are shown in Tables 5.1. and 5.2.

(1) Multi-purpose building

Table 5.1 Room Requirement of Multi-purpose Building

Ground Floor	(sqm)
Reception / Security	25.7
Utilities Room	74.2
Toilet	37.1
Community Multi-space	535.0
(Sub Total)	(672.0)
Circulation (Stairs and Slope)	42.5
Total of Ground Floor	**714.5**
1st Floor	
Island Office	
Island Chief's Room	15.9
Assistant Island Chief's Room	21.2
Investigation Room	12.6
Meeting Room	24.5
Island Development / Women Development Committee	17.9
Administration	25.2
Communication Room	8.1
Stock Room	8.1
Store Room and Equipment Room	23.1
Tea Room	8.1
Toilet	4.5
Reception Area	18.9
Hallway	12.2
Corridor	22.3
Total	**222.6**
Island Court	
Senior Magistrate's Room	15.6
Magistrate's Room	12.7
Senior Staff Room	25.9
Reception Area	7.3
Investigation Room	11.7
Meeting Room	21.7
Equipment Room	10.3
Stock Room	7.5
Tea Room	8.2
Toilet	7.4
Corridor	14.9
Total	**143.2**
Police Office	
Reception	9.6
Office	14.1
Investigation Room	8.0
Cell-1	5.4
Cell-2	5.4
Store Room	6.1
Tea Room	6.1
Toilet	5.3

Corridor	6.1
Total	**66.1**
Post Office	
Mail Operation Room	18.0
Office	20.7
Reception	6.5
Tea Room	6.3
Toilet	3.3
Total	**54.8**
Banking Booth	
Front Room	6.6
Back Room	11.4
Chief Officer's Room	9.2
Tea room	4.8
Toilet	3.3
Total	**44.5**
Community Facility	
Community Hall	27.3
Circulation	
Open Corridor and Terrace	169.2
Stair and Slope	42.5
Total	**211.7**
Total of 1st Floor	**770.2**
Total of Ground and 1st Floor	**1,484.7**

(2) Island office

Table 5.2 Room Requirement of Island Office

Ground Floor	(sqm)
Utilities Room	30.1
Toilet	7.0
Community Multi-space	185.5
(Sub Total)	(222.6)
Circulation (Stairs and Slope)	31.4
Total	**254.0**
1st Floor	
Island Chief's Room	18.5
Assistant Island Chief's Room	16.5
Conference Room	24.5
Committee's Room	24.5
Administration	18.5
Filing Room	8.3
Store Room	8.3
Photocopy / Radio Set Room	8.1
Tea Room	7.0

Toilet	5.3
Guest Room-1	18.5
Guest Room-2	18.5
Hallway	22.9
Waiting Hall	12.3
Corridor	11.0
(Sub Total)	(222.6)
Terrace	103.8
Circulation (Stairs and Slope)	31.4
Total	**357.8**
Total of Ground and 1st Floor	**611.8**

5.5 Cost Estimation

The estimated costs of the multi-purpose building and island office at the design stage were as follows:

5.5.1 Island Office

(1) Summary Table; Unit US$

No.	Item	Unit	Price
1	Building Construction Works	1 set	538,000
2	External Works	1 set	32,300
3	Furniture and Fitting	1 set	9,700
4	Equipments	1 set	20,000
	Total	1 set	600,000

(2) Breakdown Table; Unit US$

1	Building Construction Works ①+②+③+④+⑤			538,000
	①	Direct Construction Works		
		(1)	Earth Works	10,200
		(2)	Concrete Works	99,700
		(3)	Masonry Works	16,000
		(4)	Painting Works	22,500
		(5)	Structural Steel Works	12,000
		(6)	Roofing Works	19,300
		(7)	Flooring Works	14,200
		(8)	Ceiling Works	8,100
		(9)	Doors ad Windows Works	7,400
		(10)	Electrical and Plumbing Works	42,600
	Sub-total			252,000

	②	Marine Transportation fee and Unloading fee		
		(1)	Construction Materials	112,000
		(2)	Construction Equipments	
	③	Temporary Facilities Construction fee		
		(1)	Site Office	46,000
		(2)	Temporary gate and fence	
		(3)	Material and tool store	
		(4)	Fabrication yard	
		(5)	Worker's accommodation	
		(6)	Canteen	
		(7)	Toilet	
	④	Construction Equipment Rental fee		
		(1)	Backhoe	82,300
		(2)	Concrete Mixer	
		(3)	Dump Truck	
		(4)	Generator	
		(5)	Truck Crane	
	⑤	Site Expense		
		(1)	Site office worker's salary	46,000
		(2)	Traveling and accommodation	
		(3)	Communication fee	
		(4)	Insurance	
		(5)	Security Control	
		(6)	Electric and water charge	

2	External Works			32,300
		(1)	Boundary wall and Gate	
		(2)	Flag Pole	
		(3)	Water tank	
		(4)	Signboard	
		(5)	Landscaping	
		(6)	Miscellaneous	

Note; The cost of engineering fee and solar power are not included.

5.5.2 Multi Purpose Buildings

(1) Summary Table; Unit US$

No.	Item	Unit	Price
1	Building Construction Works	1 set	1,229,000
2	External Works	1 set	61,000
3	Furniture and Fitting	1 set	20,000
4	Equipments	1 set	90,000
	Total	1 set	1,400,000

(2) Breakdown Table; Unit US$

1	Building Construction Works ①+②+③+④+⑤			1,229,000
	①	Direct Construction Works		
		(1)	Earth Works	27,580
		(2)	Concrete Works	267,500
		(3)	Masonry Works	56,200
		(4)	Painting Works	49,200
		(5)	Structural Steel Works	51,200
		(6)	Roofing Works	59,200
		(7)	Flooring Works	37,700
		(8)	Ceiling Works	20,600
		(9)	Doors ad Windows Works	17,800
		(10)	Electrical and Plumbing Works	115,720
	Sub-total			702,700
	②	Marine Transportation fee and Unloading fee		
		(1)	Construction Materials	160,100
		(2)	Construction Equipments	
	③	Temporary Facilities Construction fee		
		(1)	Site Office	50,000
		(2)	Temporary gate and fence	
		(3)	Material and tool store	
		(4)	Fabrication yard	
		(5)	Worker’s accommodation	
		(6)	Canteen	
		(7)	Toilet	
	④	Construction Equipment Rental fee		
		(1)	Backhoe	191,200

		(2)	Concrete Mixer	
		(3)	Dump Truck	
		(4)	Generator	
		(5)	Truck Crane	
	⑤	Site Expense		
		(1)	Site office worker's salary	125,000
		(2)	Traveling and accommodation	
		(3)	Communication fee	
		(4)	Insurance	
		(5)	Security Control	
		(6)	Electric and water charge	

2	External Works			61,000
		(1)	Boundary wall and Gate	
		(2)	Flag Pole	
		(3)	Water tank	
		(4)	Signboard	
		(5)	Landscaping	
		(6)	Miscellaneous	

Note; The cost of engineering fee and solar power are not included.

The tender price at the contract of the Multi-purpose Building and the Island Office including Solar Powers were 354,818,000 Yen.

5.6 Construction and Implementation Plan

The schedule of the pre-qualification. tendering and construction are as follows:

1) P/Q 24 July, 2005
2) Tender Opening 20 September, 2005
3) Award and Contract 2 November, 2005
4) Construction Period Mid-November 2005 to early July 2006

5.7 Description of Solar Power Generation System

(1) General

The tsunami on 26th December, 2004 inflicted severe damage onto the power supply system in at least 95 islands (about 48% of the total islands with electricity). Electricity supply for island office and other community space was disrupted, which highlighted the importance of power supply as a lifeline in outer islands.

In case of a natural disaster, island offices, multi-purpose buildings in Environmental Protected Zone (EPZ) could serve as a shelter for the affected residents. Introduction of the “disaster-proof electric power supply system” (solar power system interconnected with existing distribution lines) will help supply minimum emergency load (e.g. lighting and communications) even in case of power outage by natural disasters.

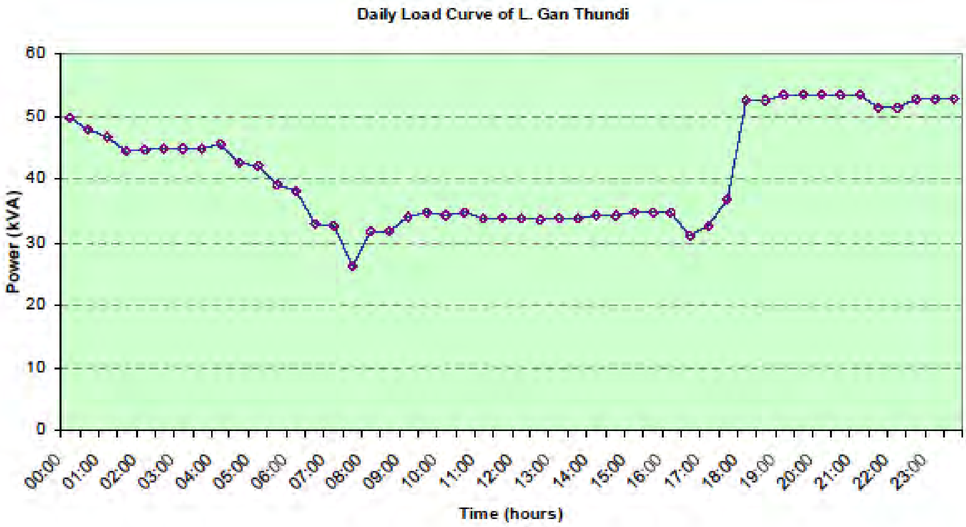
The MTC, State Electric Company Limited (STELCO), MOAD, and other international agencies are jointly undertaking the so-called SMILES project (“Strengthening Maldivian Initiatives for a Long-term Energy Strategy”). The project aims to introduce a PV-diesel hybrid system, whereby the PV system and battery bank supply power during daytime (from 07:00 to 17:50), and the diesel system during the night time (from 17:50 to 07:00). The concept of the project is to reduce fuel cost of the diesel engine generators.

Now those people who live in the tsunami-affected areas have suffered from frequent power outages, because those temporary cables and distribution boxes are not appropriately designed in consideration of existing load current. Power supply has already been recovered in many affected islands but only temporarily. Many cables are connected without jointing materials underground, distribution boxes are substituted by plastic buckets and pet bottles. Those improper installation will result in frequent line fault and cause severe damage on the consumers equipment. Electricity is being supplied by the Island Development Committees (IDCs), which lacks proper engineering capabilities to assess and repair the damaged power supply equipment.

As for generation facilities, it must be noted that two or more generators cannot be operated at once in many islands, because there is no synchronous panel (even though we introduce synchronous panel, technicians from each Island Committee shall be trained well by On-the-Job Training).

(2) Multi-purpose building

The island (Gan-Thundi) has four generators in total: 2 x 60 kVA, 85 kVA and 140 kVA; and the power system is not synchronized. The nighttime electricity load to the island is provided by the biggest generator (140 KVA – DEUTZ) and daytime load is met by two smaller generators. As the system is not synchronized, the two daytime generators feed power to the grid separately using different feeders. The estimated load pattern of the island from the data collected is shown in the figure below. Based on the estimated load pattern there is no need to run two generators during day time because just a smaller generator would be enough to cover the daytime load.

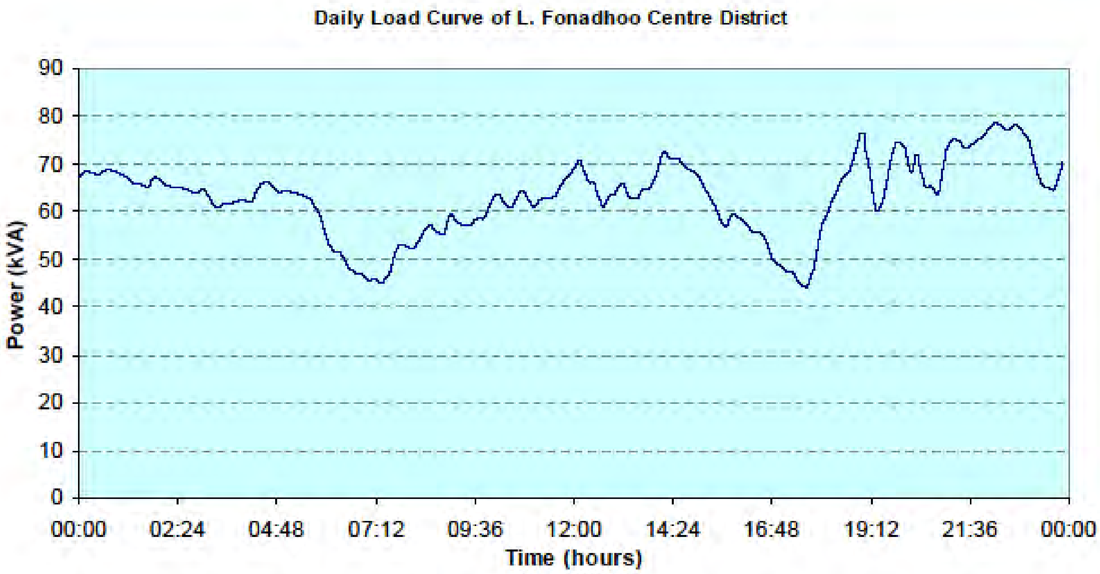


Presently, power supply to the site is not available but three phase distribution lines to the site will be installed by the island committee to use with the solar PV system and other power supply for the building.

(3) Island Office

The Fonadhoo Island has three powerhouses located at the three wards of the island. The central ward's powerhouse is planned to supply power for the upcoming island office. The central ward's powerhouse has three generators: 108 kW, 40 kW and 96 kW. The system is non-synchronized so that only one generator is used at a time. A typical daily load curve of the island measured is given below.

Presently, power supply to the site is not available. However, three phase distribution lines to the site will be installed by the Island Committee to use with the solar PV system and other power supply for the building.



The supplier shall provide simulated calculations confirming the solar radiation on each surface plane, yearly generated energy from the PV system. The supplier shall install kWh meters in order to monitor and check the value of energy generated by the PV system. The minimum requirement for the annual performance of PV system shall be 135 kWh/m^2.

All support structures components must be mounted on the roof without any drilling on the roof surface. The structures shall be designed to allow the fixing of modules on the support structures with the module tilt angle adjustable. No manual/auto tracking/tilting adjustment device is necessary.

The supplier shall provide calculations confirming the design wind force on the support structure with the maximum wind velocity (45 m/sec) assured.

