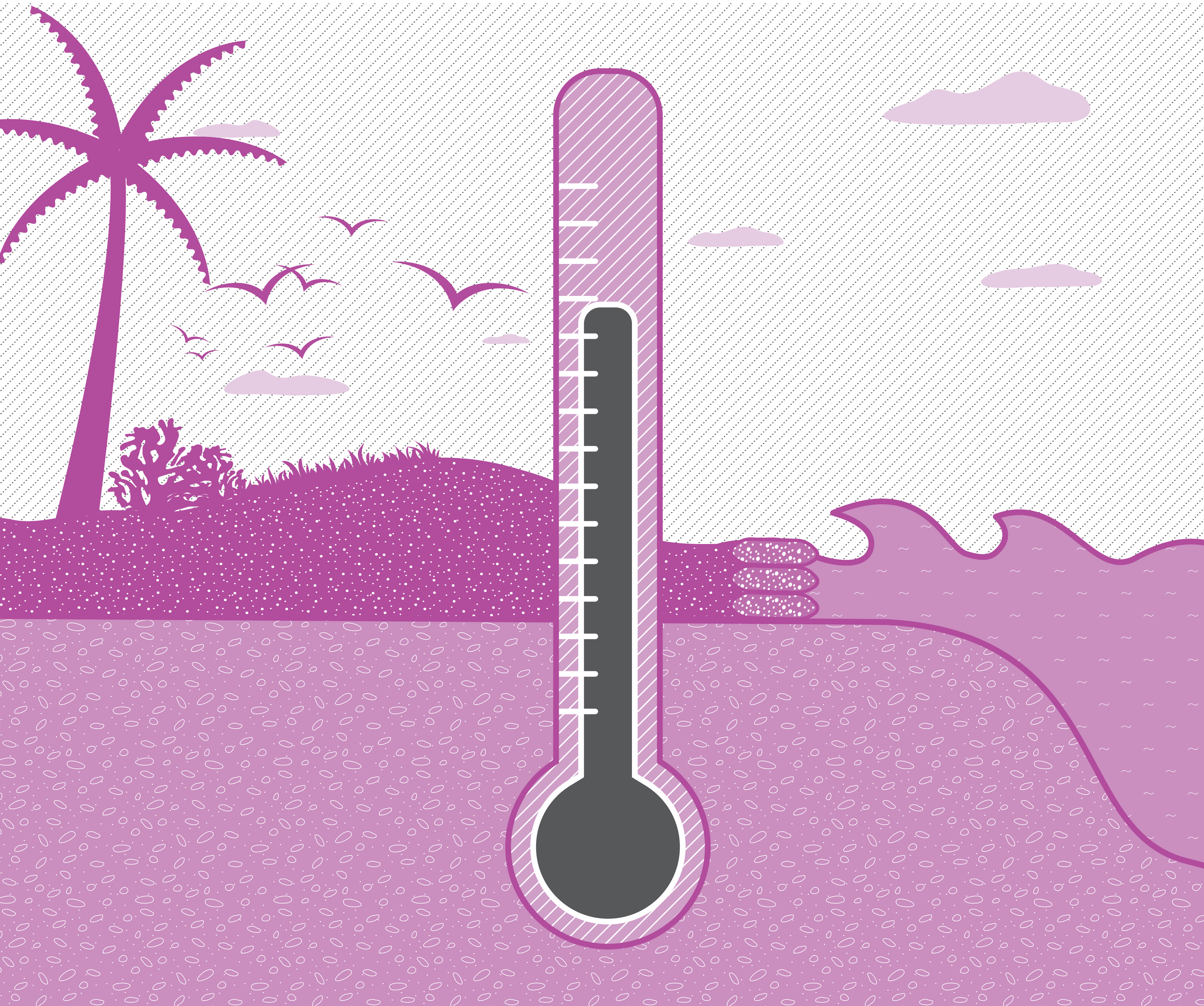
Guidance Manual for Climate Risk Resilient Coastal Protection in the Maldives



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Ministry of Environment & Energy

Guidance Manual for Climate Risk Resilient Coastal Protection in the Maldives

Final guidelines

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Foreword

Over last six years, more than 90 islands have been flooded atleast once, and 37 islands have been flooded regularly or atleast once a year. More than 97 percent of inhabited islands reported beach erosion in 2004, of which 64 percent reported severe beach erosion. More than 45 percent of the tourist resorts have also reported severe erosion. From just a socio-economic perspective, building coastal resilience is a high priority.

Nearly all of the population of Maldives is vulnerable to coastal hazard risks with 44 percent of the settlement footprints of all islands being within 100m of the coast. This translates to 42 percent of the population and 47 percent of all housing structures being within 100m of the coastline. Even for those settled further inland, it should be appreciated that nearly 80 percent of the nation is below 1.5 metres of mean sea level.

Climate change predictions suggest that existing coastal pressures from intensive rainfall, storm surges, and swell waves will be aggravated through sea level rise and alterations in weather patterns. This will compound existing trends in coastal erosion and increase the vulnerability of coastal populations and infrastructure, primarily through an increased exposure to threats from flooding and land loss.

Building coastal resilience in the face of climate change is a key component to national livelihood security and economic prosperity. Man-made coastal defences as well as coral reefs are often termed as "the first lines of defence" to the threats imposed by climate change. Currently, however, these threats, coupled with strategies for long-term coastal resilience are not integrated into the planning, design or build of coastal protection structures. This may result in their inability to resist the aggravated pressures imposed by climate change, which could lead to mal-adaptive effects and increase the vulnerability of the populations and infrastructure they should be protecting.

This Guidance Manual on Climate Risk Resilient Coastal Protection will help decision makers, planners and engineers to answer the following questions; Do we need to build coastal resilience? Do we build resilience through coastal protection? How much protection do we want? What structures will give us that protection? What structures will perform adequately and minimize environmental impact? How do we build our selected structure in the best way? Do our structures meet our protection and environmental expectations?

Through this manual the planning and implementation processes of coastal protection and development structures can be strengthened in a way that assists planners, decision-makers and technical specialists to incorporate climate change risks and to build better and more resilient coastal defences.

I wish to acknowledge with appreciation the contributions made by the Government ministries and departments, the Global Environment Facility and the United Nations Development Programme in the formulation of this guidance manual.

Thoriq Ibrahim
Minister

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Acronyms

AC	Atoll Council
ALWC	Accelerated Low Water Corrosion
DIRAM	Detailed Island Risk Assessment in the Maldives
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPPA	Environmental Protection and Preservation Act
EPZ	Environmental Protection Zone
GIS	Geographic Information System
GOM	Government of Maldives
IC	Island Council
ICCRRIP	Integrating Climate Change Risk Resilience In Island Planning
IPCC	Intergovernmental Panel on Climate Change
LUP	Land Use Planning regulations
MEE	Ministry of Environment and Energy
MHUDB	Maldives Housing and Urban Development Board
MHI	Ministry of Housing and Infrastructure
MLSA	Maldives Land and Survey Authority
MOTAC	Ministry of Tourism Arts and Culture
MSL	Mean Sea Level
NDMC	National Disaster Management Centre
NDP	National Development Plan
NEAP	National Environment Action Plan
NGIS	National GIS
SIDS	Small Island Developing States
SOE	State of the Environment Report
SoP	Standard of Protection
TRDR	Tourism Resort Development Regulations
TOR	Terms of Reference

INTRODUCTION

PART A

1. PART A: INTRODUCTION

1.1 Chapter A1: Purpose and Scope of the Guide

1.1.1 Why is a Guidance Manual Needed?

Currently in the Maldives, there are no written guidelines on how to build climate change resilience into existing and future designs for coastal erosion control, land reclamation or harbour development. In addition, Environmental Impact Assessment (EIA) requirements and land use and coastal planning regulations are very generic in terms of the specific engineering and planning guidance advice provided to the private and public sector on "climate proofing" coastal protection structure design. Various studies, such as Detail Island Risk Assessment in the Maldives (DIRAM), make recommendations on good and bad engineering practices, though there is no one report specifically prepared to provide "step by step" advice on how to build, inform on environmental consenting requirements and educate island stakeholders (private sector, regulators and island communities) about how to instill climate change resilience into future planning and contemporary construction practices for coastal protection schemes, harbour structures/ design and land reclamation projects.

In addition, the potential to make better use of soft coastal engineering techniques (sand as beach nourishment etc.) in the Maldives is required from an economic and environmental sustainability perspective. Within many small island states, there has been increased pressure to introduce more soft engineering schemes, often as part of combined integrated defence systems with more traditional hard techniques. The 2004 tsunami provided significant lessons on the appropriate use of these approaches on different island systems, with mixed success. To this end, a more focussed view on the appropriateness or such techniques is now needed for specific islands as part of a comprehensive set of guidelines.

The focus of the Guidelines is therefore on coastal engineering adaptation and resilience of coastal protection infrastructure to climate change, rather than mitigation of climate change effects on the coast through energy efficiency or carbon emissions reduction. It is about ensuring that current and future coastal protection schemes can cope with climatic changes predicted for the future. The focus of this Guidance Manual is therefore to identify ways to ensure that coastal protection techniques (hard or soft) and associated backing infrastructure can be made resilient against climate change threats in a cost-effective way. It will cover the engineering aspects of adaptation, as well as those regulatory and social responses, including expectation management, required to ensure that engineering solutions can be effective.

1.1.2 Strategic Project Context

The production of these coastal protection guidelines represent a 'component' of a larger project entitled "Integrating Climate Change Risks into Resilient Island Planning in the Maldives - ICCRRIP". The purpose of the ICCRRIP project is to ensure that climate change risks are integrated into resilient island planning in the Maldives and that national, provincial; atoll and island authorities and communities are able to prioritize and implement climate change adaptation measures. The Project is a collaborative effort between the Government of Maldives (GoM), the Global Environment Facility (GEF) and the United Nations Development Program (UNDP). Its overall goal is to increase the resilience of the Maldives in the face of the climate change and improve the country capacity to respond effectively to climate related hazards.

The "Guidelines for Climate Risk Resilient Coastal Protection in the Maldives" is a core component of the larger ICCRRIP project. The scope of this deliverable is, therefore, to formulate a guidelines document for climate risk resilient coastal protection planning in the Maldives including coastal infrastructure development, dredging and land reclamation, beach replenishment, harbour development, coastal erosion prevention, improvement and creation of access to the islands through reefs, over water structure construction and other coastal developments. Common overarching "themes" considered throughout the guidance manual cover environmental sustainability, economic development and livelihood security.

1.1.3 Specific "Component" Context

The component (this Guidance Manual) of the ICCRRIP project is prepared to demonstrate the approaches required to allow GoM and island communities to maximize their opportunity to overcome impacts from global climate change. The guidelines provide engineering and planning advice and direction to GoM, Island and atoll councils, the private sector and ultimately the island communities to undertake and deliver climate resilient coastal protection. The underlying purpose and intended outcome of the component is to develop the knowledge skills, and attitudes that key stakeholders will need to make in order to deliver robust and effective climate resilient coastal protection in the future and to help create informed decisions on key climate change adaptation issues.

1.1.4 Development of the Guide

Information for the guide was obtained from three sources. The first was from a literature review of other available guidance and documents providing accounts and lessons learnt from the use of hard and soft coastal engineering schemes with particular reference to small island states (see Appendix 1). The second source was a focused field exercise to 6 Maldivian Islands to learn about the coastal protection challenges on outer islands and the engineering design challenges that contractors are faced with. Thirdly, a practitioner workshop was carried out to obtain information and feedback on the lessons and performance issues associated with climate resilience and coastal protection in the Maldives.

1.2 Chapter A2: Users of the Guide

This guide presents the process that should be followed and the considerations required when designing climate resilient coastal protection schemes. It should be noted that in some situations where the level of risk is low not all the considerations included within the guide will need to be considered and the level of effort should reflect the level of risk. And consequently in high risk and complicated island situations, additional considerations may still be important that are not covered by this guide. The guide is therefore intended for:

- **technically competent persons** from organisations or groups with responsibilities or need for the planning and design and operation of coastal protection measures, and their advisers. Such users include asset managers, emergency and civil contingency planners and responders, appraisers and designers of coastal protection schemes, island developers and local community groups.
- **developers and contractors** (and other organisations) involved with the development or improvement of coastal protection schemes.

A key theme in the development of this Guidance Manual is that integration of efforts across sectors and with various organizations is a prerequisite to building coastal resilience. The Manual is therefore prepared in a manner that allows all stakeholders to make informed choices concerning the selection, design, engineering and build of coastal protection structures. This has the advantage that it can be provided a hard standalone copy or can be a form of e-book (in the future) for viewing on a computer or be web-based.

The anticipated users of the Guide (defined as "User Groups"), and why the Guide is to be beneficial to them is set out below in Table A1.

Table A 1 User Groups and benefits they will receive from the Guidance Manual

User Group Number	User Group Description	Benefit of the Guide to the User Group
User Group 1	GoM Permanent Secretary (high level decision makers):	Help to provide strategic advice on national island development planning.
User Group 2	GoM technical managers (middle management practitioners):	Help to provide technical guidance on engineering best practice and environmental regulatory compliance to existing laws and building code regulations.
User Group 3	Private sector (engineering contractors):	Help to provide guidance on engineering design delivery, achievability of contract standards (for land reclamations etc) and the preparation of tender specifications.
User Group 4	Private sector (international and national island developers):	Help to provide information on the required regulatory requirements prior to the selection of islands for specific land use (e.g. tourism)
User Group 5	Island Councils:	Help to equip Island Councils with the informed knowledge to “when and how” to make correct choices with respect to coastal engineering adaptation and maintenance. For example, Island Councils should (through focused training) be able to better interview on matters such as i) how to undertake minor maintenance issues, ii)how to adjust groyne field designs or iii) how to move modest quantities of beach sediments.
User Group 6	Community leaders	Help to advice communities on self-help strategies to address flood risk and also to inform communities on approaches for shoreline change observations and monitoring.

1.3 Chapter A3: Structure of the Guide

The Guidance Manual takes a user through a systematic process from understanding climate resilience in the context of coastal protection decision making and also whether the use of soft or hard engineering schemes systems are appropriate for particular island situations. The Guide presents clear performance standards and design criteria, that should be followed (adhering to international standards) to offer appropriate solutions for specific situations. It then provides guidance on optimising the delivery of improved climate resilience in coast protection designs through proposing updates to existing environmental legislation and taking other local, economic, environmental and whole life management issues into consideration to enable designs to be agreed ad finalised.

The Guidelines Manual is presented into a number of colour coded “Parts” and supporting “Chapters” as set out in Figure A1. The pages of each Part have an equivalent colour tab on the top right of each page. In addition, a series of 19 separate “Guidance Manual Note” text boxes are included throughout to identify key aspects of the guide for the reader to digest and register for future use.

Guidance Manual Note 1

This Guidance Manual is designed to be a "living document", and one that will need to be updated as new information and experiences are learned from new coastal protection structure performances and improved observations and monitoring of coastal systems around all Maldivian islands. Its design enables specific sections to be updated as more knowledge and data is made available in the coming years along with the opportunity to "Maldivianise" the design and material standards (see Part C) as more experience develops in country.

Figure A 1 Structure of the Guidelines

Part A – Introduction	Chapter A1: Purpose and Scope of the Guide Chapter A2: Users of the Guide Chapter A3: Structure of the Guide Chapter A4: Definitions Chapter A5: How to Use the Guide
Part B – Building Climate Resilience into Coastal Protection	Chapter B1: Coastal Protection and Climate Resilience Chapter B2: Review of Coastal Protection Techniques Chapter B3: Options to help Building Resilience into Coastal Protection Techniques Chapter B4: Choosing a Preferred Option
Part C – Engineering Guidelines	Chapter C1: Engineering Performance Standards Chapter C2: Design Considerations (Generic Issues for Hard and Soft Measures) Chapter C3: Design Standard Details (Hard Structure Measures) Chapter C4: Design Standard Details (Soft Structure Measures) Chapter C5 : Material Standard Details (Hard Measures) Chapter C6: Practical Construction Guidance
Part D – Planning Guidelines	Chapter D1: Updating Existing Environmental Regulations Chapter D2: Updating Existing Land Use Planning Regulations Chapter D3: Tourism Resource Development Regulations Chapter D4: Advisory Update to Current Setback Policy
Part E – Monitoring, Maintenance and Information	Chapter E1: Monitoring Coastal Protection Schemes Chapter E2: Maintaining Coastal Protection Schemes Chapter E3: Information Management: Data Storage, Sharing and Future Use
Appendices	Appendix 1: Key References Appendix 2: Staged Approach to Building Climate Resilience through EIA processes Appendix 3: Sample Project Appraisal/Review Checklist Appendix 4: Sample Inspection and Monitoring Schedules Appendix 5: Next Steps and Additional Work

1.4 Chapter A4: Project Definitions

The following definitions have been agreed upon by GoM. All Maldivian stakeholders therefore need to be versed with the definitions and explanations adopted GoM for this Guideline Manual.

1.4.1 Climate Change Resilience (in the context of this project)

To implement coastal infrastructure and development adaptation measures that improve resilience to climate change by adhering to formal risk management procedures that are designed to "future proof" decision making in the Maldives.

1.4.2 Building Resilience into Coastal Protection (structures)

Building resiliency into both hard and soft engineering measures is fundamentally an engineering or technical intervention response. It is making the structure more resilient to hydrodynamic forces and/or the increased frequency of climate induced storm events. This may manifest itself in the need to increase the robustness of the materials used in the structure (rock or strengthened geotextile membrane sand bags etc.).

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1.4.3 Standards

The term standard in this instance is defined as a legally enforceable guideline that incorporates two procedures, namely a) a design standard for coastal development protection that determines the type of technology or practice that should be adopted plus supporting construction detail parameters and b) a materials standard for the type of construction materials needed (rock, sand etc.) required to achieve the required design standard.

1.4.4 Technical Approaches

It is proposed that a series of 4 "Technical Approaches" are presented within this Guidance Manual as follows:

1.4.4.1 Hard Structure Approaches

The intent of this "Approach" is to maintain the current position of the coast and the level of defence using hard structure techniques. This does not necessarily mean that the hard defences would be maintained in exactly the same form as they are at present. There may be a need to adjust the local alignment in the future or to replace or add to structures e.g. constructing cross shore or shore-linked structures, such as groynes or breakwaters, may be one approach adopted under this Approach in specific cases. The techniques involved under this approach include seawalls, offshore breakwaters, revetments, gabions etc..

1.4.4.2 Soft Structure Approaches

The intent of this "Approach" is to maintain the current level of defence using "soft" structure techniques which allow the shoreline to move backwards or forwards, with management to control or limit movement (such as reducing erosion or building new soft structures on the landward side of the original defences). Soft structure approaches maybe used where there is a need for continued intervention to achieve a specific outcome. The overall aim is that management of the shoreline would be improved by either allowing or creating the conditions for the coast to realign. The techniques involved under this approach include beach nourishment, beach recycling, temporary groyne structures, mangrove/wetland rehabilitation and artificial headlands etc..

1.4.4.3 Accommodation Approaches

The intent of this "Approach" is to review and/or adopt new planning tools (such as "buffer zone" creation or the use of development set back techniques to enable the coast to accommodate sea level rise and storm surge inundation events). This Approach is not an engineering option, but represents a very important planning option to help coastal communities adapt to climate change. The techniques involved under this approach include building permit control; land use planning regulations; raising road levels; "climate proofing" property; evacuation route construction.

1.4.4.4 No Active Intervention

No Active Intervention (NAI), where there is no investment in coastal defences or operations occurs. A No Active Intervention Approach arises from the coast that needs to be allowed to develop naturally. Typically, it may be that erosion of a frontage is providing sediment to other sections of the coast or an island. It may, therefore, be important that the coast is allowed to continue to erode if sustainable intervention is to be achieved elsewhere.

1.5 Chapter A5: How to Use the Guide

A summary of the purpose of each Part, coupled with the likely intended audience (as per Chapter A1.2, Table 1.1) is set out below in Table A2. The colour code for each Part is also identified for ease of reference. A list of Appendices is included to cover specific aspects of the Guidance Manual in more detail.

Table A 2 Guideline Content and User Group Relevance

Guideline Content	User Group Relevance	User Group Description
PART A – INTRODUCTION: This Part outlines the structure of the Guidelines and how to use it to ensure that it is accessible in an appropriate manner to the various user groups who shall refer to its content.	All User Groups	
PART B – BUILDING CLIMATE RESILIENCE INTO COASTAL PROTECTION: This Part describes what is meant by climate resilience for coastal protection in the Maldives. It then presents the types of structures that the Guidance Manual is to be considering, how resilience can be engineered within these structures and also how to select the most appropriate option to follow in different situations.	All User Groups	
PART C – ENGINEERING GUIDELINES: This Part outlines the engineering criteria that should be considered in the selection of coastal protection structures as well as pre-construction considerations. This section is complemented by the engineering specifications and information on the material standards of structures and materials to build coastal protection structures to required performance standards.	User Group 3	Private sector (engineering contractors)
PART D – PLANNING GUIDELINES: This Part provides an outline of how the design and construction of climate resilient coastal protection structures can be linked to existing regulations (environmental and land-use planning) in addition to new national building codes.	User Group 1	GoM Permanent Secretary (high level decision makers)
	User Group 2	GoM technical managers (middle management practitioners)
	User Group 3	Private sector (engineering contractors):
	User Group 4	Private sector (international and national island developers)
PART E – MONITORING, MAINTENANCE AND EVALUATION: This Part provides the recommended monitoring and inspection protocols, in addition to data collection and storage needs and advice on scheme performance evaluation. Requirements for communication and stakeholder engagement are also covered as well as proposals for linking an asset database to the National GIS database.	User Group 2	GoM technical managers (middle management practitioners)
	User Group 3	Private sector (engineering contractors):
	User Group 5	Island Councils
	User Group 6	Community leaders

BUILDING CLIMATE RESILIENCE INTO COASTAL PROTECTION

PART B

2 PART B: BUILDING CLIMATE RESILIENCE INTO COASTAL PROTECTION

2.1 Chapter B1: Coastal Protection and Climate Resilience in the Maldives

2.1.1 Coastal Resilience in the Maldives

A working definition of resilience has been documented by the IPCC as "The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change".

If a system, such as an island, is not resilient then it can be considered as vulnerable to the effects of climate change. The IPCC have defined vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity".

The degree to which a system, such as an island has the potential to respond to climate change threats, in order to maintain functioning is termed adaptive capacity as is defined as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences".

To build resilience to combat the effects of climate change and thus maintain the functioning of the socio-ecological systems is the prime target for governments and international organisations.

2.1.2 Vulnerability on the Maldivian coast

There are a number of aspects which are projected to alter with the progression of climate change. The coastline is especially prone to such climate affects as it has not only the burden common to across all areas (such as air temperature increase, increasing variability in rainfall) but also additional pressures specific to the coastline. These could be for example, rising sea level, increased wave energy at the coast and the increased frequency or severity of tidal surges. The coastal area is thus a focal point for many of the climate effects.

The strength of the drivers of change in the coastal areas means that climate related changes are more readily apparent. In recent years, Maldives has been experiencing high frequency, low impact hydro-meteorological disasters due to changes in weather patterns, causing storm surges, and often coastal flooding. Over the last six years, more than 90 inhabited islands have been flooded at least once, and 37 islands have been flooded regularly or at least once a year. More than 97% of inhabited islands reported beach erosion in 2004, of which 64% reported severe beach erosion. More than 45% of the 87 tourist resorts have also reported severe erosion. As a consequence, building resilience on the coast is a high priority.

While much of the global population can be found clustered around coastal areas, in the Maldives this is more extreme due to its geography. The population is scattered over some 198 islands with an average population of less than 1000; only 15 islands have more than 2,000 inhabitants, while 11 have less than 200. At present, 44% of the settlement footprints of all islands are within 100m of coastline. This translates to 42% of the population and 47% of all housing structures being within 100m of coastline. Even for those settled further inland, it should be appreciated that nearly 80 % of the nation is below 1.5 meters of mean sea level. Consequently, nearly all of the population of the Maldives is vulnerable to coastal hazard risks and as such building coastal resilience is a key component for national livelihood security and economic prosperity.

2.1.3 The Multiple Dimensions of Resilience

Whilst precise definitions of resilience vary in different fields of study (e.g. physical science, disaster management, sustainable development), there is general agreement that there are a number of dimensions to resilience. These dimensions include socio-demographic, economic, natural resource use and sustainability, governance and cultural aspects. As such, interventions to enhance resilience need to be integrated and appreciate the variety of dimensions so that a suite of these can be built in a compatible and

[1] World Bank (2011) Social resilience & climate change: operational toolkit. WB 65886.

[2] Adger, et al. (2011) Resilience implications of policy responses to climate change. WIRES Climate Change, 2, 757- 766.

synergistic way to meet future uncertainties. It is also clear that vulnerability is socially differentiated[1] (i.e. affects different groups or livelihood types differently), thus responses to climate change also need to be socially differentiated. Consequently, effective climate-resilience will be intimately connected to intelligent, inclusive development for all citizens of the Maldives and for longevity of success should include aspects such as promotion of gender empowerment, human rights and civil society.

It is likely that any effective programme to build resilience will intervene in a number of these dimensions of resilience through adaptation. The intention of such interventions will be to increase the adaptive capacity of the system to maintain functioning in spite of climate change effects. However, it is noted that an excessive emphasis on controlling the external pressures does not increase adaptive capacity of the system itself. Thus, such processes have been termed "manipulation" (of the external environment) rather than "adaptation to" the effects of climate change. Trying to build resilience solely through manipulation is likely to lead to a decrease of adaptive capacity and a consequent decrease in resilience. This is especially the case when future climate projections (of the external environment) are so uncertain that manipulation of them could be futile.

In recent work[2] on the evaluation of nine current regional climate change initiatives, it was found that only three had elements that could enhance resilience as much as reducing it; the other six had effects that predominantly reduced the resilience of a system. As stated by one co-author, "*There is growing evidence that current policy approaches to climate risks can sometimes focus too much on short-term benefits and seek simple technological fixes to problems that are more complex.*"

2.1.4 Coastal Protection and Engineering Resilience in the Maldives

Coastal protection is an important technique for "engineering" resilience in the Maldives. With most of the inhabitants and much of the infrastructure so close to the sea, then the need to protect people and assets is vital. However, coastal protection involves modifying the effect of the external forces on the system and as such is a system manipulation rather than a system adaptation. Selected resistance to the forces of nature is a useful tool but must be used in a planned way and in combination with other approaches to building resilience. If coastal protection is used as the climate change response, rather than one of a portfolio of adaptation responses for islands, then adaptive capacity and resilience can be expected to decrease. Resisting climate change effects just by coastal protection becomes even more precarious when the level of "protection" which it provides is as uncertain as the future climatic conditions.

Guidance Manual Note 2

The various coastal protection techniques presented within Chapters B2 and B3 are faced with this challenge. The availability of accurate mean sea level data for individual islands (which is currently missing in the Maldives) represents one of the major challenges to delivering effective and robust engineering design in the future.