Figure 5.3 Perspective Drawing of the Multi-purpose Building

Figure 5.4 Perspective Drawing of Island Office

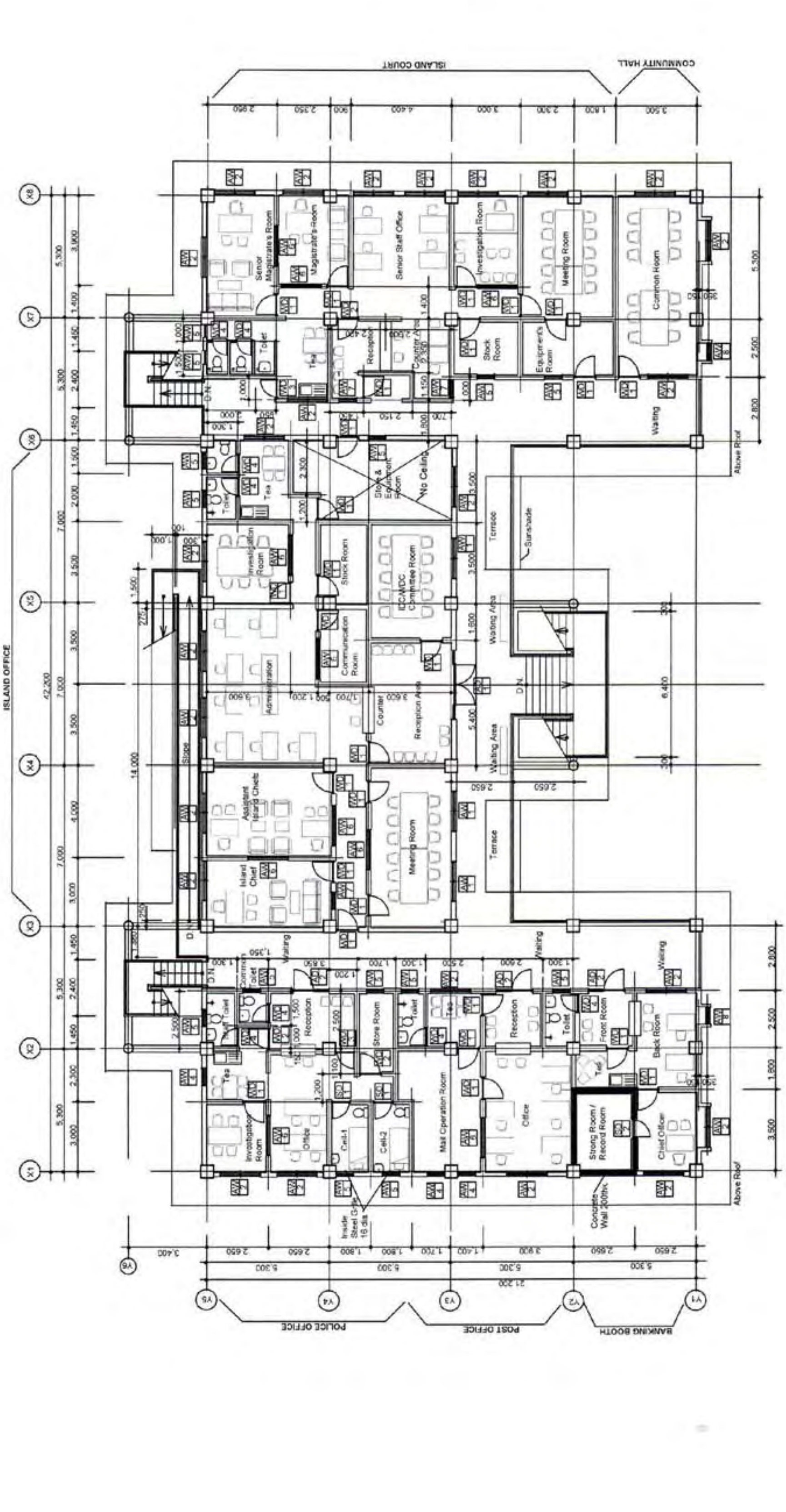


Figure 5.5 Floor Plan (1F) of Multi-purpose Building

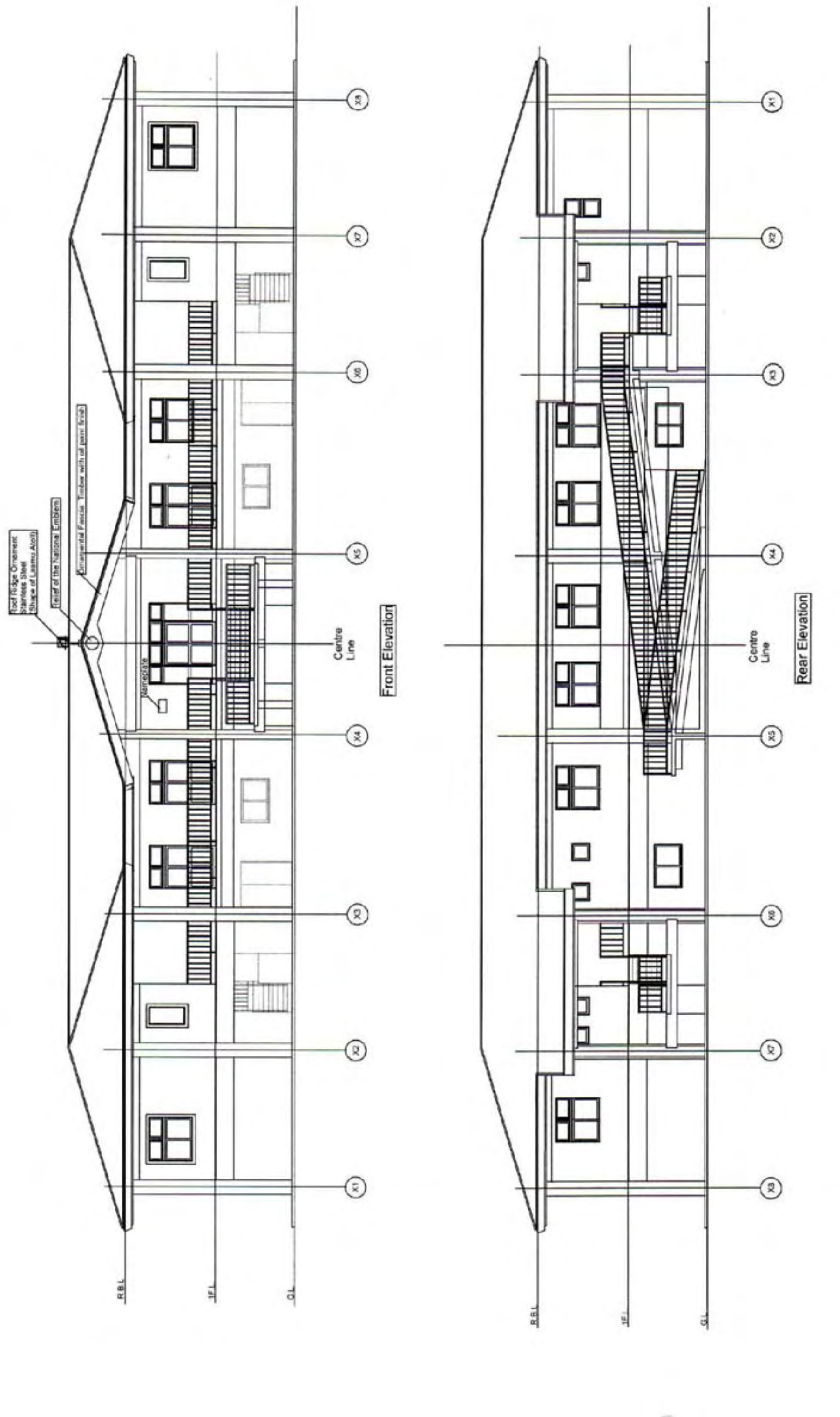


Figure 5.6 Elevation of Multi-purpose Building

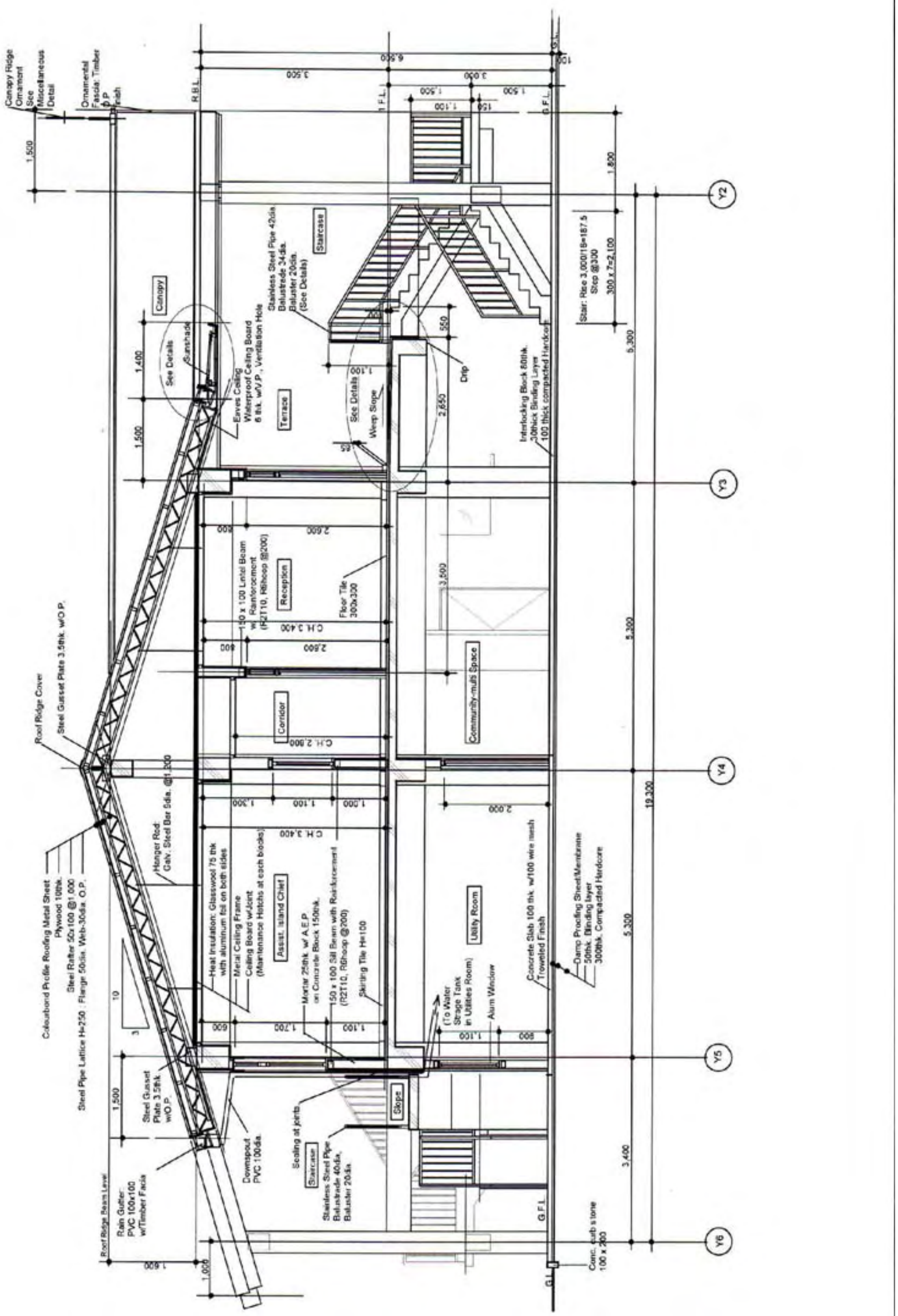


Figure 5.7 Section of Multi-purpose Building

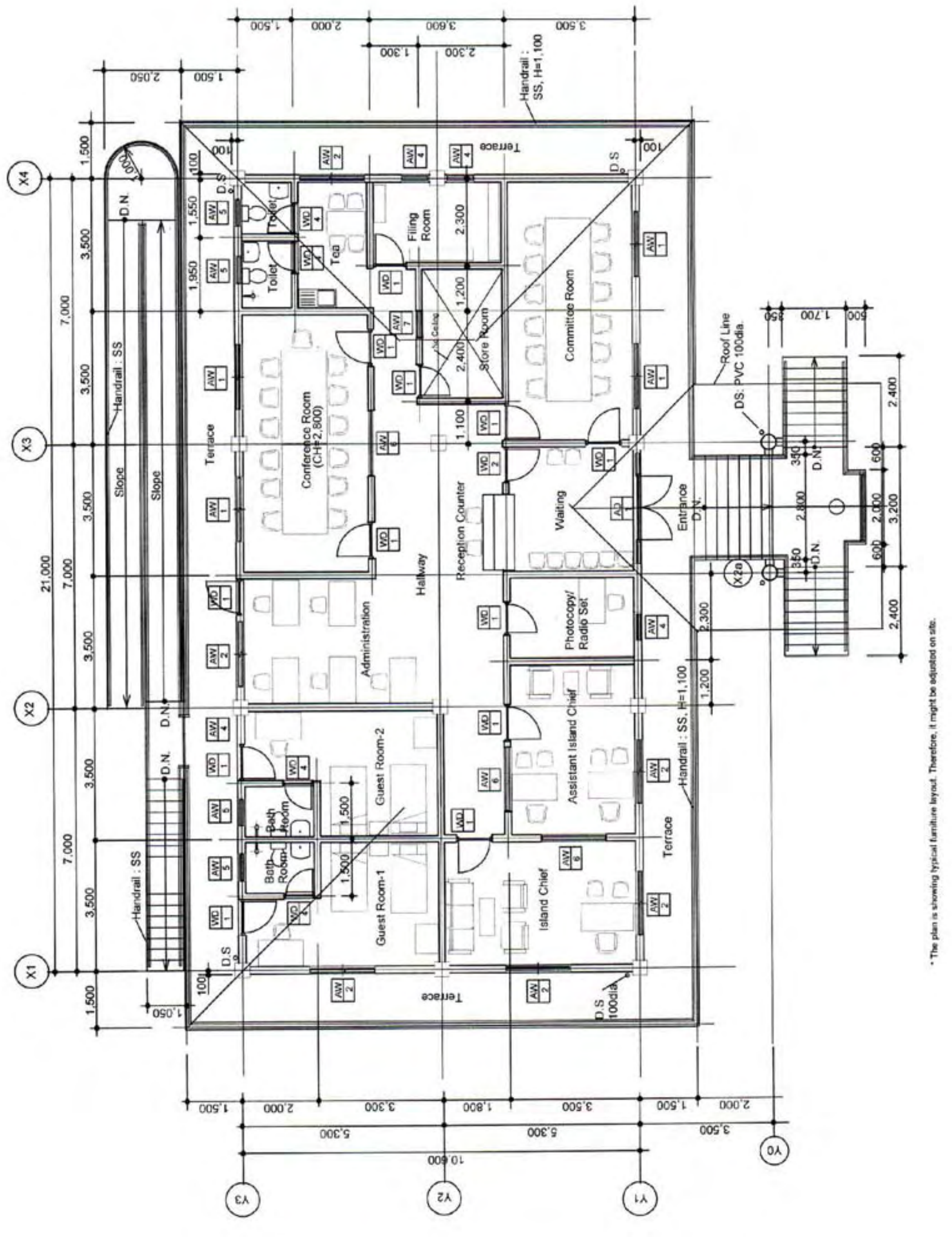


Figure 5.8 Floor Plan (1F) of Island Office

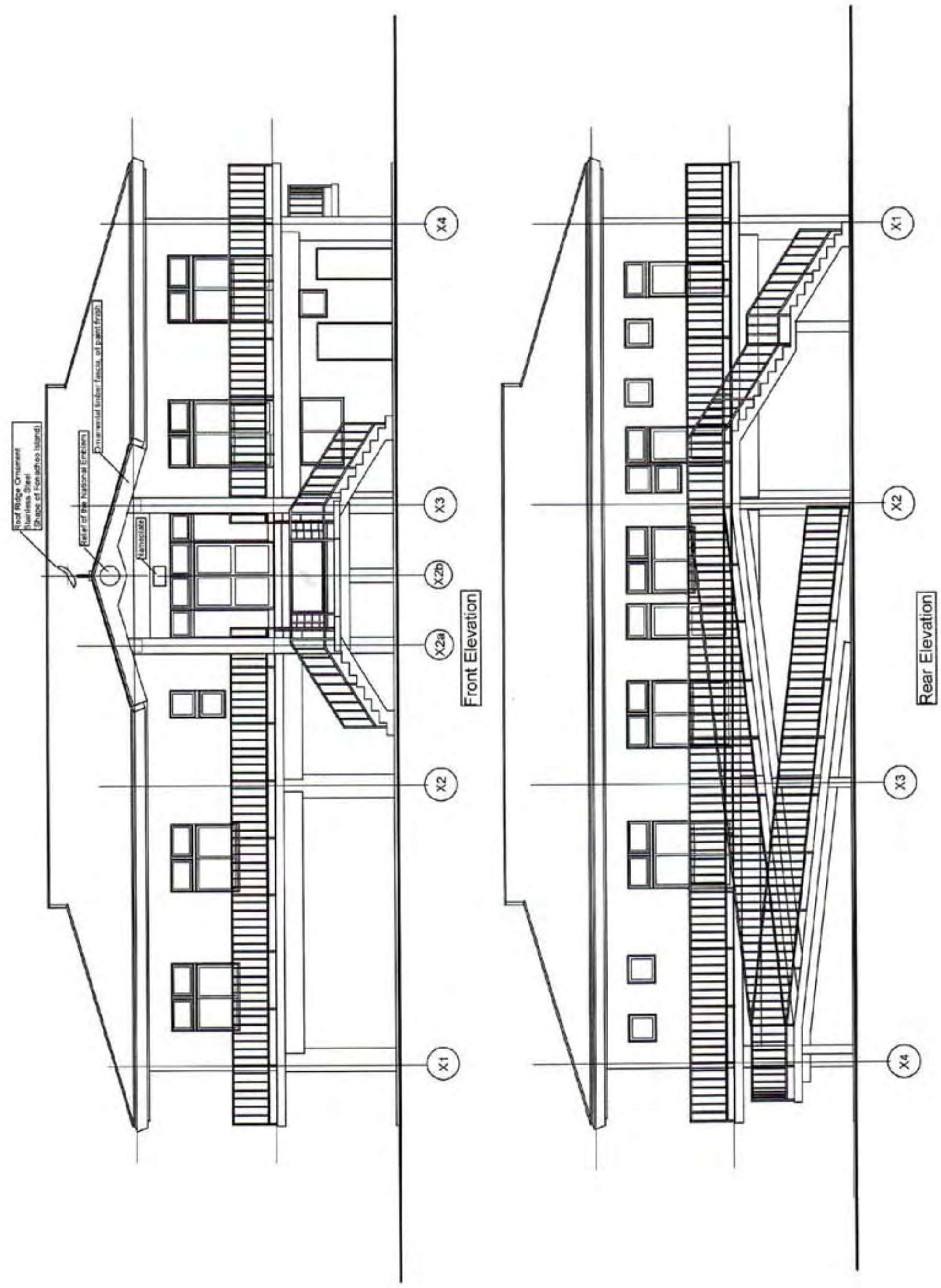


Figure 5.9 Elevation of Island Office

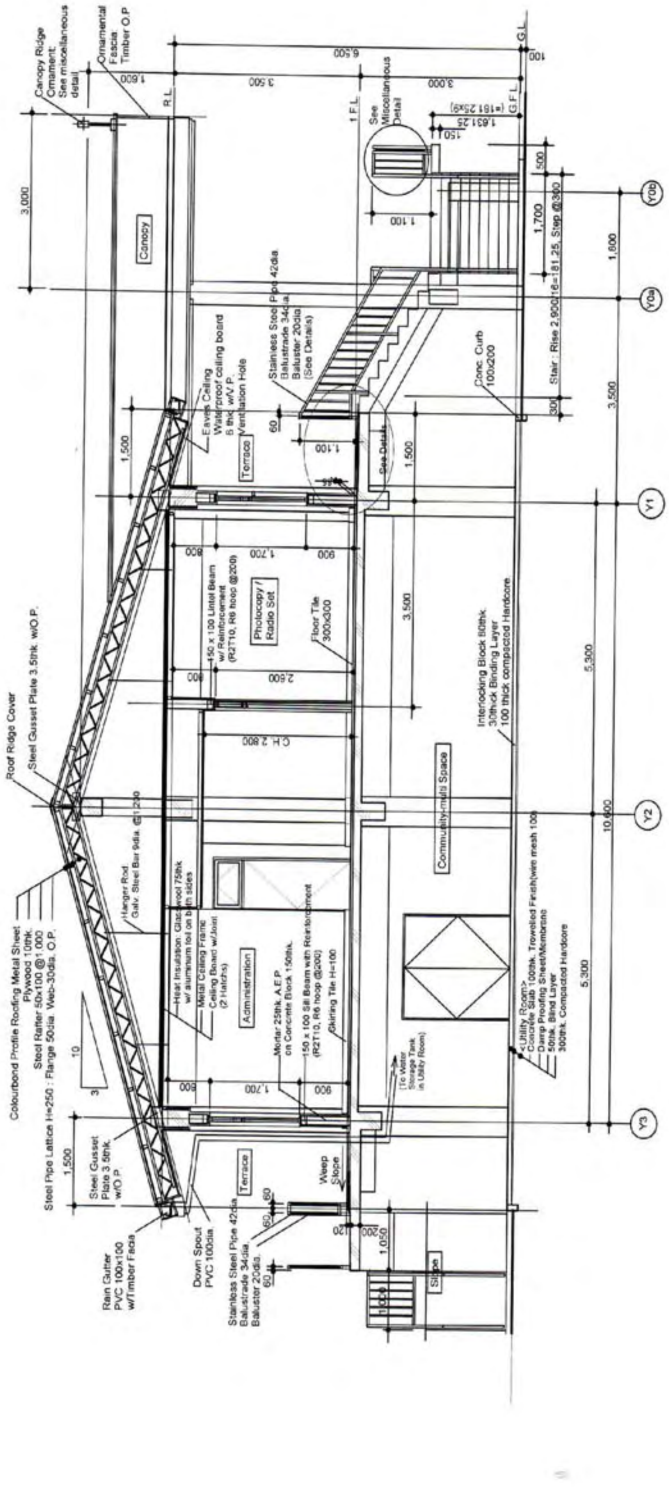


Figure 5.10 Section of Island Office

CHAPTER 6 ISLAND HARBOURS AND CAUSEWAYS

6.1 Introduction

6.1.1 Scope of the Study

The project objective is specified to reconstruction and/or repairing only damaged island harbour facilities including damaged causeways.

The scope of the project components by location this sector is shown in Table 6.1:

Table 6.1 Scope of Works in Island Harbour Sector

	Name of Atoll	Island Harbour		Coastal Protection	Causeway
No	and Islands	Structures	Dredging		JICS Projects
	Laamu Atoll				
1-1	Isdhoo*	@	@		
1-2	Isdhoo-Kalaidhoo*	@	@	@Port	
2	Maabaidhoo	@	@	@Port	
3-1	Thundi			@	
3-2	Mathemaradhoo			@	
3-3	Mukrimagu			@	
4	Fonadhoo*	@	@	@Port	
5	Maavah	@	@	@Port	
	Thaa				
1	Dhiyamigili*	@	@	@	
2	Guraidhoo	@	@	@Port	
3	Thimarfushi	@	@	@	
4	Veymandhoo	@	@	@Port	
5	Kinbidhoo	@	@		
6	Hirilandhoo*	@	@		
	Causeways				
1	Maandhoo--Kadhoo				@No.1
2	Kadhoo--Fonadhoo				@No.2
	Total Projects	11	11	11	2

Notes, 1. JICS: Japan International Cooperation System, The Implementing Agent

2. "@Port" indicates coastal protection works within the harbour premises.

3. Harbours with as asterisk mark are selected of the projects for the mid-term development by JBIC finance, (Middle of July, 2005).

In order to complete the preparation works quickly, provision of technical information is requested to MTCA by the Study Team. For example, if the soil condition is available, it will reduce the cost and risk of design and construction. The final step to be undertaken by the end of July is expected as follows:

- Detailed design and preparation of Tender Documents for the causeways,

- Basic design and preliminary cost estimation for the coastal protection works and island harbours.

6.1.2 Summary of Conclusions

(1) Coastal Protection

Coastal protection will be located along the beach eroded by the tsunami in order to preserve the coconut plantation area, school, health center, housing and access roads. Condition of sandy beach facing to the south east where the tsunami was approaching is generally sensitive. Some area has deposits and others are seriously eroded. It will take time to recover the previous condition. Protection works will be either a coastal seawall type or a group of detached breakwaters. Both will consist of rock mound including coral segment and natural rock as agreed by GOM. In cases where necessary, concrete bags may be also utilized combined with natural rock materials.

(2) Causeway

This work is to strengthen the causeway damaged by Tsunami in two locations. Reconstruction will be carried out along the remaining original structures. Causeway built in 1980's consists of two dikes: namely, a 300 m long one and a 900 m long one. Causeways connect three islands and the total length of these chains including road is approximately 16.4 km. Prior to this construction, the 16.4 km length was divided into four parts by three water passages: namely 200 m, 250 m and 650 m. These openings provided the natural passages through which seawater was able to move in and out of open sea.

It should be recorded that the sea bottom condition at the north section of Causeway No.1 is completely deteriorated. A diving inspection shows the existence of anaerobic conditions. It is assumed that this happened due to the closed water zone by natural sand dike and artificial causeway. This requires causeway to be provided with water passages to maintain aerobic conditions as before the construction of causeway. Thus, it is proposed to provide artificial openings by means of following facilities:

- Providing concrete culvert, two room of 0.9 m x 1.3 m,
- Providing a bridge with 18 m span. Causeway No.2

Main body of the causeway will be the existing bank and armor rocks revetment. Protection works will be upgraded by rock materials in 300kg to 500kg. The structural type of causeway surface will be simple pavement of 15 m wide, consisting of two lanes: 4 m road and 2 m wide cycling pedestrian way on both sides, and shoulder and pedestrian as agreed by GOM. In order to ensure that the dike foundation will rest on the hard layer, dredging of two feet-deep will be required below the datum, LAT.

(3) Island Harbours

Island harbours serves the islanders by provision of cargo terminal, domestic passenger terminal and fish catch landing areas. The Tsunami damaged the port facilities, but in many cases, Tsunami enlarged damages and accelerated cracking and settlement that already happened before. Tsunami current carried fine sand and spread it in the port basins and approaching channels. According to MOAD, the minimum depth requirement is 8 feet (or 2.4 m) below Mean Sea Level; this is equivalent to approximately 2 m below the datum, LAT. Estimated height of this unwelcome deposit is assumed to be 2 to 4 feet (or 0.6 to 1.2 m). This sand will be dredged and spread in front of the eroded beach or coastal areas, and nearby harbour, if the water depth below the datum is less than 2 m.

Coastal protection works of the nearby harbour will be either a coastal seawall type or a group of detached breakwaters similar to the coastal protection. Both will consist of rock mound including coral segment and natural rock. In case of no availability of coral segment、one of the alternatives is utilizing concrete in bags which is widely applied in Maldives.

Dredging works of about 106,000 m^3 for the island harbours is expected to clean up the channel bed to maintain the design water depth, mostly -2.0 m plus one meter allowance below the Datum, LAT. The target of dredging is sand deposit carried by the current of the tsunami. Thus no hard materials are required to be dredged. And no explosive used is scheduled in the works.

6 2 Port and Harbour Development in Transport Sector

6.2.1 Harbour Development Organization

This section deals with the general organization of island harbour development in Maldives. Organization in the ordinary year is modified to meet urgency after the tsunami and the task force was established in NDMC. Project is for the reconstruction or repairing works of the damaged harbour facilities by the tsunami. Harbour facilities also cover the coastal protection and causeways. Among these, island harbours has the highest budget.

6.2.2 Maldives Ports Authority (MPA) and Commercial Harbour

(1) Maldives Ports Authority (MPA)

This Section deals with the commercial harbour development in Maldives in ordinary years. There are two classifications of harbours: namely, the financially independent commercial harbours and island harbours as lifelines. MPA handles the former. MPA was established under a presidential decree on 1st September 1986, with the objective of developing Male' port operations and other ports. MPA is a public enterprise under the general supervision of MTCA. A board of directors was appointed to oversee the affairs of the authority. The main objective of MPA is to efficiently serve the needs of shippers and vessel operation to maintain sea-borne foreign and domestic trade.

MPA intends to establish an integrated network of ports throughout the nation by the year 2020 and make Maldives a Technical Hub in South East Asia Region. Thus, MPA is committed to implementing an integrated program for planning development, financing and operation of ports within the nation to ensure smooth, safe and economical movement of goods and passengers as a means of promoting trade.

This authority currently manages development of ports and handles operation in major ports and harbours covering HuhluMale' terminal, the northern maritime zone by Khulhuffushi port and southern area by Hithadhoo port. The last two ports are expected to start operation by year 2005. Their major characteristics are indicated below:

- Khulhuffushi port
  Quay length: 160 m (-5 m), Vessel size: 2,000 DWT
- Hithadhoo port
  Quay length: 230 m (-8 m), Vessel size: 3,000 DWT
- HuhluMale' Terminal
  Quay length: 45 m (-8 m), Vessel size: 2000 DWT

(2) Commercial Harbours

1) Male Commercial Harbour (MCH)

MCH was inaugurated on 15th September 1986 and is the main port of trade and commerce in Maldives. In the last ten years during 1995 to 2004, cargo throughput in metric tons grew from 275,000 tons to 365,000 tons or 3.2% annual growth. This growth is rather moderate compared to other major ports in Asia. After 2000, growth recovered to 9.4% 1999/ 2004. In 2004 a record high was observed of 365,000 tons; this was 20,000 tons higher than the past high of 348,000 tons in 1998. Container traffic dominates the cargo and indicates higher growth. This means increasing containerization in Maldives. Annual growth is recorded as 16.4% which is almost equal to the world average. Containers handled in 2003 were a record high of 21,729 TEUs. However it has already been exceeded since the amount in 2004 was already 30,666 TEUs. Due to few export industries available at present, there are almost no laden containers in exports. Increasing imports by high demand for consumer goods is accelerating the trade gap. This trade gap lowers the financial viability of MPA and there is no expectation to balance trade in the foreseeable future.

2) Short-term Development Plan of MPA

MPA intends to develop MCH further along with three major ports.

<u>MCH:</u>

- MPA plans to expand its area in order to reclaim half of the south basin and a limited area at the north entrance area.
- Existing godown or transit shed will be totally demolished to provide wider open area to stack

containers to meet demands.

- Two buildings at the northern area will be integrated into one in order to use the area efficiently.
- Mechanical improvement will take place by procuring one transfer crane: RTG
- Berth will extend by 100 m to the south.

These actions are required due to physical conditions such as:

- No chance to expand the port area landwards, no area
- No chance to expand port area seawards, too deep
- Expansion should be carried out during operation.

(3) Three Major Commercial Ports in Maldives

Major ports and harbours covering HuhluMale' terminal and Khulhuffushi port at the north and southern area by Hithadhoo port are being constructed at present. No damage by the tsunami is reported in HuhluMale' terminal, Khulhuffushi port and Hithadhoo port.

1) Master Plan of HuhluMale' Terminal Development

There is a plan to extend the airport with the construction of a second runway. Once HuluMale Island connects physically with Male' islands by bridges and tunnel underneath the runway, HuhluMale' terminal will have no more handicaps in term of its transport aspect. Thus, an 800 m long suspension bridge might allow HuhluMale' terminal to reach full operation capacity without any constraints.

2) Implementation and Financial Sources

MPA will design facilities and will handle tendering including prequalification. MPA will employ consultants when so required for design and construction supervision. MPA requires a loan to execute the port extension Project, due to its financial constraints. Presently two large port projects are financed by the Kuwait Fund.

6.2.3 Island Harbours

(1) Island Harbour Development

199 islands are providing area for human activities providing the stay is not long. Long-term populated islands total 87. There are five to ten islands used for industry. Related ministries are MOAD, MEC, MPND and MPND manages and handles development of island harbours, causeways and coastal protection works in ordinary years.

Since 1998, presidential orders have created Harbour Technical Committee (TC) for selecting the works to recommend to the ministerial committee. TC consists of MFT, MEC, MAD, Fisheries, and others. Meeting of TC is usually held twice a month. Concerning island harbours, MPND is annually implementing the development of five island harbours among 199 islands, two sites for dredging and reclamation, and 4 to 5 existing harbours for repairing.

(2) Basic Development Procedure

Basic procedures of decision making on harbours selection for annual budgeting,

- The government makes a list indicating priority of each work. For this purpose MPND collect recommendations from the MOAD, Ministerial recommendations and others. MPND should condense these into realistic solution with the reasoning outlined.
- Final ministerial evaluation will be carried out in three sessions: harbour section, dredging and reclamation section, and repairing section.
- MPND will prepare summary of the process and discussion till arriving at such recommendations and submit it to the Office of President for the final decision and approval.
- President will prioritize it and make it public.

Harbour project implementation will be carried out as follows:

- After the prioritization by the president, MEC will take care of project,
- MEC will select the consultants to design the facilities,
- MEC will carry out pre-qualification and tender to select the contractor,
- MEC will supervise the works and procurement under the assistance of consultants.

(3) Modeling and Standardization of Island Harbours

Modeling the standardization of harbours is made by the MPND as follows:

Basic structures of harbour consist of approach channel, outer seawall, inner seawall and quay wall. Among these, the quay wall plays major rolls in harbour activities and cargo handling. It should meet the demands of traffic for passengers and cargo. Its capacity is represented by the quay wall length（L） through which passengers and cargoes will be unloaded and loaded. Average cross length of inner basin is 250’ (or 75 m) and water depth is 8’ (or 2.4 m) below the Mean Sea Level, or 2.0 m below the Datum, LAT.

Large Island Harbour:	L = 700’ to 1200’	or	215 m to 360 m
Medium Island Harbour:	L = 500’ to 700’	or	150 m to 215 m
Small Island Harbour:	L = 200’ to 500’	or	60 m to 150 m

(4) Current Development of Island Harbours

MPND currently undertakes three year harbour improvement projects for the 24 islands. The basic idea is to implement 4 to 5 harbours a year for 45 years making harbours in 200 islands. According to MTCA, the access improvement problem is as follows:

- Length of quay wall is based on demand and budget allocated to it.
- The water depth is minimum requirement, such as 8’ lower than the Mean Sea Level.

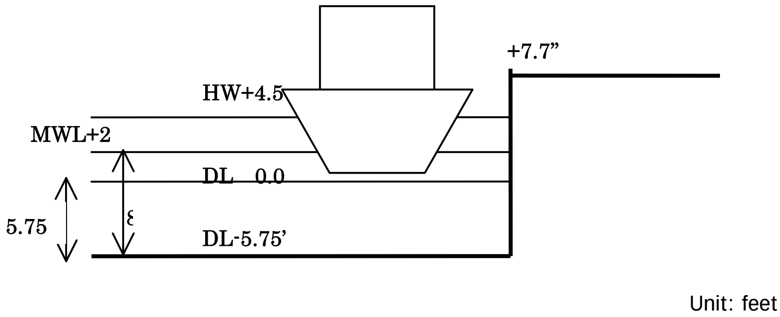


Figure 6.1 Typical Section of Quay Wall of Small Island Harbours

MPND tries to implement the works in all islands. In order to accomplish it equally to the islands, MPND tends to provide harbour facilities in step provision by stage construction since many requests to construct and to repair existing harbour facilities are submitted to MPND. However budget is limited. Average budgeting for small harbour is as follows:

- Quay wall: 4,000 Rf per liner feet or 1,320 US$/m
- To provide minimum requirements
- Basin dredging and reclamation
- Channel dredging and reclamation
- Jetty provision only when it provides economy in construction

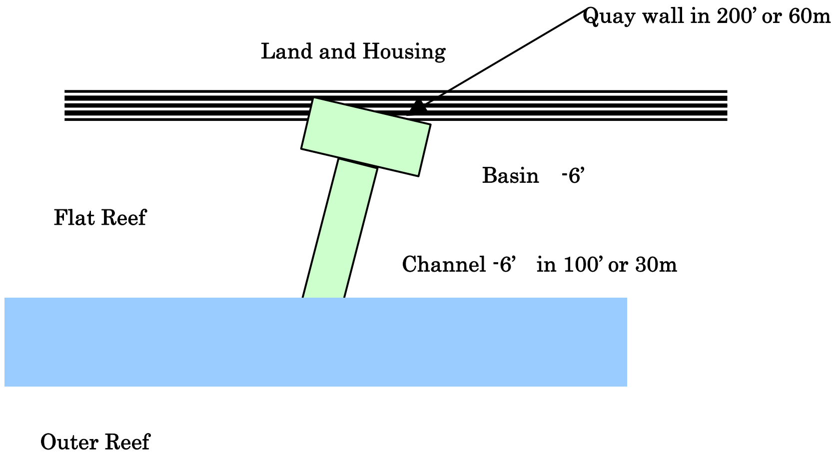


Figure 6.2 Typical Plan of Small Island Harbour

Typical island harbour cost estimation

Quay wall 200' (or 60 m) at 4,000 Rf/m =	240,000 Rf
Basin (45 m x 30 m x 2.5 m =) 3,375 m^3 x 50 Rf/m^3 =	169,000 Rf
Channel (200 m x 30 m x 2 m =) 2,000 m^3 x 50 Rf/m^3 =	100,000 Rf
Total:	509,000 Rf

Unit price is higher than the normal due to the higher mobilization amount of equipment and higher transport cost of materials. If the flat reef is wider than 500 m, it is recommended to make alternative study to see if provision of a jetty could be an economical solution.

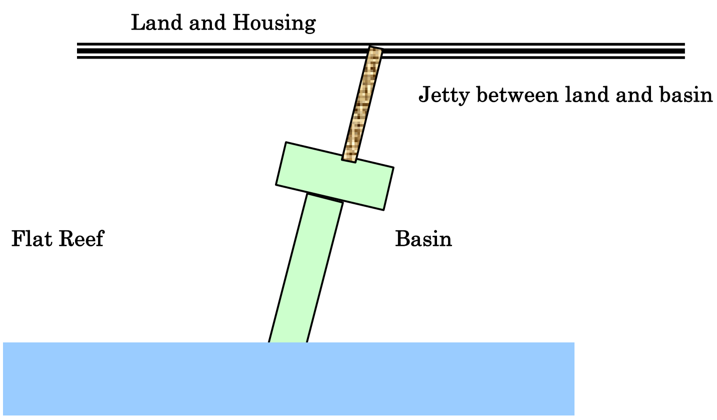


Figure 6.3 Typical Plan of Small Island Harbour of Longer Approach Channel

Figure 6.1.4 shows a cross section of a typical quay wall structure. The same materials and structure is applied to the inner seawall. Its core is filled mostly by locally available porous corals. This core is sometimes protected by outer armor layer consisting of cement bags or similar item.

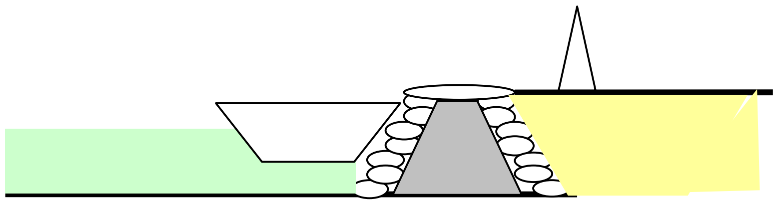


Figure 6.4 Typical Section of Quay Wall

This structure is the typical traditional scheme requiring lower initial cost but higher maintenance cost and having short life.

There are three dredges, two in MTCA and one in private construction company. MTCA's dredges are both cutter-suction dredges of 21" and 18" diameter for the pumping pipes. Private company has a larger one. It is reported that a local construction company (MMCC) has four landing crafts of 40 m LPP maximum. They can transport materials such as natural rock and aggregate for concrete from India. They can also carry construction equipment to a nearby island harbour. The dredging at the remote island harbours is to -1.5 to –2 m, thus excavation could be also done by the on-land excavating equipment. For example, a backhoe excavation is more practical to apply to a wide range of soil conditions and has easy maneuverability with lower cost. Mobilization cost of dredges will be high. Unit price of dredging works per m^3 is 20 Rf. to 50 Rf. depending on the conditions.

General procedures of backhoe are as follows. Backhoe works parallel to the axis of the channel. It excavates for about 8 m width each pass with many passes till the excavation width is sufficient.

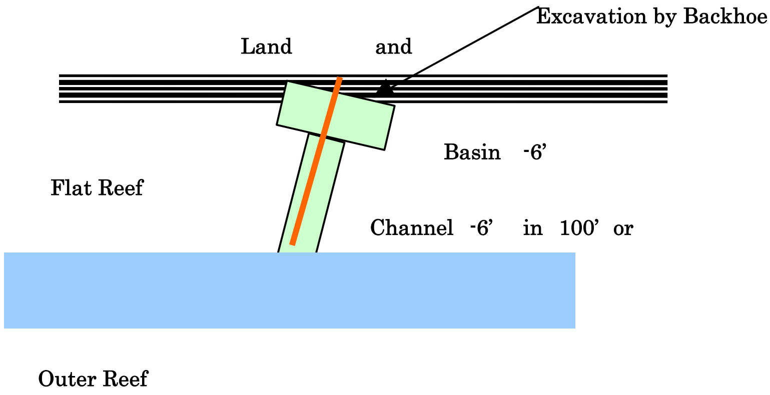


Figure 6.5 Excavation by Backhoe

(5) Design of Up-graded Marine Facilities by MEC

MEC stressed the need to introduce ordinary tough structure designs even it costs much more than easy traditional structures which have low initial cost but require higher maintenance cost. This statement is similar to the Notes provided in NRRP in the transport sector. It is quite agreeable to do this.

6.2.4 MTCA and MAC

(1) Efforts to Recovering from Damages by the tsunami

1) Reconstruction of Affected Facilities by the tsunami

MTCA is responsible to implement the works for harbours, coastal protection and causeway specified in NRRP. MTCA collaborates with MPND on projects in NRRP. MTCA is currently carrying out the field survey, design and preparation of tender documents for tendering.

2) Name and contact of related ministries managing island harbours in the NRRP in Maldives government

- Department coordinating with the Donors: MPND
- Department handling technical aspects: MTCA
- Department handling costing and budgeting aspects: MTCA

(2) MAC

MAC manages and handles reconstruction of island harbours, causeways and coastal protection Works affected by the tsunami based on the outlines shown in NRRP. MAC works under instruction of MTCA. MAC is currently undertaking the works required for reconstruction as follows:

- Following the description in NRRP and as specified by MPND
- Survey of damages and classifying them by the evaluation standards
- Preparation of general layout
- Design of Reconstruction and /or Repair works
- Preparation of simple tender document and BOQ
- Tender
- Construction supervision

This covers only civil structures constructed by the public sector. Private properties including boats and any equipment and tools are outside the scope.

(3) Technical Aspects

MAC contributes in a wide range of services as follows:

- MAC prepares the damages grade judging criteria and classifies the destruction at site for recovery plan and costing.
- MAC prepares a list indicating damages of facilities by island.
- MAC has employed two survey teams (April 2005)and plans to complete the survey of damages and design for reconstruction and/or repair by the end of May 2005.
- MAC has made order for implementation to contractors through tenders. As of 5th April, three contracts by island have been concluded for the site works. It is planned to place orders for works for the next five islands every ten days.
- MAC submits the following items to the Study Team through MPND.
  - Typical tender documents (Design and build basis)
  - Supporting data of estimated price and tender price (in Bill of quantities form)
- Dredging and reclamation
  Estimated unit price of dredging covers reclamation cost.
  - In case hauling distance is less than 100 m. 50 Rf/m^3
  - In case hauling distance is 100 m or more. 60 Rf/m^3
- MAC takes care of the reconstruction works of causeway and coastal protection.
- Budgeting Reconstruction of an island Harbour. MAC indicates the plan and standard section of structures of an island which covers the following: 1) quay wall, 2) breakwater (or outer seawall), 3) seawall (or Inner seawall), 4) basin dredging and reclamation, 5) channel dredging and reclamation, and 6) jetty provision only when it is justified

6.3 Planning Policy and Alternatives

6.3.1 Planning Policies

The planning policies for restoring facilities in the island harbour sector consist of the following:

- Quick implementation of reconstruction of damaged facilities for the affected islanders to survive
- Maximum use of locally available materials, if it is applicable,
- Maximum use of local laborers,
- Maximum use of locally available equipment and plants, if it is applicable, and
- To provide damaged facilities with durable structures against the physical forces of the environment

6.3.2 Planning of Coastal Protection Works

(1) Basic Considerations

The tsunami has damaged many of the coastal areas, which were not only limited to the coasts facing the incoming the tsunami (coast facing south east), but also other directions. Coastal protection works are required for the protection of the existing damages and for the prevention of erosion of valuable land. Island harbour is generally located facing to the inner lagoon. In its direct hinterland, there is an island village with a population of around 1,000 people. In some villages, their houses are crossing over the island and back by the outer reef facing the open ocean. When these type of villages are located on the lower land, damages were serious. For these areas, provision of the coastal protection is one of alternatives, and higher priority were given to them.

(2) Alternatives

Alternative alignments of coastal protection are as follows:

Type 1) Seawall type protection, which is placed on the coastal beach slope. This is directly protecting the coastal erosion and cuts the wave run-up.

Type 2) Detached breakwater type protection which is laid on the flat reef in 20 to 50 m off the beach. This is expensive; however, it will accelerate the sand deposit behind it.

The recommended structure is rock mound type, which is stable and easy to repair when it is damaged. This type of structure has enough transparency and porous condition through which sandy materials might get into the beach zone and stay, a kind of natural nourishment since collection of sand is difficult in Maldives.

6.3.3 Planning of Causeway

(1) Background

In the fifth national development plan, Maandhoo Island is expected the growth center of the second industry in agriculture and the fishery fields. Fish's frozen facilities operate and those production is export for Japan and Thailand. in Maandhoo fishing port which was funded by JICA Grant Aid. Moreover, the coconut and the vegetable, etc. are produced in an agricultural section, and they are shipped to Male by dhoanis. The villagers use the causeway to access the regional hospital in Mathemaradhoo, Gan Island. The causeways are well utilized by vehicles, pedestrians and cyclists. The open of the airport at Kaddhoo, has had advantage of regional air connections for passenger to capital Male' directly, and Laamu Atoll area is expected to be one of center of the tourism developments. Thus, Fonadhoo and Gan islands are chosen as Selected Islands Development Program (SIDP) in the Rregional Development Project. The existing causeways are connecting four islands namely, Fonadhoo, Kadhdhoo, Maandhoo and Gan. These causeways damaged by the tsunami wave are the only trunk road for this region. It is urgent to perform reconstruction of causeways before they are irreversibly damaged.

Note: It is reported that Causeway No.2 was urgently repaired at the end of May 2005 to welcome a visitor from USA. This repair work could continue until the commencement of construction in October 2005.

(2) Basic Considerations

This is to strengthen the tsunami damaged causeway in two locations. Reconstruction will be basically carried out along the existing alignment, except minor sifting of centre line. Causeway, built in 1980's, consists of two dikes, which are approximately 300 m and 900 m in length. Causeways connect three islands and the total length of these chains is 16.4 km as follows:

Gan Island 8 km

(There was an 200m opening between Gan and Maandhoo Island but is now closed by natural sand deposit.)

Maandhoo Island	1 km
Causeway No.1	0.25 km
Kadhoo Island	2.5 km
Causeway No.2	0.65 km (facility length 1.0 km)
Fonadhoo Island	4 km
Total	16.4 km

Project contains two causeways, namely:

Causeway No.1 Between Maandhoo Island and Kadhoo Island: Approx. 300 m

Causeway No.2 Between Kadhoo Island and Fonadhoo Island: Approx.900 m

(3) Alternatives

There are no alternatives in alignment of Causeway No.1 due to its short length. However, there are two alternatives for Causeway No.2 alignment. One is the present alignment and the other is a completely new alignment, 150 m away in the eastern reef flat. Technical reason of this removal scheme is due to the soil condition at eastern area (outer reef flat) where soil is more stabilized than in the western area since the seabed soil at the western area is repeatedly excavated and disturbed. The Study Team and MTCA/MCA held meetings and finally the present alignment with 7 meter shifting to east was selected. This is due to keep a bigger distance from the approaching surface of airplanes.

It is observed that shallow water is only at the west side of Causeway No.2 where excavation was carried out by backhoes and piled up on the eroded areas without any protection. These works are easily implemented since the water depth is shallow. Lower water level by 0.3 m from the east side is encouraging work at the west face. In this situation, the once stabilized seabed at west side is repeatedly disturbed and loosening which is not suitable as foundation of armour rock slope protection. Disadvantage of eastern area is deeper water by 0.8 m than the west: namely, 0.3 m water raising and 0.5 m deeper seabed. Alternatives in the water passage system were evaluated among the parties concern. The conclusion is that combined system between a bridge and concrete box culverts was selected to increase the space of passage, to increase the flow, and to reduce the dead water.

(4) Against High Speed Flow

The 0.3 m water difference is automatically making a high speed flow from the east, outer flat reef, to west side, of 2.5 to 4.0 m/sec. Refer to Water Flow Analysis in Sub-section 6.6.10. This high current is expected at the center of the bridge, where the flow concentration happens. Thus it is recommended to provide temporary dike at the eastern areas to cover the construction site of bridge and concrete box culverts. This dike should be strictly maintained, otherwise, causeway destruction will happen by the high speed current. This dike can be removed only when the passages are completed with the specified revetment on slope and bed. This dike will work not only as a cofferdam, but also as detour access for the islanders, if the crown area is wide enough of least 6 m. Of course, this access should be kept through out the entire construction period.

6.3.4 Planning of Island Harbours

(1) Basic Considerations

Except for very few islands, there is no access except by boat. Tramp cargo boats visit the islands only when so required. Almost no regular ferry services is provided. In these circumstances, island harbours provide not only ferry terminal services, but also a center for industrial activities. Objective of the project is not only repair works for damaged harbour facilities, but also upgrading it to meet long-term requirements. Project can be divided into two categories: namely, the Urgently Rehabilitation and Mid-term Upgrading Work. The former is the immediate work to be implemented to serve the daily life of islanders. The later is rather long-term works taking regional development into account.

(2) Damage Evaluation Criteria

Damage Evaluation Criteria was established in consultation with MTCA and MOAD. The criteria, specify four grades of damage conditions: namely, damage nil, 25%, 50% and 100%. For each grade, typical repairing work is proposed. It is recommended to repair by upgrading the structure and also fully reconstructing improved structures. As a result, concrete block structures is recommended both in the partial reconstruction at the traditional sloped quay wall and in the reconstruction of entire length of quay wall by vertical front surface. Vertical surface will provide the quay with more safety for boats berthing and cargo handling.

(3) Alternatives

Reconstruction works in the island harbours will actually concentrate on the quay wall structures. To reach the recommendation, six structural alternatives of quay wall were designed and evaluated as follows.,

- Traditional Coral Mound Type
- Traditional Coral Mound Type plus mortar grouting
- L-shaped Concrete Block Type
- Cellular Concrete Block Type
- Concrete Block Type
- Steel Sheet Pile Type

Among these alternatives, Concrete Block Type and Steel Sheet Pile Type were recommended.

(4) Seawall and Breakwater

Existing seawall was also damaged by tsunami. It is also recommended to upgrade the structural type from the traditional coral rock mound type to gravity wall strengthened by reinforced concrete. Existing breakwater is mostly consisting of coral rock mound similar to the traditional seawall. It is recommended to repair the breakwater only when it works well for the harbours.

6.4 Design of Marine Facilities and Structures

6.4.1 Design Policies

(1) Introduction

The fundamental consideration in the design study is to provide economically durable structures ensuring long life. Structural type should meet the locality and natural conditions including waves, soils and current after opening the causeway. Design of structures was conducted based on the specified planning policies. One of important goals is quick implementation, but with durable and economical structures.

In many cases of civil work design, construction study is carried out after the design is completed. Thus, there is little chance that construction method will influence the design policy. However, the design of marine facilities should be conducted in another way so that construction method study always leads the design. Thus, construction method to be employed should be carefully evaluated. In many cases in marine design, the structural style has to be examined by the possible construction method. For example, construction of a bridge at the causeway with strong cross current is one of the problems to be solved.

(2) Design Objectives

Design objectives include structures for coastal protection, causeway and port facilities in island harbours. Detailed discussion on the causeway was carried out in order to complete the detailed design. For the reconstruction of coastal protection and island harbour facilities, preliminary design was provided with necessary discussion, alternative analysis and evaluation. Detailed design of these facilities was carried out, after the financial arrangement was completed.

(3) Selection Policies of Design Criteria

It is one of design polices of the Study Team to provide various alternatives for the real client (GOM) for the best selection. It is also one of design policies to provide all background logic including calculation sheets, so the GOM experts can trace the design method employed by the Study Team. It is one expectation of the Study Team that the data and information presented in this report will contribute to other projects. For the causeway planning and design, various discussions between the Team and MTCA/MOAD including MEC have been conducted covering:

- Standard section and pavement
- Bridge and concrete box culvert passages
- Strengthening the opening area and passage against the heavy current and flows

For the island harbour structures, alternative study was conducted to select the best one. Evaluation of transitional structures in Maldives and improved structures was conducted. Final selection was carried out after the discussion among the MTCA/MEC officers and the Study Team.

6.4.2 Identification of Reconstruction and Repair Works

(1) Considerations

Projects are classified into two groups: namely, the Immediate Repair Works and the Medium Term Development Works. Implementation of the former will be undertaken under the NPGA, and the latter will be financed by JBIC soft loan, although these scopes and are not fixed yet. In the marine sector, reconstruction of causeway was selected for the former, and coastal protection and structures of the damaged island harbour were classified to the latter.

(2) Basic Method of Identification

Basic terms for identification of Immediate Repair Works are urgently required. MPND and other ministries concerns are participating in classification coordination. There is no doubt that the causeway is top priority in the marine sector in terms of urgency. Amount of budget availability is also a decisive factor for selection.

6.4.3 Common Design Criteria and Design Conditions for Marine Works

(1) Application

It is reported that BS or equivalent is usually applied to design of harbour facilities in Maldives. In this study, BS or Japanese Design Standards are basically applied. If they are not applicable to Maldives, other equivalent will be applied. Applicable Standards for this project are as follows:

- Technical Standards for Port Facility Design in Japan
- Japanese Technical Standards for Coastal Protection Works
- Japanese Industrial Standards (JIS)
- Standard Specification of Concrete Works in Japan
- Fisheries Port Planning Manual in Japan
- Fisheries Port Facilities Design Standards in Japan
- Shore Protection Manual (US Army Corps of Engineers)

(2) Natural Conditions

Design natural conditions are selected as follows:

1) Design Tidal Level

Design tidal level is proposed as indicated in the following table. Residual water level behind the quay wall is also specified.

Table 6.2 Proposed Design Tide Level

High Water Level (HWL)	DL+1.34 m
Mean Sea Level (MSL)	DL+0.64 m
Lowest Astronomical Tide (LAT)	DL±0.00 m
Residual Water Level (RWL)	
Gravity Type Structure	DL+045 m (=(HWL-LAT)/3)
Sheet Pile Type Structure	DL+090 m (=2*(HWL-LAT)/3)

2) Design Waves

Design wave for the project is proposed as indicated in the following table. Wave after breaking is also specified. Significant wave height within the inner reef flat is also specified. Outer reef flat wave is similar to the inner reef flat.

Table 6.3 Proposed Design Waves

Equivalent Deepwater Wave Height Ho'=2.3 m

Period To=5.0 sec

Wave length Lo=1.56T^2=1.56x5.0^2=39.0 m

Significant Wave Height $H_{1/3}$

Water depth h=1.8 m (Seabed Level DL-0.46 m)

Ho'/Lo=2.3/39=0.05 , h/Ho'=1.8/2.3=0.78 → Shoaling coefficient Ks=0.5 (Ks is obtained from Figure of Calculation Diagram of Significant Wave Height in Wave Braking Zone)

H1/3=Ks･Ho'=0.5x2.3=1.15 m

3) Reef Flat Waves

Waves break at the reef edge where is the physical border between the reef flat and deep reef. The former is about zero to plus 0.5 m above the datum, LAT. The latter indicates sharp slope down to minus 30 m and below. Waves remaining on the reef flat are limited in height by reef friction and depth. The equivalent offshore waves H_0' will be reduced to a certain degree.

Table 6.4 Proposed Reef Flat Waves

Water Depth h (m)	Ho'/Lo	h/Ho'	Ks	$H_{1/3}$ (m)
0.50	0.05	0.22	0.20	0.46
0.80	0.05	0.35	0.30	0.69
1.00	0.05	0.43	0.34	0.78
1.50	0.05	0.65	0.45	1.04
1.80	0.05	0.78	0.50	1.15
2.00	0.05	0.87	0.55	1.27
2.30	0.05	1.00	0.62	1.43
2.50	0.05	1.09	0.68	1.56

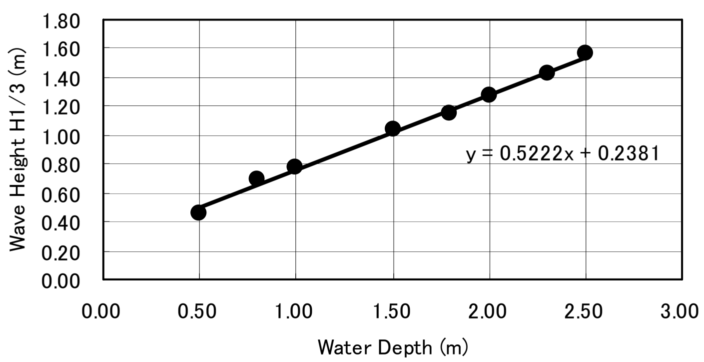


Fig. 6.6 Proposed Significant Wave Height

It is assumed that the maximum wave height on the reef flat as follows:

Hrf=0.52xhrf+0.24 m
Where: Hrf: Reef Flat Wave Height (m)
hrf: Reef Water Depth (m)

4) Water Set-up by Wave Breaking

Wave breaking falls its height: however, its remaining energy rises the water level changing the kinetic energy to static energy. Wave set-up depends upon the general environment including the seabed configuration, topographic conditions and the length of closed line. Closed line includes not only the island, but also artificial obstacles like causeway.

Table 6.5 Proposed Water Set-up by Wave Breaking

Water depth h=1.8 m (Seabed Level DL-0.46 m)	
Ho'/Lo=2.3/39=0.05 , h/Ho'=1.8/2.3=0.78	
→ Change in Mean Water Level η/Ho'=0.04	
hsu= η・Ho'=4%xHo'=0.04x2.3=0.09 m	
Mean Sea Level (MSL)	DL+0.73 m

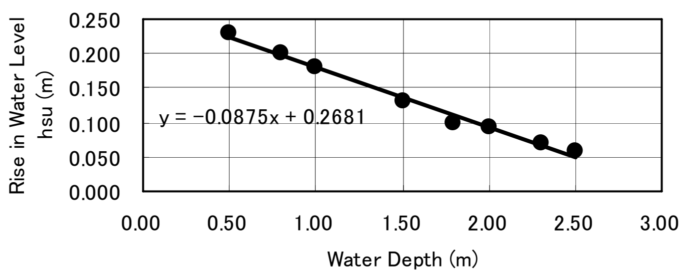


Fig.6.7 Proposed Rise in Water Level

It is assumed that the wave set-up height on the reef flat is as follows:
hsu=0.27—0.09 hrf
Where: hsu: Rise Height in Water Level (m)
hrf: Reef Water Depth (m)

(3) Existing Ground Level and Water Depth

- No topographic survey data is available at the coastal protection areas and island harbours. Topographic data at Fonadhoo Causeway is available but very preliminary. The Study Team carried out quick survey at section and water depth.

- Datum for the survey is tentatively based on the tide data of A. Gan, which changes minute by minute. The Study Team got hourly water level changes applying the tide data provided by the Meteorological Observation Center.

(4) Subsoil Conditions

The subsoil conditions applying to the entire site are assumed considering the existing soil conditions and available data. Average soil condition assumed by the Study Team is as follows:

Table 6.6 Soil Layers under Seabed

	Layers	Unit weight (tf/m^3)	Bearing capacity	Average Size	N-value	Internal friction
1	Covering Sand	1.8 tf/m^3	16 tf/m^2	0.4～0.6mm	5	28 °
2	Individual coral fragment	2.0 tf/m^3	—	40～100mm	—	—
3	Weathered coral base	1.8 tf/m^3	30 tf/m^2	—	10	30 °
4	Hard coral base	1.8 tf/m^3	45 tf/m^2	—	30	40 °

General earth covering sandy materials to be filled behind quay wall, and causeway is assumed to have the following characteristics. Debris after tsunami can be applied to limited use as specified.

Table 6.7 Reclaimed Soil Layers

	Layers	Unit weight (tf/m^3)	Bearing capacity	Average size	N-value	Internal friction
1	General earth	1.8 tf/m^3	16 tf/m^2	0.4～0.6mm	5	28 °
2	Debris after Tsunami	1.4 tf/m^3	—	—	5	28 °
3	Core of Causeway	1.8 tf/m^3	30 tf/m^2	—	15	35 °

6.4.4 Materials; Concrete and Steel

(1) Characteristics of Concrete

Concrete is a major material in marine construction which is durable to chemical action especially against corrosion. It is used as a protection material to steel materials. In the design, enough covering should be provided to reinforcing bars. Concrete is categorized in two fields: namely, ordinary concrete for casting in air and concrete placing underwater. Basic characteristics of ordinary concrete is proposed as indicated in the following table.

Table 6.8 Proportion and Standard Design of Ordinary Concrete

Descriptions	Kind of structural member	Mixing conditions			Standard design strength (kgf/cm^2)
		Max. water-cement ratio (%)	Slump (cm)	Max. size of coarse arrangement (mm)	
Plain Concrete	Filling concrete	—	15	40	135
	Crown concrete	70	8, 12	40	160
	Concrete block	65	8, 12	40	180
	Foot protection block	70	8, 12	40	160
	Coping concrete	65	8, 12	40	180
Reinforced Concrete	Parapet	65	8, 12, 15	25, 40	240
	Coping concrete	65	8, 12, 15	25, 40	240
	Pre-cast concrete	55	8, 12, 15	25, 40	240
Interlocking concrete block pavement and pedestrian way		—	2.5	25, 40	Bending 45

Underwater concrete should be specified as required by site conditions and construction methods.

(2) Classification of Ordinary Concrete

Basic classification of ordinary concrete is proposed as shown in the following table.

Table 6.9 Ordinary Concrete Classification

	Classification	Young's Modulus	Standard design strength	Allowable bending compressive stress	Allowable shearing stress	Application
1	Reinforced concrete	2.1 x 10^5	240	80	9	General use
2	Plain concrete (1)	2.1 x 10^5	180	-------	---------	Concrete block
3	Plain concrete (2)	2.1 x 10^5	160	-------	---------	Crown concrete
4	Leveling concrete					

(3) Steel Materials

The project requires various steel products, from reinforced bars to sheet piles and tie-rods. Most common steel is reinforcing bars in concrete structures. In order to provide a stiff and tough foundation of the ridge, enclosed steel sheet pile cellular boxes will be installed at both abutment end.

Table 6.10 Steel Material Classification

(kgf/cm^2)

	Type of Steel	Application	Allowable stress (kgf/cm^2)	Young's modulus	Shearing stress (kgf/cm^2)
1	Structural Steel	SS41	1,400	2.1 x 10^6	800
2	Steel Pile	STK41	1,400	2.1 x 10^6	800
3	Steel Sheet Pile	SY30	1,800	2.1 x 10^6	1,000
4	Tie rods	High tension steel	1,800	2.1 x 10^6	—

Notes:

1. Poisson's ratio; 0.30
2. Coefficient of thermal expansion; 12 x 10^-6
3. Reinforce steel bars shall be as same application to the structural steel.
4. Material in above list indicates Japanese Industrial Standards. Equivalent one can be applied.

6.4.5 Unit Weight and Angle of Internal Friction

(1) Unit Weight of General Materials

The following table shows unit weight of general materials to be applied in structural design.

Table 6.11 Unit Weight of Materials

	Type of Materials	Unit Weight (Kgf/cm^3)
1	Steel	7.85
2	Reinforced Concrete	2.45
3	Plain Concrete	2.3
4	Hard Boulder and Rocks	2.6
5	Coral debris in wet condition	1.4
6	Coral debris effective weight under water	0.8
7	Sand, gravel, rubble in wet condition	1.8
8	Sand, gravel, rubble, effective weight underwater	1.0

(2) Characteristics of Armour and Backfilling Materials

Materials for armour are mostly natural rocks durable to weathering and chemical affection by seawater. These are expected to play roles in protecting the fine backfilled materials from the current and waves. Materials for the backfilling, for example in causeway core, should be available at the site.

Table 6.12 Characteristics of Armour and Backfilling Materials

	Materials	Angle of Internal Friction	Unit weight in air	Unit weight under water	Gradient of Slope
		degrees	kgf/cm^3	Kgf/cm^3	
1	Rubble stones	40	1.8	1.0	1 : 1.2
2	Cobble gravels	35	1.8	1.0	1:2 – 1:3
3	Unscreened gravels	30	1.8	1.0	1:2 – 1:3
4	Coral debris	30	1.4	0.8	1:2 – 1:3
5	Sand	30	1.8	1.0	1:2 – 1:3

6.4.6 Safety Factor in Stability Analysis

Port structures shall be designed with enough strength and stability under the design conditions. Safety factor means grade of resistance of designed structures against the most influenced external affection, for example possible largest wave force. This factor always should exceed covering the uncertainty in the design method and assumed site natural conditions. If large uncertainty is assumed, the safety factor should be a large number.

Table 6.13 Safety Factor in Stabilization Analysis

Calculation Item	Safety Factor
Sliding of Structure	1.2
Overturning of Structure	1.2
Bearing Capacity of Foundation	2.5
Embedded Length of Sheet Piles	1.5

6.4.7 Coefficient of Fiction in Stability Analysis

Resisting force against sliding will be estimated applying the coefficient of friction. Preventing sliding of structures is one of most critical items for stability analysis of quay wall.

Table 6.14 Coefficient of Friction in Stability Analysis

	Materials	Coefficient
1	Concrete against concrete	0.5
2	Concrete against bed rock	0.5
3	Concrete against rubble	0.6
4	Rubble against rubble	0.8
5	Cellular block against rubble	0.7

6.4.8 Utilizing Conditions at Island Harbours

(1) General Descriptions

Users for the island harbours are mainly islanders and visitors. Fisheries industry also has important customers. For example, in case of emergency, all patients need to be carried by boat (dhonis) to the local hospital or medical centers because these centers are so limited in the atoll. Others users of island harbours are cargo dhonis transporting almost everything. Cargo transport for daily consumable items also requires fundamental roles to be played by remote harbours.

(2) Effective Harbour Use

According to the site observation on the harbour utilization, no regular shipping service is provided due to low demand to maintain such service. Thus random use is required to allow free berthing at any time. It is recommended to classify the quay wall for several usages for example:

- Preparation quay wall where dhonis stay only short periods before leaving.
- Unloading quay where dhonis handle in-bound cargo and passengers. The best locations should be allocated for this purpose.
- Stand-by quays where dhonis are berthing up to the time of loading.
- Anchor area where dhonis can stay for a long period. This basin should be clearly marked so as not to disturb the other calling dhonis.

(3) Design Ships and Dhoanis

Site investigation results shows the basic composition of vessels calling at island harbours. Observed maximum size of vessel was a landing craft in 40 m long in Fonadhoo of Laamu Atoll. Most probable type of fishing boat is 10 gross ton class of 15 m long. The maximum draft is about 2.2 m. For design purpose, design vessel characteristics are assumed as indicated in the following table.

Table 6.15 Design Ships, Boats and Dhonis

No	Vessel type and Categories	Gross Tonnage	Dead Weight Tonnage	Overall Length	Molded Breath	Maximum Depth
1	Fishing Boat: Large	30	—	27 m	4.7 m	2.5 m
2	Fishing Boat: Average	20	—	17 m	4.3 m	2.0 m
3	Commuter Boat	10		12～15m		2.0m
4	Ferry Boat	10		12～15m		2.0m
5	Cargo Boat: Large	100		30m		3.7m
6	Cargo Boat: Average	50		25m		2.9m
7	Others	200		40m		4.6m

Note: Other vessel characteristics than fishing boat are based on the smaller and similar fishing boat data in Japan

(4) Design Dimension and Load Conditions of Quay Wall

1) Crown Height of Quay Wall

Design crown height of quay will basically be the present level when partial reconstruction is provided. Crown height setting can be more flexible when entire quay wall is to be reconstructed. Crown height should generally be as low as possible to provide easy access for passengers and other harbour users. In case a new quay wall is to be built and no quay wall exists, the following formula will be applied to.

Ch = H.W. L + 1.5’ to 2’.5 (45 to 75 cm)

Where; Ch: Crown Height of Quay Wall
HWL: High water level

2) Design Water Depth

Design water depth in front of the existing quay and channel will basically be the original design level or deeper. Siltation parts with deposition of fine articles by the Tsunami will be basically dredged, recovering the original depth or lower. In case a new quay wall and/or channel is to be built, the following formula will be applied to estimate the design water depth.

Hd = L.W. L – 8’ to 10’ (2.4 to 3.0 m)
= LAT – (8’ to 10’)
= 12.4 to – 3.0 m
Where: Hd: Design Water Depth below the datum
LWL: Low water level
LAT: lowest Astronomical Tide

Note: Ministry of Atoll Development recommended to provide 8’ depth below the mean sea Level (MSL). Level difference between LAT and MSL is 0.64m.

This depth should be verified for the maximum types of boats calling in the past. In this project, no hard coral rock dredging is expected, since the dredging works aim to recover the original depth in this project.

3) Load Conditions

Design load strength at the harbour apron of existing quay will basically be the original design level or higher. In case that new quay wall is to be built, partially or entirely, the following loading criteria will be applied to the design of the structures. If no design data is available, the following loading conditions should be applied considering the utilization level.

Class A.	1.5 ton/m^2
Class B.	1.0 ton/m^2
Class C.	0.5 ton/m^2

It is assumed that no point load larger than three tons will be allowed.