2.1.5 Enhancing Coastal Protection Resilience in the Maldives

Coastal protection can help contribute to coastal resilience in the Maldives. However, this is somewhat limited by financial resources: conservative calculations estimate US$1.8 billion for coastal protection of 200 inhabited islands if the entire island is protected and US$1.1 billion if the present settlement areas only are considered[3]. Consequently, any approach to coastal resilience needs to use coastal protection in a selective, sparing and efficient way to maximise benefits at minimum cost. To facilitate this there is also the need to develop appropriate policy and decision-making processes to move towards a trajectory in which lead times are appropriated to allow coherent climate proof investments. As stated by UNDP[4] "*This means that action must begin today, before climate risks materialize, to protect critical socio-economic infrastructure, and to manage the risks associated with the impacts of climate change expected to occur by the middle of this century. There is a need to grow investments in infrastructure in the coming years to proactively prepare for the future*". Thus, optimal use of coastal protection means that it needs to be well planned as well as well-built; this means that is sits in both the planning and engineering domains. Chapter B3 looks in more detail at the possible engineering approaches that can be adhered to for building coastal protection resilience into existing and newly designed coastal protection schemes.

[3]Shaig, A. (2011). Survey of Climate Change adaptation Measures in the Maldives. Report prepared for Integrated Climate Change Risk into Resilient Island Planning in the Maldives Project. Ministry of Housing and Environment and UNDP Maldives.

[4]UNDP (2011) Paving the way for climate resilient infrastructure: guidance for practitioners and planners. New York, UNDP.

Guidance Manual Note 3

This Guidance Manual provides substantial detail and information on coastal protection; however it is necessary to appreciate how this detail fits into the developing overall picture of coastal resilience in the Maldives. A suite of conceptual diagrams are used in Chapter B3 to show how the development of coastal protection resilience can be enhanced through following the recommendations for coastal protection guidance set out in Parts C, D and E.

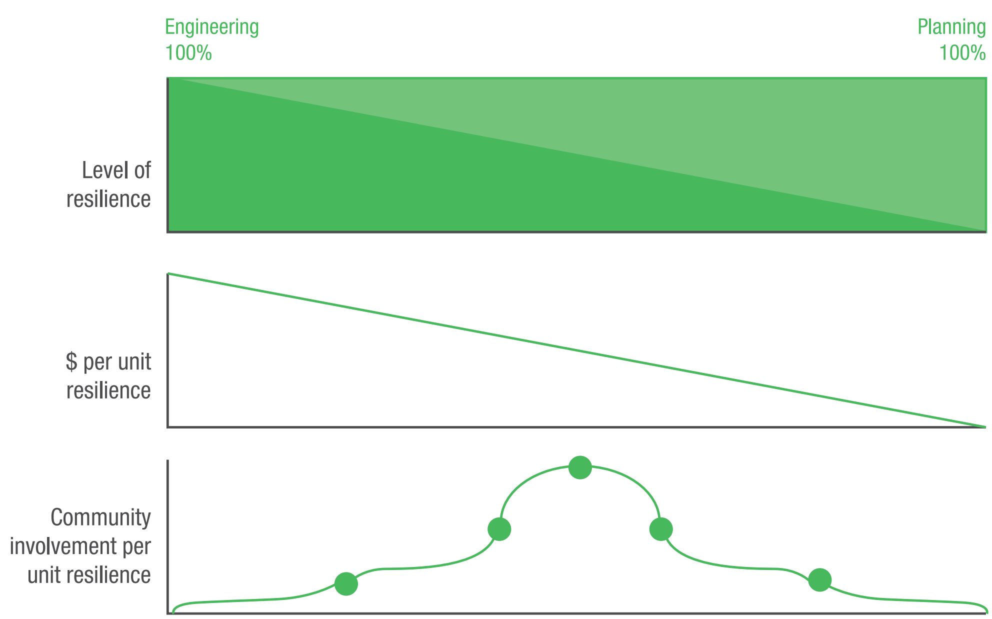
2.1.6 A Continuum of Physical Coastal Resilience.

2.1.6.1 The trade-offs for engineering and planning

It has already been noted that coastal protection involves a mix of planning and engineering construction. The planning aspects determine where critical infrastructure, or domestic developments, are positioned (land use planning), what type of building and infrastructure they use (building codes) and what design causes minimal environmental impacts (EIA Regulation). The engineering aspects determine the appropriate type of coastal protection, the final design, materials used, the build-quality and the inspection and maintenance procedures.

One could envisage a scenario in which it is possible to overcome the vulnerability of small island coastlines through excellence in coastal protection engineering (well-designed, well-constructed and well-maintained). An alternative option would be to overcome coastal vulnerability through excellence in planning (optimal land use in relation to threats, resilient design of structures and minimal environmental impacts requiring further mitigation interventions). Both approaches achieve a level of coastal resilience, but there would be a difference in terms of a number of salient features. Firstly, the cost per unit of resilience will be much higher for an engineering approach which fundamentally resists the effects of climate change, rather than the planning approach which fundamentally tries its utmost to avoid the consequences of climate change. Secondly, in a pure-engineering or pure-planning approach the involvement of the community will be low as decisions will be predominately made on technical grounds. In a more mixed approach (with good planning and good engineering) it is likely that the community can be involved through involvement in the design of protection structures, support the EIA process, deliver gains in building resilience negating some of the need for protection structures and be involved in post-construction monitoring. The trade-offs in the engineering – planning continuum are shown below as are the associated cost and community involvement relationships (Figure B1).

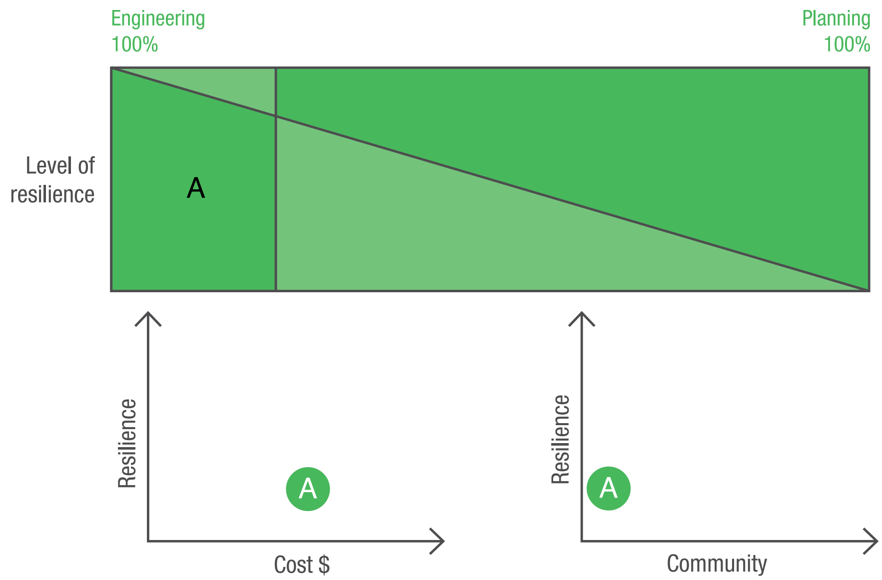
Figure B 1 The trade-offs in engineering and planning approach to building a set amount of coastal resilience (top diagram) and the associated likely cost and community involvement across the engineering – planning continuum.



2.1.6.2 Present Position of the Maldives on the "Engineering Planning" continuum

Previous reports and the work in this initiative have shown the reliance of coastal protection in the Maldives in building coastal resilience, exemplified by the pre-cast tetrapod engineering approach that it witnessed around the island of Malé but also represented by the widespread reliance on hard coastal protection schemes in other islands. Thus the present position of the Maldives is towards the engineering side of the continuum (Figure B2).

Figure B 2 The position of Maldives on the engineering-planning continuum (A) and the present position in relation to coast and community involvement.



2.1.7 Climate Change Coastal Resilience Response Trajectories for the Maldives

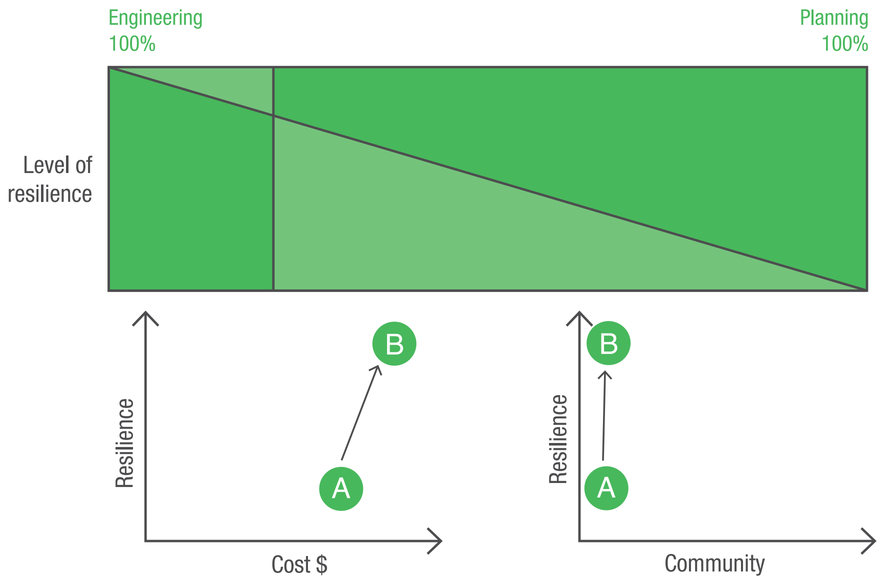
2.1.7.1 Response 1 – "Build better structures"

With climate change pressures there is the probably that the resilience provided at present in the Maldives will be reduced; or put another way, the height of the resilience y-axis will decrease for a similar investment. One option is to increase the investment, or "buy and build" more resilience (i.e.: more tetrapods placed to form a "fortress" around most inhabited islands); however, this may not be a good approach as the financial consequences are dramatic.

An alternative approach is to identify the weaknesses in the present system and to take a structured approach to enhancing resilience and building more resilience per unit $. One aspect where improvements can be made is in the quality of construction of coastal protection. A survey of various inhabited islands found a range of problems in the construction which lead to rapid degeneration of the structures, thus reducing effective operational life and increasing cost per unit protection. Better feasibility assessment and design, wider involvement of Island Councils and local people in consideration of options, following international construction standards, effective sign-off and post-construction inspection and planned maintenance can swiftly and significantly improve the level of coastal protection resilience. This option to "build better structures" is visualised below (Figure B3).

\+ Build better structures and more robust planning

Figure B 3 "Build better structures" approach (denoted by B) involves improving engineering construction standards and provides an overall higher level of coastal protection resilience (compared to B2) at a minimal increase in cost and with possibilities for improved community involvement.



Guidance Manual Note 4

Based on the resilience understanding presented within this Chapter B1), the Manual goes on to provide extensive performance standards (Chapter C1), in addition to strategic guidance on the feasibility of options and what extra information is needed to deduce a preferred structure selection choice, their design and what material construction criteria to use (Part C, Chapter C2 and C3), plus advisories on construction and post construction monitoring to follow a "build better structures" approach (Part E).

2.1.7.2 Response 2 – "More robust planning"

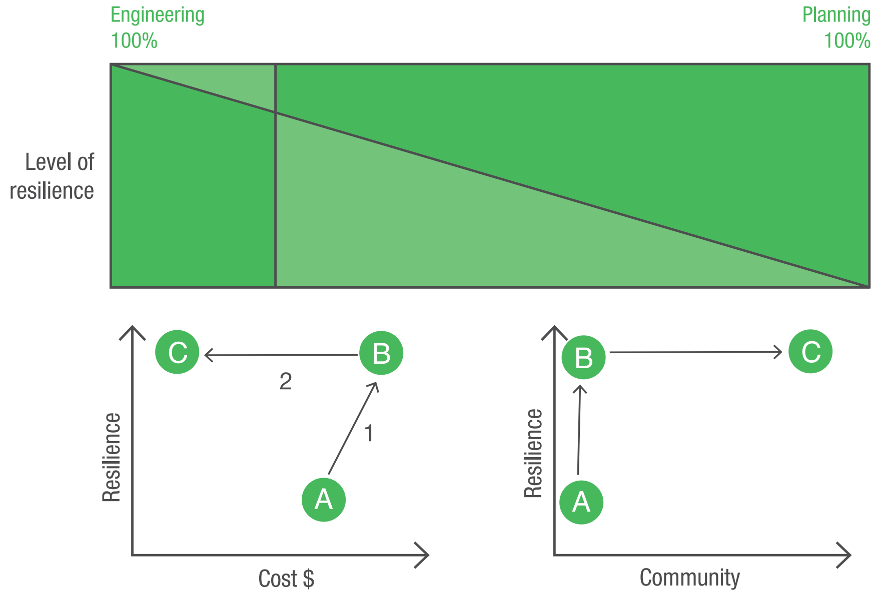
Whilst the "build better structures" approach can provide systematic improvements in the protection afforded by a majority of the ongoing coastal works and provide better value-for-money, it is still an expensive route for developing resilience. However, it is proposed that further gains can be made from strengthening the planning dimension of the coast – this is the "more robust planning" response.

In the "more robust planning" response a more coherent and comprehensive approach is taken to efficient and effective utilisation of the land and coastal hinterland of the islands. For example:

- Land use planning - positioning of new development away from eroding shoreline as much as possible.
- Building codes - infrastructure in vulnerable areas are made more resilient through raising floor levels (e.g. houses) and raising key installations (generators in powerhouses)
- Land use planning - new reclamation areas are developed which are not in high erosion areas and do not flood existing households and infrastructure.
- Environmental assessments – new developments do not cause erosion elsewhere on the island and thus necessitate further coastal protection intervention.
- Coastal protection – only used in a sparse and deliberate way when alternative planning approaches have been considered and concluded not to be viable.
- Coastal protection – all viable coastal protection techniques are considered which give the required protection performance, including soft protection options such a sand ridges and beach recharge.

The consequence of the "more robust planning" approach is shown below (Fig B4). The response means a move away from a reliance on engineering resistance and a wider use of coherent planning. The consequences are that the cost per unit of resilience dramatically reduces compared to the "build better structures" approach, and the opportunities for community involvement increase (through consultation and consensus planning in the various planning instruments).

Figure B 4 "More robust planning" response (denoted by C) provide a similar level of resilience as the "build better structures" response (B) (but more than the present situation A) but at less cost and with more possibilities for community involvement.



Guidance Manual Note 5

This Manual provides guidance on enhancing planning through strengthening of the EIA Regulations (see Chapter D1) to accommodate climate change additions to the Land use regulations (see Chapter D2) to allow future changes to be accommodated and systematic monitoring and assessment of coastal assets through a centralised database (see Part E, Chapter E2).

2.1.8 Challenges and opportunities for building coastal resilience through coastal protection

There is a real need to start adopting greater efforts, within the Maldives, to define island specific risks of erosion and flooding and how climate change is likely to influence the frequency and magnitude of such events. The key opportunity that arises from this is the need to agree upon, and endorse a series of coastal protection, "performance" standards to the land behind them which is appropriate for each island. The traditional presumption in favour of maintaining existing defences on islands, and extending them where new risks of erosion and flooding arise, now needs to be seriously challenged and reconsidered. The new "route-map" for this is defined in Chapter B3 and Part C (Chapter C2). This is because factors such as environmental damage caused by defences, their sustainability and their great cost are all weighty considerations to factor in decision making. To this end, the requirement to more formally assess risk as an integral part of the decision making (appraisal) process is vital to ensure decisions taken are robust to address climate change and are based on the awareness of the consequences and appropriate mitigation measures (identified through the EIA process – see Part D, Chapter D1).

Whilst the vulnerability of the Maldives is clear and apparent, the correct response to take with the high future uncertainty is challenging. The existing approach of relying predominately on hard coastal protection structures is expensive. This approach also raises the possibility that just resisting or "manipulating" the external forces will lead to a progressive decay in adaptive capacity to meet the uncertain future and thus decrease coastal resilience.

The "build better structures" response provides better value for money and can be implemented rapidly; as such this is a highly available and tractable response. The "more robust planning" response is longer term, but it can be used in combination the "build better structures", to provide a more cost effective medium- to long-term planning response. The additional benefit of this response is that Island Councils and local communities can be more involved in the process which will help raise adaptive capacity and build a more multi-dimensional form of resilience.

2.2 Chapter B2: Review of Coastal Protection Techniques

2.2.1 Overview

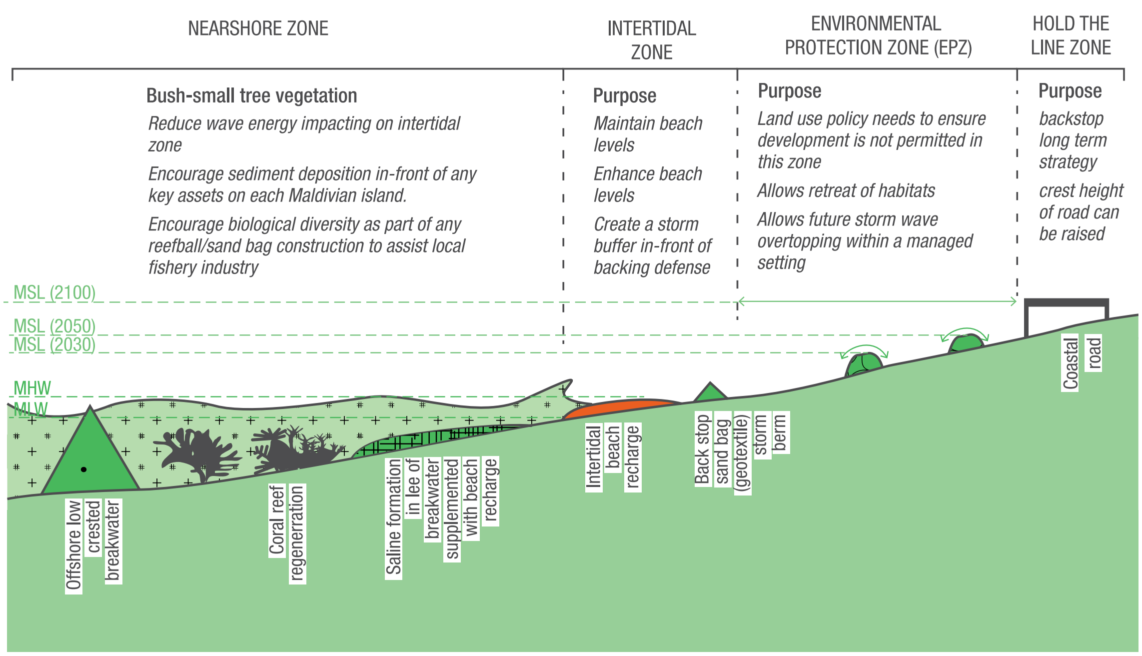
The purpose of this Guidance Manual is not to provide a detailed "text book" narrative review of all coastal protection techniques that are possible in the Maldives. This therefore is not provided. The work of Shaig et al (2011) is recommended for review on that regard.

The focus of this Chapter is, instead, on providing a review of all appropriate coastal protection techniques and their capacity to be designed or adapted to address climate change resilience. It relates to a range of possible hard and importantly, soft measures spanning the conceptual cross section of most Maldivian islands (see Figure B5).

Particular focus is now provided on presenting a succinct analysis of the climate resilience implications existing and future coastal protection works, so that answers to the following questions may be sought by GoM and private developer contractors for future revisions on this Guidance Manual:

- Can "new build" hard structure approaches be designed as being "climate change resilient"? *(if not, why and what "knowledge" or information is needed to achieve this?);*
- Can "new build" soft structure approaches be designed as being "climate change resilient"? *(if not, why and what "knowledge" or information is needed to achieve this?);*
- Can "new build" hard structure approaches be designed in parallel (or in conjunction) with soft measure approaches to improve "engineering resilience to climate change" *(if so, which measures are most complimentary and achievable in a Maldivian context and why?);*

Figure B 5 Indicative soft coastal protection measures that may (or could) occur on most Maldivian islands



The following section therefore is designed to update and develop existing relevant work undertaken by CTL (2012), Shaig (2011), Kench (2010) and McCue (2000). Its purpose is to help evaluate the climate resilience potential of all hard and soft engineered measures presented in those reports. Between the work identified above, over 50 islands spread across Maldives, including residential islands, resort islands and infrastructure islands have been visited in order to deduce a strategy to help build engineering resilience into coastal protection structures for the future in the Maldives.

- What Accommodation Approaches (i.e.: non engineering) are needed to create the necessary enabling environment for the implementation of improved engineering resilience to climate change? *(and over what time-scale is this likely to be achieved in i.e.: 0-5 years and 5-25 years).*
- Linked to the above, can dual-use infrastructure schemes be designed? *(and what studies or research is needed to achieve this?).*

2.2.2 Resiliency of Current Coastal Protection Techniques

Sections 2.2.3, 2.2.4, 2.2.5 and 2.2.6 replicate these sub-divisions and provide an indication of the engineering intervention action that could be needed to make the technique more "resilient to climate change" over two specified time periods identified below. These time scale epochs are selected as they are deemed to be realistic and meaningful in terms of planning time scales in the Maldives. These are defined as follows:

- 0 -5 years (short term to urgent action required);,
- 5-25 years (longer term planning for islands linked to tourist island lease timescales).

An "engineering" resiliency "score" is provided for each technique to give an indication of the CURRENT technical resiliency of the specific structure to climate change (i.e. how the structure is currently being designed and built). This score is categorised as follows:

- (red) **low engineering resiliency** – regardless of cost, the design has limited capacity to accommodate increased coastal hydrodynamic energy increases (waves/current) without significant design alterations or re-engineering needs and materials commonly used in its design have limited ability to be "adapted" to accommodate change in climatic conditions/seasonal sediment movement patterns with relative ease.
- (amber) **moderate engineering resiliency** – the design has potential capacity to accommodate increased coastal hydrodynamic energy increases (waves/current) without significant design alterations or re-engineering needs and materials commonly used in its design have limited ability to be "adapted" to accommodate change in climatic conditions/seasonal sediment movement patterns with relative ease.
- (green) **high engineering resiliency** – regardless of cost, the design is easily able to accommodate increased coastal hydrodynamic energy increases (i.e.: waves/current) and materials commonly used do have the ability to be "adapted" to accommodate change in climatic conditions/seasonal sediment movement patterns with relative ease (i.e.: more material to increase defence crest level or floor "build" levels".

Figure B6 outlines a summary version of the following sub-sections to provide the reader an overall idea of the purpose if its structure and intended outcome. It shows a sample 6 separate coastal protection techniques, and provides an indication of its current engineering resiliency score (i.e.: land reclamation is score as being of "high" engineering resiliency as it is relatively straight forward to engineer a robust scheme that would be resilient to climate change impacts (i.e.: increase its floor level height etc. by dredging more material etc.). Symbols are also provided to provide a strategic consideration of the techniques environmental resilience (likely long term impacts)) and its estimated cost for construction.

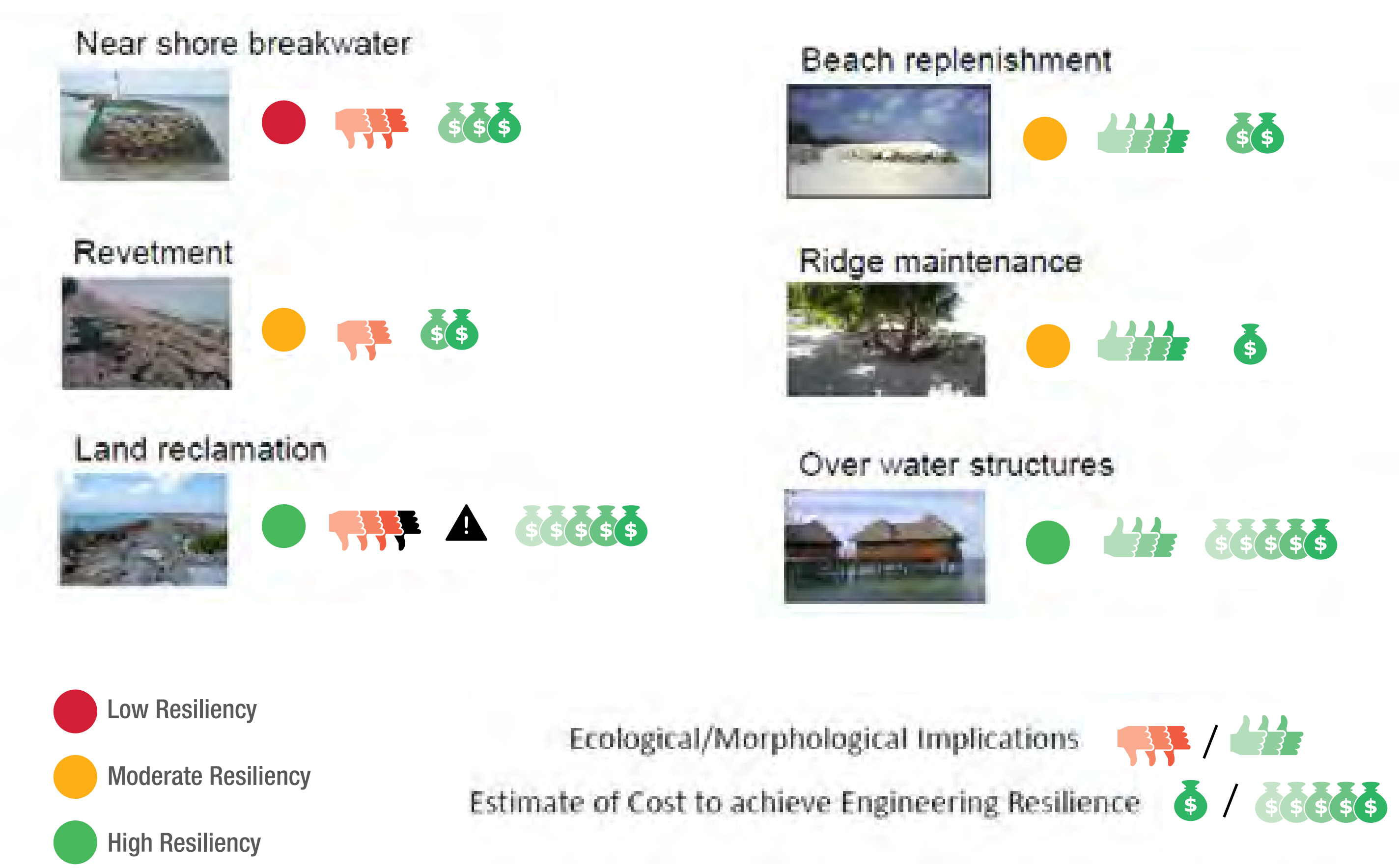


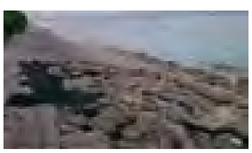
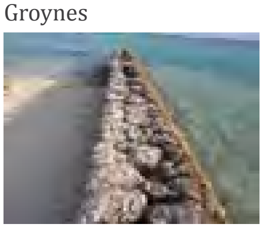
Figure B 6 Indicative resilience "scores" for 6 coastal protection measures.