6.4.9 Design of Coastal Protection Works

(1) Basic Considerations

1) Objective for Coastal Protection

The coastal current induced mainly by waves breaking is a major cause to carry sand and fine materials to the downstream. The change in current pattern may trigger coastal changes. Coastal area is getting a stabilized line and steady shape after passing of an extremely long period. Coastal area is supplying sand and fine materials to the nearby coast, and is supplied the same from the upstream side. Coastal area will stabilize only when this supply balance is maintained. In the long term, natural material supply are well balanced in plus and minus. In short-term coastal phenomenon, daily beach erosion and weekly sand deposit happen; however, it is well balanced totally.

The coastal change might happen when the natural environment is forced to change by artificial actions including construction of structures. For example, construction of the existing causeway and Maandhoo Fishing Port give a large impact to the marine environment although they are generating large benefits in terms of safety for commuting and local industries. Dredging to collect backfilling materials for reclamation and construction of the Kadhoo Airport are also providing a large influence to the marine environment. Construction of the airport can be justified in terms of maintaining basic transportation between the capital and Laamu Atoll, even though it produces an environmental impact.

The sea level raise is one of results of human activities and so-called the greenhouse effect by development of wealthy nations in the world. It is reported that such raise will be 50 cm within this century. Seawater level rising has just started on our planet. This will cause deeper water at the flat reef and allowing the propagation of large ocean waves and generation of high water in the outer reef flat. This might influence and change the direction or velocity of the coastal current resulting in new erosion and deposits on the coast. It is also believed that the coastal changes have happened before the Tsunami, although Tsunami might have accelerated such coastal changes. Thus, the planning objective for coastal protection is to take action to at least maintain the present situation and to return to the past environment as much as possible.

2) Normal Wind Wave or Long Wave (Tsunami)

There are two basic wave types: namely, ordinary wind waves including swells and accidental long wave like a tsunami. Tsunami wave has larger energy than an ordinary wave for the same wave height. It has 1,000 times more energy than the latter for the same wave height. It is understood that a long wave has a wave length greater than 10,000 m.

(2) Plan Arrangement

1) Objective of Projects

If the coastal protection works should be against the long waves, it will require a large investment. It is, thus, prudent to select the wind wave for the design. The protection objects should be clearly identified. In this project, the protection objects are for the housing area, island community and its facilities. Since, these objects might suffer by wave run-up and invasion of seawater when it is high tide, coastal protection should be sufficient to protect the objects from wave run-up. Or coastal protection should be arranged to introduce sand deposits which will indirectly lighten the wave run-up to the housing areas.

2) Alignment Plan

Alignment of protection works should be designed based on the planning requirements as follows:

- Natural conditions including the topographic and bathymetric conditions at the project site
- Behavior of coastal changes in the past and the future
- Objectives of the project

Accordingly, in this project, indirect protection of coastal area should be provided as sand deposit at the beach to lighten the wave run-up. Alternative alignment of coastal protection is as follows:

Type 1) Seawall type protection which is placed on the coastal beach slope. This directly protects the erosion of coast and cuts the wave run-up.

Type 2) Detached breakwater type protection which is laid on the flat reef 20 to 50 m off the beach. This is expensive; however, it is to accelerate the sand deposit behind the protection works.

3) Selection of the Protection Works

Recommended structure is the rock mound type which is stable and easy to repair when it is damaged. This type of structure has enough transparency and porous condition through which sandy materials might get into the beach zone to stay, resulting in natural nourishment, since collection of sand is difficult in Maldives.

(3) Design of Facilities

Design criteria of coastal protection works are prepared as follows:

1) Wave Overtopping Volume

Permissible Value of the Rate of Wave Overtopping: q is forecast by applying the following volume:

$$q=0.05\ m^3/s/m$$

The overtopping case, where slower protection works are assumed, and the above-mentioned value, is decided from the following tables.

Table 6.16 Permissible Value of the Rate of Wave Overtopping

Condition of Coastal Protection	Rate ($m^3/s/m$)
Lower protection (Separating for the Sensitive areas)	0.05
Medium protection	0.02
High protection (Closing to the sensitive areas)	<0.005

2) Wave and Tide for Design of Coastal Protection

The following wave and tide conditions are applied to the design.

Table 6.17 Wave and Tidal Conditions for Design

High Water Level (HWL)	DL.+1.34 m
Design Reef Level	DL+ 0.50 m～-0.50m
Reef Wave Height	Hrf= 0.78m～1.25 m
Reef Wave Period	T = 5.0 sec

3) Estimation of Required Crown Height of Protection Works

Estimation was carried out for the crown height by the wave intensity on the flat reef. Calculation results indicate moderate height as follows:

Required Crown Height DL+1.92～+2.25 m

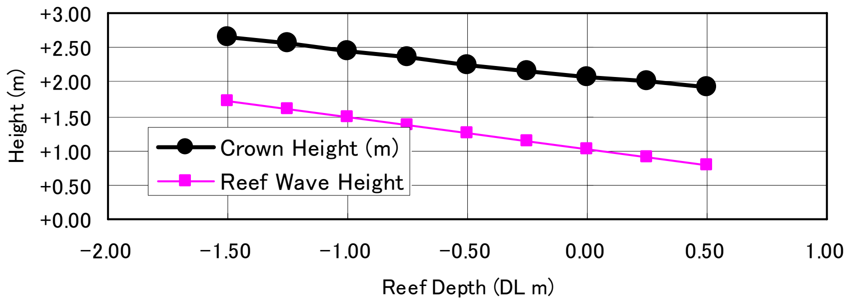


Figure 6.8 Relation between Depth and Crown Height of Sea Protection

4) Size of Amour Rocks

Required size of armour rock is estimated as follows:

Minimum Weight of armour rock: W>51 kgf～250 kgf

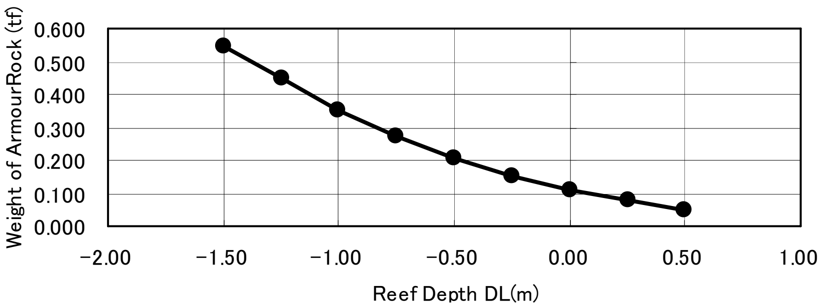


Figure 6.9 Relation between Reef Depth and Armour Rock

(4) Environmental Aspects

It is estimated that the provision of the coastal protection works can improve the present situation by natural nourishment and less seawater influence to the on-shore areas and housing zone. Detached breakwater protection should be properly provided for the damaged coast to reduce the wave height and generate sand deposit. However it may disturb the view from the coast.

6.4.10 Design of Causeway

(1) Plan Arrangement

Before these constructions, the 16.4km was divided into four parts; thus, there are three water passages: namely, 0.2 km, 250 m and 650 m. These openings provide the natural passages through which seawater is able to move in and out of the open sea. The aerial photograph indicates the following:

- Current offshore comes normally from the East to West.
- Offshore current associated with waves jumps on the flat reef and crosses over to opposite side of the inner reef edge.
- This action raises the water level.
- Flat reef current direction is normal to the reef edge, then tracing a line and curve to the inner lagoon following the coastal configuration.
- When it hits the island coastal line, it turns to the bottom area seeking the passages.
- If passage is there, it goes through the passage and to the inner lagoon. Then it goes off to the offshore area through the passages.
- If no passage is found, it returns offshore by so-called lip current.

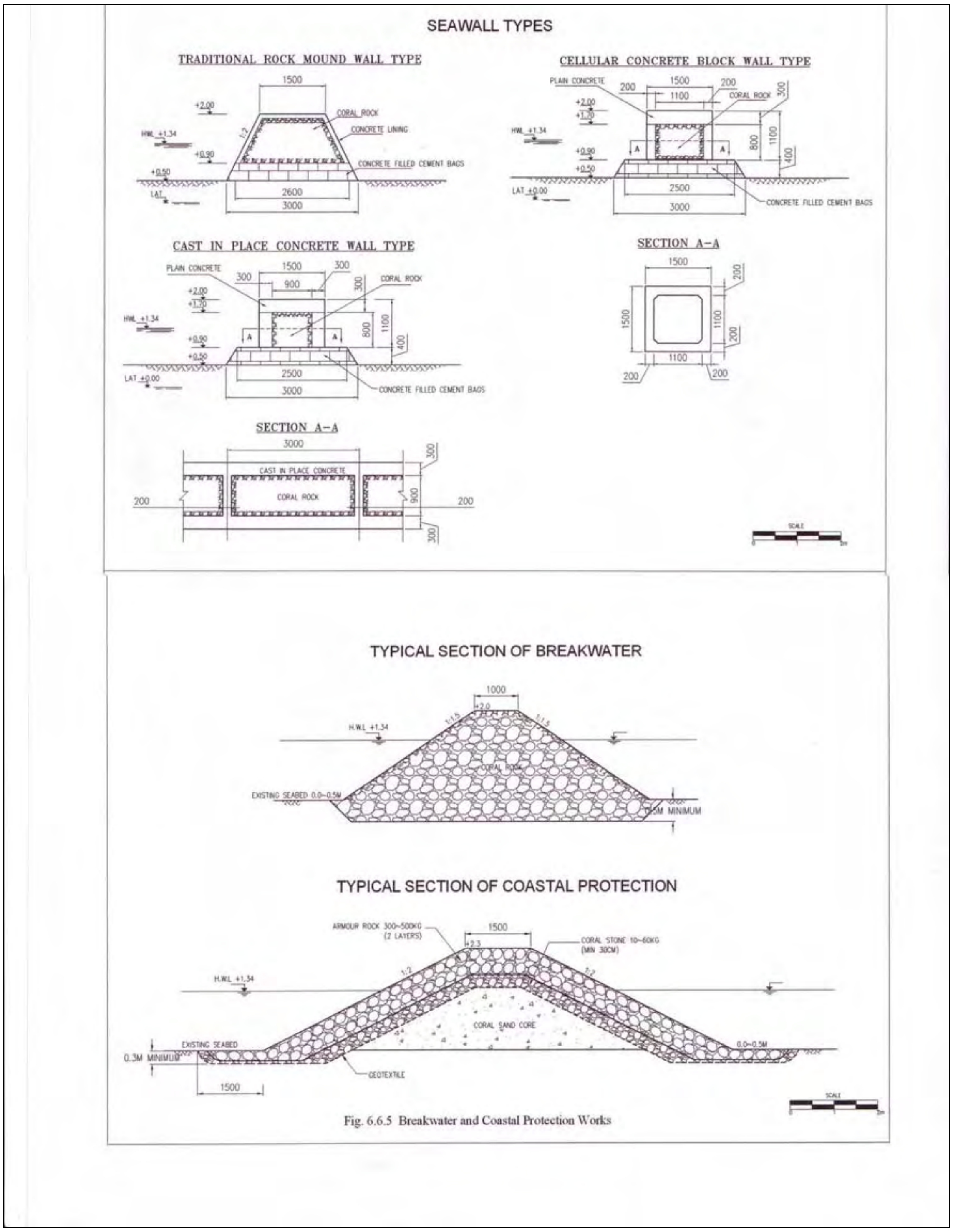


Figure 6.10 Breakwater and Coastal Protection Works

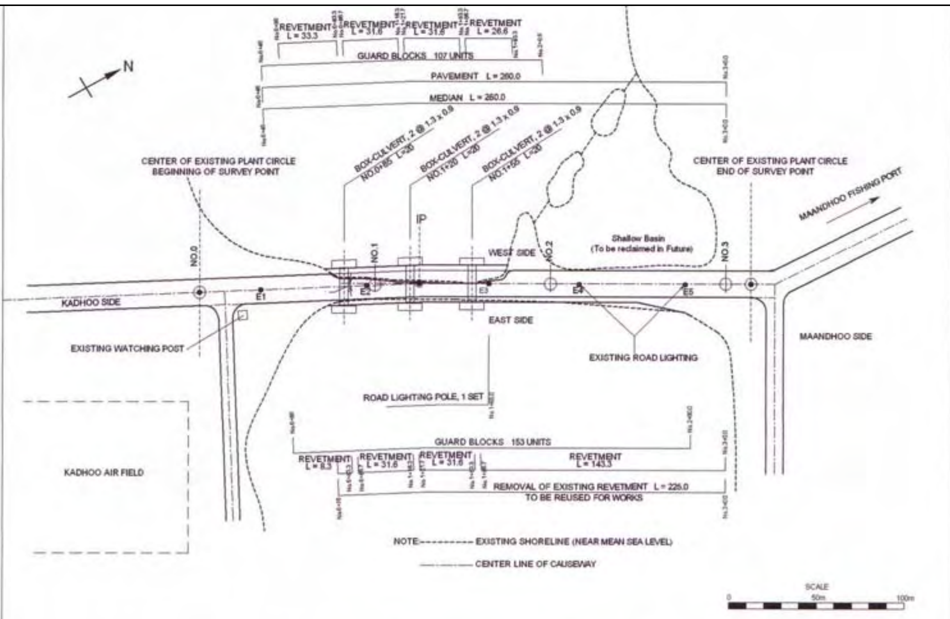


Fig. 6.6.7 General Plan of Causeway No.1 (Kadhoo-Maandhoo)

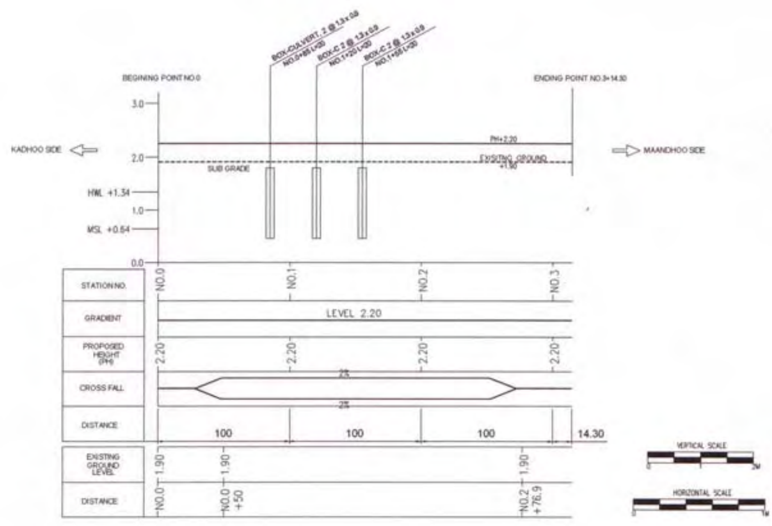


Fig. 6.6.8 Profile of Causeway No.1

Figure 6.11 General Plan of the Causeway No.1

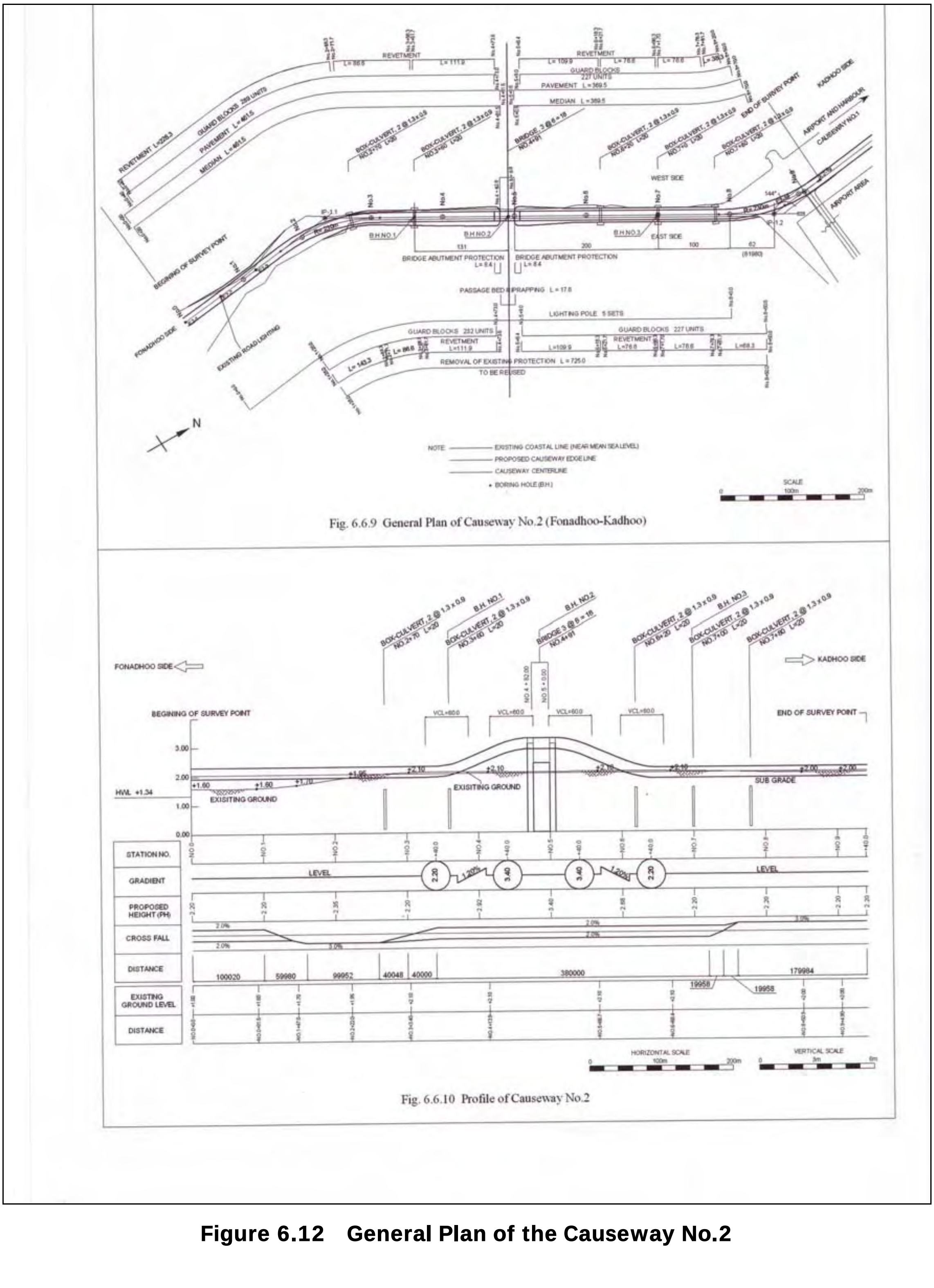


Figure 6.12 General Plan of the Causeway No.2

In case of construction of artificial causeways like in Fonadhoo, there is no choice other than the returning lip current since there is actually no water passage. As a result, the water level offshore of the coast remains high and introduces a higher wave to the coast. High wave is easily run-up the coastal zone and generates coastal current which is dangerous to erosion. Cut natural water passages by causeway are deteriorating the rate of seawater exchange and generating a dead water zone where the water quality becomes worse and worse. Supporting the above, it should be recorded that the sea bottom condition at the North section of causeway No.1. No.1 is completely deteriorated. A diving inspection shows the existence of anaerobic condition. It is assumed this happened due to the closed water zone by natural sand dike and causeway. Thus it is required to provide a water passage to get the aerobic condition before the provision of the existing causeway. This situation causes adverse effect to the causeway safety and environmental preservation. Thus, the provision of water passage is a must. It is proposed to provide artificial openings by means of the following facilities:

- Providing concrete box culvert, 2rooms x 0.9 m x 1.3 m in 8units
- Providing a bridge with 18 m span.

The reconstruction of causeways will be carried out at the same location as the existing ones, in order to maintain the construction economy and easily maintain the access for islanders. Causeway No.1 can stay at the present location; however, Causeway No.2 will be relocated parallel 7 meters to the east seeking a sound seabed formation. The basic design of the main body consists of sand core backfill, armour rock protection and simple pavement.

(2) Design of Facilities; Causeway Main Body

1) Basic Design Concept

Since the causeway will be basically reconstructed along the existing location, the main body of the causeway will consist of the existing bank, additional backfill and armor rocks. Protection works will upgraded by well-graded rock materials or fabric-mat consisting or water tight flexible textile case. The causeway surface structure will be simple pavement 15 m wide, consisting of two lanes: 4 m road and 2 m wide cycling pedestrian way on both sides. In order to ensure that the dike foundation will rest on the hard layer, dredging of two feet-deep will be required.

Total length of main body of causeway is estimated as follows:

Causeway No. 1	approx.250 m
Causeway No. 2	approx.650 m

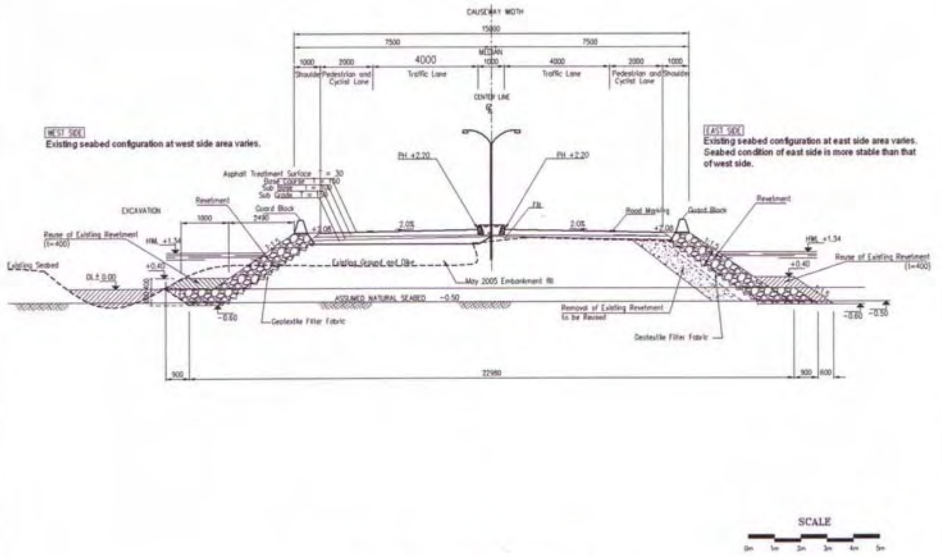


Fig. 6.6.11 Typical Cross Section of Causeway No.1

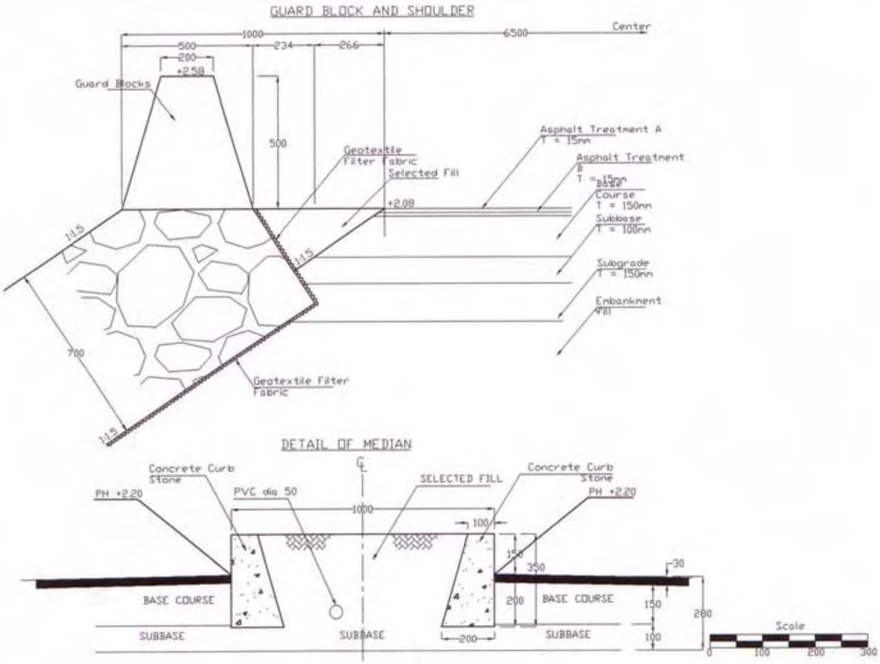


Fig. 6.6.12 Details of Guard Block and Median

Figure 6.13 Typical Cross Sections of the Causeway

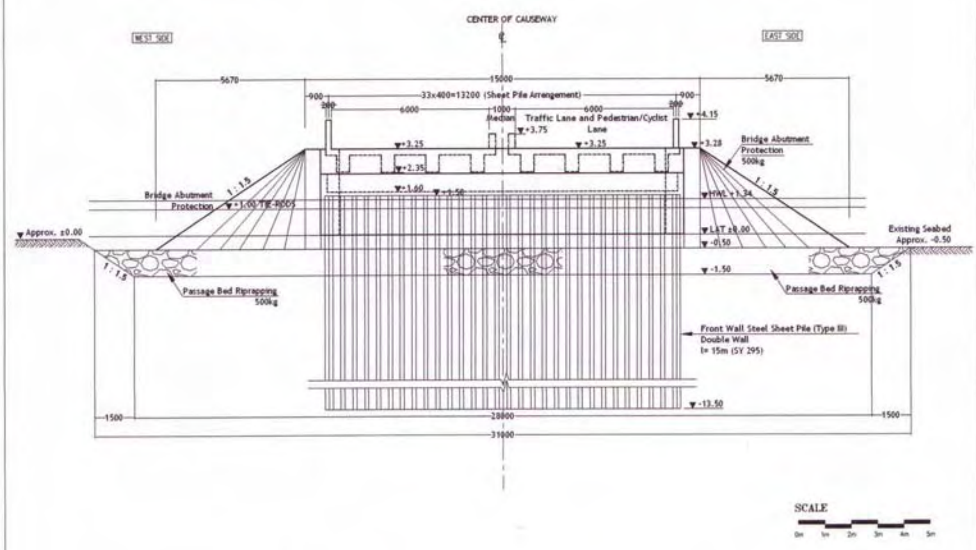


Fig. 6.6.13 Cross Section of Abutment (1)

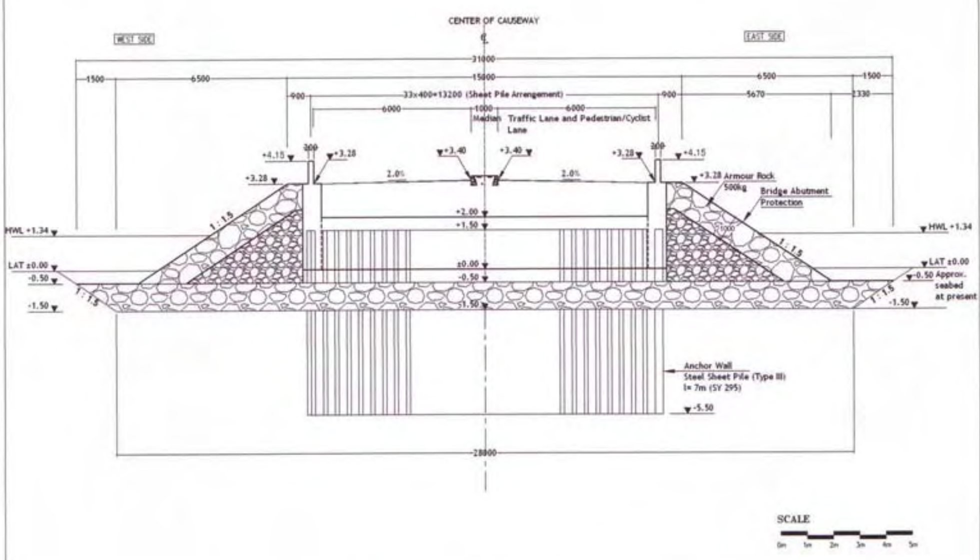


Fig. 6.6.14 Cross Section of Abutment (2)

Figure 6.14 Cross Sections of the Abutment

2) Design of Causeway

- Design Speed

Existing connecting roads to the causeway are unpaved. According to the design report, it is recommended to provide a limit speed of 50 km/h through the village and causeway. It is assumed that thus the design speed these connecting roads were to be 30 km/h. Proposed causeways will be covered by asphalt. The design speed of proposed causeway is adopted as 40 km/h which is higher than those of the connecting road.

- Cross section

Road width of existing causeway is approximately 12m. This width is properly designed to provide two traffic lanes. This arrangement is not over design though the estimated traffic is just minor, 200 hundreds vehicles a day within ten years. Proposed plan has 15m wide cross section covering two 4m traffic lames, two 2m wide pedestrian/cyclist pass, one meter wide median with curb block and one meter shoulder both end each.

- Road alignment

Causeway No.1 (Maandhoo - Kadhdhoo)

Alignments of plan and profile are similar to the current connecting roads.

Causeway No.2 (Fonadhoo-Kadhdhoo)

Alignment of plan is also similar to the existing connecting road. However the existing causeway center is relocated to the east side by 7m for setting up the proposed west revetment to avoid resting on the disturbed seabed foundation by the tsunami and coastal changes.

Alignment of profile will be matched smoothly both ends to the current road height. Proposed height of the causeway is two meter above the LTA.

- Bridge Section

The bridge section is set up with by 1.3m than ordinary section considering to provide safety clearance between the beam height and wave crest.

- Pavement

Pavement of causeway is planed to provide not only smooth traffic but also to prevent the existing dike from the washed away by overtopping waves. Pavement have to design for the design traffics. In the causeway, daily vehicle traffic volumes at present is about 100. It is assumed that the traffic will be double within ten years.

According to AASHTO Asphalt Pavement Standards, asphalt surface is applied the minimum thickness 1 inch (2.5cm). In the proposed plan, surface thickness is designed by prime court and asphalt treatment in two layers as becoming 3cm considering the quality control of construction.

Material of Base coarse, Sub base, and Sub grade are coral sand, and design CBR of Sub grade is expected more than eight. The pavement components are designed Base coarse 150mm and Sub base 100mm using the selected materials to correspond to the present traffic volumes, about 200 vehicles (5 ton vehicle equivalent) per day

- Storm Water Drainage
  The drainage of pavement surface is necessary. In this design, the drain of the rainfall is corresponded by cross fall of the causeway.

- Provision of Guard Blocks
  The guard blocks at the pedestrian shoulder is planed at both side of causeway for the vehicles from diving to the sea.

3) Structural Design Criteria

- Wave Strength to Causeway
  Design waves for the causeway are as follows. The maximum wave height by the water depth at reef flat and equivalent offshore wave will be taken into consideration. Causeway should be strong enough against the high current due to head difference between two sides. Tsunami wave is not considered in the project design, since it intensity is so large that investment cost will extremely increase.

- Current through passage
  In order to secure structural stability, causeway should be durable against the strong current anticipated through the artificial passage, bridge and concrete box culverts. It is observed that the maximum velocity of east to west flow through a 0.8 m concrete pipe indicates an intensity of 2.0 m/sec. During such high flow, the water head is 25 to 35 cm, or water surface difference between Out and In. After opening the artificial passages, this head might slightly decrease; however, continuous energy supply by waves from the outer ocean will maintain basically the head at around 25 cm.

  Current through passage was estimated applying 25m head difference between the East and the West.

  Average current speed through bridge passage==== 4.0m/sec
  Average current speed through box culvert passage==== 2.5m/sec

  Rock size of revetment near the bridge and passage bed are estimated to be 500 kg (Class I).

- Design Tide
  Similar to the coastal protection works, the design water level will be the maximum tide plus

the seawater set-up at the outer ocean section. Tide for the design will be as follows:

Ordinary tide	1.34 m above Datum, LAT
Wave set-up	0.25 m as a water level difference between Out and In.
Total	1.59 m above Datum

4) Crown Height of Causeway

According to the tentative survey results by the team, nearby land elevation to the causeway varies 1.5 to 1.7 m above the Datum, LAT. Existing causeway elevations were measured by the team as follows:

- Causeway No.1 1.5 to 1.9 m above the datum, LAT
- Causeway No.2 1.6 to 2.1 m above the datum, LAT

Crown height of causeway should be high enough to prevent it from wave over topping. Crown height is set as 2.0 m above the datum following the design method applied. Same crown height will be applied to the damaged quay wall and seawalls in the island harbours. Note: Survey results by the team should be replaced by new comprehensive survey to be carried out before the commencement of actual constriction.

5) Size of Amour Rocks

Size of armour rock on the outer slope should be designed to resist the maximum waves estimated from the ocean side. Similar to the coastal protection works, Hudson's formula will be applied to estimate the required weight of rock materials. Calculated size of armour rock by water depth is as follows:

Table 6.18 Armour Rock Size with Water Depth

	Reef Water Depth ,m	Weight of Armour Rock, kg
1	0.50	50
2	0.00	110
3	-0.50	200
4	-1.00	350
5	-1.50	550

(3) Open Ratio at Causeway No.2

The opening area of the causeway should be as wide as possible by provision of a bridge. However size of it should be limited due to financial constraints. Minimum opening requirement is considered by assuming the required opening area. Required time to exchange sea water on the outer reef side draining it to the inner reef side is estimated for the Causeway No.2 by applying the following formula:

$$A = V / (U \times T)$$

Where: A: Required opening area through the coastal line shared by Causeway No.2

T: Acceptable Time for draining the seawater volume covering by the causeway. One day

V: Total seawater volume at the offshore side,

$V = C\ W\ h$

C: Length of sharing coastal line by causeway, 4,000 m

W: Width of outer reef flat, 800 m

h: Water depth (EL-0.5m to EL+0.6m = 1.1m)

$V = 4{,}000 \times 800 \times 1.1 = 3{,}520{,}000\ m^3$

U: Speed of flow through the openings

U = 2.5 m/sec = 9,000 m/hour = 216,000 m/day

This is expected to be exchange per day; thus, required opening area is:

$A = 3{,}520{,}000 / (216{,}000 \times 1) = 16.3 m^2$

Minimum opening ratio Ro is estimated as follows:

Ro = A / (C x h)

= 16.3 / (4000 x 1.1)

= 0.37%

It is assumed the required time for 80% exchange will take a few days.

Current open ratio at the existing Causeway-2 is estimated as follows based on the observed data by the Study Team:

Ro = N x A / (C x h)

Where: Ro: Open ratio

N: Number of the existing openings 500/ 30 = 16.7

A: Average unit opening of the existing Causeway-2 = 0.15 to 0.45 m2

About a half of this is assumed as effective. 0.15 m2

C: Length of sharing coastal line by causeway, 4,000 m

h: Water depth (EL-0.5 m to EL+0.6 m = 1.1 m)

Ro = 16.7 x 0.15 / (4000 x 1.1)

= 0.06 %

Opening area of planned Causeway-2 will be as follows:

A = Bridge + Box culvert

= 18 m x 1.1 m + 2 x 1.3 m x 0.25 m x Nc

= 19.8 m2 + 0.65 x 5

= 19.8 +3.25

= 23.05 m2

Opening ratio to the existing condition is:

$$Ro = 23.05 / (4000 \times 1.1) = 0.52\%$$

Thus, open ratio is set as 10 times the present one.

(4) Connection Areas and Coastal Protection Works

The connection areas which is diversion between the main body and the on-land normal road section is to be strengthening partly and protected by the coastal protection works. Coastal protection work will consist of rock revetment works and/or fabric forms, and concrete will be provided for these construction areas. If the actual shoulder length is more than 10 m, no coastal protection works will be basically provided in order to minimize investment cost. It is expected for MTC and related agency to watch carefully the changes of coastal line, and placing necessary revetment protection measure where it is needed.

(5) Pavement Works

Surface of the existing causeway has no pavement so far. In order to maintain the surface durability, it is recommended to provide pavement. Considering the low intensity of traffic volume, asphalt pavement (but a simple one) is recommended. Pavement in two lanes with 4.0 m wide each will be provided for vehicle driving and transport. Pedestrian paths will be provided as 2.0 m wide consisting of 1.85 m of passageway and 0.15 m of curb separating from the armor revetment.

(6) Water Passage Arrangement

It should be noted that the sea bottom condition at the North section of No.1 Causeway is completely deteriorated. A diving inspection shows the existence of anaerobic condition. Thus it is required providing a water passage to get the aerobic condition before the provision of the existing causeway. Passage should be carefully designed and constructed since it may act an obstacle in the main body of the causeway. Thus, number of passages should be reduced as low as possible.

Present passage open ratio is about 0.06%.

It is proposed to provide the opening of 0.5% or more in effective water-through area against the natural conditions, or as before provision of the existing causeway. Thus, it is proposed to provide the openings by means of either of the following alternatives:

- Concrete pipe drainage of 1 m diameter in 15 m intervals. One pipe can provide a open area of 0.4 m^2 (a half section) when it works without closing.
- Concrete culvert, 1.4 m x 3.3 m. One culvert can provide an area of 0.65 m^2 (a quarter of a section) when it works without closing.
- A bridge of 18 m span. One bridge has as opening in 19.8 m^2 (between +0.64 m and -0.5 m) when it works without closing.

For the Causeway No.1

Five concrete culverts will be provided in the south section. The total effective coverage in liner meters will be as follows:

Three box culverts x 0.65m =1.95 m^2

For the Causeway No.2

A 15 m span bridge will be provided in South section. In addition to this, five concrete culverts will be provided along the North section. The total effective coverage in liner meters will be as follows:

A bridge + Five culverts =19.8 + 0.65 x 5=23.05 m^2

(7) Bridge

A bridge of 18 m span will consist of the following:

- Two steel sheet pile driven square foundation, cofferdam type
- Two middle abutments by six steel pipe pile each with concrete beam each.
- Wall protection works by rock mound
- Reinforced concrete beam and slabs in three span of six meters each.

Sheet piles at the bridge side should be driven into the approved hard stratum, at –11 m below datum. One bridge can provide a water passage area of 23.05 m^2 when it works without closing.

(8) Concrete Box Culverts

Concrete culvert, 1.4 m x 3.3 m, will consist of the following:

- Rock foundation or equivalent should be provided
- Two rooms of 0.9 m high and 1.3 m wide each.
- Wall thickness will be 8 to 10 inches of reinforced concrete
- Pre-cast concrete might be introduced.
- Two Cutoff wall should be provided each entrance.
- Total length of culvert will be 20 m each at the standard section

One culvert will provide 0.65 m^2 when it works without closing.

(9) Piping Passage

Concrete pipe drainage of 1 m diameter will consist of the following:

- Sound foundation should be provided
- Outlet of the pipe should be protected by rock or concrete fabric form
- Reinforced pre-cast concrete pipe should be provided.
- Wall thickness will be 4 inches or 10 cm of reinforced concrete pre-cast.
- Joint works should be as required in order to maintain connection

- Concrete strength should be more than 210 kg/cm^2.
- One water cut flanges should be provided for each pipe.
- Total length of piping will be 19 m each after connection

One pipe will provide a water passage area in 0.4 m^2 (a half of section) when it works without closing. As a result, no pipe passage was introduced due to technical reason.

(10) Temporary Route during Reconstruction and Repair Works

Temporary route during reconstruction and repair works of causeway should be provided from time to time for a passage. Necessary notice board and safety reflector marks should be provided. This consideration should follow the regulations in Maldives. General Idea is as follows:

- No pavement is required
- Six meter wide space including shoulder at +1.7m or higher above the datum
- Permanent works can be utilized for this
- Maintenance work for this should be included in the contract.

These temporary works can be utilized for the dike to cut off the seawater flow down to inner flat reef, in the west.

Damaged Causeway No.2

Before repair in the end of May.

West side

Damaged Causeway No.1

West side

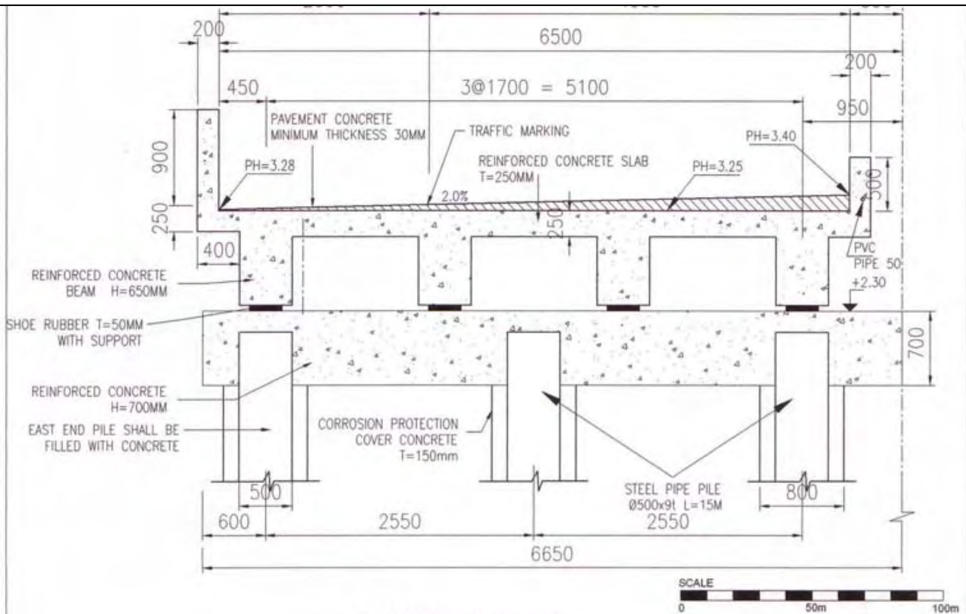


Fig. 6.6.15 Cross Section of Bridge

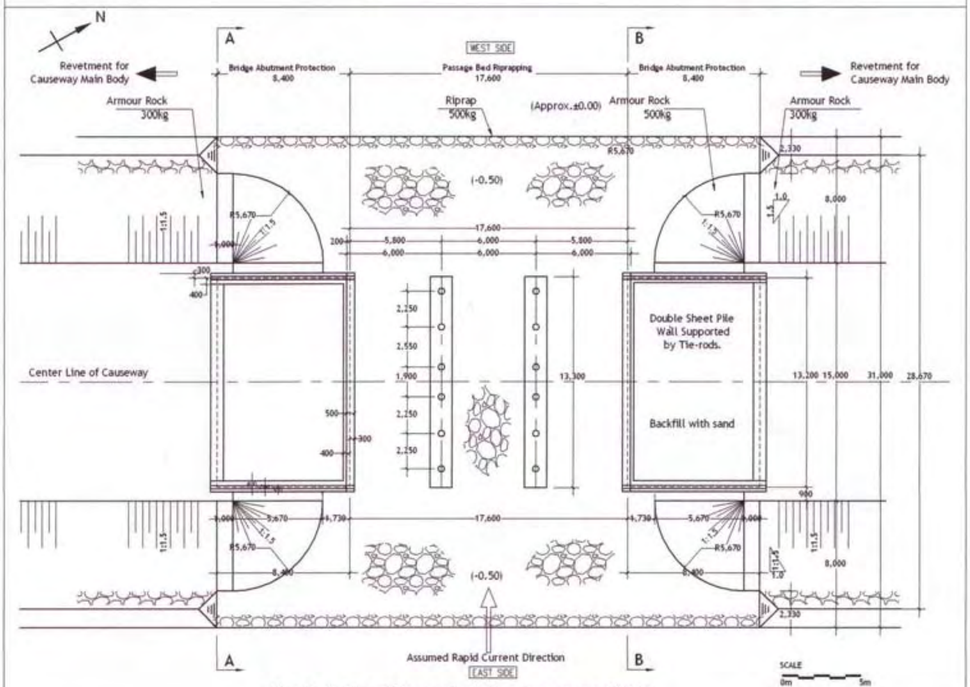


Fig. 6.6.16 Pile and Passage Protection Arrangement of Bridge

Figure 6.15 Design Drawings of the Bridge

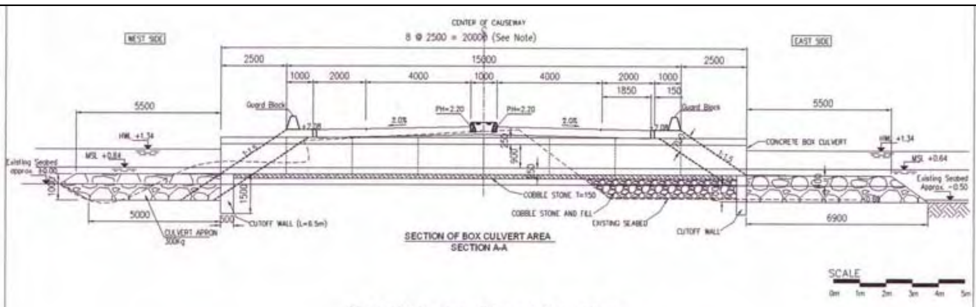


Fig. 6.6.17 Section of Concrete Box Culvert

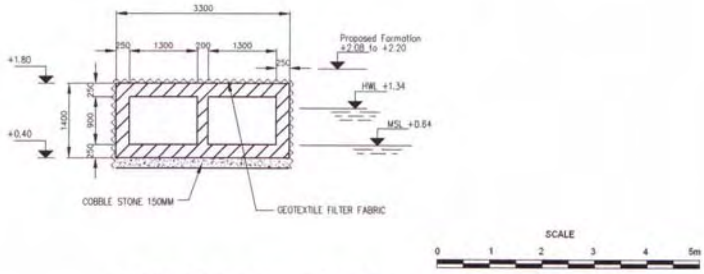


Fig. 6.6.18 Section of Concrete Box Culvert

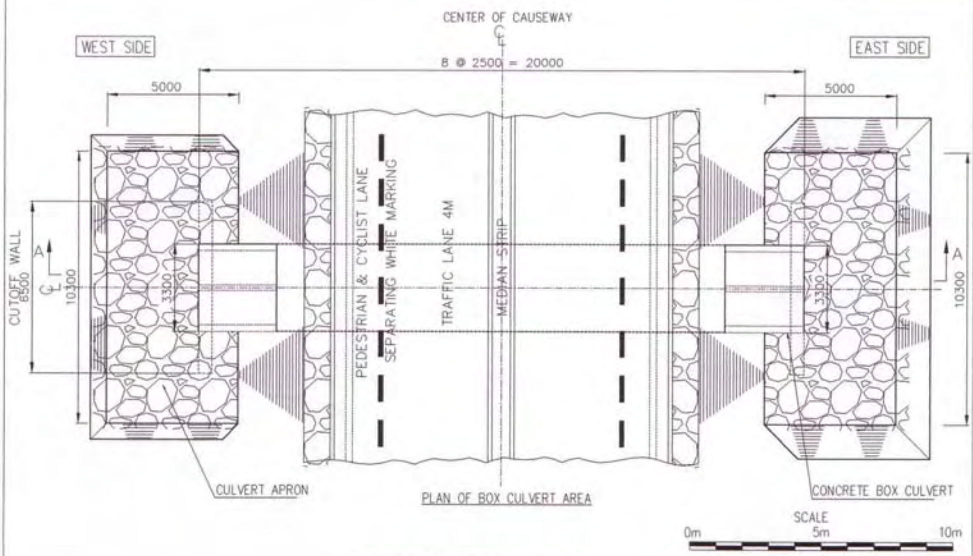


Fig. 6.6.19 Plan of Concrete Box Culvert

Figure 6.16 Design Drawings of the Box Culvert

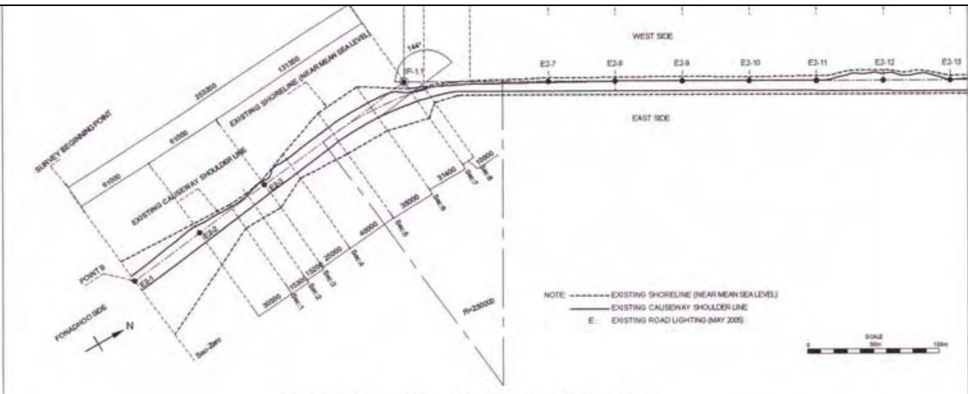


Fig. 6.6.20 General Plan of Causeway No.2 (Southern Half)

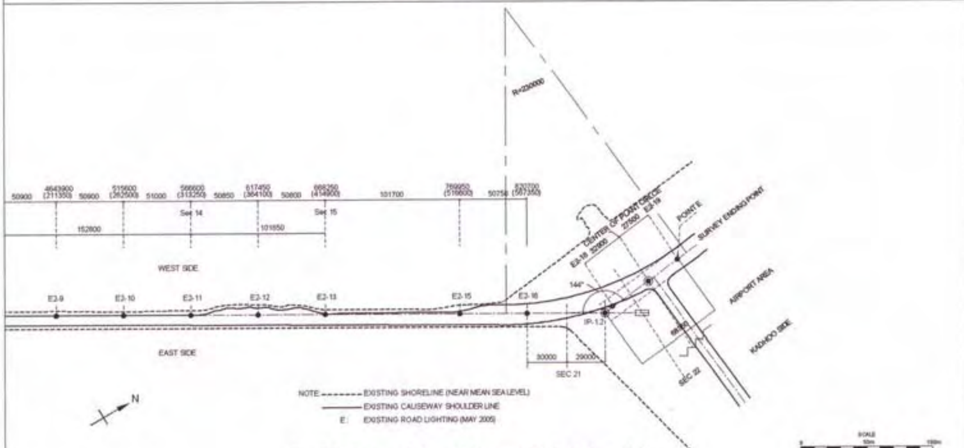


Fig. 6.6.21 General Plan of Causeway No.2 (Nothern Half)

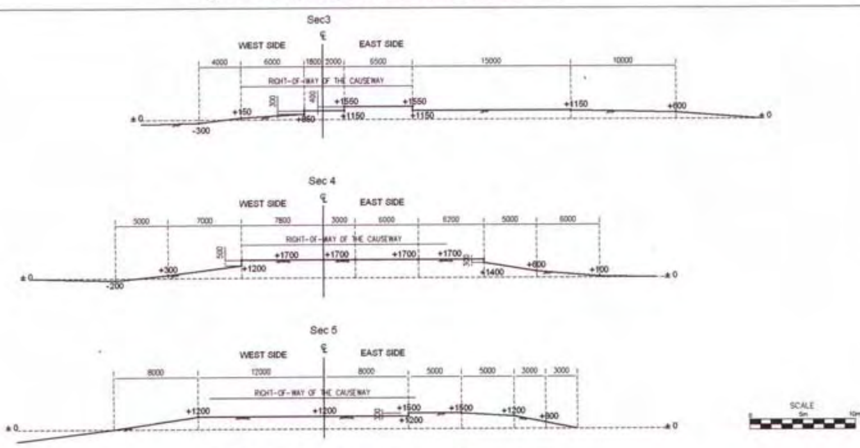


Fig. 6.6.22 Existing Cross Sections of Causeway No.2

Figure 6.17 Design Drawings of the Causeway No.2

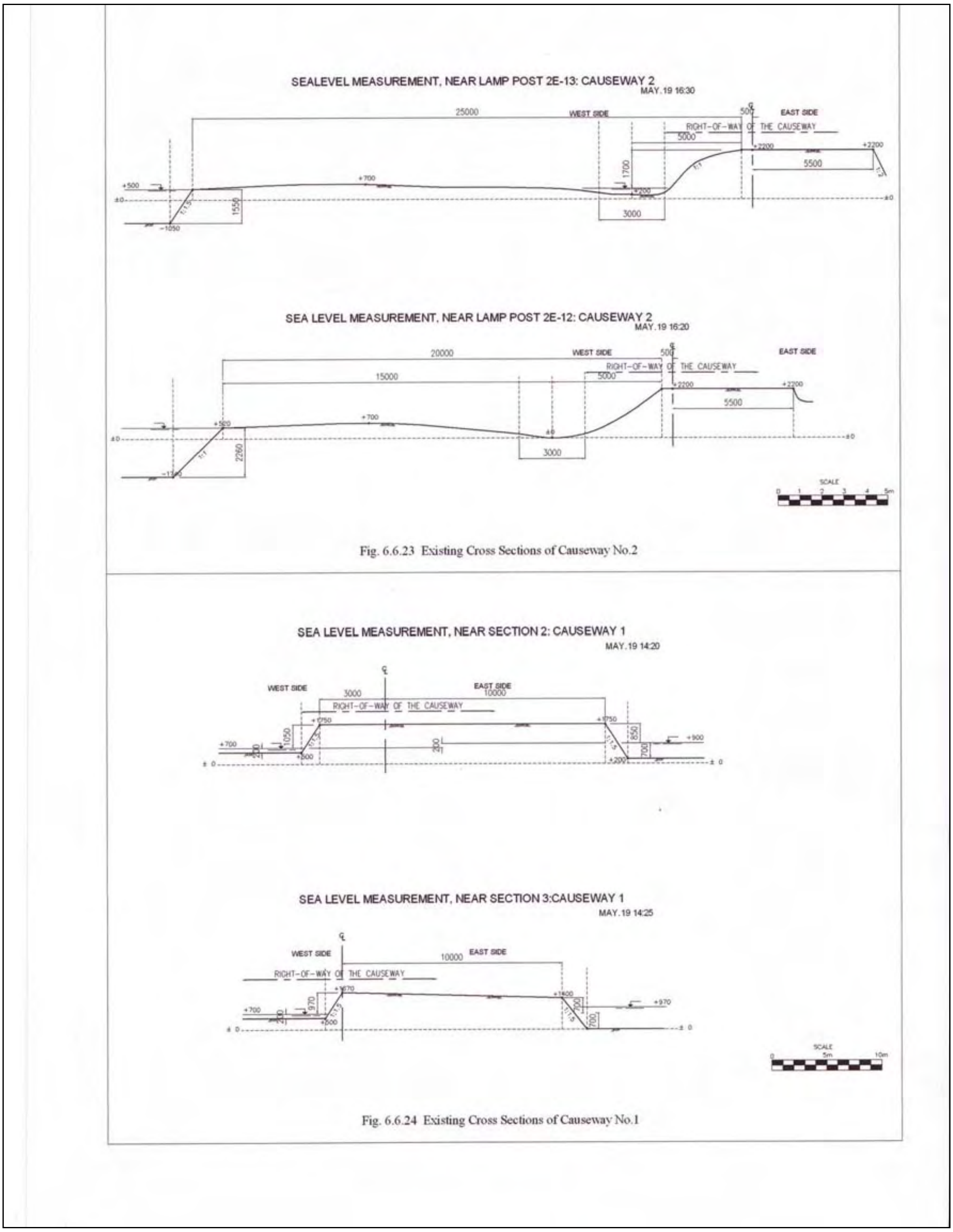


Figure 6.18 Design Drawings of the Causeway No.1

6.4.11 Design of Island Harbours

(1) Basic Considerations

1) Summary of Observation

The Study Team visited the sites and investigated it several times; they cover 11 islands in Laamu Atall and Thaa Atall. The number of island harbours visited was 11 excluding three natural island harbours in Gan Island like Thundi. The Study Team made a preliminary survey on the alignment and structural outlines. Observation on the port structures indicates that there is a common situation in damaged structures as follows:

- Structures requiring repair work.
  Most of harbours were affected by the tsunami and belong to this category.
- Restart the suspended works to completion.
  For example, quay wall at Dhiyamigili Island Harbour in Thaa Atall is not completed yet. Construction of its quay wall of 158.3 m and south seawall of 87.6m were suspended three years ago and not planned to restart.
- Construction of a new island harbour beside the existing one.
  Island chiefs of Veymandhoo and Kinbidhoo intended to develop new island harbours beside the existing one.

Among these, last two situations are not related to the damaged by the tsunami; however, due to its important and influence to the society, it is recommended to be included in the project, subject to approval of GOM.

2) Objective for Repair Works

Project can be divided into two categories: namely, the Urgently Rehabilitation and Mid-term Upgrading Works. The objective of the project is not only repair works but also upgrading to meet long-term requirements. The former is the immediate work to be implemented to serve the daily life of islanders. The later is rather long term works taking the regional development into account.

3) Underwater Investigation

The Team carried out an underwater investigation of every island harbour and causeway. Results of this study indicates the general summary of facilities under the Low Water Level, as follows:

- Almost no proper protection underwater was provided to the core of gravity wall, rocks and coral debris.
- Collapsed and tumbled conditions were observed in the serious damage areas.
- Some structures in air are sound; however, there are serious damages underwater.

4) Common Structural Characteristics

In most harbours, following situations were very frequently observed:

- Stair and steps are seriously damaged.
- End of quay walls are damaged.
- Most of the breakwater protection of the approaching channel was damaged.