In the following sub-section tables, an additional column is introduced to declare how easy it could be to adapt its design (as an individual scheme or as part of a collective scheme of a few techniques) to improve the resiliency "score" (i.e.: from a "red" to "amber" score etc.). To achieve an improved "score", this may be achieved through adopting one of the following "management approach options" as follows:

- Option 1: Modification of individual structure design (i.e. pre-construction) to improve individual structure performance (i.e.: focus on the structure design prior to construction);
- Option 2: Modification (retrofitting) of existing adjacent hard structures (that are already in situ) to improve overall scheme performance;
- Option 3: Using soft structure measures to help modify existing adjacent structure strategic design to improve overall coastal protection performance (i.e.: focus on merging hard with soft measures as part of an integrated scheme);
- Option 4 – Modification and review of land use planning (i.e.: focus on accommodation measures, strategic placement of key features on an island and to reduce key infrastructure in "at risk" locations).

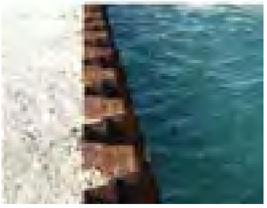
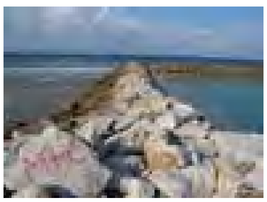
These 4 management approach options are defined and developed further with conceptual examples in ChapterB3.

2.2.3 Hard and Soft Measure Approaches (Erosion Mitigation Measures)

Measure Type	measure Heading	Key Purpose	Resiliency Implication (0-5 years)
Seawall/bulkhead 	Hard	Armouring structure	Assessment of overtopping frequency (averaging 0.5 – 1m above high tide) and from this, maintain standard of protection levels as dictated by the backing land use or assets at risk. Immediate actions may include engineering a crest splash wall of circa 0.3m height.
Foreshore Breakwater (rock, concrete filled barrels or nylon geo-bags) 	Hard	Shore stabilisation	Possible increase in crest height (usually designed to be circa +2m in crest height) which may be an extra level of geo-bag or rock. Decision likely to be based on an assessment of the sediment accretion volumes generated by the structure and whether accreted sediment is making the structure more robust (i.e: part buried etc).
Near shore breakwater 	Hard	Shore stabilisation	Commonly used in high energy zones. As a result, short term resiliency is dependent on material used for construction (geo-bag, rock, coral boulder, sand cement plastered bags etc). Mesh likely to require replacement on coral boulder breakwaters on ocean side within 5 years). Design impacts on wider hydrodynamic regime make this structure poor in terms of wider resilience to the coastal environment.
Revetment 	Hard	Armouring structure	Sand cement bag revetments (e.g.: on Hulumale showing signs of "blow out" see image) will need constant maintenance. Concrete interlocking "S" or "Z" block revetments are more modular in their design and hence more resilient to accommodate change. Maintaining standard of service is dependent upon revetment material being available on island (resiliency of structure may therefore be jeopardised as a result if material is needed via importation). The success of the structure on Hulumale is partly due to the "space" being available for the structure. This doesn't apply to many smaller islands foreshores.
Groynes 	Hard and Soft (depending on materials used)	Shore stabilisation	Depending upon material used for construction, short term resiliency can be accommodated into regular maintenance programmes. The initial groyne field spacing strategy is most likely "ad-hoc" and not strategically planned on any island. Short term beach volume impacts are most likely the result of poor groyne field placement on most islands.
Adhoc Reclamation 	Hard	Erosion control/ prevention	Continued use of solid waste or reclamation "spoil. Often this is never consolidated and is easily dispersed by high tides. Not a resilient coast protection option

Resiliency Implication (5-25 years)	Resiliency "Score"	Options to improve resiliency score (see Chapter B3)	impact on island dynamics	Cost
Likely upgrade to the standard of protection afforded by the structure (increase crest level height – circa 0.5m). Possible re-setting of sheet piles if being undermined.		Option 1 Option 3		
Depending on material used for breakwater. Rock being more resilient to wave energy than nylon bags). Possibly removal, relocation or re-design of the structure to better afford protection to assets at risk. Possible sediment recycling/ redistribution if structure is proving too effective in accreting sediment volumes. Geo-bag (nylon bags) revetment most likely have to be upgraded with new bags.		Option 1 Option 2 Option 3		
With no formal design criteria, there is a high risk of toe failure within this time period and so structure resiliency is predicted to be weak and in need of structure re-build. Crest height will need re-designing to counter water level fluctuations and to improve performance. Whilst structure can be designed to be robust, its wider impact on sediment dynamics over longer time scales makes this not a preferred option form climate resilience unless properly constructed and designed at the outset.		Option 1 Option 2 Option 3		
Modular "block" type revetments (not made of coral boulders or sand) are more durable and robust and hence more resilient to climate change. Increasing slope angle or crest height may be required in this time epoch depending on fronting beach condition. Replacement of geotextile membrane likely (see image opposite) within this time epoch. Lack of "side" protection will reduce the resiliency of any revetted structure and hence will require engineering intervention at some time in the future (if not present at the start).		Option 1 Option 2 Option 3		
Coral boulder groynes can be re-designed to capture more sediment transport around islands by extending their length into the house reef area. Availability of material is dependent upon this strategy. The longer term impact of this approach is likely to result in downsteam beach erosion especially if sediment budgets are in a net loss phase. Sand (moveable) groynes are less resilient to storms, but provide a better "shoreline management" resilient approach.		Option 1 Option 2 Option 3		
No inherent resilience associated with this option long term.		Option 3		

2.2.4 Hard and Soft Measure Approaches (Island Access Infrastructure)

Measure Type	MEASURE HEADING	Key Purpose	Resiliency Implication (0-5 years)
Quay Wall 	Hard	Access infrastructure	As this structure is built purposely for access needs, issues surrounding short term resilience have to be directly linked to maintaining its standard of service to wave overtopping. In the short term, this refers to regular maintenance of the structure and any engineering modification needed to ensure its performance (to continually ensure island access) is maintained. Their impact on wider island geomorphological processes (exacerbating coastal erosion) has to be linked to the mitigation measures set out in the EIA. Methodological "standards" taking forward more strategic shoreline management should be implemented prior to its construction.
Harbour Breakwater 	Hard	Access infrastructure	As this structure is built purposely for access needs, issues surrounding short term resilience have to be directly linked to maintaining their standard of service. In the short term, this refers to regular maintenance of the structure and any engineering modification needed to ensure its performance (to continually ensure island access) is maintained. Their impact on wider island geomorphological processes (exacerbating coastal erosion) has to be linked to the mitigation measures set out in the EIA. Methodological "standards" taking forward more strategic shoreline management should be implemented prior to its construction.
Entrance Channel Protection	Hard	Access infrastructure	As this structure is built purposely for access needs, issues surrounding short term resilience have to be directly linked to maintaining their standard of service. In the short term, this refers to regular maintenance of the structure and any engineering modification needed to ensure its performance (to continually ensure island access) is maintained. Their impact on wider island geomorphological processes (exacerbating coastal erosion) has to be linked to the mitigation measures set out in the EIA. Methodological "standards" taking forward more strategic shoreline management should be implemented prior to its construction.

2.2.5 Hard and Soft Measure Approaches (Measures to reduce land shortage and coastal flooding)

Measure Type	Key Purpose and Measure type	Resiliency Implication (0-5 years)
Land Reclamation 	Reduced land shortage (Hard measure)	Actual engineering effort to make land higher is relatively simple, assuming appropriate materials are available at suitable costs. However, unless formal "protection" measures are provided to the newly reclaimed land, the resiliency of the operation (even in the short term) is likely to be reduced (ie: edge treatment works etc).
Bridge / causeway	Reduce land shortage / coastal flooding Hhard measure)	Assuming causeways are built to enable water flow (i.e.: on piers/with ducts) then the short term resiliency of the structure AND the impact on adjacent islands is reduced (though not classified as "low"). If the causeway is solid, thus impacting on natural hydrodynamics, then the ability to engineer resilience basically means the causeway is built to a higher crest level, though at major negative impact on the natural water flow around the island.

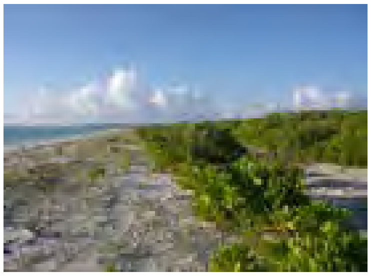
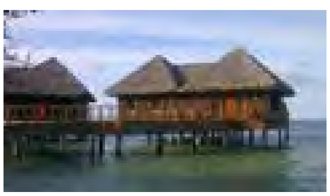
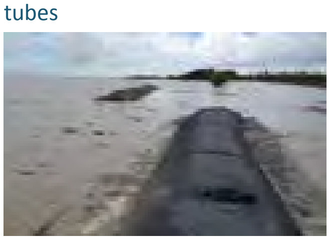
Resiliency Implication (5-25 years)	Resiliency "Score"	HOW TO IMPROVE RESILIENCY SCORE (see Chapter B3)	IMpact on Island dynamcs	Cost
As a structure (in this time epoch) it is likely to be resilient to climate change, assuming this is made of robust materials that can be replaced/added to as part of a regular maintenance schedule. The fact that it is a "fixed" feature, also equally makes this of "low resilience" to climate change. Its resilience as a strategic measure to counter wider climate impacts is questioned though has to be linked to the mitigation measures set out in the EIA. Methodological "standards" taking forward more strategic shoreline management should be implemented prior to its construction.		Option 1		
As a structure (in this time epoch) it is likely to be resilient to climate change, assuming this is made of robust materials that can be replaced/added to as part of a regular maintenance schedule. The fact that it is a "fixed" feature, also equally makes this of "low resilience" to climate change. Its resilience as a strategic measure to counter wider climate impacts is questioned though has to be linked to the mitigation measures set out in the EIA. Methodological "standards" taking forward more strategic shoreline management should be implemented prior to its construction.		Option 1 Option 4		
As a structure (in this time epoch) it is likely to be resilient to climate change, assuming this is made of robust materials that can be replaced/added to as part of a regular maintenance schedule. The fact that it is a "fixed" feature, also equally makes this of "low resilience" to climate change. Its resilience as a strategic measure to counter wider climate impacts is questioned though has to be linked to the mitigation measures set out in the EIA. Impacts on nearshore reef habitats (footprint of protection placement)etc are most likely impacted upon over the longer term.		Option 1 Option 4		

Resiliency Implication (5-25 years)	resiliency score	HOW TO IMPROVE RESILIENCY SCORE (see Chapter B3)	impact on island dynamics	
Assuming protection measures are provided to the land reclamation area (i.e. measures identified in Section 3.3.2) then the resiliency of the land reclamation exercise (to climate change) is high. Otherwise, the short term epoch implication will be reduced.		Option 1 Option 4		
Assuming causeways are built to enable water flow (i.e.: on piers/with ducts) then the short term resiliency of the structure AND the impact on adjacent islands is reduced (though not classified as "low"). If the causeway is solid, thus impacting on natural hydrodynamics, then the resiliency of the structure is low (as per the short term epoch outcome).		Option 1 Option 2 Option 3 Option 4	(if a solid structure).	

2.2.6 Hard and Soft Measure Approaches 'Quick fix' measures (short-timeframe)

Measure Type	**Key Purpose and Measure Type**	**Resiliency Implication (0-5 years)**
Beach replenishment 	Shore stabilisation (Soft Measure)	Very popular and often effective short term measure. Its resiliency in the short term is linked to the sediment budget of the island in question. If the island experiences a net negative sediment budget, then even short term re-nourishment programmes can have wider impacts on island dynamics.
Temporary seawalls and groynes 	Erosion control/prevention (Soft and/or Hard Measure)	The temporary nature of these structures, coupled with the fact there is no formal design model to follow, renders the structures of being of low resilience to climate change in the short term. Despite this the "ad hoc" nature to these structures makes then able to be quickly built to address an urgent or immediate need.
Demountable Flood Barriers (urban areas) 	Hard measure – de-mountable flood barrier build into the design of existing or future roads	Retrofitting such designs are more challenging than when designing a new road.
Multi-purpose Flood Barriers 	Hard measure (flood protection) – built into the design of existing roads or properties	An alternative approach would be to build "speed humps" that double up as flood barriers and are in place at all times
Recreational Area "multipurpose" infrastructure  	Hard measure (flood protection)	Multi-purpose seating along promenade/quay areas that can be used as flood barriers

Resiliency Implication (5-25 years)	Resiliency "Score"	How to improve resiliency score?	impact on island dynamics	cost
As re-nourishment programmes often last up to 10 seasons (ie: circa 5 years), the resiliency of the approach has to be proven during the first time epoch (ie: a demonstrated success). If the island experiences a net negative sediment budget, then even short term re-nourishment programmes can have wider impacts on island dynamics. If sediment budgets are "neutral" though sediment recycling is adopted (accreting areas replenishing eroding areas), then resiliency of the approach can be high so long as no other dredging or man induced activity takes sediment out of the sediment budget "system".		Option 1 Option 2 Option 3		
These structures play no role in providing a long term resilient defence approach. It is common for such structures to have a residual life of possibly 2 seasons (1 year). Bolstering sand bagged seawalls with concrete or placing a sand/concrete mix within sandbags may enhance the residual life of such structures, though the failure of the nylon bags (cheaper than geotextile) often results in structure failure during storm conditions.		Option 1 Option 2 Option 3		
		Option 1 Option 2 Option 4		Depending upon technique chosen
		Option 1 Option 4		
		Option 1 Option 4		

Coastal vegetation retention 	Shore stabilisation (soft measure)	Preserving existing "green belt" vegetation is a clear resilient measure to adopt on islands that have enough littoral space and are large enough to accommodate this. It is not a resilient measure if the island is too small to retain a suitable natural vegetation line. It becomes a good resilient measure in the short term if a natural vegetative zonation is prevent on an island. Pioneer vegetation is only likely to initially "take hold" during this time epoch.
Ridge Maintenance 	Shore stabilisation	This technique inherits best practices of natural resiliency with regards to "using nature" to enable natural coastal geomorphological ridge formation to develop. Short term resiliency measures may include artificially bolstering storm ridge integrity.
Artificial reefs 	Erosion control/prevention	Establishing the platform and environment to create artificial reefs can be relatively simple. Using pre-cast units (i.e.: Reef Balls – see image) is one effective way of setting this approach up (though expensive). Their resilience to storms depends on how they are anchored to the seabed.
Coastal structures on stilts 	Reduce land shortage / coastal flooding	The lack of design guidance regarding pile distance and crest design heights makes short term resilience difficult to quantify, however, assuming initial structure height is appropriate, then resilience to climate induced storms in this time epoch is deemed as high.
Submerged sand filled geotextile tubes 	Erosion control/prevention	Commonly used in high energy zones. As a result, short term resiliency is dependent on material used for construction (geo-bag, sand cement plastered bags etc). Geotextile bags (poor quality) may require replacement in high energy wave environments within 5 years). Design impacts on wider hydrodynamic regime make this structure poor in terms of wider resilience to the coastal environment.
Seagrass / mangrove planting 	Erosion control/prevention	Short term resiliency is dependent upon the level of protection that is given to enable the growth of the seagrass or mangrove seedlings. The main factors to consider when planting mangroves are the spacing of the propagules, number of propagules planted together, time of year when propagules are planted, handling of propagules prior to planting and the frequency of inundation. Often sand bag structures/defence blocks are needed to ensure that suitable protection is afforded to the newly planted mangrove propagules.

NB: Chapter C3.1 and C3.2 should be viewed for design performance standard details for most of the above techniques.

Maintaining the necessary landforms for sustained vegetation growth is paramount over the long term. Linking this to ridge maintenance is key is resiliency of this option is to occur. It is more useful in “high exposure” islands and undertaken in tandem with other soft engineering schemes.	Option 1 Option 3
Longer term planning to design artificial “ridge crests” may be introduced in areas to improve the longer term resiliency of the ridge. This is likely to involve sediment recycling or re-nourishment operations in addition to vegetation planting programmes (see above). This technique needs to be promoted more on inhabited islands for long term implementation.	Option 1 Option 3
Longer term resilience of artificial reefs depends on the water quality conditions to enable reef colonisation to occur on the platform used (or pre-cast units). It is often not considered as a long term solution to dealing with erosion on islands due to poor strategic planning and commitment to monitoring and adaptation of design.	Option 1 Option 2 Option 3 Option 4
The lack of design guidance regarding pile distance and crest design heights makes long term resilience difficult to quantify, however, assuming initial structure height is appropriate, then resilience to climate induced storms in this time epoch is deemed as high. Should design height not be appropriate, then retrofitting the height of the construction is challenging and hence its resilience to climate change is very much dependent upon its original design.	Option 1 Option 4
With no formal design criteria, there is a high risk of toe failure within this time period and so structure resiliency is predicted to be weak and in need of structure re-build. Crest height will need re-designing to counter water level fluctuations and to improve performance. Whilst structure can be designed to be robust, its wider impact on sediment dynamics over longer time scales makes this not a preferred option form climate resilience unless properly constructed and designed at the outset.	Option 1 Option 2 Option 3 Option 4
Long term resilience of this approach is dependent upon the long term maintenance and management of the “protection” afforded to the propagules in the short term epoch. If this is undertaken, and mangrove/seagrass beds are encouraged in suitable quiescent locations, then this has a good longer term resilient potential.	Option 1 Option 2 Option 3

2.3 Chapter B3: Options to help Build Resiliency into Coastal Protection Measures

2.3.1 What Options do Engineers and Planners Have?

For the purpose of this Guidance Manual, four "management approach options" (as listed in Chapter B2) are presented for consideration for engineers and planners as follows;

- **Option 1**: Modification of individual structure design (i.e. pre-construction) to improve individual structure performance *(i.e.: focus on the structure design prior to construction);*
- **Option 2**: Modification (retrofitting) of existing adjacent hard structures (that are already in situ) to improve overall scheme performance*;*
- **Option 3**: Using soft structure measures to help modify existing *adjacent* structure strategic design to improve overall coastal protection performance *(i.e.: focus on merging hard with soft measures as part of an integrated scheme);*
- **Option 4** – Modification and review of land use planning *(i.e.: focus on accommodation measures, strategic placement of key features on an island and to reduce key infrastructure in "at risk" locations).*

These are now considered in turn, though are presented at a conceptual level. Specific designs (for Options 1, 2 and 3) for the Maldives are not prepared here as the procedure for determining the exact performance standard (see Chapter C1), design standards (see Chapter C2) and material standards (see Chapters C3.1 and C3.2) all need to be understood at the outset of any design in light of specific knowledge on the assets at risk and the perceived risk on each island. For that reason, indicative suggestions are provided which should be focused on in more detail during each EIA (see Part D, Chapter D1) that needs to consider coastal protection issues or as part of a series "pilot project implementation" programmes (international donor funded projects) in the coming years.

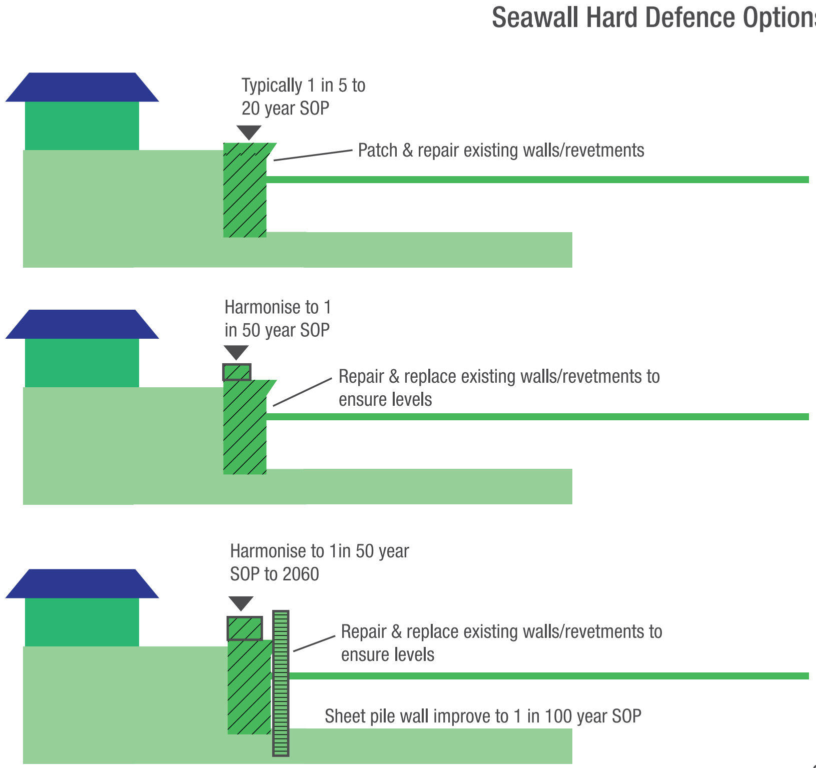
2.3.2 Option 1 - Modification of individual structure design (pre-construction)

This management approach option relates to the ability to engineer performance improvements (at the design stage0 to better address climate resilience. Chapter C1 sets out clearly a new set of performance standards to help the delivery of this option and hence the design of new climate resilient coastal protection schemes. Chapter C1 also clearly sets out a series of Standards of Protection (SoP) that should be adhered to that reflect the assets at risk behind the structure being designed. The SoP will be ultimately influenced by the land use and livelihoods (commercial or residential) that the defence is protecting. Chapter D2 addresses this issue with regard to the recommended updates to existing land use regulations in the Maldives and the selection of the most appropriate SoP that should be adhered to.

Figure B7 outlines a conceptual approach to modifying an individual structure (seawall – hard structure measure) by increasing its SoP from a 1 in 5 year defence standard to a 1 in 50 defence standard through the incorporation of a splash wall "added" to the existing crest of the seawall. The structures SoP is significantly increased with the introduction of floodgates (or de-mountable flood barriers – see Section 2.2.6) in front of the structure.

The key message from Option 1 is that once a preferred technique is selected (see Chapter B4), the integration of other supporting techniques or "add-ons" to the design can significantly improve its SoP.

Figure B 7 Conceptual cross sections to demonstrate how to increase climate resilience to protect housing



SOP - Standard of protection

2.3.3 Option 2 - Modification (retrofitting) of existing adjacent hard structures

This management approach option relates to "retrofitting" ADJACENT structures that maybe located close by to the proposed "footprint" site of the new scheme under discussion. Examples could include the re-positioning of a groyne field to better improve sediment drift to new locations. It could also include the example of altering the SoP of a seawall that is adjacent to a newly proposed harbour breakwater that is proposed for construction (i.e.: potential for increased alterations to tidal currents or increased risk of wave overtopping).

The example presented in Figure B8a is that of a lower cost rock filled gabion basket structure. Gabion basket structures are not commonly used in the Maldives, though examples do exist on outer islands where coral boulders remain the only tangible source of defence material to use. Their performance is more successful in quieter lagoon environments, away from higher energy waves and so the geographic placement of such structures away from the reef edge is very important. Gabion basket defences can be "retrofitted" as follows. In addition to raising the crest level to improve the SoP (as shown in Figure B8b), the material (rock) used to place into the baskets can improve resilience, along with the wire mesh that is used and the "angle" at which the gabion baskets are actually placed (see Figure B8b). Often, most baskets are placed flat on the ground, however, engineering practice dictates that an improved engineering resilience and performance is achieved by tilting the baskets landward by about 20 degrees and incorporating a rock gabion mattress to support the "cages" once placed. This mattress also helps improve drainage from the structure which is a common defence failure mechanism in many low cost techniques found on the islands.

Figure B 8a Retrofitting a coral rock gabion structure

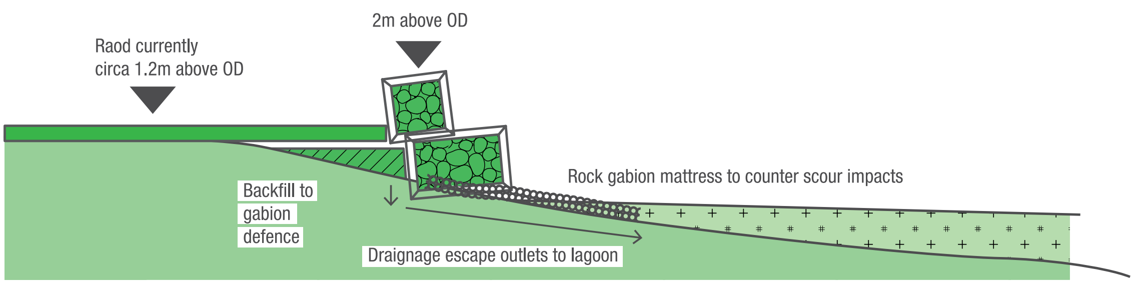
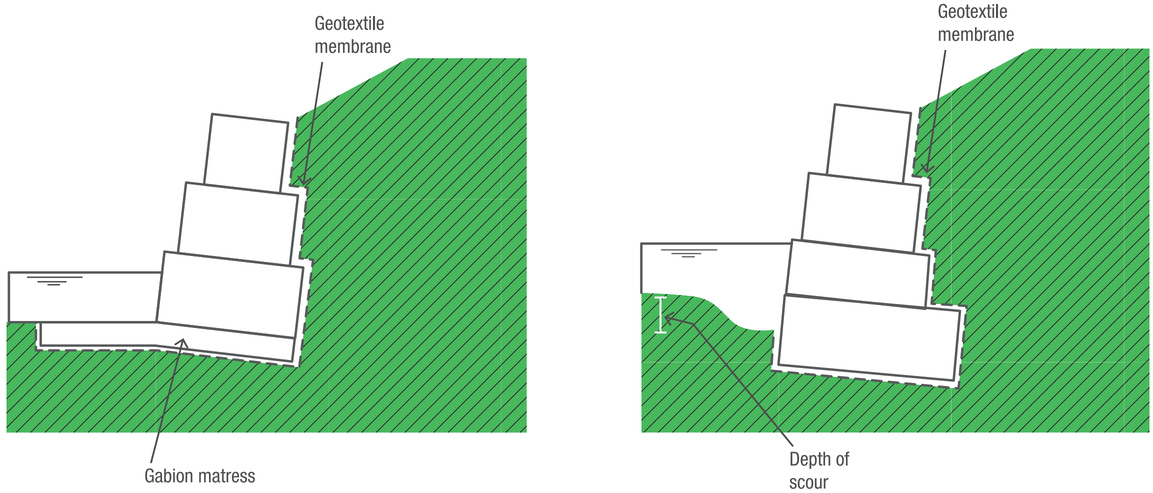


Figure B 8b Building resilience into a gabion structure by placing structures at 6 degree inclines



2.3.4 Option 3 - Using soft measures to help modify existing adjacent structure strategic design

This management approach option relates to the use of soft structure strategic thinking through the modification of adjacent structures. The most appropriate example of this option) with specific relevance to the Maldives) is in the design of individual groynes and groyne "fields". Groynes and jetties (if not on piles), often contribute to up-drift sand deposition and beach consolidation, usually at the expense of down drift erosion problems. They can also lead to further complications especially if the constructions are poorly designed. Problems often arise if no consideration is given to their spacing, composition and height. As a result, quite significant alterations to the sediment regime can result around an island and importantly, may affect the quantity of material naturally passing by an island to neighbouring ones that maybe dependent upon these sediment supplies.