Common problems observed is three holds: namely,
- Most of structures were built 2 to 8 years ago.
- Loose core wall structure consists mostly of coral debris.
- Foundation is too weak to support the weight of super structures.
- Falling core comes out of the wall and forms a cave one meter deep

These are confirmed by underwater observation of the Study Team. It is believed that this deterioration pattern might continue until collapsing completely. This will be reflected into the design of repair and reconstruction of structures.

Notes**:** Quay wall is the places where boats can berth for loading and unloading operations. Seawall is not the place for berthing, but for the mooring fittings. Seawall often has a narrow passage. Breakwater is placed on the wind side along the approach channel. Mostly breakwater is formed of coral debris obtained after dredging. Thus, it is not easy to distinguish between real breakwaters and fake ones because it is not clear if it is a breakwater or just piling up dredged materials when the channel was constructed.

5) Grade of Damages and Scope of Recommendation

The Team prepared a list and standards to judge the grade of destruction. In order to judge the grades, the Study Team used a simple formula as follows.

Table 6.19 Damage Evaluation Criteria

	General Situation	Score by Engineers	
1	No repair works are required.	0	
2	Minor repair works at crown concrete are needed.	25%	Crown repair works
3	Minor repairs at front surface are needed.	50%	Four feet repair works
4	Using but nearly falling down	100%	Full reconstruction
5	No Deck Level and Not Usable	100%	Full reconstruction

This criteria is a similar one to the standards prepared by the MOAD.

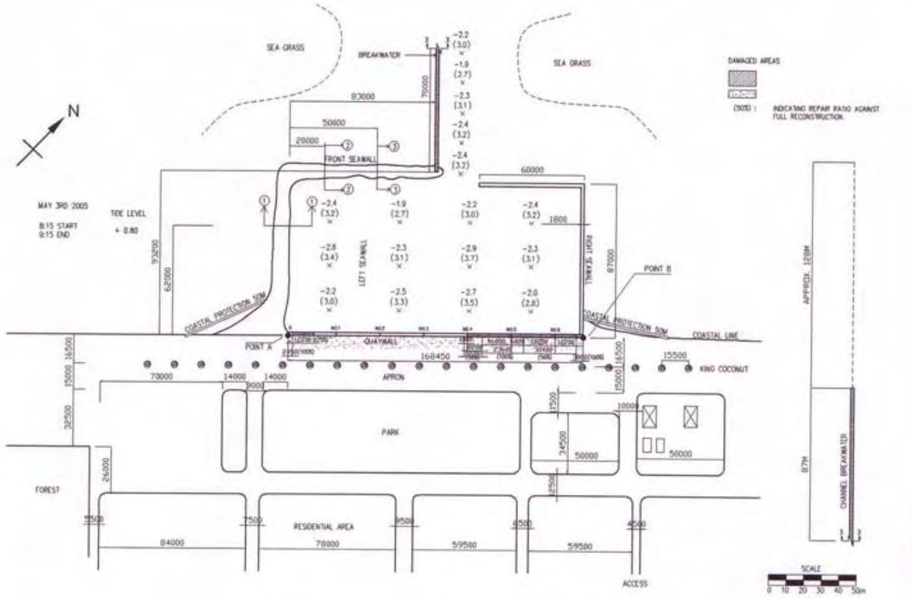


Fig. 6.6.25 General Plan of L-4 Fonadhoo Island Harbour

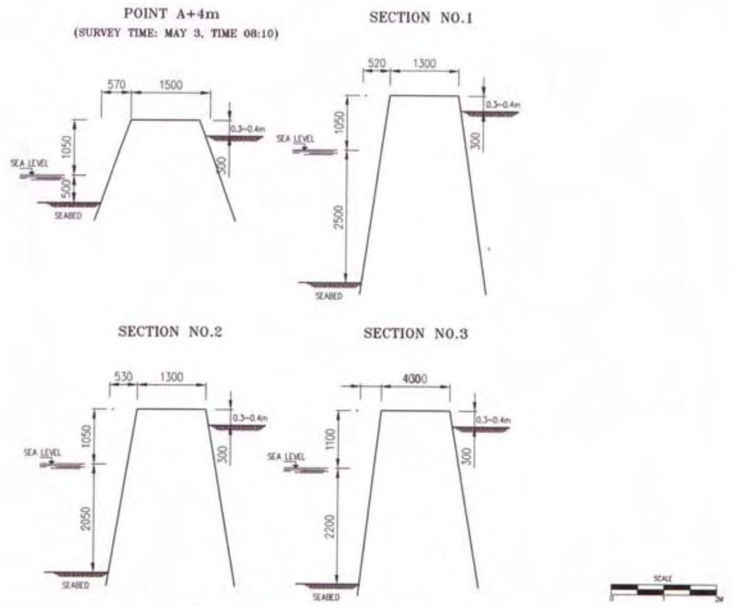


Fig. 6.6.26 Existing Quaywall Sections (L-4 Fonadhoo)

Figure 6.19 Design Drawings of the Fonadhoo Island Harbour

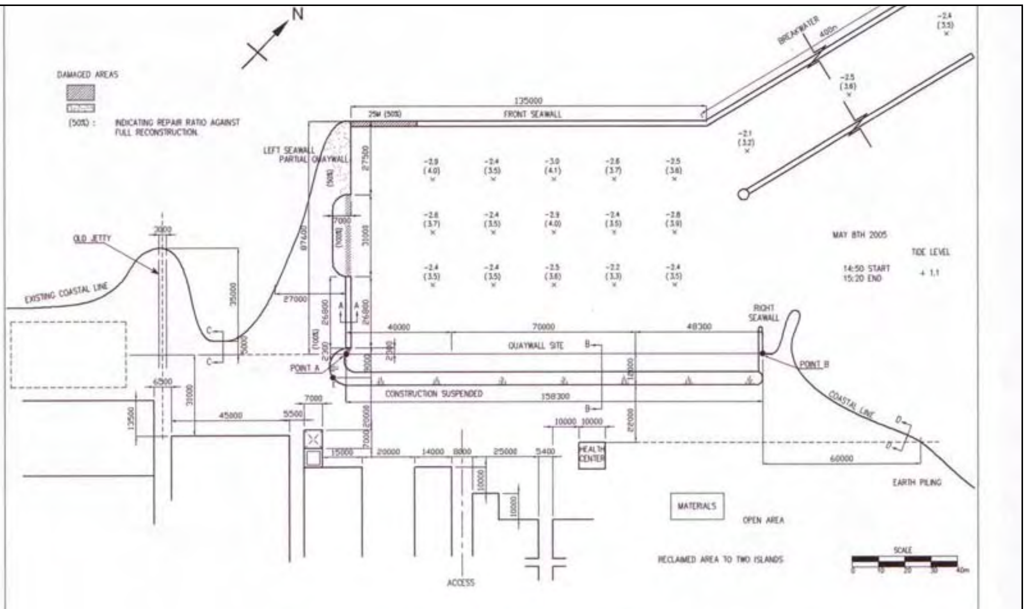


Fig. 6.6.27 General Plan of TH-1 Dhiyamigili Island Harbour

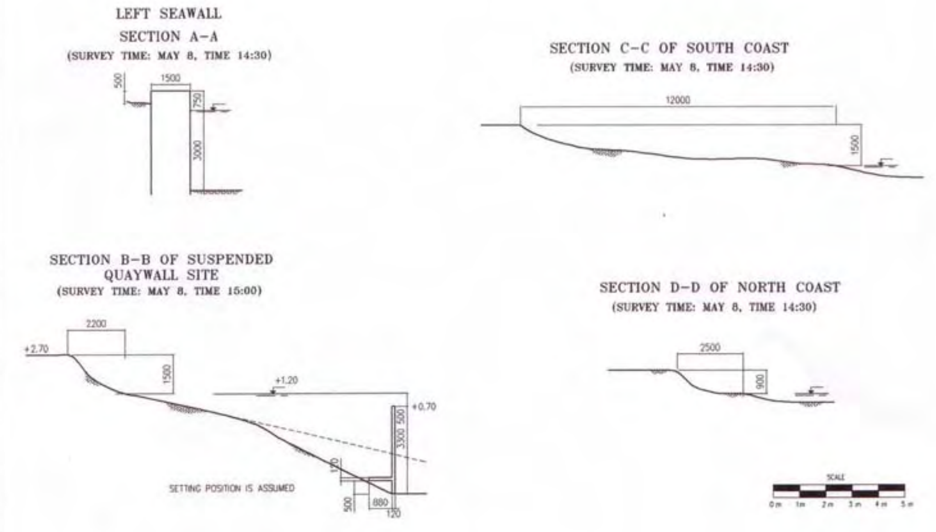


Fig. 6.6.28 Existing Quaywall Section & Others (TH-1 Dhiyamigili)

Figure 6.20 Design Drawings of the Dhiyamigili Island Harbour

(2) Plan Arrangement

1) Alignment Plan

Design normal line at the harbour quay wall, seawall, breakwater and channel will be basically as per the original design. In case the harbour area is to be expanded in the project stage, proposal of the expanded area should be included in the study report. Detailed design of this area is not required until the budget for it is obtained.

2) Selected Reconstruction Works

Selection of the reconstruction or repair works at the damaged structures are to be carried out by the joint study team consisting of each island office and the Study Team considering the grade of damages and its location.

(3) Damage Records and Damage Classification

Based on the damage judgment criteria, the Study Team evaluated all structures in the sites. The damage ratio for Thaa Atoll quay wall is about 29.9% and 7.5% for the seawall. The same indication for Laamu Atoll is about 46.9% and 4.2%.

(4) Quay Wall Design Criteria

The Team prepared design criteria of quay wall structures as follows:

1) Design Criteria for the Quay Wall

- Crown Height: DL +2.0 m
- Front wall inclination: Perpendiculars or inclined 13.4^{o}
- Surcharge: 1.5t/m2
- Water depth as required but not deeper than -3.5m
- Backfilling soil condition: Internal friction angle 30^{0}, unit weight 1.8 t/m^3
- Water level difference behind the wall: one third of the range between HWL and LWL
- Quay apron by interlocking concrete pavement will be provided of 3 m wide.

2) Application

Above condition is applied only to the reconstruction of quay wall.

Table 6.20 Damage Situation of Island Harbour Structures and Causeway (Laamu Atoll)

Unit : m

No.	Atoll and Island	Original Dimension of Facility				Damaged Situation							
	Laam Atoll	Quaywall	Seawall	Breakwater	Pier	Quaywall			Seawall			Breakwater	C.Protection
	Damage Ratio					25%	50%	100%	25%	50%	100%		
1-1	**Isdhoo**	108.5	168.3	70				10	30	15/15		70(50%)	0
1-2	**Kalaidhoo**	93											120
2	Maabaidhoo	131	254			27.8	16.7	51.5			20※		110
3-1	Thundi	There is no Quaywall and Seawall at Present											100
3-2	Mathemaradhoo	There is no Quaywall and Seawall at Present											150
3-3	Mukrimagu	There is no Quaywall and Seawall at Present											150
4	**Fonadhoo**	168.45	323.2	appr. 285		12.2	40.4	29.85				appr. 157	100
5	Maavah	183.2	330				113.7	9.7				120	50
		684	1075	35				314			45		
								46.90%			4.20%		
	Causeway												
1	Maandhoo–Kadhoo	Total Pavement Length 260 m				Refer to Section 6.6.10							
2	Kadhoo–Fonadhoo	Total Length Pavement 849 m				Refer to Section 6.6.10							

Note: 1. Maabaidhoo ※mark : Foundation of Navigation Aid at the head of Left Seawall shows a deep crack damage (Area 5 m×6 m).

2. Fonadhoo: Dimension of damaged breakwater area is based on the survey results shown in the First Report (April,2005)

3. Harbours in bold letters are JBIC Study objectives assigned by GOM agreed by GOM.

Table 6.21 Damage Situation of Island Harbour Structures (Thaa Atoll)

Unit : m

No.	Atoll and Island	Originl Dimension of Facility				Damaged Situation							
	Thaa Atoll	Quaywall	Seawall	Breakwater	Pier	Quaywall			Seawall			Breakwater	C.Protection
	Damage Ratio					25%	50%	100%	25%	50%	100%		
1	**Dhiyamigili**	158.3/60.1	135/27.5	appr. 800				※-1/2.3		25/27.5		appr. 600	150
2	Guraidhoo	224.45	349.6	appr. 205		25			40/5,5	30		※-2	50
3	Thimarafushi	216.7	401.4	99.2									350
4	Veymandhoo	There is no Quaywall at present			31.25/24.2			N 159		86	N 179		50
5	Kinbidhoo	53.95	105.1			27.95	26			6	2.1		0
6	**Hirilandhoo**	141.1	172.8								N 120	N 78.5	0
		793	1163					237			83		
								29.90%			7.10%		

Note: 1. Dhiyamigili ※-1; Construction of 158.3 m and 31 m Quaywall (West seawall of 30m is used as qauywall) was suspended

2. Dhiyamigili; Dimension of Breakwater and damaged Greakwater is based on the escription in First Report(April,2005)

3. Guraidhoo ※-2; Root of West Breakwater 25 m (25% damaged), Top of West Breakwater 25 m (25% damaged)

4. Harbours in bold letters are JBIC Study objectives assigned by GOM agreed by GOM.

(5) Standards Design; Quay wall

Based on the field observation and repairing method study and discussion with the line ministry, rehabilitation works are subdivided into four categories: namely, Crown Repair works, Four Feet Repair works, Partial Reconstruction works, Entire Reconstruction works and supplemental works by Coral Rock Mound Strengthening works

1) Crown Repair works

This is for the lightest damages at the upper part of quay structures. The crown part will be removed to one foot deep and replaced by cast in place concrete with right reinforcement.

2) Four Feet Repair works

This is for the medium damages at the upper part of quay structures. Crown part will be removed to four feet deep and be replaced by concrete with right reinforcement.

3) Partial Reconstruction works

Reconstruction of this category will be limited to only part of quay wall damaged classified as 50% or more. In this case, the original shape of quay front face should be kept in the reconstruction section.

4) Entire Reconstruction works

In case of necessity of entire quay length replacement, this work will be undertaken with wider flexibility.

5) Supplemental Works by Coral Rock Mound Strengthening

For about a half of quay wall, the core material is filled with coral debris obtained from the basin and channel dredging. Coral debris are light weight and fragile; however, it is necessary to use it for the marine wall structures, since there are no rock materials in Maldives. Method of strengthening of these structures is limited. One method is grouting mortar into clinks and gaps in order to connect them.

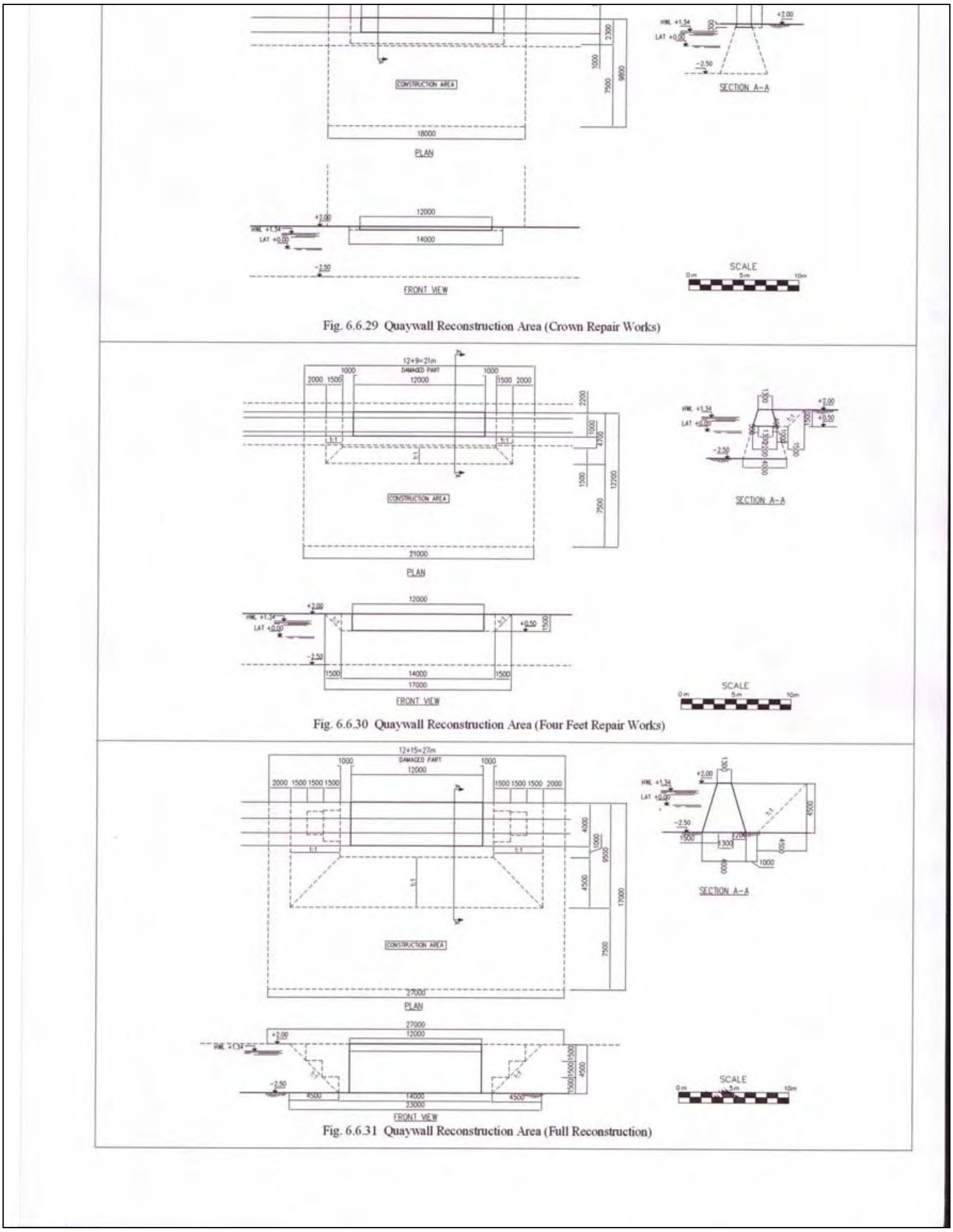


Figure 6.21 Design Drawings of the Quaywall

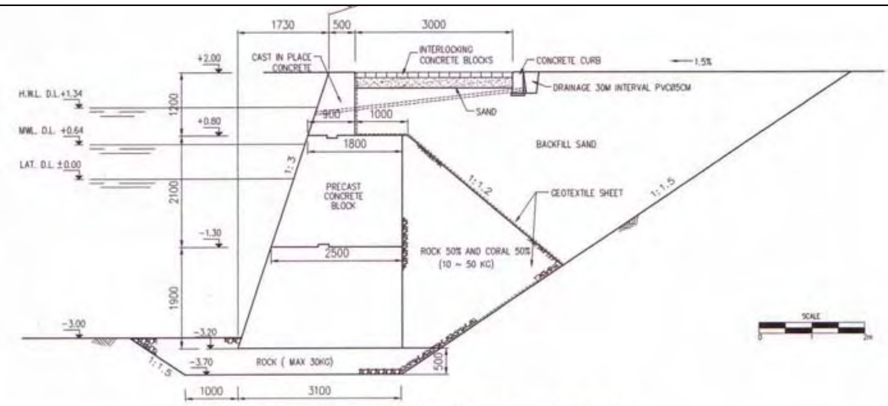


Fig. 6.6.32 Partial Reconstruction Plan of Quaywall (Depth: D.L.-3.00)

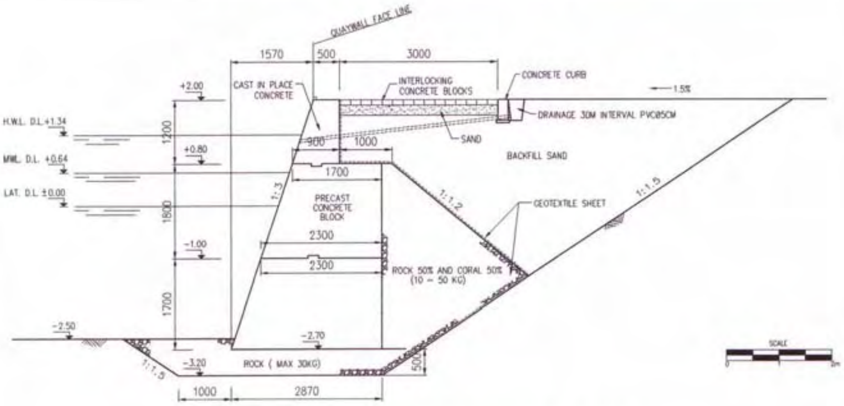


Fig. 6.6.33 Partial Reconstruction Plan of Quaywall (Depth: D.L.-2.50)

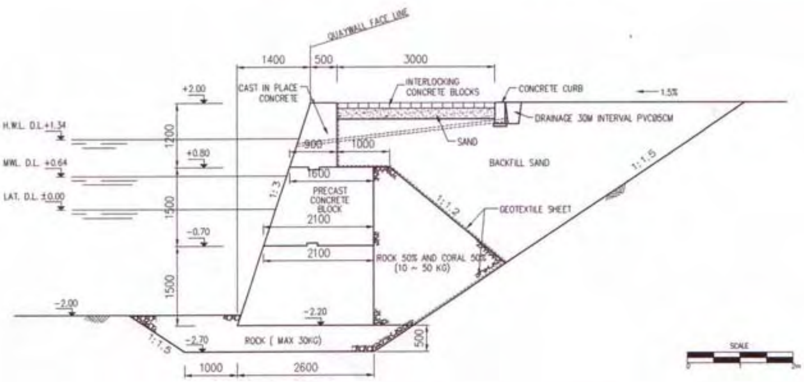


Fig. 6.6.34 Partial Reconstruction Plan of Quaywall (Depth: D.L.-2.00)

Figure 6.22 Design Drawings of the Quaywall (Partial Reconstruction)

(6) Quay Wall Reconstruction

1) Summary

Alternative design of quay wall will be carried out for following four structural types together with three traditional type: namely,

- Traditional Rock Mound Type
- Traditional Rock Mound with Mortar Grout Type
- New Traditional Rock Mound with Mortar Grout Type
- L-shaped Concrete Block Type
- Cellular Concrete Block Type
- Concrete Block Type
- Steel Sheet Pile Type

2) Recommendations for Full Reconstruction

In case not partial, but full reconstruction works are needed,

- It is recommended to adopt the Concrete Block Type; Inclined In case え ntire full reconstruction works are required,
- It is recommended to apply the Concrete Block Type; Vertical or perpendicular. And followed by L-shaped Concrete Block Type, Cellular Concrete Block Type and Steel Sheet Pile Type

Table 6.22 shows the comparison table of quay wall structural type.

Table 6.22 Comparison Table of Quay Wall Structure Type

Comparison item	Structural type of Quay Wall Entirely Replacing					
	Traditional Coral Mound Structure	Traditional Coral Mound Structure plus Grouting	L-shaped Concrete Block	Cellular Concrete Block	**Concrete Block**	Steel Sheet Pile
1.Cost	◎	○	○	○	○	○
2.Construction Ease	◎	△	△	△	○	◎
3.Local Material Availability	◎	○	○	○	◎	△
4. Durability and Life	×	◎	◎	◎	◎	◎
5. Maintenance Intensity	×	○	◎	◎	◎	○
6. Environment Aspects	◎	△	○	○	○	◎
Comprehensive Evaluation	×	△	○	○	◎	○

◎ Excellent, ○ Good, △ Fair, × Poor

Notes:

1. This table should be applied to the quay wall which is justified to reconstruct entirely by a vertical wall structure.
2. Partial repair of quay wall should be carried out to meet the existing structures, which is mostly an inclined wall type.

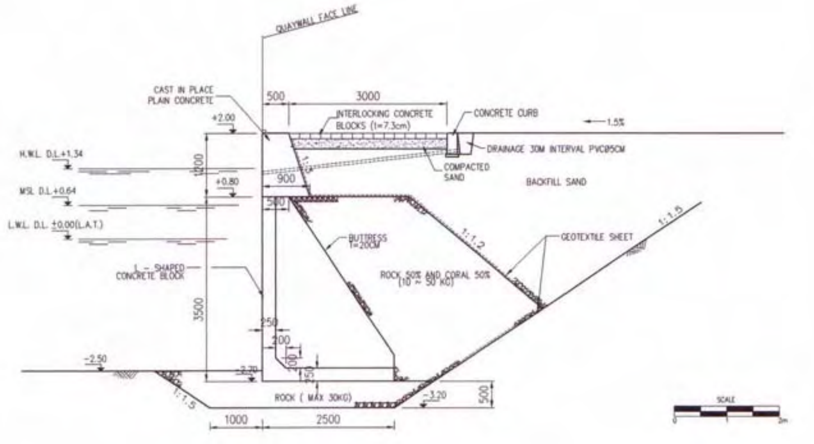


Fig. 6.6.35 L-Shaped Concrete Block Type Quaywall

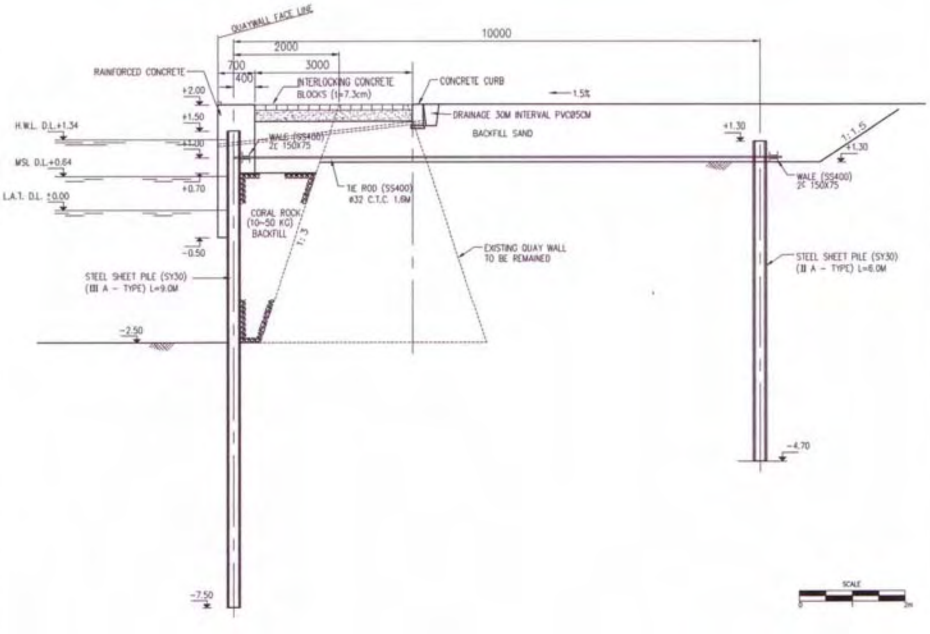


Fig. 6.6.36 Steel Sheet Pile Type Quaywall

Figure 6.2.3 Type of the Quaywalls-1

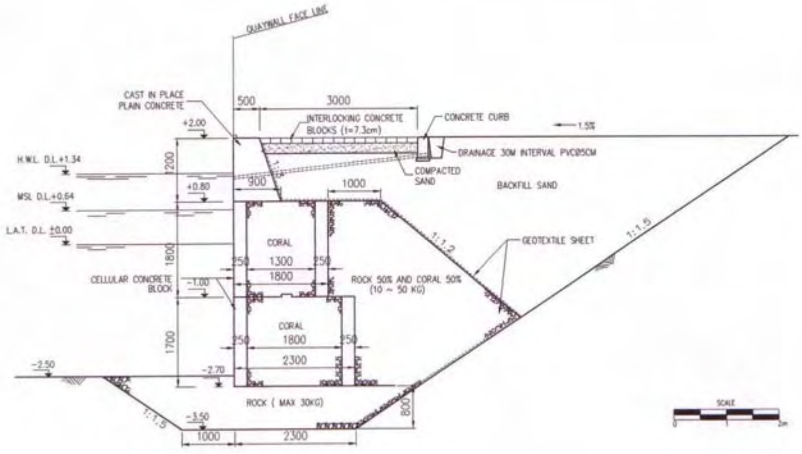


Fig. 6.6.37 Cellular Concrete Block Type Quaywall

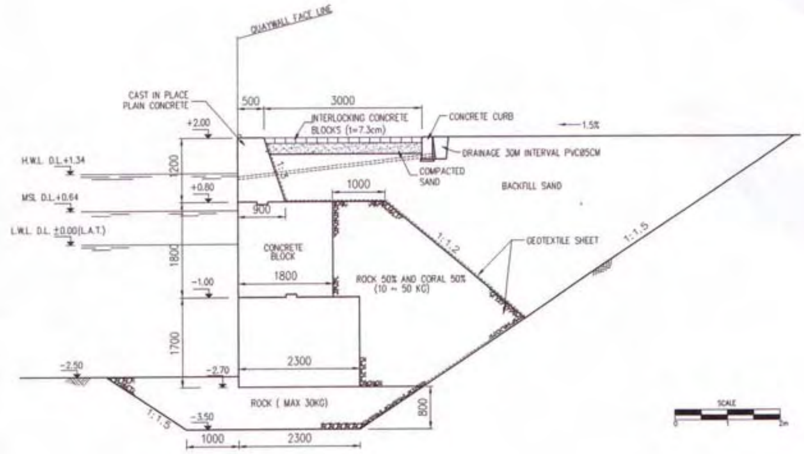


Fig. 6.6.38 Concrete Block Type Quaywall (Perpendicular Wall)

Figure 6.2.4 Type of the Quaywalls-2

(7) Island Harbour; Seawall

1) Existing Structural Type of Seawall

Existing structural type of seawall is rather simple. It consists of the coral debris mound lining by thin concrete covering its top. It is so often replaced by concrete bags in the important structures or when no coral debris is available. Seawall is normally located in the open flat reef; thus, no earth is contained behind it. However some seawall retains earth behind due to land reclamation or natural sand deposit.