Engineering a resilient approach to this problem is important in the Maldives, and the following technique is proposed for consideration and piloting. It combines sediment recycling (soft measures) with the construction of innovative concrete "unit" groynes ("Sedi-Tunnel groynes") to help maintain sediment dynamics and to create sand filled groyne bays in front of vulnerable areas. This approach would be innovative and unique to the Maldives. The philosophy behind the concept is that in areas where baseline data on sediment dynamics and budgets is lacking, a modular "pilot" approach to capturing a sufficient amount of mobile littoral sediment is preferred. This is an advantageous approach where littoral drift rates and the subsequent timing and amount of groyne bay "filling" can be managed to provide the necessary fronting beach protection required to protect hinterland assets and improve beach amenity. It can also be easily re-designed to ensure downdrift erosion is kept to a minimum.

For this option, each groyne can be designed to be any length that is deemed appropriate to each island (see Figure B9). It is modular in its design and comprises of a number of 1m"Sedi-Tunnel" units. Each unit shall rest on a purposely designed "Sedi-Tunnel" base unit that is buried to secure the units remain in place. These base units are built in modular 5m lengths to facilitate ease of transport and to enable the modular concept of the "Sedi-Tunnel" to adapt to local situations (see Part E). Figure B9 shows the cross sectional design of each groyne, its location along the beach profile and how its design should accommodate for beach access along the foreshore. It also shows how backshore protection (through maintaining existing beach vegetation levels or re-planting) is possibly needed to stabilise the back beach.

With each unit being placed on a specific 1.2m wide concrete base (which may be buried 30cm beneath the beach surface on first installation), the opportunity to re-orientate each unit by 90 degrees is presented in the design (see Figure B10). This will enable different rates of littoral drift to be experienced through the groyne structure and makes the approach more environmentally friendly than any other design of groyne (i.e.: existing rock structures are designed to block 100% of sediment movement between groyne bays). Figure B11 displays the design criteria for each "Sedi-Tunnel" unit. Each unit is pre-cast locally and made of a re-enforced concrete mix. The design life of each unit (when exposed to salt water and encrusted with algae and marine crustaceans) is estimated to be circa 5 years. As a result, continued maintenance and "ownership" of such a scheme by the local communities is needed to ensure the scheme is a success and that unit replacements can be planned for the future.

Figure B 9 Design of the "Sedi-Tunnel" approach for Maldivian Islands

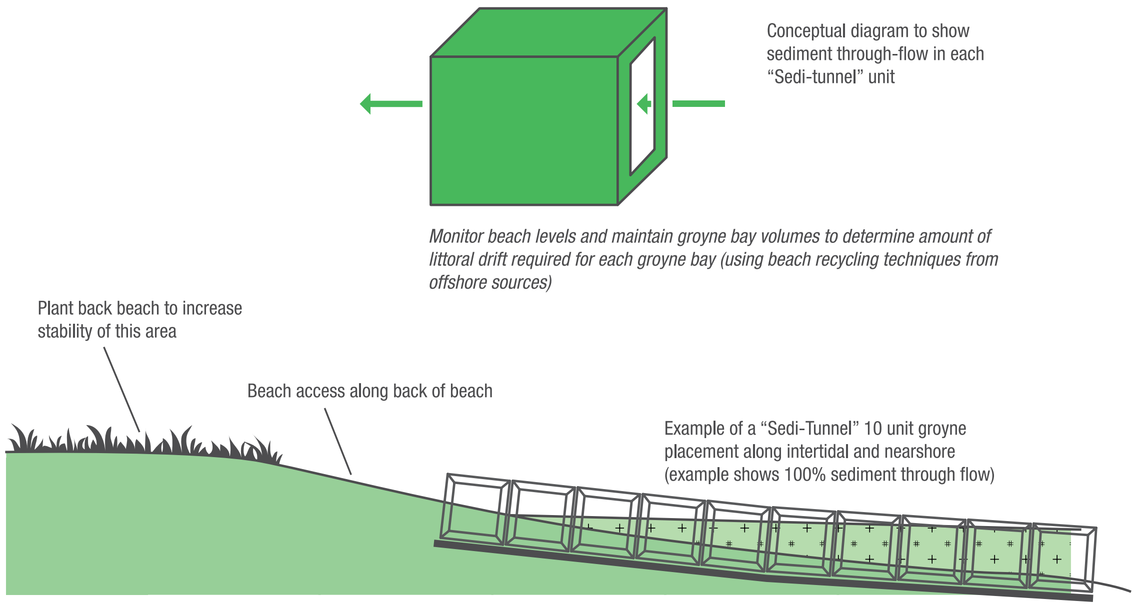


Figure B 10 Figure B10 – "SediTunnel" design options to help manage monsoonal sediment movements around islands.

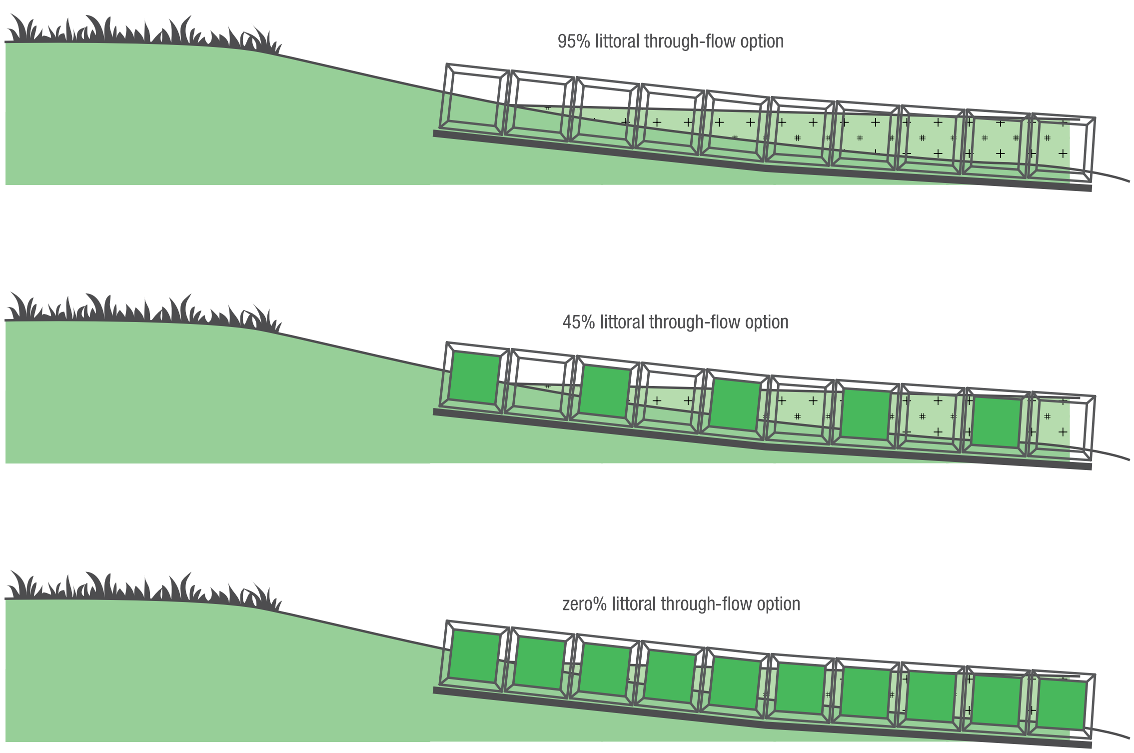
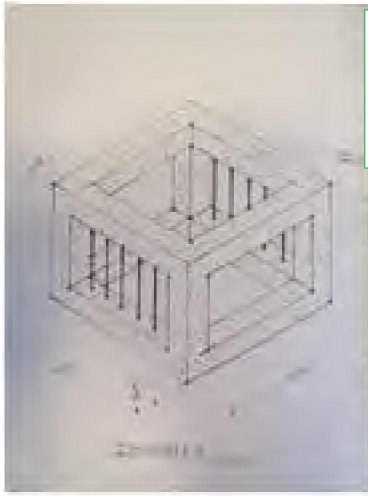
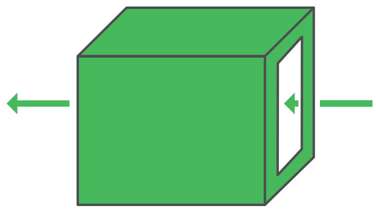


Figure B 11 "Modular unit design details of the "Sedi-Tunnel" groyne approach.



A bespoke concrete block mould is to be designed specifically for use a "modular" groyne structure. Each unit has 2 open faces and 4 solid faces. The proposed design has dimensions of 1 m x 1 m x 0.75 m (height)



Conceptual diagram to show sediment through-flow in each "Sedi-tunnel" unit

2.3.5 Option 4 Modification and review of land use planning

This management approach option relates directly to planning for a change and is applied in situations where there are no immediate benefits in investing in expensive coastal engineering schemes on an island (or part thereof). Chapter B4 should be reviewed to help identify whether this option needs to be pursued (see Figures B12 and B13). Part D (Chapters D2, D3 and D4) are then of relevance for Island Councils and GoM planners to consider with regard to compliance to existing Land Use Planning Regulations in the Maldives and update advisories to current set back policy.

2.3.6 Barriers to implementing Climate Resilient Coastal Protection Schemes

2.3.6.1 Uncertainty

Uncertainty is perceived as the biggest single barrier to change. Currently the 'risk' of over-investment on unnecessary engineering resilience is seen as greater than the risk and consequences of failure (i.e.: why embark on an experimental pilot study if there is a chance it will fail). This situation is probably not helped by relatively short-term investment appraisals (i.e.: the tourism sector in the Maldives) and high uncertainty of political support if success is not instant.

2.3.6.2 Lack of Understanding

There are a large number of climate effects (and coastal hydrodynamics impacts) which are not properly understood in the Maldives or are not yet quantified at a sufficient level of certainty to support any specific changes in approach towards coastal protection design (especially the use of softer engineering schemes. While there are forecasts and models provided by the Meteorological Bureau, there are computational limits on processing data for climate forecasts – particularly given the processor hungry nature of the models that are currently being constructed. Part C (Chapter C2) and Part E (Chapter E3) focuses on this issue in more detail

2.3.6.3 Funding

Availability of funding is as ever a challenge and the current and future economic circumstances in which infrastructure will exist is highly uncertain. From a regulatory perspective, it is suggested that standards need to be agile to remain relevant and that there is little support or sponsorship from Government to enable a standards setting process. The introduction of Private Public Partnership approaches (e.g.: Pevensey Bay – Sussex, UK) or the introduction of "Waterfront Taxes" should be considered further in the Maldives (see Appendix 5: Project 7).

Guidance Manual Note 6

In order to address the issue of uncertainty of "what to do next", it is strongly advocated that each island Council undertakes a "pilot implementation" phase for interpreting and understanding the use of the Guidelines. This could present a series of options and "visualisations" to help convey the implication of each "scenario" raised earlier or policy options as presented (see Appendix 5; Project 7).

2.4 Chapter B4: Choosing a Preferred Option

2.4.1 Overview

Every action has a cost; this is the reason that, in a context of climate resilient coastal protection in the Maldives, each approach considered must be fully thought through beforehand (scope of the island in question etc., stakes of island assets to be preserved, etc.). The approach will vary depending on the different situations (tourist or inhabited island etc.) that could occur should a seawall break or how much residential or commercial island land becomes exposed to increased hazard or risk, etc.). In a given situation, opting for one type of structure, or for a combination of two or more structures, is always a compromise between the specificity of the problem being solved (persistent erosion at the shoreline, flooding of low-lying areas within the EPZ, etc.), the morphological conditions (the house reed conditions and position and the beach-profile type), the land-use (residential, recreational, agricultural, etc.), and the anticipated impact of structures on coastal and reef processes.

2.4.2 Preliminary studies to assist Option Selection

The choice of techniques to mitigate erosion and flooding on Maldivian islands partly depends on risks which are expressed by the combination of hazards and stakes. The stronger the hazard and stakes, the stronger the risk is. The "erosion" hazard is determined by a sedimentary budget study of the littoral and shoreline or sensitive area long term evolution.

The flooding hazard depends, on one hand, on a historical study of island flooding, and on the other, a frequency analysis of oceanic parameters, (mainly mean sea level change). Reflection on these stakes must highlight the differentiation between current and future stakes. There are three main stakes:

- Human stakes;
- socio-economic stakes;
- environmental stakes.

They concern more particularly island development issues (e.g.: island population and infrastructures), local fishing activities, navigation needs between islands, culture, the economy and the surrounding reef environment. For the current stakes, risk management measures are considered (prevention, surveillance, pointing out dangers, prohibiting access, etc.). For future stakes risks must be reduced as far as possible. To do this, the zones (prevention) where infrastructures may be constructed (risk level, etc.) must be clearly identified and studied within the Island Land Use Plan or for new developments through the existing EIA process (see Part D: Chapter D1).

GUIDANCE MANUAL NOTE 7

This Guidance Manual strongly advocates that future Island Land Use Plans (see Chapter D2) make a more robust use of "Vulnerability Assessments - VA" as a key stage that must precede the choice of management interventions. VA is not explicitly part of the EIA, but it is included implicitly in that needs to be assessed in terms of climate change threats to a development's environmental impact in order to get cumulative / overall impact in terms of physical vulnerability. The wider aspects of VA are not, however considered. As a result, Chapter D2 recommends that this assessment should consist of drawing up a vulnerability report using indicators (hazards, stakes, risk perception policies and management measures taken). This would then clearly report for each island measures of damage that could be caused by the hazard should it take place. Chapter D2 considers this technique and its role in more detail.

The implementation of any coastal protection solution must be followed up by studies which assess the relevance of the work carried out and its environmental impact. Gathering data on climate resilience needs (as part of the EIA process) is already addressed in Chapter D1 and represents an important stage in order to understand site dynamics.

2.4.2.1 Island Community Recollections

A detailed analysis of past flooding (or climate related) events on islands, incorporating relevant data already collected for various purposes, enables a decision maker (including an Island Council) to learn from past experiences (by tapping local knowledge). Sharing data with other stakeholders, who may be engaged in monitoring or follow-up activities, is highly commendable and cost effective (see Part E). Including the island community in the decision process (using appropriate island communication programmes) is therefore important. Thus community knowledge must not be neglected as part of the preferred option decision making process.

2.4.2.2 Economic evaluation

An economic evaluation of development projects is necessary. This consists of identifying functions and services provided by island ecosystems and assessing effects linked to climate change and coastal erosion, whether positive or negative. This data must be integrated to development related expenses to obtain an estimate of the economic profitability of the development solution to address climate change in the future.

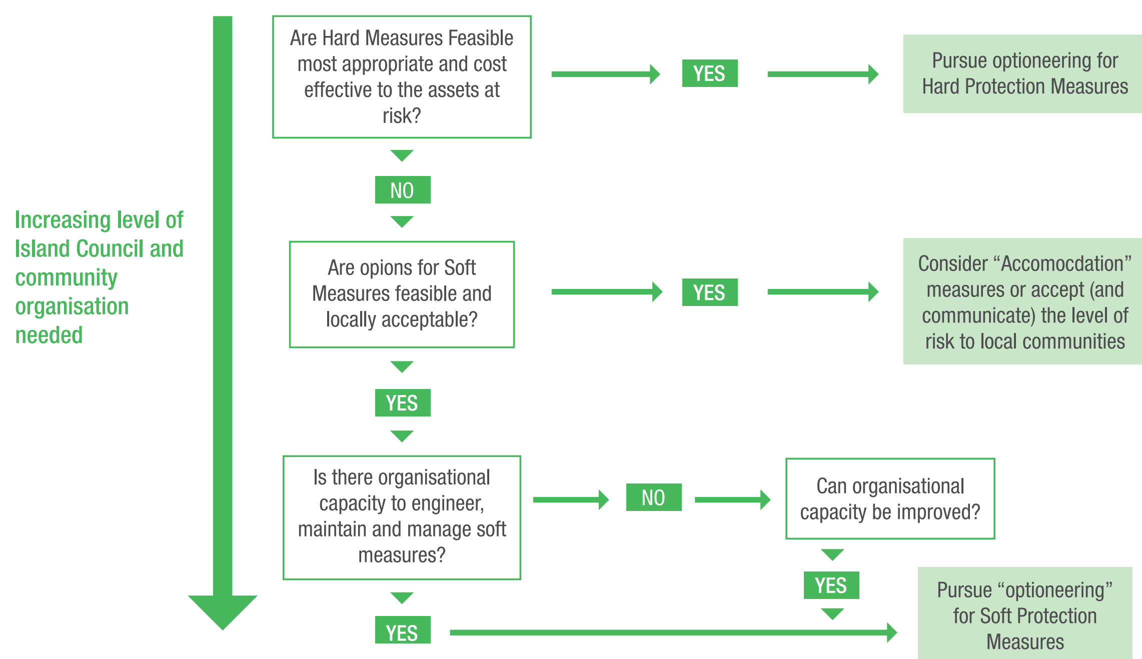
2.4.3 Deciding Between Hard or Soft Measures

As stated in Chapters B2 and B3, it is especially important to remember that any structures put in place, whether hard or soft structure measures, negatively impact the surrounding environment (sediment transport and budget, noise pollution, increased marine traffic, interrupted recreational use, perturbation of littoral biodiversity, etc.). It is essential to know the real need (knowledge of the hazards and stakes) for protection and how the various techniques impact the environment.

As stated throughout the "management approach" options defined in Chapter B3, the distinction between "hard" and "soft" solutions is not simple. On beaches, for example, it is generally strongly advised to combine several geotechnical approaches and to associate them with another "soft" method, such as re-vegetation. Applying this method does not aim to fight against erosion but rather to accompany natural processes and increase climate resilience. The nature of materials employed can also be taken into consideration (see Chapter C4), so that they integrate into the surrounding environment.

To help with decision making, Figure B12 presents a simplified "decision tree" diagram, tailored specifically for the Maldives. In order to derive an effective outcome from that flow chart, the preliminary assessments (identified in Section 2.4.2) maybe needed to help select the most effective direction of choice.

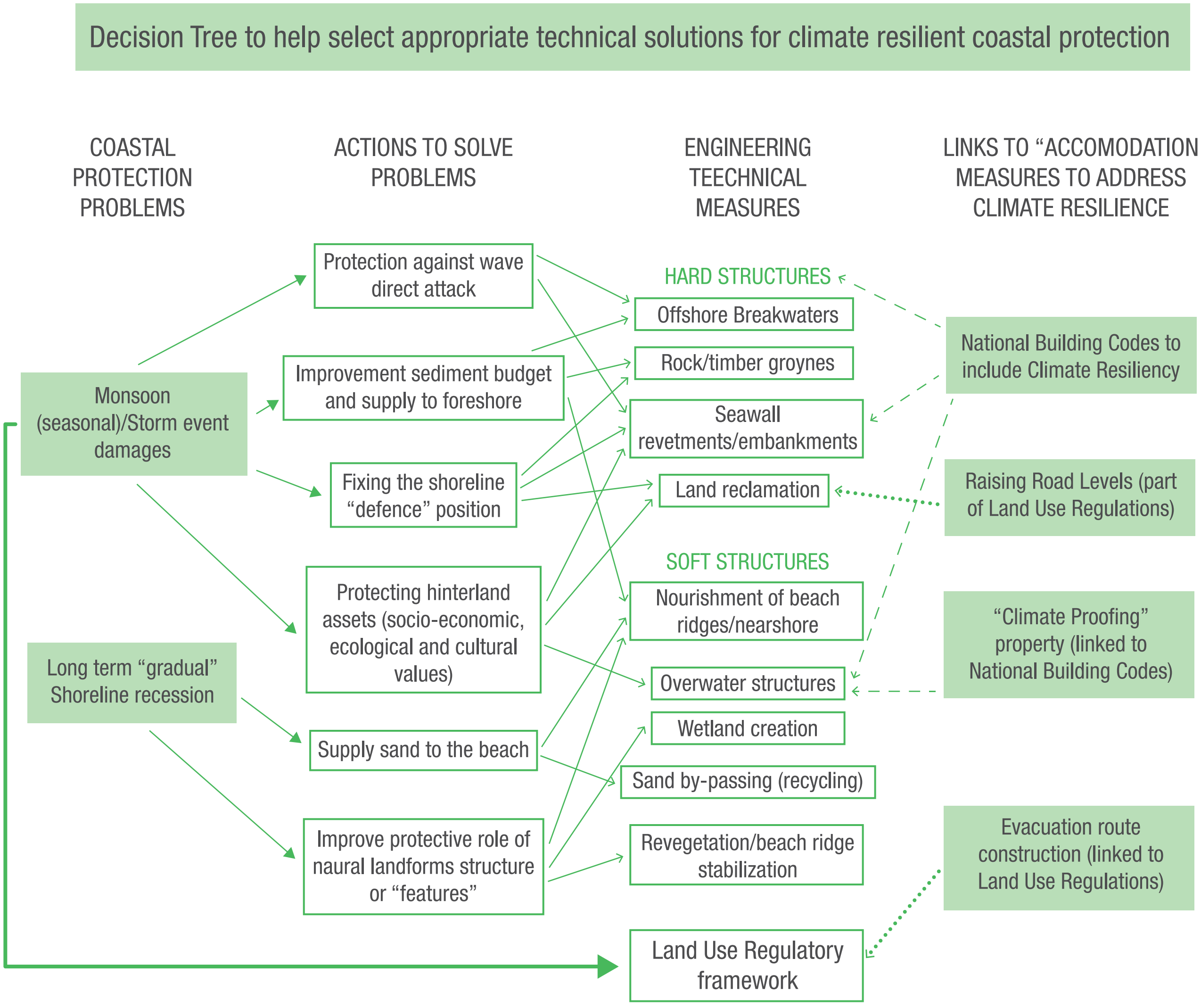
Figure B 12 Decision tree to help select between hard and soft option approaches



Once the above Decision Tree has been followed, another is prepared (Figure B13) that can be used at a strategic level to help identify the selection of individual coastal protection techniques to address climate resilience for coastal protection on Maldivian islands. Engineering details (performance standards, information requirements, design and material standards associated with these interventions) are categorised and presented in Part C.

+ Deciding between hard or soft measures

Figure B 13 Decision Tree for the selection of appropriate technical solutions in the Maldives.



ENGINEERING GUIDELINES

PART C

3. PART C: ENGINEERING GUIDELINES

3.1 Chapter C1: Engineering Performance Standards

3.1.1 Overview

The design of structures for coastal protection should be made in consideration of their intended performance standards. From an engineering perspective, these standards relate to the achievement of the structure purpose such that it has the desired outcome and effect; in this case the provision of coastal protection that confers climate change resilience to islands and their communities. From a planning perspective, performance standards relate to the desired level of protection and the duration protection should be provided for; these are covered in Part D, Chapter D2.

Performance *Standards* for climate risk resilient coastal protection structures[5] provide criteria against which the performance of the services they provide can be evaluated in terms of the ***durability*** of the structures and the ***level*** of protection they will provide. The performance standards describe the nature of activities that will be required in order to determine a measure of requirements for durability and level of protection.

The Engineering design performance standards proposed for coastal protection structures in the Maldives are based on those provided by the British Standard, American standard and EN Eurocodes. They are adapted to reflect Maldivian needs and situations (where possible or where available information allows this to be dictated). They have an objective of ensuring a uniform level of building quality to ensure fitness for purpose. The standards that have been used and the resultant recommendations for performance standards of materials and structures are given within this Part C.

The intention is that these performance standards will be reviewed, adapted and included within a specific new "Code" that shall, in time, be incorporated within future revisions of the National Building Code (2008 and see Figure B13).

3.1.2 Application of Performance Standards

The two performance standards that are proposed for application are as follows:

- Design standard details for coastal protection structures (see Chapters C3.1 and C3.2);
- Material standard details for coastal protection structures (see Chapter C4).

Both fall within the framework of the Environmental Protection and Preservation Act of Maldives (Act No. 4/1993) and the provision contained therein for Environmental Impact Assessment (Environmental Impact Assessment Regulations, 2007).

[5]For the purposes of this Code, 'coastal protection structures' is deemed to include any form of hard or soft engineering intervention and includes harbour, jetty and overwater structures.

The performance standards aim to ensure a pre-determined standard of protection (see Chapter B3) to island assets and communities from the increased risk of inundation (flooding) and loss of land presented by climate change scenarios is met.

The performance standards shall be applied to the design, build, monitoring and maintenance (see Part E) of all coastal protection structures constructed to contribute resilience to island assets and communities from the risks presented by climate change. The performance standards shall also apply to all locations where new development (including harbours and land reclamation), takes place and at locations where erosion[6] control/management is required.

GUIDANCE MANUAL NOTE 8

It is important to stress that these performance standards are designed to ensure that coastal and engineering resilience is incorporated directly into the structure of all future EIA reports that focus on any development that includes coastal protection structure. The performance standards will need to be assessed within all Environmental Management Plans prepared and all mitigation measure assessments. This is to ensure that the following aspects are addressed:

- Coastal structure design wave / water level conditions account for climate change effects;
- There is an assessment of the adequacy of the design of coastal structures;
- Consideration is always given to building resilience into coastal protection design (to optimise performance in reducing wave overtopping);
- There are basic assessments of how overtopping of existing coastal defence structures may change and how this relates increasing risk to vulnerable populations and assets.

The performance standards specifically address the scheme requirements to be considered in the planning and design of all coastal protection structures, and hence should be assessed and evaluated throughout the EIA process (see Chapter D1 for details). It should be noted that they are designed to ensure that coastal protection structures and/or schemes are fit for purpose AND address the future threats posed by climate change, i.e., they are climate proof.

3.1.3 Using the Performance Standards (agreeing to performance outcomes)

The performance standards provide a range of "performance outcomes" that coastal protection structures must achieve to demonstrate compliance to the standard. Acceptable outcomes (from the achievement of performance outcomes) are provided in Table C1.1, and represent ways in which the relevant performance outcome can be met. Table C1.1 defines the judgement criteria for building in climate change into the EIA process in addition to levels of climate change factors (the specifics if known) that need to be included in designing and building coastal protection structures.

These outcomes refer to various measures that shall govern the design its construction, monitoring and maintenance of coastal protection structures (see Chapter C2 and C3).

[6]For the purposes of this Code it is acknowledged that not all erosion is a direct consequence of climate change but it is accepted that climate change will exacerbate existing erosional forces in addition to leading to new erosional pressures.

Performance outcomes	Acceptable outcomes
1. Coastal Protection structures in an flood/erosion prone area subject to climate change risk	
Development that requires supporting coastal protection work is: consistent with the land use plan that has been prepared for the area, or to protect coastal-dependent development, preventing the risk of flooding/ erosion for areas adjacent to the development footprint to the maximum extent feasible. The above is in response to a demonstrated need to protect existing permanent structures from an imminent threat of climate change impact, flooding and/or coastal erosion, if abandonment or relocation of the structures is not feasible.	Design and build of coastal protection structures having regard to: Flooding/erosion threats are reduced to an acceptable level consistent with the planning horizon of the facilities requiring protection. Where flooding/erosion protection structures are necessary, maintaining physical coastal processes outside the area subject to the coastal protection work is required to avoid adverse impacts on adjacent coastal landforms and associated ecosystems. *Note: Coastal protection structures to ameliorate the impacts of climate change and provide flooding/erosion control are only to be initiated where the climate change risk and/or erosion presents a threat to public safety or infrastructure that cannot practicably be removed or relocated.* *threat is an event (including waves and storm tide) with a return interval of a minimum of a one in 20-year or the planning horizon for the development/facilities to be protected whichever is the longer.* *Note: Applications are to be supported by a report certified by a registered professional engineer that demonstrates this performance outcome will be achieved.*
Provision mitigates any increase in risk to people and property from adverse climate change risks/flooding/coastal erosion impacts considering climate change predictions and planning horizons of built assets.	Design and build of coastal protection structures [1]having regard to: Installing and maintaining on-site flood/erosion control structures. The practical design life of the structure in the context of future flood/erosion threat. The ability of structures to be adapted as climate scenarios become better defined and/or altered in the light of new data. Installation and maintenance of coastal protection works to mitigate adverse impacts to people and property from coastal flooding/ erosion at the location. *Note: Applications are required to provide the following information to demonstrate compliance with this performance outcome:* *assessment of the flooding/erosion hazard at a property scale[2];* *plans showing the intended location, materials and method of construction for any structures;* *a report certified by a registered professional engineer that demonstrates this performance outcome will be achieved.*
Coastal protection structure construction in a flooding/ erosion prone area within the Environmental Protection Zone (EPZ) under the jurisdiction of each Island Council are required to ensure they: maintain vegetation on coastal landforms outside a development area or harbour, where its removal or damage may: destabilise the area and increase the potential for flooding/ erosion; or interrupt natural sediment trapping processes or dune or land building processes; maintain sediment volumes of beaches and near-shore coastal landforms, or where a reduction in sediment volumes cannot be avoided, increased risks to development from coastal flooding/erosion are mitigated by location, design, construction, and operating standards; maintain physical coastal processes outside the development footprint for the structure, including long shore transport of sediment along the coast; do not increase risk of shoreline erosion for areas adjacent to the development footprint unless the structure is an erosion control structure.	If the development: does not alter or otherwise minimises impacts on the physical characteristics of beach and reef (lagoon) systems including beach (and beach ridge) height and sand volume; does not alter or otherwise minimises impacts on the physical characteristics of the seabed near the structure including flow regimes, hydrodynamic controls and tidal water; is located outside the active sediment transport area or otherwise maintains sediment transport processes as close as possible to their natural state; ensures activities associated with the operation of the development maintain the structure and condition of island vegetation communities and avoid wind and water runoff erosion. *Note: Applications are to be supported by a report certified by a registered professional engineer that demonstrates this performance outcome will be achieved.*

Performance outcomes	Acceptable outcomes
Coastal protection work that involves beach nourishment or beach sediment recycling (reflecting island monsoonal conditions of sediment drift) to control coastal flooding/ erosion is preferred over hard engineered structures wherever feasible.	Coastal erosion is mitigated by: beach nourishment undertaken in accordance with a program of nourishment works; or the construction of an erosion control structure where it is demonstrated that installing an hard engineered structure is the only feasible option for protecting existing permanent structures from an imminent threat of coastal flooding/erosion at the location. *Note: Applications for flooding/erosion control structures must demonstrate the consideration of beach nourishment techniques and include a statement of why nourishment (in whole or part) has not been adopted as the preferred means of controlling the erosion risk.* *Where coastal protection work is required to protect existing permanent structures from coastal flooding/erosion threats, beach nourishment is favoured in preference to hard engineered structures, such as seawalls and groynes. The location and materials for beach nourishment works are to ensure the natural characteristics and landform of the beach or foreshore is maintained.*
Where utilised, beach nourishment or beach recycling is to be undertaken so that: the nourishment works are suitable for the location; source sediment is of a suitable quality and is of a type and size which matches that of the native sediment usually found at the location; the methods of placement are suitable for the location and do not interfere with long-term use of the locality or environmental values within or neighbouring the proposed placement site; there is sufficient supply of source sediment to maintain long shore transport processes and coastal landforms adjacent to the site of the source sediment.	Acceptable outcomes will be island or site specific and not identified. *Note: Applications for coastal protection work must be supported by a report certified by a registered professional engineer that demonstrates how the engineering solution sought by the work will be achieved.* *Sediment should be sourced such that the extent of supply does not limit long shore transport of sediment to cause erosion elsewhere.*
Development of coastal protection structures are located, designed, constructed and operated to: maintain wave overtopping levels, or where a reduction in heights cannot be avoided, mitigate risks to development from wave overtopping and storm surge inundation; maintain or enhance coastal ecosystems and natural features such as mangroves and coastal wetlands, between development and tidal waters where they protect or buffer communities and infrastructure from sea-level rise and coastal inundation impacts, or where changes to these features cannot be avoided mitigate risks to development from coastal hazards; where changes to the natural features cannot be avoided mitigate risks to development from storm-tide inundation and permanent inundation due to sea-level rise; ensure structures can sustain flooding from a defined storm tide event; maintain the safety of people living and working on the premises from a defined storm tide event.	Development avoids, or where this is not feasible, minimises reducing overtopping heights. Development maintains existing natural environmental features such as mangroves and wetlands to mitigate impacts from storm-tide inundation and permanent inundation due to sea-level rise. Development ensures: habitable rooms of built structures are located above the defined storm tide event level, or a safe refuge is available for people within the development site during a defined storm tide event, or at least one evacuation route remains passable for emergency evacuations during a defined storm tide event. Structures are designed to prevent the intrusion of waters from a defined storm tide event to facilities used for the manufacture or storage of hazardous materials in bulk. *Note: Applications must assess the risk of storm-tide inundation releasing or otherwise exposing hazardous materials including appropriate emergency planning and contingency measures.* *Applications are to be supported by a report certified by a registered professional engineer that demonstrates this performance outcome will be achieved.*

Performance outcomes	Acceptable outcomes
In areas of high ecological significance (i.e.: a biosphere reserve), coastal structures designed to complement/enhance the coastal protection function of natural reef and marine ecosystems	Development avoids interrupting, interfering or otherwise adversely impacting on underlying natural ecosystem components or processes and interactions that affect or maintain the identified ecological values within an area of high ecological significance such as water quality, hydrology, geomorphology and biological processes. Measures are incorporated as part of location and design to protect and retain identified ecological values and underlying ecosystem processes within and adjacent to the development site to the greatest extent practicable. *Note: Applications for development within and adjacent to mapped areas of high ecological significance will be required to identify and describe the ecological values, ecosystem components and processes within the area that coastal protection structures are designed to complement and how enhancement is to be achieved.*
Coastal protection structures built adjacent to areas of high ecological significance (HES) do not adversely impact the natural function of those areas.	retaining vegetation in situ to the extent possible to stabilise the land and prevent soil erosion and water quality impacts off the development site. rehabilitating undeveloped areas of the site immediately following completion of the development. ensuring alterations to natural landforms, hydrology and drainage patterns on the development site do not significantly affect adjacent areas of HES. Where impacts cannot be avoided, the impacts are minimised and an environmental offset provided for residual impacts.
2. Dredging	
Extraction below high water mark is to: maintain the ability of the site or adjoining land to function as a barrier protecting lands from coastal waters and coastal hazards; maintain foreshore stability; allow physical coastal processes to continue to supply sand to foreshore areas; maintain the stability of the extraction area.	Any adverse effects on sediment transport processes from sand extraction activities are mitigated or otherwise remediated by suitably planned and implemented beach nourishment and rehabilitation works.
Contaminated dredged material is not to be disposed of in coastal waters.	No acceptable outcome is identified.
Capital and maintenance dredging and material disposal is to be undertaken according to a management plan prepared for the activity.	Disposal methods and disposal sites for the disposal of material are identified in a management plan for the construction and operational phases of the development. The development is undertaken in accordance with the management plan prepared to direct the operation of the development including the removal and disposal of dredged material. *Note: A management plan for dredging should be included as supporting information for an application of an EIA that includes a provision for dredging*
3. Reclamation	
Reclamation only occurs if it is necessary for: maritime development within a designated development area identified in the LUP, or development supported by a statutory land use plan in a port, harbour or for aeronautical facilities associated with an airport, or development of essential community service infrastructure, or minor public marine development, or coastal protection work.	Reclamation only takes place in support of identified development needs. The reclamation plan identifies adjacent areas of impact and proposes mitigating actions.

Table C 1 Table C1.1 – Judgement Criteria building in climate resilience into Performance Standards for coastal protection

3.1.4 One Size Doesn't Fit all

In terms of options for future engineered structures, there is a preference for 'more-of-the-same' as one location sees structures built at another location and assumes that such a structure is also applicable to their situation and needs – the reality is that often simple replication of structures between sites is not appropriate and can lead to either new coastal erosion/protection issues and/or exacerbate existing ones. The urgency of coastal issues around many islands also does not afford sufficient 'proving' time for built structures, whether hard or a soft option, before demand to replicate at other locations is faced.

Often a consequence of these issues and pressures to find solutions to coastal protection issues means that, for internationally led projects, structures are over engineered resulting in new/exacerbated 'downstream' issues. In contrast, Maldivian led projects are often under engineered leading to structures that do not function correctly and are frequently 'overtopped'.

Another feature of soft engineering options is that they often require some time to 'mature' before they become fully operational and functional, for example, any planting to stabilise mobile sediments is susceptible to damage and loss of functionality until the plants reach a certain size. This may mean that some form of temporary hard engineering is required to allow time and space for soft options to reach full functionality.

It is therefore critical that the performance standards set out in this Guidance Manual are considered on a "site by site" basis.

3.1.5 Defining the information required for the Performance Standards

In order for the performance standards to be applicable across all Maldivian islands and all situations, there needs to be specific information requirements and also it is necessary to have a common methodology to adhere to. It is recognised that following a common methodology, without having island specific data (i.e.: mean sea level to calibrate against more easily derive island topographic data) will likely lead to different outputs for different locations within and between islands. This is desirable as each location is likely to present a unique range of states and conditions such that a "one-size fits all" application of performance standards would be inappropriate. The following sub-sections outline the measures and factors that should be considered in setting the performance standards that should be adopted for EIA in the Maldives specifically in order to accommodate climate change (this is related in the new EIA Regulations Appendix (Supplementary Guidance) set out in Chapter D1).

Specific design related information that needs to be available, and presented through the EIA process, is clearly set out in Chapter C2.

3.1.6 Assessing climate change risks in relation to performance standards

Determining the risk presented by climate change, within the Maldives, is fraught with debate and uncertainty. The recent RIMES (2012) study "*Development of high-resolution regional climate model for the Maldives*"[7] deduced that the maximum sea surface height changes for Male during 2001 to 2100 fluctuates from 0.4 to 0.48m with an uncertainty range 0.36 to 0.5m. This range and associated uncertainty is comparatively larger for northern atolls than southern atolls. According to the IPCC, during the last 100 years, sea-level has risen at a rate of 1- 2 mm/yr and is projected to rise 10 - 90 cm by the end of the present century. However, the findings need to be accepted with caution, since the inhabited islands of Maldives are highly modified and their natural adaptation to any future climate change is yet to be determined.

Climate change predictions also suggest that storm intensity and frequency will increase which will impose an additional component of sea level rise through storm surges and swells that should be accommodated in determining the performance standards of coastal protection structures. Other jurisdictions[8] have adopted storm surges and swells that can be expected from the 100 year average recurrence interval extreme storm event or water level as providing a suitable measure to be included.

[7] The term 'structure' means any built intervention of a hard or soft engineered nature for the purposes of coastal protection.

[8] Property scale is the scale of frontage under erosional forces at the specific site/location in relation to the assets at risk from the erosional forces.

[9] RIMES (2012). Development of high-resolution regional climate model for the Maldives. Report 4 Climate change scenarios and their interpretation for Maldives.

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For the purposes of the Maldives, it is proposed that all future EIAs that require a clear assessment of sea level rise predictions, use the following within all reporting documents:

- Adopt the sea-level rise figure of 0.9 metres by the year 2100 (relative to 1990) based on the upper limit of the projections published by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (2007). This is compatible with the RIMES study (2012) and applies a worst case precautionary principle;
- Factor in a 10 per cent increase intensity of storm events (surge impacts etc) by 2100. This can be used for any modelling studies undertaken as part of an EIA or for planning and assessment purposes. This represents the one per cent (or 1 in 100) probability storm event, formerly referred to as a 1 in 100 average return interval (ARI) storm event (the defined storm-tide event).

The performance standard information that relates to different land uses (standards of protection required to protect specific land assets over different time periods) are clearly articulated in Part D, Chapter D2. In addition, advisories for reviewing setback policy and the definition of the Environmental Protection Zone (EPZ) are set out in Chapter D4.

3.2 Chapter C2: Design Considerations (Generic issues - Hard and Soft Measures)

3.2.1 Pre-construction considerations

Resilience to climate change is not an add-on but should be an integral part of the design and construction of coastal structures. Before commencing on the design of any coastal protection structural elements relating to coastal erosion structures or harbour design an archive, assessment must be carried out to determine what background information is available. This must include but not limited to the following:

Geological Conditions

- Structure and composition of overlying seabed deposits;
- Depth to rockhead and type and condition of rock (see Section 3.2.3).

Topographic and Maritime Conditions (see Section 3.2.2)

- Island shape and position within the atoll;
- Description of land area / topographic conditions;
- Hydrographic conditions;
- Aids to navigation existing;
- Manoeuvring and navigational conditions.

Water Level Recordings (see Section 3.2.2)

- Tidal variations;
- Depth references;
- Corrosion characteristics (corrosion, deterioration of concrete, attacks by marine borers).

Wind generated offshore (see Section 3.2.2)

- Wind force, duration and compass;
- Critical wind forces and direction.

Waves generated offshore (see Section 3.2.2)

- Wave heights caused by wind, significant wave length, maximum wave height and wave direction;
- Swell;
- Waves from passing vessels.

Currents (see Section 3.2.2)

- Strength, direction and duration;
- Erosion and siltation, sea bottom conditions.

There are a number of engineering issues that also need to be considered prior to selection of an appropriate approach and option. From a Maldivian perspective, the key aspects are set out in Section 3.2.3.

3.2.2 Pre-construction Considerations (Hydrodynamic Related)

It is important that options for engineered structures are assessed for their feasibility against the performance standards they are expected to meet. This is necessary to ensure that the coastal protection provided can protect the coastal properties and assets at risk. In the case of the Maldives there are three particular 'features' that are critical to assess for feasibility of planned engineering structures in order to determine the 'constructability' of the design and their cost estimates, namely (i) Island shape and proximity within the atoll system; (ii) Regional tide conditions; (iii) Design water level; and (iv) Design wave level. These features largely drive the coastal erosion pressures faced by islands in the Maldives and which lead to the flooding pressures and risk faced by island infrastructure and communities. Each of these are detailed in the following sub-sections.

[10] For example Queensland, Australia.

3.2.2.1 Island shape and proximity within the atoll system

The physical setting of the Maldivian atolls shows great variation in the types and shapes of islands and reefs present. Most of the larger islands occur around the margins of the atolls but there are also islands within the atoll lagoons forming patch reefs, knolls or "thilas", micro-atolls and faros (ring-shaped reefs with their own lagoon). Island shape and position within the atoll are useful indicators of the adaptive nature of an island to future development. Figure C1 displays a simple diagram that outlines the crude position of an island within its specific house reef, whilst Figure C2 presents a series of conceptual island shapes that characterise many of the island types occurring in the Maldivian archipelago.

Figure C 1 Typical Island Positions within Atolls (from McCue 2000)

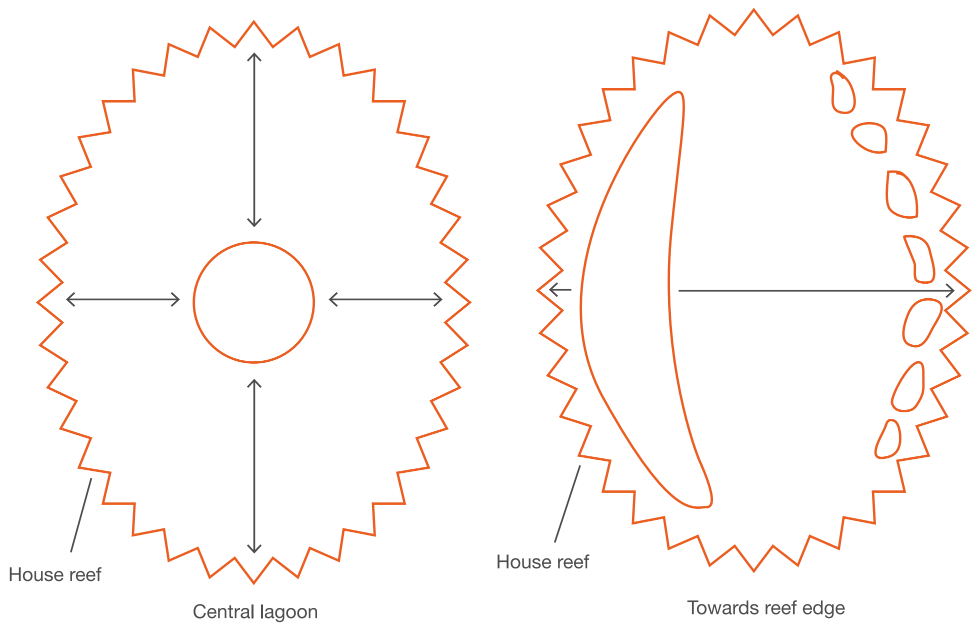
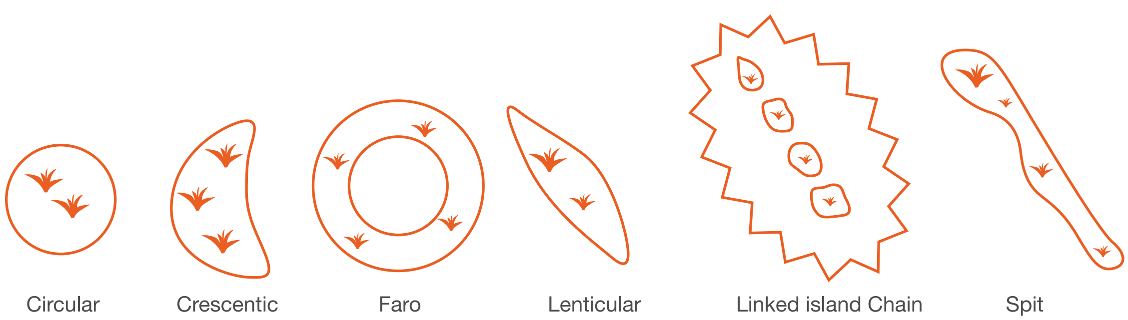


Figure C 2 Island Shapes (from McCue 2000) (a: circular; b: crescentic; c: faro; d: lenticular; e: linked island chain; f: spit)



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3.2.2.2 Maldives Regional Tide Conditions

Details of tidal and wave conditions for the Maldives are detailed in the Final Technical Standard and Design Manual July 2012, Oriental Consultants Co., Ltd. The key data from that document is replicated in Table C2.1 below.

The Maldives tidal ranges can be summarised as follows covering the regions from north to south:

Table C 2.1 Mean Sea Level (MSL) has been adopted as the Work Datum Level for harbour and coastal defence projects.

Regions in the Maldives	Observed Islands	HAT	HWOST	MSL	LWOST	LAT
Upper North Region	Sh. Funadhoo	+0.55	+0.32	0.00	-0.32	-0.55
North Region	B. Eydhafishi	+0.64	+0.34	0.00	-0.36	-0.56
North Central Region	K. Male	+0.64	+0.34	0.00	-0.36	-0.56
Central Region	Th. Dhiyamigili	+0.60	+0.37	0.00	-0.37	-0.60
South Central Region	L Fonadhoo	+0.42	+0.28	0.00	-0.28	-0.42
Upper South Region	Ga. Dhaandhoo	+0.56	+0.42	0.00	-0.42	-0.56
South Region	Se. Gan	+0.63		0.00		-0.75

3.2.2.3 Extreme water levels

Extreme water levels contain a number of components:

- Astronomical tidal levels;
- Tidal surge due to barometric pressure;
- Surge due to wind and wave effects;
- Fluvial /drainage influences, and
- Tidal amplification for harbour projects.

An analysis of the offshore wind climate and offshore wave climate will need to be carried out to help calculate the design return period of wave heights. These will then be combined with the return period water levels in a joint probability analysis. A joint probability analysis of water levels and wave conditions takes into consideration the correlation between the probability of extreme water levels and extreme wave conditions occurring at the same time. The tidal range in the Maldives reaches a maximum of ~1.2 m (Kench et al 2010). This suggests that there is a maximum clearance of structures of 0.9 m above maximum tidal limit (see Chapter C3.1 for proposed design standards for hard structure measures).

3.2.2.4 Design wave level

According to Technical Standards and Commentaries for Port and Harbour Facilities and Japan (2002), it is advised that design wave levels shall be determined with consideration of the encounter probability based on the return period and the design life of the harbour and coastal defence projects to assess wave conditions. The Encounter Probability for marine structures in the Maldives islands is outlined in the Final Technical Standard and Design Manual July 2012, Oriental Consultants Co., Ltd.

Waves are specified by the wave height, H (vertical distance from crest to trough), the wave period, T (the time between the passage of successive waves), wave direction (angle between wave crest and shoreline), and the still water depth, h (the water depth in the absence of waves). The wave length, L (horizontal distance from wave crest to wave crest), is determined from the wave period and water depth by the dispersion equation. If the water depth is greater than half the wave length (h > L/2), then conditions are considered deep water and the deep water wave length, L_0, may be written as

Equation 1:

$$L_0 = \frac{gT^2}{2\pi}$$

Where:

g is the acceleration due to gravity.

When wave conditions are generated by winds, there are always multiple waves. There are many wave heights, periods, and directions existing simultaneously. It is convenient to represent this collection of waves by a single representative wave height, period, and direction. The significant wave height, H, is related to the average of the highest 1/3 of the waves. The spectral wave height, H_{m0}, is equal to four times the square root of the total energy in the waves. In deep water, these two are taken to be equivalent.

A meteorological and tidal effects assessment will be carried out using recognised industry standard procedures. This study is required to indicate the maximum predicted water levels at the relevant project site. This will be achieved by:

- Compiling information on wind magnitude and direction;
- Undertaking a site specific numerical wave model to predict wave and surge conditions;
- Collating information on climate change to predict the rise in water levels over the next 50 years;
- Calculating maximum predicted water level, taking into account tidal influence, meteorologically induced surge, climate change, local wind and wave induced surge effects, and
- Effects of local water courses.

The offshore climate is used as input parameters for a wave model which propagates the waves into the harbour or coastal defence project site to the nearshore zone, allowing the waves to decay and also grow with the local wind effects.

The challenge in the Maldives is that there is little wave and storm surge information on which to base design heights. Despite this lack of records, recent extreme events and the fragmentary wave records that do exist provide an indication of potential extreme water levels. Measurements of shoreline wave heights in the Maldives indicate that waves can reach in excess of 1.0 m on the outer reef and close to the shoreline, under westerly monsoon and exposed island shoreline conditions (Kench et al., 2006, 2009a,b).

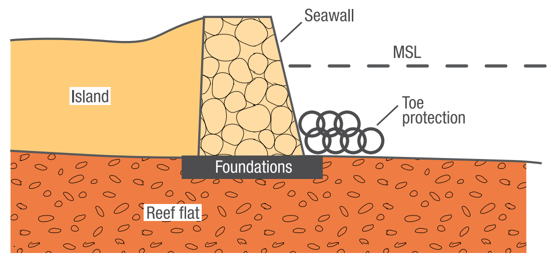
3.2.3 Pre-construction Engineering Considerations (possible failure mechanisms)

In order to evaluate the design and performance of coastal protection structures it is instructive, during the pre-construction stage, to undertake an exercise to evaluate and assess all possible criteria that may influence structure performance that may contribute possible failure. Figure C3 (taken from Kench 2010) provides a useful overview of the parameters that need to be assessed prior to construction. A more formal procedural approach to capturing this information is presented in Appendix 3.

Figure C 3 Conceptual Diagram of potential failure mechanisms for coastal defence schemes (from Kench 2010)

1. Foundation Conditions and 2. Toe Protection

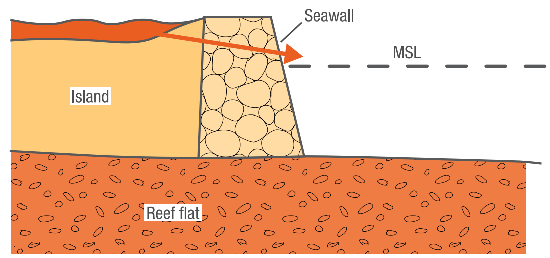
1) Structure foundations must be positioned at sufficient depth to avoid scour and undermining. 2) Structures must also have adequate toe protection to prevent structure being undermined.



3. Drainage

Structures should provide for adequate land drainage.

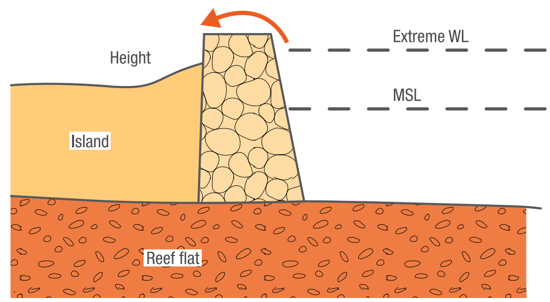
One of the biggest reasons seawalls fail is the inability to drain water from the land. Water ponded behind walls places pressure on structures and can promoted toppling.



4. Height of Structure

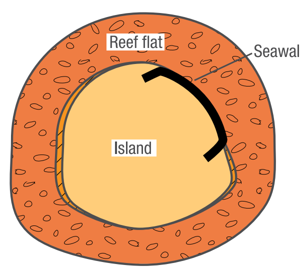
Structures should be build high enough to avoid wave overtopping and flooding of the island surface.

In the Maldives many structures have been overtopped leading to slumping of the island surface and structure and ultimately leading to the collapse of some structures.



5. Secure Terminal Ends of Structure

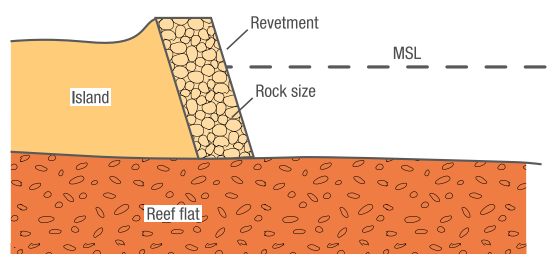
The ends of structures must be securely fixed to the island to avoid erosion at the ends of structures and accelerated erosion. This type of erosion is known as "flanking".



6. Size of Aggregate

The size of material used in structures should be of sufficient size to withstand wave energy.