2) Damage of Seawall by Tsunami

Similar to quay wall, selection of the reconstruction or repair works at the damaged seawall structures will be carried out by the joint study team. They are inspecting the grade of damages and its location. In order to judge the grades, the team used a simple formula.

3) Common Damages

In most island harbours, the following situation were observed in the seawall:

- Relatively minor damages are observed.
- Some seawall damaged due to the coastal changes (erosion) by strong tsunami current.

(8) Seawall Design Criteria

The following conditions are applied to the seawall design.

1) Design Criteria

- Crown Height; Varies from DL 1.6 m to DL +2.0 m.
  Connecting seawall to the quay wall which is expected to be used as quay wall should follow the elevation of the quay wall.
- Front wall inclination; Inclined 1:0.3 (1 vertical to 0.3 horizontal). Vertical wall is also acceptable.
- Surcharge: None
- Water depth as required but not deeper than DL -1.0 m
- Mound materials of coral rock; Internal friction angle 30^{0}, unit weight 1.4 t/m^3

2) Application

Above condition is applied to the reconstruction works of seawall.

(9) Standards Design; Seawall

Since the structure is rather simple, repair grade is limited in two ways as shown below.

1) Crown Repair works

This is for the lightest damages at the upper part of quay structures. Crown part will removed to one foot deep and replaced by concrete with right reinforcement. Refer to Figure 6.10.

2) Reconstruction works

Reconstruction of this category will be limited to only part of seawall damage classified as 50% or more. Concrete bags will be used. Refer to Figure 6.10 for the typical seawall sections including structural alternatives.

(10) Seawall Reconstruction

1) Summary

Alternative design of seawall is to be carried out for following three structural types: namely,

- Improved Traditional Rock Mound Wall
- Cast-in-place Concrete Wall
- Cellular Concrete Block Wall

2) Recommendations

- It is recommended to adopt the Cellular Concrete Block Wall.

(11) Island Harbour: Breakwater

Existing breakwater constructed along the approaching channel. Breakwater in Maldives consists generally of coral debris excavated at the channel. It works well since it lies mostly on the wind side of the channel. Since coral rock has been placed in it, seawater can go through for better water exchanges.

(12) Breakwater Design Criteria

Crown height of breakwater will be planned by the maximum wave intensity. The following formula can be applied:

$$Hc = hh + hr + 0.6H$$

Where: Hc: Crown height above the datum, LAT

hh: High water spring, +1.34 m above datum

hr: Water rise due to wave set-up, 0.25 m

H: Equivalent offshore wave, 1.0 m

Thus, $Hc = 1.43 + 0.25 + 0.6 \times 1.0$

$= 1.43 + 0.24 + 0.6$

= 2.25 m

(13) Standards Design; Breakwater

Standard design of breakwater could be similar to those of coral rock mound or combined coral rock with concrete bag mount and is recommended. Due to simplicity of structures, material collection will carried out by dredging of the nearby seabed.

6.4.12 Design Calculations

(1) General Procedures

Design calculation for the proposed structures was carried out following the design standards in Japan. Results of the study are summarized including the calculated safety factors. Summary of detailed calculation sheets are attached in the Supporting Report-2, S2-1.

(2) Coastal Protection

Technical study on the coastal protection was carried out for the following aspects:

- Wave run up
- Size of armour rock

(3) Causeway

Technical study on the causeway protection was carried out for the following aspects:

- Current flow study
- Wave run up
- Size of armour rock
- Pile bearing force analysis
- Bridge concrete structures study
- Concrete box culvert analysis

(4) Island Harbours

Preliminary technical study on the island harbour facilities was carried out for the following aspect:

- Alternative quay wall structural stability analysis

6.5 Construction and Project Implementation

6.5.1 Recommendation in Construction Aspects

(1) Introduction

It is understood that the keyword for the reconstruction is quickness. Contrary to the on-land structures like a road and housing, design of marine structures shall be undertaken carefully based on natural forces. They are always vibrations by waves and current. Seabed might change by variation of oceanographic conditions. These natural actions are repeating and making the structures fragile and weak in terms of strength. Damaged structures by the tsunami are currently struggling to survive against these natural forces. Exposed core rock of existing causeway is being washed out every second. Quick action for its reconstruction will give better condition to both people and structures. Thus, it is recommended to implement reconstruction and repair works urgently as soon as possible.

It is recommended to undertake the project implementation taking the following considerations into account:

- To maximize the participation of local expertise
- To maximize the use of locally available materials
- To employ local people as a way of providing job opportunities
- To provide the local people with safe access, especially to the causeway construction
- To carry out safe construction taking account of sever seawater flow due to the water head difference between outer reef flat and inner reef flat.

It is recommended to prepare a harmonious environment among the parties concerned for good project implementation.

(2) Master Schedule

The schedule of the pre-qualification. tendering and construction are as follows:

1)	P/Q	7 July, 2005
2)	Tender Opening	31 August, 2005
3)	Award and Contract	21 November, 2005
4)	Construction Period	December 2005 to mid September 2006

6.5.2 Major Work Components and Quantities

The project in the transport sectors covers two Atolls: Laamu and Thaa. The following list indicates major works:

- 5 sites for the coastal protection works
- 2 causeways

- 11 island harbours

The Study Team carried out 4 times of recognizance surveys for observing the existing situation of damages and general conditions of the sites through direct interviews to the Island Offices. General plans and design drawings are to be prepared upon obtaining the technical study and survey results. All the works estimated from drawings are indicated in the format known as the bills of quantities.
Major work quantities of project are as follows:

Coastal Protection

- 1,380 m in length (Coastal Protection 900m plus protection within port premises 480m)
- Combination of rock mound type and seawall type
- Requires approx. 5,000 m^3 of rock and/or coral rock

Causeways

- 2 causeways in 1,110 m long in pavement length
- 15 m width with two traffic lanes of 4 m wide each, two pedestrian/cycling access ways of 2 m each, 1 m wide median and 1 m shoulders each.
- One bridge and 18 concrete box culverts
- 15,000 m^3 of sandy soils of backfilling
- 14,600 m^3 of rock armor to be imported
- 13,320 m^2 of bitumen sealing pavement or similar
- Seven lighting poles and connecting wiring

Island Harbours

- 11 island harbours
- 550 m long reconstruction of quay wall
- 150 m long reconstruction of seawall
- 1,100 m long reconstruction of breakwater
- Approx. 106,000 m^3 of dredging works at the harbour basins and approaching channels
- Apron pavement in 3 m wide with interlocking concrete blocks, approx. 6,000 m^2

Among these, the causeway will be financed by NPGA because they are the projects of most urgent requirement. Island Harbour related project might be partly financed by soft loan of JBIC, subject to the agreement between two governments.

6.5.3 Construction Schedule

It is assumed that the contract of JICA/JICS projects might be concluded by October, 2005 and construction will commence in the same month for 8 month period. In order to make a balance in work quantities and to provide more chance for the tenderers to get projects, works and projects are regrouped as follows:

- Coastal protection and island harbours regrouped in appropriate numbers
- Causeways from Fonadhoo Island to Maandhoo Island will make a group

According to the bar chart analysis, the required construction periods are estimated as follows:

- 8 months for the reconstruction of causeways
- 8 months for each island harbour group covering coastal protection

6.5.4 Construction Method Statement; Coastal Protection Works

(1) Basic Structural Type and Alignment

The basic structural type of coastal protection work is rock mound. The dike will be installed either along the existing beach or in the flat reef detached about 20 m off the existing coastal line.

(2) Site Conditions

Site is the flat reef and site condition is generally good. Subsoil condition is not confirmed by geotechnical borings; however, it is assumed to be mostly coral rock with partly sand deposit. Surface is generally flat and there is no obstacle to construction. No live coral has been found yet.

(3) Basic Construction Method and Procedures

Construction site is generally available in between the coconut forest and housing areas; however, negotiation with the land owners should be undertaken. Access to the site is provided by 5 m wide access road which is unpaved, but its surface condition is fairly good. Access is connected with island harbour nearby. There is no approaching method from the ocean side, since the water depth is too shallow to tow floating equipment. Only the land side access is available; thus, all the works could be possible from that side. A short temporary access will be installed connecting between the site and access roads, through which all the materials and construction equipment could be carried in.

6.5.5 Construction Method Statement; Causeway

(1) Background Conditions

In Maldives, the construction of causeway and the improvement of existing causeway are accomplished under the authority of the MPND. However reconstruction of damaged causeway by Tsunami is managing by MTCA.

(2) Basic Structural Type

The basic structural type of causeway is dike type consisting of sand core protected by rock armor on the exposed outer slopes. This protection work will be provided on both sides: the east (outer flat reef and ocean side) and west (inner lagoon side). Upper surface of dike will be paved bitumen sealing for traffic lanes and interlocking concrete blocks for pedestrians and cyclists. Water passage consisting of a bridge and concrete box culverts will be provided.

(3) Work Volumes of Causeway Reconstruction

Main work volume of causeway is shown in Table 6.23.

Table 6.23 Main Work Volume of Causeway

Main Works	Unit	Quantities	Reference
(1) Pavement	M2	13,320	Asphalt treatment (t=30)
(2) Revetment	M	1,743	
(3) Box culvert	M	160	2@1.300*900
(4) Sub structure			
Sheet pile	M	2040	
Capping Beam	M	82	
Steel pipe pile	M	180	
(5) Super structure	M2	234	Width 6.5 length 6.0m

(4) Site Conditions

Site is on the flat reef. Site condition is rather complicated because of seabed configuration changes after the causeway construction about 10 years ago.

Seabed condition in the east (ocean side) and west (inner lagoon side) are completely different.

The west side is generally more shallow by 0.5 m than west due to sand deposit transported by south to north coastal current drifting from the south inner flat reef. Sand is deposit due to no more flash out effect by current through the natural passage which was cut by existing causeway. Due to the existing causeway constriction, there is water head difference of 0.3 m between both sides. Outer reef side always keeps higher water head. This makes design of facilities complicated and construction methods difficult. Water depth is about the datum, LAT. Seabed condition varies by place and sand deposit, and water pond which the Tsunami washed out. This deposit might have been generated by the earth materials of causeway before. Previous causeway study report indicated this situation, "Study of a Road Project in Laamu Industrial Zone, Final Report, March 1993. MTI ".

The east side is the upper stream side and rather stabilized in terms of seabed configuration. Water depth is about 0.5 m below the datum. Subsoil condition is assumed as sandy layers with coral rock base. Surface is generally flat and there is no obstacle to construction. No live coral was found yet.

(5) Construction Site Information

1) Outline of Site

Access to the site is provided by 12 m wide access road which is unpaved, but its surface condition is fairly good. Similar to the coastal protection works, there is no approach method from the ocean side since the water depth is too shallow. It is only 1.8 m at the spring high tide. Only the land side access is available; thus, all the works could be carried out from the land side. Existing causeway has good access through which all the materials and construction equipment could be carried in. For the islanders use, additional space of 6 m wide should be prepared and installed besides the existing causeway structures. This access could be a part of permanent works of causeways.

For the Causeway No.1, construction site is available along the existing road. For the Causeway No.2, construction site is available along the existing road near the northern end of airfield.

2) Existing Facilities

In the west coast and near the Causeway No.2, there is an old earth jetty which could be reused after certain repair works. There is also a harbour in front of the Kadhoo Airport gate. Near the northern end of Causeway No.1, there is a fisheries port which a private company own. It is believed the Airport has an asphalt plant, which may be used to provide asphalt mixtures for the project.

3) Water Level

Water level on both side differs by 15 cm when open ocean is calm condition, and 30 cm when the sea is rather rough. It is believed that the water level raises waves breaking at the reef edges. It is also understood that kinetic energy is partly consumed and changed to static energy and this might raise the water level. Thus, it can be understood that about 10% of wave height could be the rise of water. This head generates high current velocity once a water passage is provided. It is observed by the Team that there is about 2 m/sec velocity at the existing pipe passage of 80 cm diameter. This indicates the necessity of careful construction when the passage is formed. Opening of the passage should be done only after its completion. Or temporary cofferdam should be installed just to cut the water flow to the west. For bridge construction, a dike should be constructed to maintain the water tight condition and so no high speed current will occur at the site until the completion of the bridge works.

(6) Collecting Sandy Soil from Seabed: Causeway No.1

The amount of sand required for backfilling is approximately 3,000 m^3. Approximately 1,200 m^3 of the sand material can be supplied from the excess sand generated through the excavation works and culvert installation. The remaining volume of 1,800 m^3 must be procured through other methods, with consideration to environment, cost, and engineering aspects. Two alternatives are proposed. Table 6.7.3 shows the location of the alternative sites and procurement methods. The two alternatives are then compared in terms of environment, cost, and engineering aspects in Table 6.25.

Table 6.24 Alternatives for Sand Material Procurement

	Location	Amount	Method
Alternative 1	Small island north of the	30mx30mx1m=900m^3	Excavation and dredging

	causeway. See Figure 6.7.2		with grab or backhoe
	Approximately 10 m from west side of the causeway See Figure 6.7.2	130mx15mx1m=1,950m^3	Dredging with grab or backhoe
Alternative 2	Two channels between the small islands north of the causeway. See Figure 6.7.2	30mx15mx1mx2=900m^3	Dredging with grab or backhoe
	Approximately 10 m from west side of the causeway (Same location to Alternative 1) See Figure 6.7.2	130mx15mx1m=1,950m^3	Dredging with grab or backhoe

Figure 6.25 Proposed Sand Procurement Sites for Causeway No.1

Table 6.25 Comparison of the Alternatives in Terms of Environment, Cost, and Engineering Aspects

	Environment	Cost	Engineering
Alternative 1	The water quality of the dead water area behind the island should be improved by excavating of the small island. Possible minor loss or disturbance to adjacent seagrass or coral.	\$2.5/m^{3}x2,850m^3=\$7,125	Excavation of the island could be time consuming.
Alternative 2	The water quality of the dead water area behind the island should be improved by deepening the channels. Possible minor loss or	\$2.5/m^{3}x2,850m^3=\$7,125	No major engineering obstacles.

	disturbance to adjacent seagrass or coral.		

There are no differences in cost between Alternative 1 and 2. From an engineering perspective, the excavation works of the island in Alternative 1 could be time consuming, whereas dredging works is only involved in Alternative 2. From an environmental perspective, both alternatives should improve the water quality of the current dead water area, though Alternative 2 should be more effective due to the larger water exchange area. Based on the above considerations, Alternative 2 is proposed as the better option for sand procurement.

(7) Collecting Sandy Soil from Seabed: Causeway 2

The amount of sand required for backfilling is approximately 12,000 m^3. Approximately 3,500 m^3 of the sand material can be supplied from the excess sand generated through the excavation works, and bridge and culvert installation. The remaining volume of approximately 8,500 m^3 must be procured through other methods, with consideration to environment, cost, and engineering aspects. Three alternatives are proposed. Table 6.7.5 shows the location of the alternative sites and procurement methods. The alternatives are then compared in terms of environment, cost, and engineering aspects in Table 6.26.

Table 6.26 Alternatives for Sand Material Procurement

	Location	Amount	Method
Alternative 1	Approximately 10 m from the west side of causeway See Figure 6.7.3	580mx15mx1m=8,700m^3	Dredging with grab or backhoe
Alternative 2	Sandy area west coast of southern part of Fonadhoo Island, which is approximately 3 km from the causeway.* See Figure 6.7.4	580mx15mx1m=8,700m^3	Dredging with grab or backhoe. Dredged sand will then be transported to the causeway with pick-up truck.
Alternative 3	New Thundi Port in Gan Island, which is approximately 10 km from the causeway.	8,700m^3	Utilization of dredged material from the new Thundi Port. Dredged sand will then be transported to the causeway with pick-up truck.

*: The exact location should be where there are no seagrass or corals and that is easily accessible to the road.

Figure 6.26 Proposed Sand Procurement Sites for Causeway No.2 (Alternative 1)

Figure 6.27 Proposed Sand Procurement Sites for Causeway No.2 (Alternative 2)

Table 6.27 Comparison of the Alternatives in Terms of Environment, Cost and Engineering Aspects

	Environment	Cost	Engineering
Alternative 1	Possible loss or disturbance to the adjacent seagrass and coral.	2.5US$/m^{3}x8,700m^3=21,750 US$	Some of the quality of the sand may not be suitable for backfilling due to the possible presence of anaerobic conditions and clay soil.
Alternative 2	Possible loss or disturbance to the adjacent seagrass and coral. Increase in traffic volume.	10US$/m^{3}x8,700m^3=87,000 US$ (Includes cost for transportation)	The quality of the sand should be adequate.
Alternative 3	Increase in traffic volume.	15US$/m^{3}x8,700m^3=130,500 US$ (Cost only for transportation)	The quality of the sand should be most suitable within the alternatives.

From an environmental perspective, Alternatives 1 and 2 may have some minor impacts to the adjacent seagrass and corals. The cost is lowest for Alternative 1. The cost of Alternative 2 and 3 is higher due to the long transportation distance to the causeway. From an engineering perspective some of the sand of Alternative 1 may be unsuitable due to the possibility of anaerobic conditions and presence of clay soil. At the moment it is difficult to determine the best option since each Alternatives has its positive and negative aspects. However, Alternative 1 appears to be the most feasible option, and if not adequate, then the other Alternatives may have to be utilized.

(8) Collection of Rock Materials and Concrete Aggregates

It is assumed that all rock materials and aggregate for the concrete works will be imported from nearby countries like India.

(9) Work Program

The work program is determined depend on each work volume to be introduced. In the work, critical pass will be mobilization, importation of armour rock and concrete aggregate, bridge foundation works, Box culvert works, sand collection and backfilling and slope revetment works. The required work period is estimated of eight months to ten months.
The works should cover the followings:

- Temporary dike to maintain safely constructing conditions against a high sped current originating from the unlimited volume of water, the sea.
- Temporary access to provide the islanders with the access with six meter wide.
- Environmental considerations should be kept into account for the dredging works and sand fill works.
- Sectional completion should be considered in the Causeway No. 1 providing that it shall be completed within six month after the commencement of works.

(10) Construction Sequence in Main Body; Causeway No.1

The center line of existing Causeway No.1 will be maintained as it is since the damaged area is limited in south half of west side and there is no space to remove the center due to the area limit by the Kadhoo Airfield. Reconstruction of Causeway No.1 will consist of the following execution orders, and sequence. Refer to Table 6.28 for the construction schedule of the Causeway No.1.

<u>West Main Body Construction</u>

1) Collection of rock materials and sandy materials of slope protection and backfilling.
2) Dredging or excavating of the existing natural sand bank at the north-west area.
3) Backfilling by sand at the damaged west face.
4) Placing geotextile sheet and armor rock on the slope except the location of the planned box culverts.

Concrete Box Culvert Construction

5) Prefabricating concrete box culverts and placing at the east half section first. Box culverts will be placed where the serious damages are observed.
6) Providing temporary water-stoppers and at the culvert entrance (East side) preventing a large amount of water leakage into the culvert under 30 cm head.
7) Excavating the existing dike or backfilled earth and placing the west half of box culvert and connect with the east one.

Surface Treatment, Pavement and Safety Installation

8) Reinstallation of the lighting poles will be carried out accordingly
9 Provision of pavement and surface works will be carried out.
10) Sign boards will be install at each end of causeway indicating separating use between the vehicle traffic and pedestrian/cycling.

Coastal Protection at Connection Areas between Main Island and Causeways

11) Coastal area at the connecting areas between main island and causeways will be protected against erosion and wave run-up.

(11) Construction Sequence in Main Body; Causeway No.2

The center line of existing Causeway No.2 will be removed by 7 m east ward to escape the serious damaged and washed-out seabed. This shifting does not affect the area limit for the Kadhoo Airport. The reconstruction of Causeway No.2 will consist of the following execution orders and sequence. (See Figure 6.29)

East Main Body Construction

1) Collection of rock materials and sandy materials of slope protection and backfilling.
2) Dredging or excavating of the sand along the new east edge line for armor rock foundation.
3) Installation of the seabed foundation for slope armor rock.
4) Placing geotextile sheet and armor rock on the slope except the location of the planned box culverts.
5) Backfilling by sand at the newly widen area at east.
6) All the construction period, the contractor should provide a safe access for the islanders of 6 m wide unpaved space.

West Main Body Construction

7) Dredging or excavating of the sand bank at the west area.
8) Backfilling by sand at the damaged west face.
9) Placing geotextile sheet and armor rock on the slope except the location of the planned box culverts.

Bridge Construction

10) Temporary dike construction at the east of bridge site.
11) Driving steel sheet piles shaping two boxes and installation of tie-rods maintaining the scheduled shape.
12) Driving sheet-pile box piles for the pier foundation
13) Excavation of the seabed and providing apron consisting of rock bed against high speed current.
14) Sand filling in the enclosed area by sheet pile wall
15) Concrete capping and beam at the top of sheet piles for forming the abutment and piers to support the bridge consisting of reinforced concrete superstructures.
16) Placing reinforced concrete bean and slab constituting the bridge.

Concrete Box Culvert Construction

17) Prefabricating concrete box culverts and placing at the east half section.
18) Temporary dike construction along the box culvert area.
19) Or providing temporary water-stoppers and at the culvert entrance (East side) preventing a large amount of water leakage in to the culvert under 30 cm head.
20) Excavate the backfilled earth and placing the west half of box culvert.

Surface Treatment, Pavement and Safety Installation

21) Reinstallation of the lighting poles will be carried out accordingly
22) Provision of pavement and surface works will be carried out.
23) Sign boards will be install at each end of causeway indicating separating use between the vehicle traffic and pedestrian/cycling.

Coastal Protection at Connection Areas between Main Island and Causeways

24) Coastal area at the connecting areas between main island and causeways will be protected against erosion and wave run-up.

Causeway No.2 in May 20, 2005

View from the North

Causeway No.1 in May 20, 2005

View from the south

Whirlpool by head difference

between the east and west.

Table 6.28 Construction Schedule of the Causeways No.1(Mandhoo/Kadhoo)

No.	Description
	Tender Open
	Tender Evaluation
	Contract
	Mobilization
	Earth Breaking Ceremony
1.0	Kadhoo - Maandhoo Causeway (6 Months)
1.1	Main Body
1.1.1	Excavation 1
1.1.2	Foundation mound
1.1.3	Core buckfilling
1.1.3A	Material collection
1.1.4	Saving buckfilling by exisiting dike
1.1.5	Armor rock
1.1.6	Geotextile sheet
1.1.7	Curbs
1.1.8	Subbase
1.1.9	Surface
1.1.10	Lighting Poles
1.2	Bridge
1.3	Concrete box culverts
1.3.1	Excavation 1
1.3.2	Foundation mound
1.3.3	Use of existing dike
1.3.4	Use of existing armor rock
1.3.5	Concrete of CB culverts
1.3.6	Reinforcement of CB culverts
1.3.7	Joints
1.4	Coastal protection
1.4.1	Excavation 1
1.4.2	Foundation mound
1.4.3	Core buckfilling
1.4.4	Armor rock
1.4.5	Geotextile sheet

Table 6.29 Construction Schedule of Causeways No.2 (Kadhoo/Fonadhoo)

No.	Description
2.0	Fonadhdhoo - Kadhoo Causeway (10 Months)
2.1	Main Body
2.1.1	Excavation 1
2.1.2	Foundation mound
2.1.3	Core buckfilling
2.1.3A	Material collection
2.1.4	Saving buckfilling by exisiting dike
2.1.5	Armor rock
2.1.5A	Material collection
2.1.6	Geotextile sheet
2.1.7	Curbs
2.1.8	Subbase
2.1.9	Surface
2.1.10	Lighting Poles
2.2	Bridge
2.2T.1	Tenporary Dike and Access
2.2.1	Excavation 1
2.2.2	Foundation mound
2.2.3	Core buckfilling
2.2.3A	Material collection
2.2.4	Saving buckfilling by exisiting dike
2.2.5	Armor rock
2.2.6	Sheet piles
2.2.7	Tie-rids 36mm L=
2.2.8	Tie-rids 36mm L=
2.2.9	Concrete of main abutment
2.2.10	Reinforcement of main abutment
2.2.11	Piling
2.2.12	Concrete of Piers
2.2.13	Reinforcement of piers
2.2.14	Subbase
2.2.15	Surface
2.2.16	Bridge Concrete
2.2.17	Bridge Concrete reinfoecement
2.2.18	Prefabrication
2.2.19	Reinforcement
2.3	Concrete box culverts
2.3.1	Excavation 1
2.3.2	Foundation mound
2.3.3	Use of existing dike
2.3.4	Use of existing armor rock
2.3.5	Concrete of CB culverts
2.3.6	Reinforcement of CB culverts
2.3.7	Joints
2.4	Coastal protection
2.4.1	Excavation 1
2.4.2	Foundation mound
2.4.3	Core buckfilling
2.4.4	Armor rock
2.4.5	Geotextile sheet
	Final Test
	Taske over
	Handing Over Ceremony
	Demobilizsation

6.5.6 Construction Method Statement; Island Harbours

(1) Basic Structural Type

As shown in Section 6.6.11, basic structural type of island harbours are gravity structures for quay wall, seawall, jetty and breakwater. Most of existing structures are rock mound or concrete bag mound, covered by thin concrete above the mean sea level. Proposed structural type is rather improved compared to the existing traditional style. Proposed structures are basically concrete structures that can avoid easy damages by external forces and water pressures. All the designs are carried out for the normal conditions other than the tsunami condition, since the tsunami-durable structures would be so expensive.

Damaged area will be reconstructed or repaired depending upon the grade of the tsunami damages. Construction will be done not only the damaged part, but also for the area required for the construction in order to cover the working space and ensure the safety of facilities to remain.

(2) Site Conditions

Site is the old flat reef and site condition is generally good. No boring investigation was carried out. Subsoil condition is assumed to be sand or coral rock with partly sand deposit. Apron surface is generally flat and there is no obstacle to construction. No live coral at the harbour basin has been found yet at the site by diving investigation of the Study Team. Water quality is rather worse by concentration of solid waste and transparency is less than 3 m. This situation might affect the underwater works by divers. Wave condition is very calm due to the double protection of outer reef and inner reef flat.

Most of island harbours are constructed at the center of village. Thus access to the site from land is provided by 6 to 8 m wide access road which is unpaved, but its surface conditions is fairly good. There are wide apron and port park area just behind the quay wall. These can be applied as the temporally construction area; however, negotiation with the island office should be undertaken.

There is good approach method from the ocean side; however, width of channel and its water depth is limited. Thus both the land side access and seaside access are available. Berthing by 20 m long dhonis is the usual pattern at the island harbour. A 40 m long landing craft owned by MMCC was berthing at the inner basin of the Fonadhoo Island Harbour on18 May 2005. This craft might work well for the reconstruction works. Temporary landing site will be installed at the quay wall or natural seawall connecting to the apron thus site, through which all the materials and construction equipment could be carried in.

(3) Basic Construction Method and Procedures

Basic construction method and procedures of harbour facilities are rather simple. The following is assumed as the quay wall construction method, with seawall and breakwater at the typical harbour.