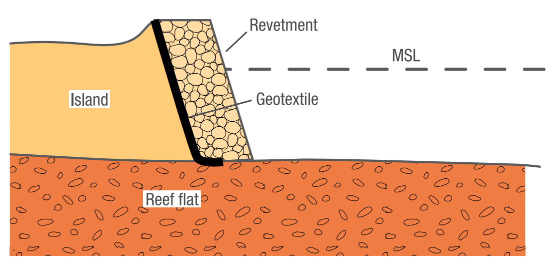
In the Maldives limited supplies of aggregate have led to the use of cement sand bags and coral boulders. These materials have low wave thresholds (~0.5m). Consequently, structures are susceptible to rapid degradation and failure.



7. Minimize Void Spaces

In block structures it is important to ensure void spaces between blocks (coral, cemebt bags) cannot allow island sediments to be washed through. This can be achieved using graded fill on the landward side and/or geotextile matting that prevents the movement of sediment, through the structure.

Where sediment can leak through the structure the land surface subsides promoting erosion and eventual collapse of structures.



With specific reference to rock structures in particular (from Figure C3), in addition to selecting the appropriate rock armour weight and size, there are other important components of rock structures (e.g.: breakwaters and revetments etc.) to consider during pre-construction design. The form of construction of rock revetments, breakwater and groynes (as examples) will vary for each site location and will be dependent on the following environmental factors:

a. Location and exposure of the site;
b. Geotechnical ground conditions;
c. Bathymetry including beach profile;
d. Topography and commercial, residential and industrial usage in the coastal hinterland. This is directly related to the slope of the revetment structure and the allowable overtopping permitted at the individual site locations;
e. Wind direction;
f. Offshore wave conditions;
g. Nearshore wave conditions;
h. Current and siltation issues;

Other engineering factors that need to be considered during the pre-construction phase include the following:

Type of Underlayer - A permeable underlayer is placed beneath the armour layer. This layer provides drainage to avoid build-up of excess hydraulic pressures beneath the armour, prevents migration of fines out of the bank, and provides a suitable surface for placement of the armour. Build-up of excess pressure beneath the revetment is one of the most important failure modes for revetments. Permeable revetments and underlayers allow dissipation of this pressure as water can flow out of the armour layer. Also, the subgrade must be geotechnically stable for the static and dynamics conditions associated with the design. This may require compaction or other improvements of the subgrade prior to placing filter and armour layers.

Type of Geotextile Filter Fabric - If geotextiles are used, it is key to ensure that the porosity and permeability requirements are satisfactory. The fabric provides separation between the underlayer and the subgrade, preventing loss of fines but allowing the flow of water. In general, the equivalent opening size (EOS) of the fabric (EOS = 95 per cent smaller opening size) should be EOS = D50 subgrade. The fabric permeability should be at least 10 times the subgrade permeability. The fabric must have suitable strength capabilities in elongation, puncture, and shear. If the fabric will be exposed to sun light, it must also be UV stabilized.

Articulation - Flexibility of the armour layer is a consideration with using articulating concrete block systems. The revetment system should allow for individual units to adjust to differential settling of the underlying material. Any settlement beneath a rigid revetment system may result in voids beneath the armor layer, causing points of weakness which will lead to failure.

Toe protection — Toe protection may be necessary to prevent failure of the structure caused by scour and undermining. Common alternatives are:

- Place a scour blanket of hydraulically stable material;
- Place larger stones or blocks on the toe;
- Trench the toe beneath the depth of maximum anticipated scour;
- Use geotextiles to contain the armor at the toe, or
- Use ground anchors or screws for restricting block motion.

Flank Protection - The lateral ends of the revetment may be susceptible to damage. The flanks may be stabilised using techniques similar to the toe. If the revetment is placed on a shoreline experiencing chronic erosion, then it may be necessary to tie the revetment back into the slope using wing walls. This will reduce the tendency for the revetment to be flanked.

Runup/overtopping - If the revetment is intended to prevent backshore flooding caused by waves, then the height of the revetment must be sufficient to prevent wave overtopping. If wave overtopping is expected, but is allowable, then the berm of the revetment may require additional stabilisation. The techniques used on the toe are applicable. Along the berm, it may also be possible to use bio-stabilization methods.

The required rock armour size can be determined using either the Hudson equation or the van der Meer equation. The Hudson equation is shown below:

$$W_{50} = \frac{\gamma_r H_s^{3}}{K_D \Delta^{3} \cot\alpha}$$

$$\frac{H_s}{\Delta D_{n50}} = (K_D \cot\alpha)^{1/3}$$

or

$$\frac{H_s}{\Delta D_{n50}} = 6.2 P^{0.18} S^{0.2} N^{-0.1} \xi_m^{-0.5}$$

$$\text{when } \xi_m < [6.2 P^{0.31} (\tan\alpha)^{0.5}]^{1/(P+0.5)} \text{ and}$$

$$\frac{H_s}{\Delta D_{n50}} = 1.0 P^{-0.13} S^{0.2} N^{-0.1} (\tan\alpha)^{-0.5} \xi_m^{P}$$

$$\text{when } \xi_m > [6.2 P^{0.31} (\tan\alpha)^{0.5}]^{1/(P+0.5)}$$

The van de Meer equation is:

"in which N is the number of waves (maximum value of 7,500), P is the notational permeability, and S is the damage level. The two equations account for different breaking wave types based on slopes of 1V:1.5H to 1V:3H, S = 2; and for slopes 1V:4H to 1V:6H, S = 3".

The thickness of the riprap layer should be $2D_{n50}$, but not less than 300 mm. Care must be taken when placing the riprap to ensure that the stone sizes are uniformly distributed over the full slope. End dump construction often results in the larger stones at the toe with smaller material on the upper slope.

An underlayer beneath the riprap provides pressure dissipation, drainage, and containment of the fines in the subgrade. Because a riprap revetment is widely graded, the underlayer size requirements are more restrictive than a stone armour revetment. The size of the underlayer is given by:

$$D_{85\,\text{underlayer}} \geq 0.2 D_{15\,\text{cover}}$$

in which $D_{85\,\text{underlayer}}$ is the diameter at which 85 percent of the underlayer sizes are finer and $D_{15\text{cover}}$ is the diameter at which 15 percent of the riprap stone sizes are finer. An approximate underlayer size is given by:

$$W_{50\,\text{underlayer}} = \frac{W_{50\,\text{cover}}}{50} \rightarrow$$

$$D_{n50\,\text{underlayer}} = \frac{D_{n50\,\text{cover}}}{3.7}$$

3.2.4 Pre-Construction Considerations (Wave Overtopping or Coastal Inundation)

Wave overtopping (or coastal inundation on islands) can affect the structural integrity of buildings and infrastructure, as well as limiting pedestrian access to an area. A number of reports including the Eurotop Manual[9] and Revetment Systems against Wave Attack: A design manual[10] provides guidance on tolerable overtopping discharge levels. Tables C2.2 to C2.4 show the tolerable discharges for pedestrians, vehicles and infrastructure as defined by the Eurotop Manual. Given the low discharge rates, required to make the site safe for an unaware pedestrian at the 1 in 200 year return period including climate change, a tolerable discharge rate of *1-10 l/s/m* would be desirable.

Table C 2.2 Limits for Overtopping for Pedestrians.

Hazard Type and Reason	Mean Discharge	Max. Volume
	q(l/s/m)	V max i/m
Trained staff, well shod and protected, expecting to get wet, overtopping flows at lower levels only, no falling jet, low danger of fall from walkway	1-10	500 at low level
Aware pedestrian, clear view of the sea, not easily upset or frightened able to tolerate getting wet, wider walkway	0.1	3-2 t high velocity

Table C 2.3 Limits for Overtopping for Vehicles.

Hazard Type and Reason	Mean Discharge	Max. Volume
	q(l/s/m)	V max i/m
Driving at low speed, overtopping by pulsating flows at low flow depths, no falling jets, vehicle not immersed	10-50	100-1000
Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets	0.01 – 0.05	3-2 t high velocity

Table C 2.4 Limits for Overtopping for damage to Defence Crest or Rear Slope.

Hazard Type Reason	Mean Discharge
	Q(l/s/m)
Embankment Seawalls/sea dikes	
No damage of crest and rear slope are well protected	50-200
No damage to crest and rear face of grass covered embankment of clay	1-10
No damage to crest or rear face of embankment if not provided	0.1
Promenade or revetment seawalls	
Damage to paved or armoured promenade behind seawall	200
Damage to grassed or lightly protected promenade or reclamation cover	50

[11] http://www.overtopping-manual.com/eurotop.pdf

[12] http://www.icevirtuallibrary.com/content/book/100862

3.3 Chapter C3.1: Design Standard Details (Hard Structure Measures)

3.3.1 Overview

The following text provides the engineering design standards for hard structure measure coastal protection in the Maldives. The sub headings used within this Chapter reflect those set out in the Terms of Reference (ToR) for the project. It should also be emphasised that designs presented within this Chapter (in tandem with those discussed by Shaig (2011) and Kench (2010)), are limited to those coastal structures that have already been designed by the Engineering Section of MEE.

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This Guidance Manual is designed to be a "living document". This means that when more accurate baseline information is available (for example on mean sea level data for differnet atolls), improved quantitative design parameters can then be provided in future editions (see recommended project in Appendix 5 of this Guidance Manual). At present, and learning from lessons from Shaig (2011) and Kench (2010) as well as from stakeholders during the CTL Consult Ltd contract period (September 2012 to January 2013), it is deemed inappropriate to present any detailed quantifiable design parameters for islands where information is sparse or, at best, subjective. This is to prevent the inappropriate use of a hard structures conceptual design on an island where the performance criteria are not appropriate. No formal designs are also presented forsmall-scale community interventions at the coast, despite visual observations being made of these attempts by the authors.

The Guidance Manual is designed to provide ***strategic guidance*** *from immediate effect. This means that for the basic standards and tools are provided, though additional studies (to collect baseline data) are still needed to formalise the actual engineering design. Therefore, design standards and parameters are only provided where it is believed that international performance standards (set within this Guidance Manual) can be achieved (or a close equivalent depending on the performance standard required that is commensurate with the land use it is seeking to protect). For soft structure measures, only detailed design performance standards are presented for beach replenishment/nourishment schemes. Other "tried but not formally tested" techniques, at this time are not included for the reasons set out above. For generic commentary on specific strucutres, the reader is recommended to review the overview (in Chapter B2) and the compendium of soft options outlined by Shaig (2011).*

3.3.2 Coastal Infrastructure Development Guidelines

Although this category was included within the ToR for the Guidelines, no clear differential "feature" falls neatly into this category that hasn't already been covered elsewhere. Features such as coastal outfall pipes or desalination structures can be defined as "coastal infrastructure", however, they play no direct role in providing a coastal protection function. Likewise, industrial or commercial "service" infrastructure (that occurs on the coast including telecommunication stations, roads and/or airstrips) do not play a primary coastal protection role and ultimately falls under a land use specific issue, therefore it cannot be separated out for specific consideration and design standard setting . Consequently no specific guidance is provided.

3.3.3 Land Reclamation Guidelines

3.3.3.1 Formal Land Reclamation

Overview

Formal land reclamation is the process of creating new land under government instruction and is often used where space is limiting social and/or economic activity. Land reclamation for the Maldives is likely to increase in the coming years, with increasing pressure to develop and provide land for the existing and growing population. It has caused a boom in the tourism industry and a revolution to island geography by altering the shape, size and potential of many islands forever. In fact, the Maldives would not be at the present level of development without reclamation. At present (for example) Hinnavaru and Naifaru islands are both nearly twice their original size as a consequence of reclamation. Despite this, land reclamation has the potential to create a range of environmental problems during its creation and post-construction and careful regard must be paid to evaluating/modelling the impacts of newly reclaimed land on existing coastal processes, how these processes may become modified and the impact on existing natural systems.

Key stages in the development of land reclamation projects are as follows:

- Planning dredging and reclamation works, incorporating relevant laws, land ownership, national strategies and site conditions.
- Design issues addressing reclamation levels, sourcing fill, ground improvements, types of shore protection and their construction methods and costs, environmental effects

and the treatment of weak or contaminated sediments.

- Construction methodology for reclamation, which looks at the types of dredgers, their working methods and fill placement techniques.
- The control of operations including survey information, environmental monitoring and mitigation methods as well as the monitoring of dredgers.
- The project implementation covering pre-qualification of contractors, contract documentation, tender analysis and project control.

Details of material standards for dredging and land reclamation is addressed in Chapter C4, Section 3.5.2"Dredging and Reclamation".

Reclamation Height Guidance

Currently, reclamation is constructed to the same level as the land on each island (i.e.: not formal consideration of sea level rise and overtopping unless specified in the EIA). The implication of this is that often landward of the reclamation, this creates a topographic "low" point thus causing drainage problems and channels need to be cut through the new reclamation to alleviate flooding and drainage problems. Better consideration of land topography and merging new reclaimed land into the natural design of the island is needed.

For the Maldives, reclamation height level calculations will vary from atoll to atoll and island to island. The challenge relates to a lack of island specific data relating to actual recorded mean sea level at each island. To determine reclamation height requirements it must be mandatory to ensure that the EIA (see Part D, Chapter D1) carried out water level recording measurements over different monsoonal periods to enable sufficient data to be collated to allow modelling of overtopping frequencies to be determined. Only then can the crest height of new land reclamation schemes be established. For reclamation projects it is recommended that a mandatory clause is included in all reclamation contracts (before an EIA is accepted) that at least 1 month (lunar tidal cycle) of water level recording data is needed to help calibrate and establish ACTUAL MSL on specific islands. Securing permanent survey benchmarks are also needed on each island.

As an interim "guide" it is advised that a reclaimed height of between 1.5m and 1.75m above mean sea level is needed for newly reclaimed islands.

3.3.3.2 Adhoc reclamation

This type of reclamation involves placing material on the eroded slope either at the same height of the ridge or at a slightly raised level. There is a major aesthetic issue with these structures but locals generally feel that eroding areas are rarely used for any recreational activity. No formal design is proposed for ad hoc reclamation within this Guidance Manual.

Whilst it is understood that solid waste management itself is a serious issue in most islands and that options for outer islands maybe to combine erosion mitigation and solid waste disposal, and that the use of construction debris to permanently reclaim erosion hotspots is a wide spread practice in the inhabited islands surveyed the, recommended approach would be to adhere to the design standard prepared for "formal land reclamation" (section 3.3.3) in addition to reviewing the performance material standards for "Dredging and Reclamation" (Chapter C3, Section 3.5.2).

3.3.4 Harbour development (dredged basins, quay wall options and floating breakwaters)

3.3.4.1 Overview

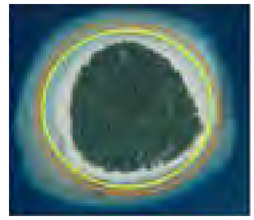
Harbour development in the Maldives is perhaps one of the most important infrastructures for an island because it is the "bridge" between the island and development. During harbour development projects, large volumes of sand are extracted from the sea bed and the excess sand is used to reclaim part of the lagoon, consequently transforming the geography of the island within as short a period as three to six months. These structures themselves are not adaptations to climate change or natural hazards but their designs can be adapted to suit the natural hazards facing the island. Harbour development involves a range of different types of engineering structures that have a range of functions. For this section of the Guidance Manual, focused attention is provided for harbours, dredged basins and various quay walls designs. Details on breakwaters and entrance channel dredging is addressed in a later section.

3.3.4.2 Strategic Design Location Considerations for Maldivian Islands

Kench (2010) proposed the following with regards to harbour basin location. This is accepted as appropriate strategic practice for the Maldives (see Table C3.1)

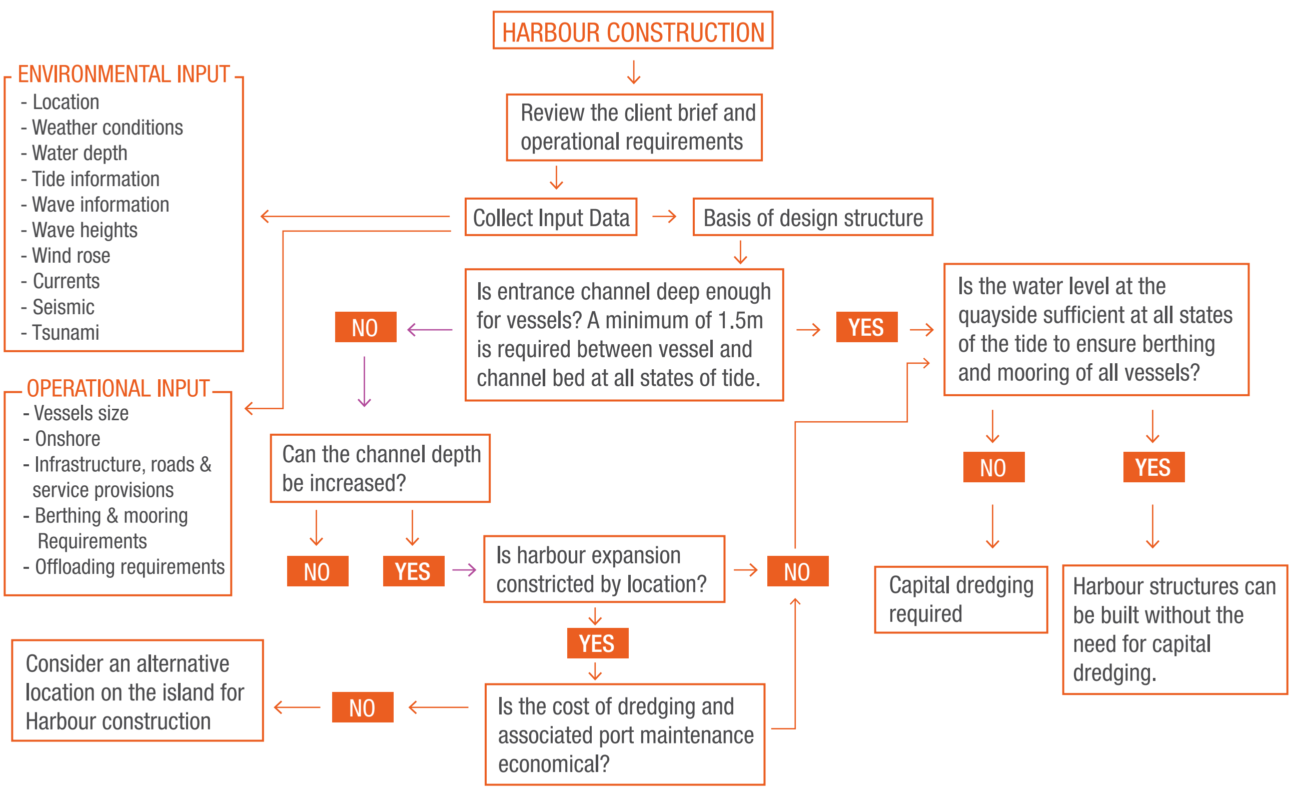
Table C 3.1 Strategic Design Locations for harbours in the Maldives

Harbour design – strategic considerations for maldivian islands

Description	**Island "Type" or position in the Atoll**
For smaller islands (a), harbour basins should ideally be located off the edge of the reef platform. Location of harbours off the reef edge would reduce impacts on reef platforms wave and current processes and minimize impacts on island shoreline dynamics. Piled jetties should connect the harbour basin and shoreline. If harbour basins are detached and located on a reef flat it is expected that environmental impacts will be similar to those predicted with breakwaters. For larger islands (b), harbour basins should be located away from the island shoreline with a minimum separation of 30 m.	(a) 
Ledgend Zones within which the shoreline exhibits significant variation between seasons Diretion and pathways of neashore currents	(b) 

Developing Table C3.1 further, Figure C4 is a flowchart that is recommended to be adopted for future harbour planning decision making (regards to location of harbours on islands).

Figure C 4 Proposed flow chart to assist in establishing the location of harbours on Maldivian islands



Design Guidance

The design process for all harbour structures is as set out in the work undertaken by Oriental Consultants Ltd (2012). It is advised that this Technical Standard and Design Manual (already accepted by MEE) is adhered to for this aspect of the Guidance Manual.

This Guideline strongly proposes that before any harbour application and concept design is agreed, MEE must be content that sufficient background information and interpretive analysis has been provided on the following. If it is not available, then all efforts must be made to obtain this information so that an appropriate design can be carried out with a suitable degree of confidence. The specific information required to assist with harbour design is set out in Table C3.2.

Table C 3.2 Harbour Design Information Guidance

Information required prior to any harbour Design is accepted.
Geological Conditions
Structure and composition of overlying seabed deposits;
Depth to rockhead and type and condition of rock.
Topographic and Maritime Conditions
Description of land area / topographic conditions in the close proximity to the dock frontage;
Hydrographic conditions;
Manoeuvring and navigational conditions.
Water Level Recordings
Tidal variations;
Depth references;
Wind generated offshore
Wind force, duration and compass;
Critical wind forces and direction.
Waves generated offshore
Wave heights caused by wind, significant wave length, maximum wave height and wave direction;
Swell;
Waves from passing vessels.
Current Data
Strength, direction and duration;
Erosion and siltation, sea bottom conditions.

Existing harbour construction guidelines for the Maldives and are presented below in Table C3.3. These should be adhered to though updated on an island by island basis subject to the new data collated in Table C3.2.

Table C 3.3 Existing Maldivian Harbour Construction Guidelines

1. An enclosed dredged basin.
2. Minimum quay length shall be the length of the longer side plus 50 meters of quay on either side of the basin.
3. A breakwater to protect against adverse wave conditions (required for all harbours except AA. Rasdhoo).
4. An entrance channel 23 meters wide (single entrance channel) connecting the dredged basin and deeper sea.
5. Sufficient protection to entrance channel shall be provided with breakwater. The length of this protection shall not be less than 10 meters on either side of the channel.
6. Harbour basin shall be fully enclosed except for the entrance channel and any other openings required for water circulation.
7. Any openings provided for circulation shall be designed in such a way to avoid movement of sandt into the basin. Number of openings provided for circulation shall nmot be more than 2 and shall not be wider than 2 meters each.
8. Sand filling at the side of the quay wall shall be protected with a suitable revetment and/or breakwater. The length of this protection shall not be less than 15 meters on either side.
9. All approvals required in relation to the project shall be the responsibility of the contractor including Environmental Impact Assessment.

Design Criteria:

1. Harbour basin and entrance channel shall be dredged to a minimum depth of 3 meters below Mean Sea Level (MSL).
2. The harbor basin shall be enclosed such that it provides a safe mooring area throughout the year.
3. Entrance channel shall be oriented in a direction that gives maximum safe usage during the year.
4. Entrance channel shall have sufficient protection from waves.
5. The harbour shall be designed with adequate water circulation.
6. Harbour design layout shall ensure minimum sediment accumulation at the entrance channel and inside the basin to allow for a maintenance dredging period of not less than 5 years.
7. Harbour component shall be designed for a minimum maintenance free period of 10 years. Design life of all structures shall not be less than 30 years.
8. The main breakwater shall have a minimum clear crest height of 1.4m above the mean sea leve.
9. Top of quay shlal be the higher of the following
    a. 1.3m above MSL
    b. 15m above ground level
10. Access stairs shall be incorporated into the quay wall (4 sets of stairs)
11. Mooring Hooks at intervals of not less than 5m shall be provided.
12. All reinforced concrete shall be a minimum of grade C35 and a minimum concrete cover of 50mm shall be provided to all steel reinforcement.

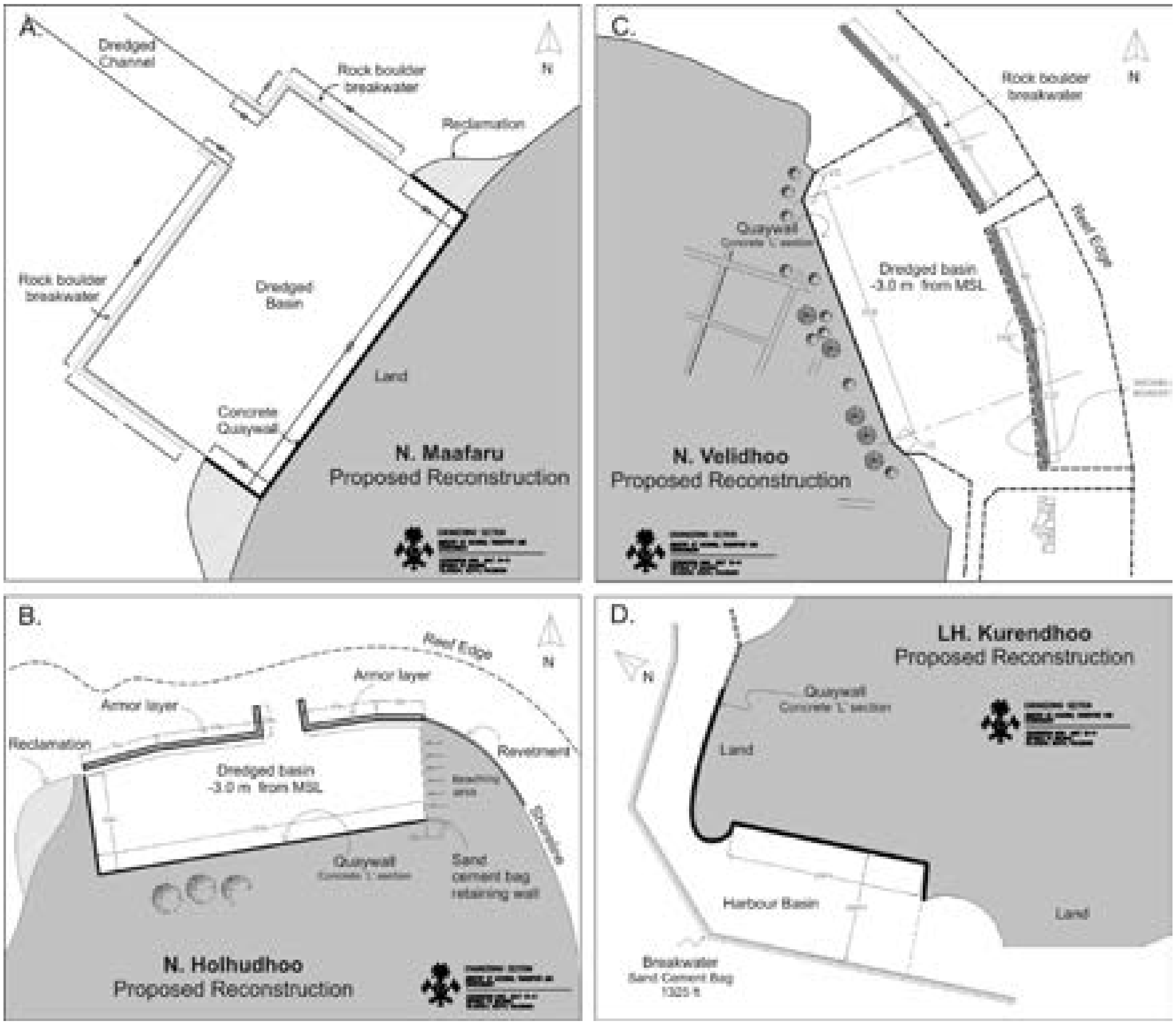
3.3.4.3 Dredged Basins

Overview

Until recently boat harbours tended to conform to a single design in terms of the dimensions of the basin and structural design of quay walls, etc.. However, it should also be noted that there has been a more recent shift away from a 'one-design' boat harbour to consider alternative options to provide safe anchorage. More recent designs have been characterised by shoreline detached breakwaters with the aim of allowing currents to flow through the harbour (see Figure C5). In the Maldives, most harbours have been constructed in a way that modifies the plan form configuration of the island shoreline. For example, most protrude from the shoreline across the adjacent reef flat by up to 50 m (see Figure C5).

Land reclamation is common on either side of the harbour basin and most have hard shore-parallel structures at the shoreline (such as quay walls, as described earlier). It is also common for the majority of harbours that have dredged basins in close proximity to the island shoreline with dredged channels that bisect the adjacent reef flat allowing safe passage of boats at all tidal stages.

Figure C 5 Example dredged basin construction plans for 4 islands (from Kench 2010)



Design Guidance

The design process for a dredged basin design is as set out in the work undertaken by Oriental Consultants Ltd (2012). It is advised that this Technical Standard and Design Manual (already accepted by MEE) is adhered to for this aspect of the Guidance Manual.

This Guideline strongly proposes that before any dredged basin application and concept design is agreed, MEE must be content that sufficient background information and interpretive analysis has been provided on the following. If it is not available, then all efforts must be made to obtain this information so that an appropriate design can be carried out with a suitable degree of confidence. The specific information required to assist with harbour design is set out in Table C7 (as for harbour design through with additional sediment dispersal modelling studies as mandatory – see Appendix 3).

3.3.4.4 Quay Wall Design (Steel Sheet Piling)

Design and Construction Guidelines

Piles are driven in panels using conventional pile driving equipment, either from a marine spread or from land based plant. The piling rig moves progressively along the length of the wall with the installation of the anchors, walings and tie bars following on behind. Once driven, drainage filters and fill are placed behind the wall up to the desired grade and paving or other surfacing applied as required.

There is no requirement to remove soft material before pile driving, however it may be necessary to do so before backfilling.

A continuous concrete coping beam is constructed along the top of the wall. This may be for aesthetic reasons, but it may also be designed to carry fendering and/or mooring points. In this case the cope would need to be designed to distribute fender and mooring loads along the length of the wall, and may be heavily reinforced.

Engineering Decisions for Consideration – Guiding Principles

It is important that the following considerations are adopted to ensure engineering success of this structure type. The most likely causes of failure are a result of extending the operating envelope beyond the design envelope, deterioration or physical damage.

- Over-load - There is always the potential to overload if the structure has been under-designed, for example if soil conditions have not been adequately assessed. The effect of soil liquefaction in seismic areas is one extreme example of this.
- Overloading the apron area behind the wall may damage quay structure. Increased soil pressures on the back of the wall may damage the sheeting as well as the tie bars and anchor points. A common cause of this type of overloading is from inadequately supported crane outrigger pads, which may also have tragic consequences for the crane and operator.
- Removing material from the seabed at the bottom of the wall reduces toe restraint in this area and the capacity of the wall to resist loadings from the rear of the wall. A common cause of this is over-dredging beyond the permitted tolerances; and propeller scour, which can be reduced by seabed scour protection.
- Corrosion - Corrosion is a common problem but rarely leads to catastrophic failure without another influence. Sheet piling is often left unpainted but nonetheless, with appropriate corrosion allowances and/or painting systems (outside face only), with or without cathodic protection, they can have a life of several decades. Sacrificial anodes are vulnerable to impact damage, especially from small vessels and boats, and they are not often used in preference to alternative protection systems.
- Corrosion patterns are similar to those for any steel structure in a marine environment, with most occurring around the splash zone or water line. Accelerated low water corrosion can occur, as its name suggests, further down and is evidenced by orange corrosion products.
- Corrosion usually results in holes in the piling, with the eventual loss of fill from behind the wall. This can be accelerated by the passage of water (e.g. waves) through the now porous structure. Loss of fill in turn eventually leads to cavities behind the wall and possible subsidence of the apron above.
- Corrosion of anchor tie systems, either the tie bar or its end fittings, can result in failure and bulging of the face of the sheet pile wall. Usually the bulging occurs at the top, but it can extend down and eventually result in failure of the clutches. This is usually a local feature; however failure of the anchor itself (not usually a result of corrosion) is much more serious and could result in a more global failure.
- Physical Damage - Damage to the face of the wall is primarily a result of impact from vessels using the quay, and can be minimised or eliminated by the provision of a suitable fendering system and operating practices.
- Major, but localised, damage can be caused as a consequence of a heavy or uncontrolled berthing and usually includes the cope as well as the piling. This type of damage is not usually designed for, although it may be mitigated against. Minor damage is usually in the form of indentations and scrapes from hull impacts, particularly from vessels with belting. If such damage is left unattended and allowed to escalate, more serious damage such as wall penetrations or clutch splitting may result. This type of damage can be prevented by appropriate fender design and maintenance.

3.3.4.5 Quay Wall Design (Reinforced/Pre-stressed Concrete)

Design and Construction Guidelines

Reinforced concrete is a versatile, economical and widely used construction material. It can be mounded to a variety of shapes and finishes. Usually it is durable and strong, performing well throughout its service life. However, it does not perform adequately as a result of poor design, poor construction, in adequate materials selection, exposed to a more severe environment than anticipated or a combination of these factors.

Concrete durability depends on the individual properties of its constituents, particularly the cement content, the water/cement ratio, the fine aggregate shape, and the coarse aggregate reactivity, soundness and porosity. Durability also depends on the control of the heat of hydration during curing and the consequent limitations of early thermal cracking. Reinforced concrete in a marine environment will corrode unless the concrete is so designed to prevent an impermeable barrier. Reinforcement should be carefully detailed and concrete shapes should be selected to minimise exposed corners.

Concrete structures either comprise reinforced concrete or pre-stressed concrete elements. The concrete can either be cast in situ or delivered to site as individual precast units. The benefit of using precast concrete units is that the units can be cast in factory controlled conditions giving greater control over durability.

Concrete is generally used in the construction of vertical edge structures in quays or as deck slabs on jetties or dolphin structures.

To make durable reinforced concrete structures in marine environments the selection of proper materials and mixing proportions is only the first step. Sufficient attention must also be given to the concrete production and construction practice.

Concrete durability depends on the individual properties of its constituents, particularly the cement content, the water/cement ratio, the fine aggregate shape, and the coarse aggregate reactivity, soundness and porosity. Durability also depends on the control of the heat of hydration during curing and the consequent limitations of early thermal cracking. Reinforced concrete in a marine environment will corrode unless the concrete is so designed to prevent an impermeable barrier. Reinforcement should be carefully detailed and concrete shapes should be selected to minimise exposed corners. In general cover to the reinforcement should be 75 mm but reinforcement should be detailed to limit crack widths. Pre-stressed concrete units used to form the soffits of open piled quay structures are designed to cancel out tension stresses in the concrete therefore cancelling out the formation of cracks.

Engineering Decisions for Consideration – Guiding Principles

It is important that the following considerations are adopted to ensure engineering success of this structure type. For vertical edge structures the potential modes of failure are similar to those for sheet pile wall structures due to overloading behind the vertical edge structure and reduction in the depth of embedment of the vertical edge structure.

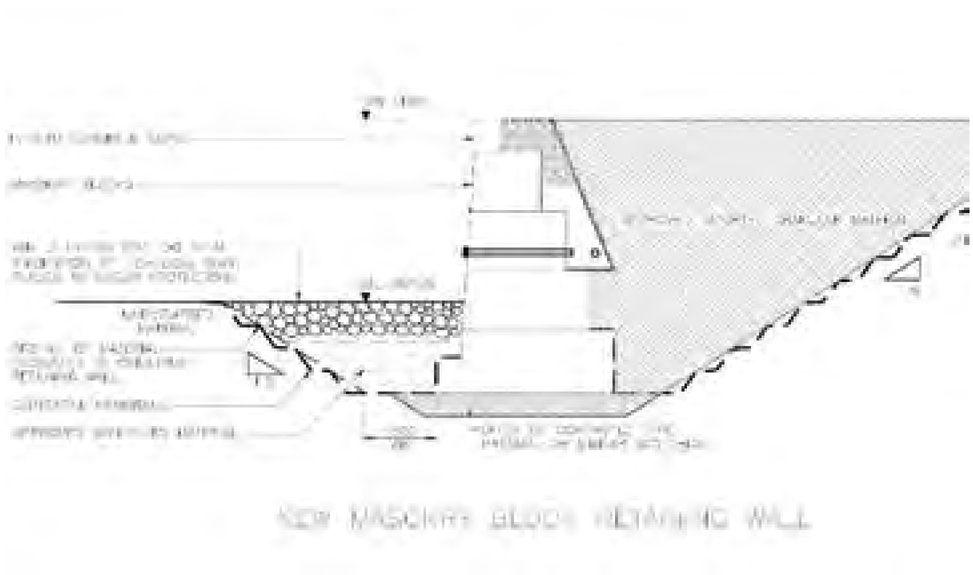
For concrete deck slabs used on jetties or dolphin structures the main causes of failure are deterioration of the concrete in the marine environment, overloading the deck slab due to plant and equipment and vessel impact.

- Deterioration/degradation - Degradation of concrete structures in a marine environment mostly sets in under combined action of internal and external factors. It is a complex process determined largely by the physiochemical properties of the concrete matrix and the usage and loading on the concrete structure in its entirety. The main factor to consider in the design of concrete structures in a marine environment are those which determine the quality and the durability (i.e., the way it is made, placed, and cured), and others such as shrinkage, creep, and thermal effects.

  External causes of deterioration are broadly grouped as physical, chemical, or mechanical. Main physical factors are the fluctuations of moisture content, temperature, freezing and thawing (that occurs in natural weathering), and fire. The main chemical factors are aggressive gases and liquids, and the main mechanical factors are load, friction and vibration.

  To control the source of deteriorations of reinforced concrete structures it is necessary to include the environmental assessment with regard to the effect of reinforced concrete structures in the planning stage, so as to design the structure sustainably

Figure C 6 New masonry block retaining wall



3.3.4.6 Quay Wall Design (Masonry Block Wall)

Engineering Decisions for Consideration – Guiding Principles

It is important that the following considerations are adopted to ensure engineering success of this structure type. Masonry block walls are a more cost effective method of construction than reinforced concrete cantilever wall. This is because blocks can be cast in factory controlled conditions and there is a shorter construction period than reinforced concrete wall of a similar height. Blocks can also be cast with natural-looking blockwork front facing (see Figure C6).

The disadvantages include they are susceptible to structural stability problems, as a result of differential settlement caused by liquefaction or presence of bands of compressible material at depth. Vessel impact damage could also occur and this would require significant repair works. Also, the construction cost increases significantly with vertical edges requiring corner details/changes in direction. Special blocks will require casting for these locations. Finally, increased craneage, together with additional plant and equipment required for placement of blocks is often needed. For total efficiency, an independent precast yard is required on site though this is not practical on many Maldivian islands due to space requirements. Transport of blocks from precast yard required. Environmentally, the design should consider how to mitigate against wave.

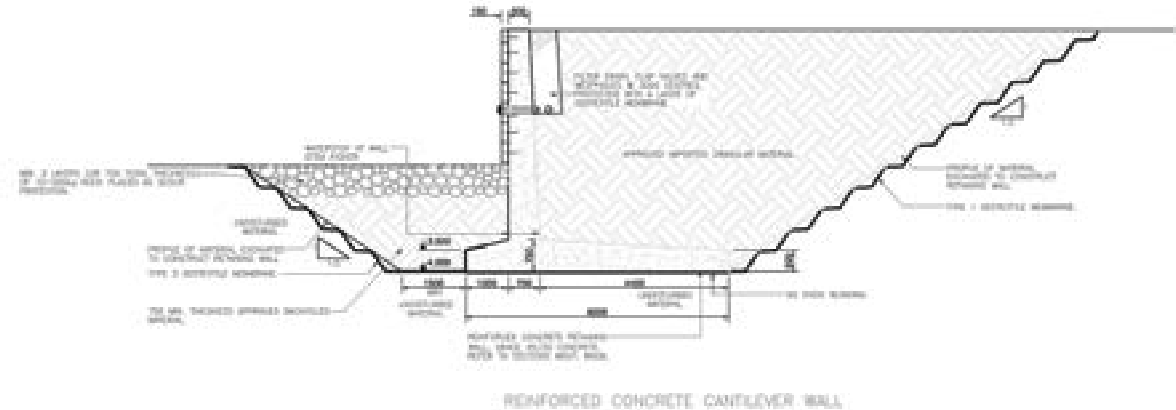
3.3.4.7 Quay Wall Design (Reinforced Concrete Cantilever Wall)

Engineering Decisions for Consideration – Guiding Principles

It is important that the following considerations are adopted to ensure engineering success of this structure type. Reinforced concrete cantilever walls are designed to be stiff structures that are not susceptible to potential structural stability problems as a result of differential settlement. They can be a cost-effective method of construction for vertical walls where there are many corner details/changes in direction. Linked to this, there is often the need for good detailing and quality control will limit annual maintenance and repair works required.

The issues for key consideration are that the approach is a more expensive construction cost than masonry block wall and reinforced earth wall options. Also, additional *in situ* front facing requires to be cast, in order to resemble natural blockwork. As for other walls, it is subject to reflecting wave impact (see Figure C7).

Figure C 7 Reinforced concrete cantilever wall



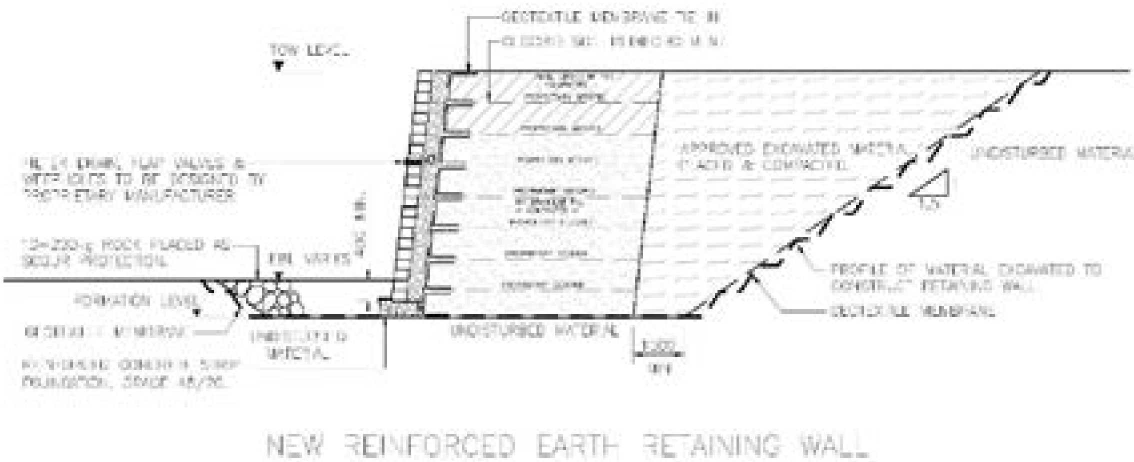
3.3.4.8 Quay Wall Design (Reinforced Earth Retaining Wall)

Engineering Decisions for Consideration – Guiding Principles

It is important that the following considerations are adopted to ensure engineering success of this structure type. Reinforced earth walls or geo-grid reinforced walls are often a more cost-effective method of construction than reinforced concrete cantilever wall and reinforced concrete counterfort wall. Blocks can be cast with natural looking blockwork front facing. There is increased construction speed where reinforcement and facings are delivered to islands ready for use. There is unrestricted site access because reinforced soils/sand is stable throughout construction. Finally, any fills or "voids" are strengthened by the reinforcement process (see Figure C8).

The issues for key consideration are that the approach is susceptible to structural stability problems, as a result of differential settlement caused by liquefaction or presence of bands of compressible material at depth. Any storm impact damage could require significant repairs. Construction costs increase significantly with vertical edges requiring corner details/changes in direction. With regards to any geotextile used, there remains some uncertainty concerning long-term material properties and their durability and the possible damage to geotextiles caused during storage handling and installation (see Figure C8).

Figure C 8 New reinforced earth retaining wall



3.3.4.9 Floating Breakwater Design

Overview

A floating breakwater can be a cost effective alternative method of construction to fixed breakwater structures in sheltered coastal locations where the design wave height is not in excess of 2.0m (i.e.: internal lagoon islands are most appropriate for this). The design environmental conditions (wind, wave and currents) are calculated for floating breakwaters using the same procedure for fixed nearshore breakwater and coastal revetment structures (see Section 3.3.5).

The method of construction of a floating breakwater should consider the following:

- Proprietary floating breakwater comprising articulated floating units. The movement (both horizontal and vertical) between the articulated units is designed based on the critical design wave height;
- The floating breakwater is restrained either by vertical driven guide piles or seabed anchor blocks dependent on the nature and strength of the seabed deposits;
- Aids to Navigation are needed
- Shore connection, bank seat.

Engineering Decisions for Consideration – Guiding Principles

It is important that the following considerations are adopted to ensure engineering success of this structure type. They are a potentially more cost effective solution than fixed breakwater solutions, however, this may not be the case if ground conditions are not suitable and the floating breakwater cannot provide the required design life. Their installation is significantly quicker than constructing fixed breakwaters (attractive parameter for many resort islands) and as a result there is no need to carry out the bathymetric and geophysical surveys. For resort islands, it is useful as breakwater elements come to site prefabricated and hence the structure can assembled on site. It does not impact too severely on existing landscape and there is reduced visual impact because the floating breakwater will be at natural sea level.

Design issues to also consider include that concrete anchor blocks would only be used for restraining the floating breakwater for relatively shallow water depths because the breakwater is held in position by the catenary action of the holding down chains and the deeper the water the more there is the potential for the breakwater to move out of position. Specialist floating piling plant will be required if installation of restraint piles is needed. A degree of visual inspection is required after every severe environmental event to ensure the structural integrity of the floating breakwater elements is maintained. Finally, their design life is not as long as a permanent breakwater (circa 20 years).

3.3.5 Coastal Erosion Protection Guidelines (erosion prevention measures)

This Guidance Manual considers the following seven types of structure that could be utilised to provide coastal protection against erosion.

3.3.5.1 Rock Armour/Rip Rap Revetment Design

Rock armour/rip rap revetments can be used effectively in erosion protection schemes. Established design guidance is available to ensure that rock structures are built to give optimum performance and cost (CIRIA/CUR, 1991). The required rock sizes will vary according to structure function, wave conditions, water levels, structure slopes, permeability and acceptable damage criteria. Rock has the advantage of durability and flexibility, meaning that structures can suffer some damage without failing and can be rebuilt or even removed if necessary. As with gabions, rock revetments can be buried to reduce their visual impact under normal conditions, but may be re-exposed during storms. In Maldives, good quality rock is generally imported from India and will have an effectively unlimited life.

Design Guidance

The rock armour design will comprise a number of key activities. Initial work will be needed to define the design parameters with quantification of the design wave height and period at the structure crucial for determining the rock armour size. Offshore wave data (wave height, direction and period) and extreme return period values, if not already available, will need to be purchased from the UK Meteorological Office (UKMO). With the use of a numerical model (as part of the EIA process – see Part D), these will then be transformed inshore to the site to provide our design wave parameters.

Once the design wave conditions and water depths are defined, the engineer would need to determine whether the shallow or deep water formula is applicable. Both are industry standard design formula and are described in detail in CIRIA Report C683 – The use of rock in hydraulic engineering (2007). In addition to the metocean conditions, there are several input parameters to that require quantification. These are as follows:

1. N – number of incident waves at the toe (dependent on the wave period and storm duration);
2. Δ – relative buoyant density, ρr / ρw – 1;
3. Sd – damage level parameter (dependent upon the amount of permissible repair and maintenance allowed);
4. P – permeability of the structure (dependent upon rock armour slope composition – increasing porosity from rock armour lain on geotextile, double layer armour plus core, homogenous rock mound); and
5. α – slope angle.

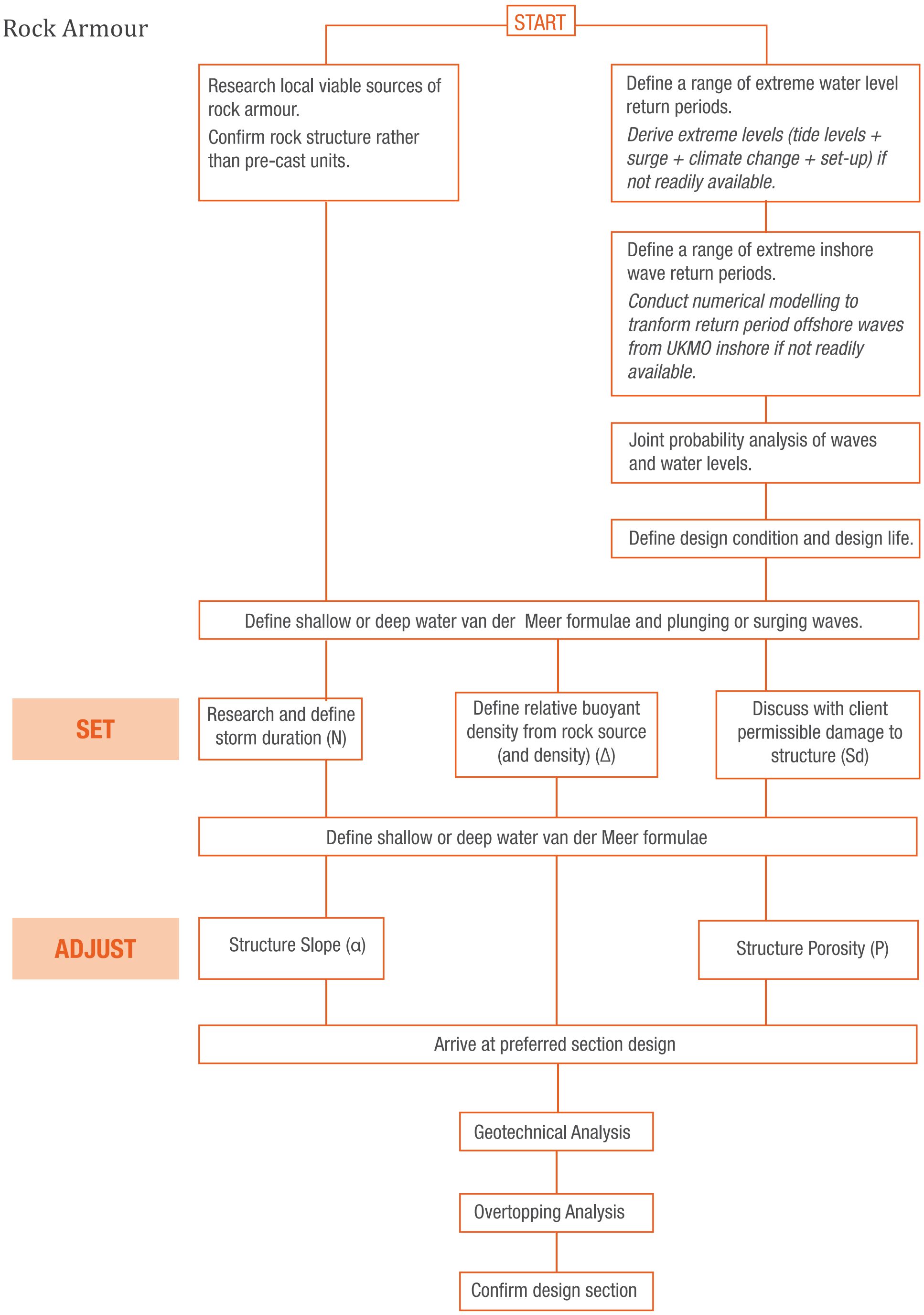
Items 1-3 are affectively static once a storms duration (and wave period), the viable rock source(s) and density are understood. The damage parameter should be discussed with the client as for extreme conditions it may be acceptable that damage occurs to the structure.

Items 4 and 5 can then be adjusted to arrive at a preferred design to account for cost, buildability and H&S considerations, preferably in consultation with a contractor.

The completed design section will need to be assessed from a geotechnical perspective to ensure that it will not fail due its interaction with the underlying soils and/or rock. Knowledge of the ground conditions are therefore key to ensuring that the geotechnical design is accurate. Scour at the toe of the structure due to tidal currents and/or waves will also be investigated to ensure that the toe detail is appropriate for the conditions.

A final part of the design work will be to compute the wave overtopping. This should be done using the Eurotop Manual (2007), another marine engineering best practice design document. This will be done to quantify the wave overtopping discharge for a design storm and to compare this against thresholds for pedestrian safety, maintenance staff safety and damage to vehicles, buildings and the structure itself. The design process for using rock armour in coastal protection scheme design (that is applicable for adoption in the Maldives) is summarised in Figure C9.

Figure C 9 Design Process – Rock Armour



3.3.5.2 Seawalls (Foreshore Breakwaters) and Revetments

In the Maldives, the term foreshore breakwater is often used to refer to a sea wall. For this Guidance Manual it should not be confused with nearshore/offshore breakwaters (see later section). Sheet pile seawalls are generally constructed for multi-purpose usage of the shoreline, usually as a quay wall. Sheet piles are driven to the reef bed and a capping concrete beam is constructed. Its usage is restricted due to high costs.

The use of armour rock as a foreshore breakwater is a recent development and present mainly in internationally funded projects like Th. Vilufushi redevelopment, Ga. Viligilli redevelopment and Addu Link Road development. The aim of these structures is to prevent erosion and coastal flooding.

Innovative materials have been introduced recently for seawalls. The use of large nylon or 'jumbo bags' filled with sand was used successfully in R. Dhuvaafaru while concrete filled empty oil barrels were used in AA. Bodufolhudhoo, with mixed results. Some resorts have opted for 'geo bags' or sand filled bags made of geo-textile material.

Design Guidance

The design height of the structures should be fairly constant with about 0.5 to 1 m above high tide. The seaward slope of the structures varies from island to island particularly between resorts and inhabited islands. Structures constructed under the 'safe island concept' have heights reaching +2.4 m MSL while that of S. Feydhoo is barely +1.6 m MSL. Regardless of the material used in construction (cemented sand bag, interlocking blocks etc.), the following guidance is provided for the design of these structures.