Quay Wall and Seawall

1) Preparation of materials
2) Preparation of equipment
3) Setting up the construction site by stage and marking at the site
4) Giving notice to the island chief that indicates the construction details
5) Divers inspection on the existing condition of foundation areas.
6) Excavation of the existing backfill for the reconstruction site.
7) Demolishing the existing facilities
8) Reconstruction of the proposed facilities
9) Backfilling and section completion

Breakwater

1) Preparation of materials
2) Preparation of equipment
3) Giving notice to the island chief that indicates the construction details
4) Reshaping the breakwater and adding coral rocks as necessary

Dredging

1) Preparation of equipment
2) Giving notice to the island chief that indicates the construction details
3) Excavating seabed and carry out to dumping area

Dredging volume per island harbour is about 9.600 m^3; thus, there is no requirement to introduce dredgers. Excavator mounted on the barge can carried this out.

6.7.7 Environmental Consideration

For the environmental considerations, refer to the Chapter 10..

6.7.8 Cooperation Among Parties

(1) Cooperation Committee

It is proposed to set up a cooperation committee for overseeing each contract. Committee will see that routine communication is maintained among the parties: Island community, the contractor and the engineer. They can discuss anything for the construction related aspects for improving circumstances.

(2) Safety Maintenance

All the works are reconstruction and repairing existing facilities. Thus, the works will be implemented in the same area where users handle cargo and tuna catches. These daily activities may disturb the construction works. Or the works may disturb the user's activities at the facilities.

Safety of users during the works shall be ensured by the contractors. Also the working condition as specified in the contract should be provided for the contractors.

Coastal protection

As mentioned above, rock materials will be transported only by road access from the nearby harbours. Truck will go through the village and carry the necessary construction materials and equipment to the site.

Causeways

Access of islanders shall be ensured by the contractors. Islander should accept the narrowness of access during the reconstruction. Such access should have the following characteristics:

- Effective width is 6 m
- Marking poles every 20 m indicating the construction site
- Running speed of construction vehicles and islanders should be within a safe range.
- Deck height of temporary access for the islanders should be 1.7 m or higher above the datum, LAT.
- Islanders should accept not to use the temporary access 24 hours a day.

Island Harbours

Scale of the reconstruction is minor; however, site length for damaged quay wall will reach 50 to 100 m within the total 200 m long quay wall. This means that harbour users can utilize the remaining parts of it.

It is essential to have harmony between the harbour users and the contractors. The contractors should ensure that users can share maximum length, for example 100 m, and issue reports from time to time on the progress of works and schedule for the future. Construction site should be clearly marked by the contractors. The contractor should light up the site at night to prevent accidents.

6.6 Cost Estimation

6.6.1 Basic Considerations on the Costing

(1) Costing Criteria

The basic costing criteria for the project are as follows:

- Time of estimation: May 2005
- Exchange rate: 1 US$= 106.24 Yen
- Engineering cost: Covered

- Tax and duties: Basically to be provided of Tax Exemption
- Unit rates: Taken from similar project in domestic and foreign, May 2005.
- Contingency: 10％ to 20% mainly for the physical changes happening
- Estimate construction Period:
  Causeway of 8 Months to 10 Months
  Island harbour of 6 to 8 Months by the damage grade
  Costal protection of 6 Months by the damage grade

The Study Team spent time for setting up the unit rates taken from similar project in domestic and foreign sites. For these purpose, the following estimation data were referred to.

- Descriptions in NRRP
- Similar project experience in domestic project, namely MTCA/MPA projects.
- Similar project overseas
- Estimation by MTCA and MAC
- Estimation by the Team based on the formula to be applied

It should be noted that MTCA was well consulted with by the Team not only in technical discussions but also the cost estimation. MEC also gave advices on the structural types and environmental aspects.

Note: In this Section, MTCA is still remaining as the line ministry for supervising the project. Due to the recent reorganization of ministries in GOM, successor as the line ministry is nominated to MTC: Ministry of Transport and Communication.

6.6.2 Basic Contents of Cost Estimation

(1) Classification

In this project, there are two project categories in terms of urgency, namely the urgently required projects and the projects required in mid-term range of time factor for the social recovery. All the projects belong to the infrastructures, which the islanders can use or should use for their lives in. The urgent works shall be undertaken immediately in order to maintain lifeline of them. Reconstruction of damaged causeways at Fonadhoo belongs to this category, while some of island harbours in Laamu Atoll and Thaa Atoll are classified to the medium-term project. The former require detailed cost study to fix and prepare budgeting. The latter, however, requires only preliminary cost to evaluate the project viability study.

So that accuracy of cost estimation is slightly different between theses two groups.

(2) Tsunami Inflation

MTCA officers declared that cement price has raised by 15% since the beginning of the year 2005. Urgent rehabilitation on the damaged facilities should be undertaken without delay. It is assumed that approx. US$100milion will be spent annually for the reconstruction for next three years. IMF estimated that it results the consumer price rises by 7% a year.

It is assumed that construction cost might be hike to 10% at least. However this is not considered in the cost estimation due to various uncertainty.

(3) Consideration to Causeway

1) Composition of the Project Cost for Urgent Rehabilitation

The project cost is comprised of the sum of the construction cost and the engineering service cost. The contingency is included in the construction costs.

The construction cost consists of direct cost direct cost.

The direct cost is calculated as sum of the multiplication of the unit rate and quantity of each work item. The unit price consists of material cost, labor cost and equipment cost of each work item, and also for so called as general item covering mobilization demobilization, site office and laboratory installation.

Table 6.28 Cost Component of Project

Items		Remarks
1. Construction		
1.1 Direct cost		
	Mobilization	As general items
	Demobilization	As general items
	Equipment cost	
	Material cost	
	Labor cost	
1.2 Indirect cost		
	Transportation	
	Office	Including laboratory and residence
	Temporary works	For construction work
	Temporary works and Security	For existing traffic flow
	Countermeasure of Environment	For construction
	Testing	For quality and environment control
	Insurance	
	Overhead	
2 Contingency		
	Physical	
	Price	
3Engineering Cost	Supervision	

2) Direct Costs

The direct cost that is a part of the construction cost is calculated as the sum of the multiplication of the unit price and estimated work quantity derived from the final design drawings ans specifications. The unit price is estimated using applicable unit rates of labor, equipment, and material in May 2005. The unit price is further adjusted applying the production ratio taking the actual efficiency of works in the marine environment which easily affects to the productivity of site works.

3) Indirect and Other Costs

Indirect cost generally includes the items shown below.

1) Transportation

Cost of Worker, staff, accommodation material and construction equipment

2) Office, labor and staff residence

Cost of housing, water and electric supply and sewage system

3) Temporary work

- Construction of Temporary Access for public use
- Detour dike for construction of Causeway Bridge and Box-culvert
- Cost of construction, maintenance and dismantling of detour dike

4) Indemnify for interference with traffic and adjoining properties

Cost of fence flagging and lighting for conducting the traffic

5) Environmental countermeasure and monitoring for construction

Cost of countermeasure and monitoring

6) Testing cost for quality control

Cost of testing

Other Costs cover.

1) Demobilization and site clean up: Cost of machine and office demobilization
2) Insurance: During the construction and retention period
3) Overhead: This cost is including general administration and field management.

6.63 Estimated Costs

(1) Cost Summary

This sub-section deals with the project cost summary on the reconstruction and repair of the coastal protection works, causeways, and island harbours. As a matter of decision, grade of structural type was upgraded slightly as recommended in NRRP. Team provided a wide alternative structure for selection of better solution. There are two project categories in which the grade of design accuracy is slightly different.

- Conceptual Design; the reconstruction of the coastal protection works and island harbours. (as Mid-term Development Project)
- Detailed Design; the reconstruction of causeways. (as Urgent Project)

It is anticipated that urgent projects should be implemented as soon as possible. Thus it is requested that the cost for the causeways has estimated in detail.

Total cost on the reconstruction of the coastal protection works, causeways, and island harbours is 18.47 million US$ or 1.96 billion Yen. This covers the following:

- Direct Construction Costs 16.0 million US$ (or 1.70 billion Yen)
- Engineering Costs 2.50 million US$ (or 0.266 billion Yen)

The basic matrix of Project components by Location in the transport sector is shown in Table 6.1.1.

This report covers all these facilities. However description of them is separated into two Sections: namely, Island Harbour Section including the Coastal Protection, and Causeway Section.
Project components may be changed if it can provide a better technical and economical solution.

(2) Cost Breakdown by Project Components
Cost breakdown by three project components are shown below.

Table 6.29 Project Cost Summary

	Works	Construction Cost Million US$	Engineering Cost Million US$	Total Million US$	Total billion Yen	Notes (Share)
1	Island Harbours	10.68	1.78	12.46	1.32	67.3%
2	Causeways	5.29	0.72	6.01	0.64	32.7%
3	Total of 1 plus 2	15.97	2.50	18.47	1.95	100.0%

Rate: 1 US$=106.24 Yen

Island harbours cover also the required costs of Channel Dredging Works and Coastal Protection Works.

Total project cost amounts to 18.47 million US$ or 1.96billion Yen. Among this, required cost for the coastal protection works and island harbours amounts to 12.46 million US$ or 1.32 billion Yen or about 67.3% of the total. Required cost for the causeway works amounts to 6.01 million US$ or JY 0.64 billion or about 32.7% of the total.

(3) Preliminary Cost Breakdown by Island Community
The required preliminary costs for each 14 islands estimated are shown in Table 6.30. This indicates also the cost breakdown by the facility. Cost for the causeway in this preliminary stage estimation (May 2005)was kept in the detailed cost estimation(June 2005) due to the fixed budget by NPGA.

Table 6.30 Preliminary Cost Estimation of the Island Harbour and Related Works

	Name of Islands	US$	I. Harbour Stuructures	I. Harbour Dredging	Coastal Pro.	Causeway
A	Island harbours					
	Coastal Protection					
1-1	Isdhoo	281225	Structures	Dredging		
1-2	Isdhoo/Klaidhoo	449640	Structures	Dredging	Port*	
2	Maabaidhoo	876119	Structures	Dredging	Port	
3-1	Thundi	350000			Coastal Pro.	
3-2	Mathemaradhoo	735000			Coastal Pro.	
3-3	Mukrimagu	735000			Coastal Pro.	
4	Fonadhoo	1063395	Structures	Dredging	Port	
5	Maavah	689772	Structures	Dredging	Port	
	Laamu Total	**5180151**				
1	Dhiyamigili	2844080	Structures	Dredging	Coastal Pro.	
2	Guraidhoo	530110	Structures	Dredging	Port	
3	Thimarafushi	1331505	Structures	Dredging	Coastal Pro.	
4	Veymandoo	1474008	Structures	Dredging	Port	
5	Kibidhoo	632275	Structures	Dredging		
6	Hirilandhoo	466698	Structures	Dredging		
	Thaa Total	**7278676**				
	Total Island H.	**12458826**				
	Breakdown of Total					
	(Construction + Conti)	**10678959**				
	(Engineering Cost)	**1779868**				
B	**Causeway**					
1	**Causeway No.1**					300M
	Maandhoo-Kadhoo	896500				Causeway
	Engineering 15 %	122250				
	Subtotal	1018750				
2	**Causeway No.2**					900M
	Kadhoo -Fonadhoo	4389000				Causeway
	Engineering 15 %	598500				
	Subtotal	4987500				
	Construction	5285500				
	Engineering	720750				
	Total Causeways	**6006250**				
C	**Grand Total**	**18465076**				
	(A + B)					
	Breakdown					
	Construction					
	Engineering	**2500618**				
	General Notes	Condition of Preliminary Cost estimations				
	1	Contingency:	20% for Island Harbors including Coastal Protection			
			10% for Causeway			
	2	No tax				
	3	Engineering:	20% for Island Harbors including Coastal Protection			
			15% for Causeway			
	4	Port* means coastal protection works beside the port area.				

(4) Causeway Costs

The required cost for causeway is estimated based on unit price in May 2005. Refer to Table 6.31.

Table 6.31 Required Cost of Causeway

No.	Description	Contents	Cost: million US$	Remarks
1	Indirect Cost		1.00	
2	Direct Cost			
		General Items	1.09	Mobilization etc.
		Causeway No.1	0.56	
		Causeway No.2	2.60	
		Total Direct Cost	4.25	
3		Total	5.25	

The tender price of the causeways at the contract were 713,701,000 Yen.

6.6.4 Detailed Discussions

(1) General Descriptions

Tender documents are prepared for the tenderers to submit their quotations with necessary data and information. Cost estimation by them will be carried out by their knowledge and business considerations. The cost estimation is actually much more complicated and requires a wide range of knowledge in construction, natural conditions and characteristics of the permanent structures. Among these, selection of applied construction methods is the most important in the costing of the marine construction.

Tenderers can install their own prices independently based upon their experience, know-how, available equipment and manpower. Normally the price should cover all expenses covering materials, laborer cost, fuel cost, equipment/plant costs, tax and duties, transportation costs, mobilization/demobilization cost, environmental preservation costs, and temporary work costs.
It is not clear that once the reconstruction starts everywhere in Maldives, it will hike the unit price of every input including the materials, fuels, laborers and plants. It is strongly expected that GOM will take necessary measures and actions to keeps the prices at the present level, otherwise the scope of works should be reduced.

(2) Materials and Products Unit Cost

Cost estimation covers the material and product costs at the project site of two atolls: Laamu and Thaa. Material and product costs total about 40% in the marine construction works excluding dredging. Island harbour structures consist of high material cost totaling 50% against the total direct costs. Construction of causeway and coastal protection works also includes material cost totaling 50% against the total direct costs.

Table 6.32 indicates a list of unit cost of major construction materials together with local availability and major import origins.

Table 6.32 List of Unit Cost of Major Construction Materials

	Descriptions	Unit	US$
1	Rocks	ton	35
2	Fresh water sand	ton	145
3	Concrete aggregate	ton	137
4	Cement	ton	193
5	Reinforcement	ton	1047
6	Steel Sheet Piles	ton	1260
7	Steel Pipe Piles	ton	1495

It is recommended to apply the locally available materials for the works as much as possible. Unit price of materials is largely affected by the transport costs. Most materials make one stop at the Male' Commercial Harbour then transit to the destination after the necessary documentation and customs clearance. Unit cost should cover the required cost for this processing.

(3) Laborers Unit Cost

The cost estimation covers the labor costs at the project site of two atolls: Laamu and Thaa. Most laborers might be temporary immigrant workers of Moldavian origin. It is expected that the contractor can employ islanders as much as possible before coverage by the immigrants. Cost covers salary, pension cost and others including 13 months payment as enforced in the laws and regulations in Maldives. Construction workers consist of three categories: namely, foreman, skilled workers and unskilled workers. Minimum wedge of Maldivian government workers is 2,000 Rf. increasing by 600 in two years ago. This translates to 150 US$/month or 1 US$/hour. Immigrant workers get about US$2/hour covering the basic wage and allowance.

Table 6.33 List of Unit Wages including Indirect Cost of Major Work Categories

No.	Descriptions	Unit	US$
1	Diver	US$/day	47
2	Operator	US$/day	39
3	Skilled Labor	US$/day	31
4	Unskilled labor	US$/day	24
5	Forman	US$/day	39
6	Carpenter	US$/day	31
7	Driver	US$/day	35

(4) Fuel Unit Cost

Civil works including the marine construction requires a large amount of fuel when the project covers dredging and earth works. Major works in the causeway construction requires dredging, excavation and backfilling of the main dike body by sand, to be dredged nearby. Cost estimation covers the fuel costs at the project site of two atolls: Laamu and Thaa. It is assumed that the contractor might carry the necessary fuel in his barges.

Table 6.34 A List of Unit Cost of Fuel and Lubricant Oil

N0.	Descriptions	Unit	US$
1	Diesel Oil	Lit.	0.553
2	Petrol	Lit.	0.558
3	Kerosene	Lit.	0.592
4	Lubricant Oil	Lit.	2.35
5	Lubricant Oil	Lit.	4.00

(5) Constructional Equipment and Plants Unit Cost

Cost estimation covers the equipment and construction plant costs at the project site of two atolls: Laamu and Thaa.

Coastal protection works are planned at the coast facing to the open ocean side and consist of only rock works along the coastal area. Maximum size of rock is less than 500 kg per piece and the works can be done from the land side since the water depth is too sallow to tow the barges and access to site from the ocean side is dangerous due to wave breaking. Reconstruction of the causeway has the same conditions as coastal protection work sites. All the works will be carried out as land side works. This simply indicates a dredge will not be employed. Only excavators can approaching the site from the land side. They will go to the site from Fonadhoo Island, Kadhoo Island or Maandhoo Island through the existing damaged causeway. Repairing works at the island harbours consist of reconstruction or part repairing works of quay wall, seawall, and breakwater. The works also cover the basin dredging and channel dredging. All the works except the dredging can be carried out from land side.

Most of works consist of earth works, rock works, and concrete works. Due to the necessity of a bridge and concrete box culvert passage provision at the causeway, pile driving works including steel sheet piles and steel pipe piles are required in order to ensure the structural safety of a bridge abutments and piers against strong current at the openings. It is recommended to apply the locally available equipment and construction plants for the works as much as possible. Unit price of equipment is largely affected by local availability. It is assumed that availability study is required to cover the areas including Male' and similar project sites at the other island.

Local availability study indicates there are certain categories of equipment in Maldives. In case of temporary imports, most plants have one stop at the Male' Commercial Harbour and then transit to the destination after the necessary documentation and customs clearance.

Table 6.35 A list of Unit price of Equipment and Construction Plants by Necessity

No.	Descriptions	Unit	US＄	Notes
1	Bulldozer	Hour	45	D51
2	Dump Truck	Hour	31	10ton
3	Backhoe	Hour	115	1.4m3

4	Wheel Loader	Hour	102	3.5m3
5	Vibration Hammer	Hour	42	90kw
6	Hydro-shovel	Hour	102	3.5m3
7	Truck Crane	Hour	61	25tons
8	Soil Compactor	Hour	9	4tons vibration

It is assumed that there are no large scale mobilization costs in the project. Only a pile driver, several dump trucks and excavators might be enough. Several small barges might be required only for supplemental purpose. Thus, there is very little floating equipment requirement. It is expected all the equipment including floating ones could be available at Maldives; thus, no large scale mobilization and demobilization are required for the project

(6) Tax and Duties

The projects are basically exempted from taxation in Maldives. In case the contractor imports construction materials, he is not requested to pay import tax and customs. In case the contractor imports temporary equipment, he is also not requested to pay tax, or pay temporarily a certain amount as the bond to be refunded after the works are completed. However the most cases, it is very difficult to separate part of the tax already paid. Thus it is prudent that unit cost for the materials and equipment already available in the Maldives simply follow the market prices.

(7) Transportation Cost

Cost estimation covers the required transportation costs to and from the project site of two atolls: Laamu and Thaa. As mention earlier, it is recommended to apply the locally available materials and equipment for the works as much as possible. Unit price of materials and equipment is largely affected by the transport costs. Most of imported materials have one stop at the Male Commercial Harbour and then transit to the destination after the necessary documentation and customs clearance. Maybe the procedures can be simplified for example to exempt documentation for the reconstruction project to the damaged facilities by the Tsunami.

(8) Mobilization Cost and Demobilization Costs

Cost estimation covers the required mobilization cost and demobilization cost to and from the project site of two atolls: Laamu and Thaa.

As earlier discussed, it is assumed that there are no large scale mobilization costs in the project. Thus there is very little floating equipment requirement. It is expected that all the equipment including floating ones is available at Maldives; thus, no large scale mobilization and demobilization is required for the project. However it is supposed that the concentration of the reconstruction works might trigger a hike in the local price and require importing them.

(9) Environmental Preservation Cost

Cost estimation covers the required cost for the environmental mitigation measures at the project site of two atolls: Laamu and Thaa. Necessary discussion was carried out between the environmental expert of the Study Team and experts in MEC. MEC provided the basic procedures for clearance of environmental regulations. IEE of causeway and screening data were prepared by the Team and were commented on by MEC. One of the comments covers the necessary measures to be taken during the dredging works.

Table 6.36 List of Works for Environmental Preservation

	Descriptions	Notes
1	Silt Protection Curtain	For entire length of Causeway
2	Environmental monitoring	Teat and Analysis Fee in US$20,000
3	Observation works	Covering in monitoring seagrass/coral
4	Others	

(10) Temporary Works Cost

Cost estimation covers the required cost for the temporary works at the project site of two atolls: Laamu and Thaa. Temporary works are required for installation of permanent works. Works should cover the temporary works necessary to complete the whole works. The temporary works can be subdivided by two categories: namely,

A. Temporary works where the contractor can arrange the method by his opinion. Temporary works except mobilization and demobilization costs are normally to be covered by the unit rate in the permanent works. All the necessary temporary works to install or to supply a certain item should be including in it.
B. Temporary works which the client specifies in the contract documents for the implementation of the project. For this, the contractor should follow and comply simply with the documents. These might cover the following:

- Provision of the temporary access for (six meter wide at +1.7m crown height or higher) ensuring safety of islanders commuting among the islands.
- Traffic safety control
- Temporary dike to protect the natural current against the works
- Others as required

(11) Engineering Cost

Cost estimation covers the required cost for the engineering and construction supervision at the project site of two atolls: Laamu and Thaa. Engineering is 15% to 20% of the construction costs. However, these costs are separated from the construction costs. Engineering cost covers the following:

- Conceptual design
- Basic Design, and preliminary cost estimation
- Detailed design including planning, design and design calculations and preparation of tender documents
- Detailed cost estimation

(12) Contingency

Contingency cost for the physical changes and price modification is taken into consideration in the preliminary cost estimation. Rate of contingency is 10% to 20% of the direct construction cost. Most probable changes may involve in this project is soil conditions. There is no soil data at the site. The Team collected and evaluated the geotechnical conditions for four projects as follows:

- At the north
- Male' seawall construction projects
- Maandhoo Fisheries Port project
- At the South

As a result, the available four boring data at the Maandhoo fisheries port project was taken for all the projects. This is located at the west side of Maandhoo Island which is very close to the target causeways. This indicated the general soil condition as follows:

- Generally sandy layers are prevailing
- Standard penetration values (N values) exceeding 40 around minus 12 m depth. It shows the bearing stratum at this level.
- Four boring holes indicate a similar condition.

This should be verified by the boring at the site especially at the construction site of a bridge of Causeway No.2. New boring at Causeway No.2 is carrying out at present (end of July 2005). This data will apply to the design and Tender Documents immediately after the conclusion of boring.

In the final cost estimation of the causeway in June 2005, no contingency is taking into account, since the construction period is short and almost no physical uncertainty.

6.6.5 Cost Study of Causeway

(1) Estimated Unit Price with Construction Products

Quantity of construction works was estimated from the design drawings such as plans, typical cross sections and general view of structures.

Cost items and units were counted out by work items instead of individual materials; for instance, pavement works were counted at the unit price per carriageway length.

For the cost estimation, each cost item is conceived of in three stages: plant product, site products, and work items. The work items conform to cost items for unit price contracting. Plant products and site products are the items of the breakdown of each work item. Specially, plant products are materials produced and delivered by a field plant, such as concrete mixture. Concrete mixture is transported, placed, compacted and cured, which is a site product. Work item is, for example, asphalt pavement for causeway consisting of site products: sub-base course, asphalt treatment B and asphalt treatment A. The unit price of each work item, such as per meter in case of pavement, is multiplied by the quantity calculated through designing, in estimating each cost item.

Plant product items, site products items and work items are listed in Table 6.37.

Table 6.37 Items of Products and Works

Products and Work Description	Unit	Price (US$)
(1) Plant Products		
Mixed concrete class A	M3	391
Mixed concrete class B	M3	378
Mortar	M3	92
(2) Site Products		
Subbase course	M3	41
Prime coating	SQM	3.2
Asphalt treatment (B)	SQM	7.3
Asphalt treatment (A)	SQM	12.0
Manual excavation	M3	38
Forming for concrete works	SQM	33
Reinforcing for concrete works	Ton	1197
Concrete Class 1	M3	433
Concrete Class 2	M3	419
(3) Works		
Excavation	M^3	5
Embankment fill	M^3	7
Removal of the Existing Revetment	M	18
Structure Excavation	M^3	22
Backfilling	M^3	9
Bituminous pavement	M	139
Median(Curb & selected fill)	M	25
Curb	M	22
Guard Blocks	Piece	31
Revetment for Slope	M	844
Culvert Apron	M	541
Bridge Abutment Protection	Place	13,926
Passage Bed Riprapping	M	2,743
Cobble Stone Basement	SQM	20
Box-Culvert (2@1.3m x 0.9m)	M	2,109
Steel Sheet piles	M	109
Capping beam	M	1,812
Steel pipe pile	M	197
Pier beam	M	5,870
Bridge slab	Place	35,274
Road Lightings	Places	2,330

Note: These work unit cost covers no indirect costs.

(2) Estimation of Indirect Costs for Proposed Causeway

Indirect cost for the causeway is estimated for reference to verify the budget fixed already.

Table 6.38 Indirect cost

Unit; 1000 US$

Items and Coverage	Estimated Cost
(1) Temporary work	65.7
(2) Indemnify for interference	10.0
(3)Environmental countermeasure	33.6
(4) Testing cost for quality control	30.0
(5) Insurance	180.0
(6) Overhead	684.0
Total	1,003.3

Diving for quay wall damage observation at Hirilandhoo by the Study Team, May 14. 2005.

6.7 Recommendations

(1) Quick Disbursement

Quick response to the various improvements requested by affected people due to tsunami should be a most important aspect. They require materials, facilities and spiritual help and assistance for survival. They will welcome the better works delivered in two months rather than the best ones delivered in two year. Thus the key focus of the project should be “time conscious planning”. Also it should be kept in mind that reconstruction should be prepared well as permanent works and provide a durable long lasting life. Construction method should be carefully arranged to minimize the disturbance to the natural environment, as requested by MEC.

(2) Quality Insurance and Design Base

On page 66 in the footnotes of NRRP, the following statement is provided. The Study Team has seriously taken this logic into account.

Note:

The total cost of reconstruction for the transport sector is more than the amount reported in the Joint Assessment Report. The increase amounts to US$ 48.1 million. This is because the plan for reconstruction envisages the use of better and more reliable technologies in harbour construction than before. The seawalls and breakwaters built using traditional construction methods will lead to cracks and often the collapse of structures resulting from scouring underneath and the seepage of water through these structures. Although the initial investments are higher in these estimates, it will substantially reduce the long-term cost of repair and maintenance or reconstruction.

During the site investigation conducted by the Team, traditional structures of seawall and quay wall were observed at every island harbour. The traditional structural type is coral mound dike with lining of thin concrete layer at the upper section. Top elevation is about +2.00 m above the datum. Crown width varies from 1.2 m to1.7 m. Front surface has slightly inclining in slope of one to three. This coral is often replaced by concrete in bags. Combined structures of these two were also observed. About one third of these structures are damaged with cracks 2 mm to 5 mm. More serious damages than these are also observed. In case of wide crack of 20 mm or more, repair will be determined subject of the investigation results. Structural weakness of these traditional quay walls is assumed as follows:

- Back-filled fine material is easily washed out by the changes of tidal level,
- Sand under the coral rock basement might be sucked down as sediment,
- These events may have been accelerated by the tsunami actions.

In order to resolve these problems, the Study Team has prepared alternative design of quay wall and seawall.

(3) Environmental Considerations

It is recommended to provide necessary environmental mitigation measures during the reconstruction works, such as dredging and reclamation. The Study Team has been advised by MEC to provide such note in the technical specifications. Introduction of silt-curtain by the contractor will be specified in order to reduce sediment dispersion. MEC has also advised that underwater blasting is prohibited near the live coral areas. Seawater pollution inside the harbour basin was observed by the Study Team for almost every harbour. This is due to the limitation in water exchange of the harbour basin, which was more prominent with harbours with long channel. Also wastes from fisheries activities might also worsen the water quality. This is a difficult issue to solve since quay wall locates at the end basin and fisheries are the main industries in all the islands. One solution is separation of fisheries sector activities and cargo/passenger terminals. Another solution is to provide seawater passage to accelerate its exchange with fresh water.

(4) Construction Aspects

Preparation of design was carried out in parallel with the preparation of construction program. Available equipment in Maldives and temporary import of equipment also are taken into consideration. Concrete aggregate and rock materials for armour rock revetment should be imported anyway. However, filling material for the causeway core should be collected nearby the site.

General view of Causeway No.1 from the south

Causeway No.2 View from the north