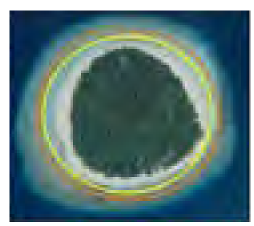
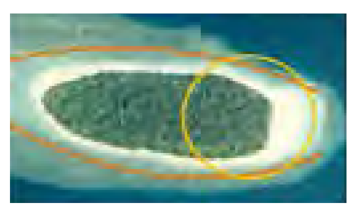
- The design and construction of impermeable revetments and seawalls requires the services of competent coastal engineers and contractors. Guidance is available from various publications, including "Coastal Protection" (Pilarczyk, 1990), "Designing Seawalls" (Thomas and Hall, 1992) and "Revetment systems against wave attack – A Design Manual" (McConnell, 1998).
- Revetted seawalls should have a sloping face extending well below the normal beach level to allow for future foreshore erosion.
- The revetment crest should be set according to expected wave run-up levels, and can be topped by a vertical wave wall if further backshore protection is required. The crest elevation will be higher than required for a rock revetment as the structure will suffer greater wave run-up over the smooth and impermeable surface.
- Structure face slopes are a compromise between flatter faces that absorb more wave energy, and therefore suffer less scour, and steeper faces that give the structure a smaller foot print and lower construction cost. A slope of 1:2 is a reasonable compromise, and is in keeping with the natural dune slope.
- The face must be able to withstand impact and uplift forces during storms. Where blockwork is used the units must interlock or otherwise connect to form a unified surface, as the loss of a single unit will cause rapid deterioration of the whole structure. A sound foundation of geotextile and a crushed rock bedding layer will reduce the potential for damage due to hydraulic forces acting from below the revetment face.

Strategic Design Location Considerations for Maldivian Islands

Kench (2010) proposed the following with regards to shore parallel (seawall) structures and their location. This is accepted as appropriate strategic practice for the Maldives (Figure C10). Chapter B3 also should be viewed to provide alternative ideas on the approaches that could be adopted for building resilience into designs of seawalls or revetments.

Figure C 10 Strategic Design Locations for seawalls in the Maldives

Seawall design – strategic considerations for maldivian islands

Description	Island "Type" or position in the Atoll
Shore parallel structures (seawalls) are permitted on island shorelines where the width of vegetated backshore from island edge to asset is less than 5.0 m or where the asset is a critical public lifeline or service structure. Shore parallel structures should not be sited on sectors of shoreline that act as major transfer pathways for sediment movement. Shore parallel structures must not protrude from the plan form configuration of the coastline. Where such structures are permitted, monitoring of island shorelines should occur to assess whether the structure is exacerbating island erosion.	(a)  (b)  (c) 

Ledgend

Zones within which the shoreline exhibits significant variation between seasons

Diretion and pathways of neashore currents

3.3.5.3 Gabion Basket Design

Overview

Rock filled gabion baskets have frequently been used for coastal defence, and have earned a poor reputation. Gabions have been known to fail when used in unsuitable locations, placed and filled with insufficient attention to recommended construction practices, or when managers have not attended to proper maintenance. Damaged baskets release cobbles or quarried rock onto the beach, and the baskets themselves become a hazardous eye-sore of rusting wire. However, when designed, built and maintained correctly gabions can provide good service with minimal ecological or visual impact. Life expectancy before a major re-build can be as much as 20 years, though 10 years is more likely. Gabions will last longer, have less environmental impact and be less intrusive on the coastal landscape if they are buried into the dune face, only reappearing during severe erosion events. Under accreting conditions gabions can be buried by windblown sand, and will allow dune vegetation to be re-established. On open coasts, gabions may only be appropriate as sloping revetments. In sheltered islands in the Maldives, where wave attack will be less severe, they can also be used to form other structures such as groynes. Baskets and appropriate rock are easily obtained for most sites.

Design Guidance

- The manufacturers recommendations should be followed as regards basket materials, methods of filling, lacing up of individual panels and the placement of spacer wires needed to maintain panel shape. The need for careful hand packing cannot be over emphasised. Poorly packed gabions will be rapidly damaged due to abrasion caused by movement of the stone.
- Gabions used in lower energy or estuary situations can use PVC coated wire. Under more active conditions the coating is soon cracked, becoming relatively useless in preventing corrosion. In general galvanised wire of a larger diameter will provide better service than finer non-galvanised wire with a PVC coating.
- Structure face slopes are a compromise between flatter faces that absorb more wave energy, and therefore suffer less toe scour, and steeper faces that give the structure a smaller footprint. A slope of 1:2 is a reasonable compromise, and is in keeping with natural dune slopes.

3.3.5.4 Offshore / Nearshore Breakwaters

Overview

Nearshore breakwaters are segmented, shore parallel structures built along the upper beach at approximately high water mark. They are normally built of rock, but can be formed of concrete armour units. At maximum tide levels their crests are still visible, but they may be separated from the shoreline. The gaps allow some wave energy to reach the upper beach and even the dune face.

These structures are distinguished from foreshore reefs that are built within the intertidal zone and are thus submerged at high tide. Breakwater schemes can have a significant impact on the shoreline and should not be implemented without specialist assistance from a competent coastal consultant and contractors. Information on the design of rock structures is available from the CIRIA/CUR “Manual on the use of rock in coastal and shoreline engineering”. The accompanying figures provide initial guidance but this should be confirmed for each site.

As with all rock structures on the shoreline the rock size, face slopes, crest elevation and crest width must be designed with care. Rock size is dependent on incident wave height, period and direction, structure slope, acceptance of risk, cross-sectional design, and the availability/cost of armour rock from quarries. Rock size may need to increase if the structures are built further down the beach face where wave action is stronger.

Design Guidance

In order to apply the guidance, a reasonable knowledge of the prevailing conditions at the potential site for the scheme is required. Prior to outline design, a general assessment of coastal processes along the shoreline segment to be protected should have been carried out. This assessment needs to provide an understanding of the sediment transport processes, erosion/accretion and historical morphological development taking place at the site. In order to proceed with this guidance, it is necessary to have gathered data on waves, tides, sediment characteristics, and the existing nearshore bathymetric and beach profiles at the location.

The required beach and shoreline response (salient, tombolo) needs to be established before applying this guidance. This involves considering a number of factors, including, for example, impacts on the wider coastal environment, the desirable beach width and crest elevations. For further guidance the reader should refer to the *Beach management manual* (CIRIA 2008).

A staged design guide is proposed for the construction of offshore breakwaters as follows (from Environment Agency 2010)

- Stage 1: Fix the offshore distance by reference to the amount of longshore sediment transport that should be bypassed to down-drift beaches in order to minimize down-drift erosion. In general, the amount of transport bypassed to downdrift beaches (downdrift of the breakwater scheme) reduces as X/Xb increases.

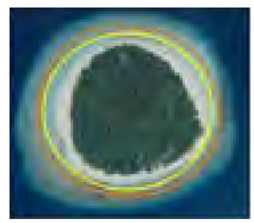
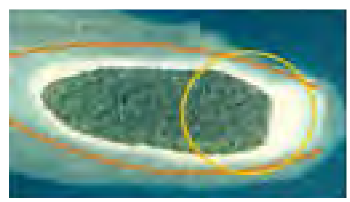
- Stage 2: Once the optimum offshore distance of the breakwater has been determined, it is then straightforward to calculate X/Xb. Next, calculate the breakwater length (Ls) for the desired beach response (in the lee of the breakwater), including the effect of tidal range. Decisions will need to be taken regarding the preferred beach response (limited response, salients or tombolos). Clearly, tombolos will be more disruptive than salients to the longshore movement of sediment, but will offer more protection during severe storms6 and offer a greater amenity area.
- Stage 3: Determine the breakwater crest level based on the desired salient length using the design graph shown in Figure 2.4. In general, the salient width (and also the beach level) reduces as the depth of water over the breakwater crest at high water increases.
- Stage 4: Lastly, estimate the gap width between the breakwaters based on the maximum shoreline erosion (MSL shoreline) allowed in the breakwater bays.

Strategic Design Location Considerations for Maldivian Islands

Kench (2010) proposed the following with regards to breakwater (excluding floating versions) location. This is accepted as appropriate strategic practice for the Maldives (Figure C11).

Figure C 11 Strategic Design Locations for offshore breakwaters in the Maldives

Offshore Breakwater design – strategic considerations for maldivian islands

Description	**Island "Type" or position in the Atoll**
Breakwaters should be provided on small islands (a) where their construction is designed to alter the process regime that affects the entire island shoreline. Breakwaters are permitted in (b) and (c) islands on sectors of shoreline which do not show a high degree of seasonal change.	(a)  (b)  (c) 

Ledgend

Zones within which the shoreline exhibits significant variation between seasons

Diretion and pathways of neashore currents

3.3.5.5 Permanent Groyne Design

Groynes are cross-shore structures designed to reduce longshore transport on open beaches or to deflect nearshore currents for sheltered Maldives islands. On an open beach they are normally built as a series to influence a long section of shoreline that has been nourished or is managed by recycling. In sheltered Maldives islands they may be single structures.

Design Guidance

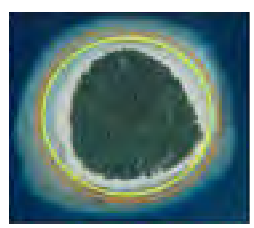
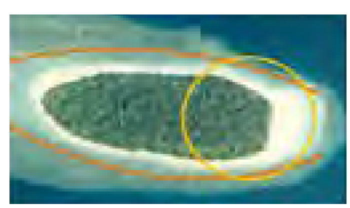
- Groynes can have a significant impact on the shoreline, and schemes should always be undertaken under the supervision of a competent coastal consultant. Information on the design of rock structures is available from the CIRIA/CUR "Manual on the use of rock in coastal and shoreline engineering" with further detailed guidance on the use of groynes found in the CIRIA "Beach Management Manual".
- As with all rock structures on the shoreline the rock size, face slopes, crest elevation and crest width must be designed with care. Rock size is dependent on incident wave height, period and direction, structure slope, acceptance of risk, cross-sectional design, and the availability/cost of armour rock from quarries.
- In general 1-3 tonne rock will suffice for the landward parts of the groynes, provided that it is placed as at least a double layer, with a 1:1.5 to 1:2.5 face slope, and there is an acceptance of some risk of failure. Larger rock, probably 3-6 tonne, may be needed for the more exposed body and seaward head of each structure. The structure should be constructed within a shallow trench and a geotextile filter should be laid under the rocks to prevent the migration of sand upwards and the settlement of the rocks into the beach. The geotextile should be wrapped around the base layer of rocks, and the rock toe should be set below the lowest expected beach level.

Strategic Design Location Considerations for Maldivian Islands

Kench (2010) proposed the following with regards to groynes and their location. This is accepted as appropriate strategic practice for the Maldives (see Figure C12). Chapter B3 also should be viewed to provide alternative ideas on the approaches that could be adopted for building resilience into designs of groyne fields.

Figure C 12 Strategic Design Locations for permanent groynes in the Maldives

Groyne design – strategic considerations for maldivian islands

Description	Island "Type" or position in the Atoll
Permanent shore perpendicular structures (groynes) are prohibited from Type A and B island shorelines. Such structures compromise natural processes and shoreline movements and should not be permitted. Permanent shore perpendicular structures (groynes) are permitted on Type C island shorelines. Structures should be kept away from the terminal ends (or most dynamic parts) of island shorelines.	(a) 
Ledgend Zones within which the shoreline exhibits significant variation between seasons  Diretion and pathways of neashore currents	(b)  (c) 

3.3.6 Access Improvement to islands Guidelines

3.3.6.1 Reef Entrance Channel Design

For this Guidance Manual, the decision tree process set out in Figure C4 applies to both harbour design location planning and that for reef entrance channel planning. The reader should refer to that diagram as the proposed guidance.

3.3.6.2 Jetty and Pontoon Design

Design and Construction Guidelines

Pontoons shall be stable under the most adverse combination of dead and live loads applied to the pontoon deck. Under such loads, unless permitted otherwise, the following requirements shall be met:

- For pontoons with a rectilinear flotation system, the minimum freeboard shall be the greater of 50 mm or 5% of the moulded depth of the pontoon, measured from the top of the flotation unit;
- For pontoons with a horizontal cylindrical flotation system, the minimum freeboard shall be the greater of 50 mm or 25% of the diameter of the cylindrical float, measured from the top of the
- flotation system;
- The pontoon chine shall not emerge; and
- The angle of tilt shall not exceed 15 degrees.

Consideration shall be given to marine growth when designing pontoons. Pontoon stability shall be calculated in accordance with the metacentric height method.

Any restraint from adjacent piles or moored vessels shall not be taken into account in calculations for pontoon stability. Pontoons composed of a number of compartments shall be designed so that the stability requirements above are met with a single compartment flooded. All compartments should be accessible from hatches in the pontoon deck and consideration should be given to ventilation of all compartments.

Pontoon decks shall be designed to have a positive fixing to the flotation unit. Such fixings shall be capable of supporting the deck in the event the pontoon turns over.

Consideration should be given to the "ride" of the pontoon together with its suitability for the proposed wave and wind climate. Factors such as weight, freeboard and form of restraint shall be considered in the pontoon design.

Engineering Decisions for Consideration – Guiding Principles

The deterioration of concrete maritime structures is predominantly caused by the corrosion of steel reinforcement and pre-stressing tendons as a result of chlorides in the marine environment coming into contact with steel. Steel corrosion shall be minimised by designing durable concrete structures and limiting concrete crack widths. Common methods used to achieve the above include, but are not limited to the following:

- Use of plain concrete members;
- Use of high strength, low water to binder ratio concrete mixes;
- Use of chemical absorption agents in the concrete mix;
- Use of pore blockers in the form of admixtures to wet concrete or surface applications to finished concrete;
- Painting of concrete members;
- Use of non-corrosive reinforcement such as galvanised steel, stainless steel, plastic filament and carbon fibre;
- Designing for low stresses in steel reinforcement;
- Minimising the use of thin sections particularly in the wetting and drying zone;
- Encapsulating pre-stressing tendons in watertight plastic conduits;
- Use of epoxy coatings to reinforcement;
- Use of cathodic protection systems; and
- Careful attention to structural detailing particularly with respect to constructability and maintainability.

Whilst steel is a suitable material for use in the construction of maritime structures, particular where design loads are high, its vulnerability to corrosion after exposure to seawater should be considered when using carbon steel in the marine environment. In the design of steel members, designers shall consider appropriate protection systems to protect and maintain steel members. In addition, designers shall also consider methods for installation and connection of steel members to prevent damage to pre-applied protection systems.

Consideration should be given to the selection of steel members to allow ease of application and maintenance of protection systems and not simply based on the most efficient size or shape with regard to strength.

Timber has many applications in maritime structures, particularly in small craft facilities such as jetties, ramps, skids and steps due to its ease of workability. Timber can be used on its own to construct complete structures (including piles, headstocks, bearers, joists and decking) or in conjunction with other materials to provide economical and durable structures. The deterioration of timber is usually by rot or attack by living organisms. Timber durability is dependant predominantly upon the species chosen in the design.

3.3.7 Over-water Structure Guidelines

Within the Maldives, at present, designs are fairly constant for most resort islands. Most constructions are on concrete stilts with pad foundations and raised to at least one m from the high water level. The stilts go at least 3-5 m inside the vegetation line. The following provides some formal guidance of over water structure deck levels and investigatory studies required.

Design Deck Level

For pier structures and open piled building structures over water the design deck level will be determined depending on the environmental conditions existing at site. The underside deck level of all pier structures will take into account the following:

- Extreme still water level for return period determined from the project Terms of Reference;
- Add on an allowance for design wave height for return period determined from the project Terms of Reference;
- Add on a freeboard allowance of 500mm.

Site Investigation

Site investigations are an essential part of the planning and design of maritime structures. Consequently, site investigations should be undertaken to provide sufficient information for the design and construction of any maritime structure.

It is anticipated that site investigations will be aimed at two levels. The first level, preliminary investigation, will be aimed at collecting information to assess whether the proposed facility is feasible. This assessment will usually be carried out based upon a site inspection and a review of existing data.

The second level, detailed investigation, will generally proceed following development consent and will usually be based on detailed hydrographic surveys and geotechnical investigations.

Geotechnical investigations are required in order to determine the properties and constituents of the seabed and underlying rock strata and the depths of the various layers comprising the seabed.

Information required from an investigation might include some or all of the following:

- Soil, sediment and rock classification;
- Grain size distributions and shape;
- In-situ soil density;
- Stratigraphy;
- Soil strength parameters;
- Soil deformation parameters and;
- Chemical composition of any sediments to be dredged.

Collation of Background Information

Before the design of any pier or wharf structure commences an archive search to be carried out to collate the following information:

- Wind climate;
- Wave climate;
- Currents;
- Water levels (tidal range, storm surge, flood levels, seiching);
- Coastal processes (accretion, erosion); and
- Services.

Design Loadings

The design for ultimate strength, serviceability, stability and other relevant limit states shall take into account appropriate design actions in accordance with the relevant design codes and standards. In particular, the following design actions shall be considered, where appropriate:

- Permanent actions (dead loads);
- Imposed actions (live loads);
- Wind actions;
- Current and debris actions;
- Hydrostatic actions;
- Wave actions;
- Construction and maintenance actions;
- Lateral earth actions;
- Boat wash; and
- Earthquake actions.

Fixed structures (including piers and jetties), other than gangways, shall be designed for a minimum uniformly distributed live load of 5.0 kPa or a minimum concentrated live load of 4.5 kN whichever produces the more adverse effect.

Building structures located on piers shall be designed for a minimum uniformly distributed live load of 10.0 kPa for each floor of the building.

Gangways shall be designed for a minimum uniformly distributed live load of 4.0 kPa or a minimum concentrated live load of 4.5 kN whichever produces the more adverse effect.

Floating structures shall be designed for a minimum flotation load of 3.0 kPa or a minimum stability load of 2.0 kPa.

Pile Design

Piles shall generally be designed and installed in accordance with the relevant design codes and standards. Consideration shall be given to achievable tolerances when installing piles over water when designing elements of structures to later be connected to such piles. Consideration shall be given to marine growth when designing piles.

Where timber piles are used they shall have a minimum toe diameter of 300 mm.

3.4 Chapter C3.2: Design Standard Details (Soft Structure Measures)

GUIDANCE MANUAL NOTE 11

Except for beach replenishment guidelines, the following Guidance for soft structure measures is very strategic in its nature and presentation. It is strongly recommended that an update to this Chapter is carried out following a separate "Training and Communication" exercise on local inhabited islands is undertaken in 2013. In addition, a tailored approach directed at tourist islands is to be encouraged that links in with the "proxy" monitoring project identified in Appendix 5. It is apparent that resorts are generally more positive towards soft engineering solutions but are skeptical about their effectiveness and value for investment. To this end, a focused strategy of engagement and communication (building in community and resort focused pilot projects) is recommended. The outcomes and outputs shall update future revisions of this Chapter of the Guidance Manual.

Chapter C4 (Materials Standards) have some information of direct relevance to soft structure measures and should be reviewed by engineering contractors as required.

3.4.1 Beach Replenishment and Recycling Guidelines

3.4.1.1 Overview

The primary rationale for beach replenishment is to mitigate or compensate for erosion or loss of beach. Although beach replenishment itself does not address the causes of erosion, it is seen as a temporary fix which, in aesthetic terms, provides value for money, particularly for resort islands. Replenishment in these projects both target erosion mitigation and creation of a new beach. Other rationales for beach replenishment include creating a new beach in previously rubble environments and to create a buffer between infrastructure or property and beach. In the past replenishment has been used as an excuse for land reclamation making it difficult to determine the ideal width for a replenishment project. The EPA has designated 10 m from the existing shoreline as allowable width for replenishment. This figure is deficient for some island settings and should be reconsidered based on the physical environment and historical erosion rates in a given site (see Chapter D4).

A number of resorts now have their own sand pumps and conduct regular or periodic replenishment. The basic design principle for these islands is to pump sand to wherever erosion in prevalent. A specialized team is employed, usually in the maintenance department, to undertaken this activity. Costs for these activities are usually budgeted annually.

The general method of beach replenishment construction is to deploy a sand pump on a floating barge within a distance that matches the technical limits of the sand pump and to pump sand directly onto the beach. Loaders are used to distribute the sand and manual labour is used to profile the beach. Smaller projects may be implemented by a group of 5-10 people.

Larger projects may involve the use of multiple sand pumps, dredgers or excavators to dredge material from the lagoon, and loaders and bulldozers to place and profile the beach. Sometimes, like in Shangrila at Viligilli Island Resort, sand may be sourced from a distant reef system and transported in barges to the destination beach.

The following Guide does not consider appropriate methods for nourishment schemes involving transfer of sediment from the outer sea; these larger scale operations are covered with strategic advice within the CIRIA Beach Management Manual (2009).

3.4.1.2 Design Guidance (replenishment)

1. Changes are proposed to the existing regulations on beach replenishment for resort islands and all islands in general. The 10 m fixed width for beach replenishment in resort islands is inadequate in some instances and an over design other instances. For example, islands with severe erosion in the past require extension of beach line beyond 10 m to compensate of the area lost and prevent significant loss. Moreover, placing of a 10 m of beach does not compensate for potential immediate erosion following replenishment.
2. A new guideline (as stated by Shaig 2011) should specify the following to facilitate best practices:

i. Beach width could be generally fixed at a figure but should have the flexibility to change based on submission of scientific evidence of past erosion and coastline changes;

ii. Sediment budgets on the existing island should be estimated;

iii. The volume of sediments required to replenish should not be over designed and limited to a percentage of the sediment budget;

iv. Sediment source should be clearly identified and a minimum distance between shoreline and sediment source should be defined;

v. Material used for beach replenishment shall be larger than or equal to the existing beach material.

vi. Restrictions should be placed on replenishment activities in certain areas of the islands depending on seasons.

3.4.1.3 Design Guidance (Sediment Re-cycling)

Finding "reservoirs" of sand on island systems for effective re-cycling or nourishment can be a problem. Re-cycling involves moving material from a point of accretion to a point of erosion within a local process area. The accretion point may be further along the shoreline, for example next to a breakwater or within the house reef system.

Wherever the source of the re-cycled sediment it is critical to establish whether removal will create a new erosion problem or whether the impact will be negligible. It is also important to establish that the source material is compatible with the erosion area in terms of hydraulic response, impact on the ecosystem and impact on recreation. Annual, or even post-storm, re-cycling may be required to provide on going protection. The following guidance is provided for sediment re-cycling:

Design Guidance

- The recycled material should be as similar as possible to the indigenous sediment.
- Sediment size, grading, shell content and material should match the upper beach and beach ridge. The material should also be clean and free of seeds.
- If these conditions are not met then the nourishment may cause unwanted changes to the beach and ridge profiles, to the ecology and overall appearance. Coarser sediments can be used, and may be more stable, but they are likely to cause the beach gradient to increase and will be less likely to form new fore-dunes. Ideally, environmental and hydraulic assessments should be carried out to determine the acceptability of sediments that do not meet the optimal criteria.

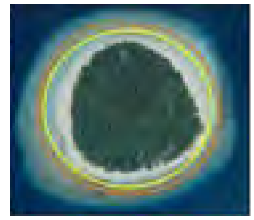
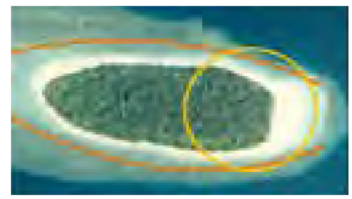
NB: Replenished profiles are rarely perfect and they may undergo rapid erosion in the first few months until a naturally adjusted or an 'equilibrium profile' for the monsoon period is reached. If an area has been replenished due to severe erosion, the area may continue to erode after replenishment, if the causes of erosion have not been addressed. Hence, the absence of designs and engineering considerations for most replenishment projects may have significantly contributed to faster than normal loss of replenished sand and unwanted environmental impacts.

3.4.1.4 Strategic Design Location Considerations for Maldivian Islands

Kench (2010) proposed the following with regards to beach nourishment. This is accepted as appropriate strategic practice for the Maldives (see Figure C13). Chapter C4 also should be viewed to provide standard advice on materials and placement guidelines to help build beaches.

Figure C 13 Strategic Design Locations for beach re-nourishment design in the Maldives

Beach Renourishment design – strategic considerations for maldivian islands

Description	Island "Type" or position in the Atoll
When adopting the use of nourishment it is recommended that: i) The shoreline sediment budget is estimated. ii) The estimated volume of sediment required to replenish the shoreline sediment reservoir is identified. It is important not to overfill the sediment system as this could also lead to adverse environmental effects. iii) Nourishment material is equivalent or larger than the native beach sediment. iv) An available source of sediment is identified. v)Placement occurs during calm weather conditions to avoid adverse impacts on the reef system. vi) Avoid nourishing the shoreline under the most active sediment transport period in any season. vi) Sediment placement occurs either on the land surface or beach system, within the dynamic envelope of beach change.	(a)  (b)  (c) 

Ledgend

Zones within which the shoreline exhibits significant variation between seasons

Diretion and pathways of neashore currents

3.4.2 Coastal Erosion Protection Guidelines (Soft Measures)

3.4.2.1 Sand Bag Structures

Overview

Sand bag structures normally make use of sturdy geotextile bags, filled on site using local sand. In most cases both the bags and sand are easily available. As the bags are liable to damage, both from natural causes and vandalism, structures are best buried with re-cycled sand, only to be exposed during extreme storms when they will act as a final line of defence. Damaged bags will release the enclosed sand harmlessly back to the beach, leaving only the geotextile to be retrieved. Structures are likely to have a life of only about 10 years.

Design Guidance

- Bags should be filled and closed according to manufacturer's recommendations. Care is required throughout to avoid selection should be governed by the anticipated methods of filling and placing on site. Labour intensive operations will limit bags to about 50kg and will only be appropriate for small schemes in low wave energy conditions. Large schemes will require filling and lifting equipment. A practical bag size limit is about 3m x 1.5m x 0.5m, containing about 3 tonnes of sand. Long tubes have been used in the past, but these are more likely to fail, as a single tear will affect the whole tube.
- Prior to construction the beach foreshore/backshore face will need to be dressed to form a plane slope on which bags can be laid evenly. This slope should not be steeper than 1:1.5. Sandbags should be stacked against the beach face. The bags should be placed with their long axes parallel to the beach line. A minimum thickness of 2 bag widths is recommended, with a thickness of 3 bag widths for the lowest course to reduce scour. The seaward line of bags should be treated as sacrificial. The bags should be filled in-situ, by hand or by pumping in a slurry of sand and water. Fill material can be recycled or imported sand or fine gravel. The toe of the completed revetment should be landward of the limit of normal wave run-up to avoid scour problems. The crest should be about 1m above the limit of run-up during storms to avoid overtopping damage to the beach face.

3.4.2.2 Temporary Groyne Design

Overview

Temporary groynes are primarily used for emergency or seasonal erosion mitigation. This practice is most prevalent in resort islands, especially in resorts which are conscious about the aesthetic impacts of hard engineered structures. Temporary sea walls are also used during storm events when erosion is most dramatic.

The most important use of temporary groynes is to prevent the seasonal loss of beach in specific erosion hotspots. The rationale may be either due to concerns over damage to property or loss of beach as a tourism product in certain section s of the island. These structures are designed to arrest part of the sand migrating to other parts of the coastline. The structures are usually removed once the monsoon season reverts. This practice is usually found in resort islands who prefers to have year round beach.

There are no standard designs for temporary seawalls or groynes and due to their temporary nature, coupled with differing island hydrodynamics within an atoll, not standard guidance advice can be provided within this Guidance Manual. Each resort island tends to have their unique ways deploying, removing and arranging the structure. The most common material used for construction is nylon bags filled with sand. There are variations in the material ranging from coir weaved bags to geo-textile bags. The common features of these structures are that the individual modular units are small and can be easily transferred from one location to the other using manual labour.

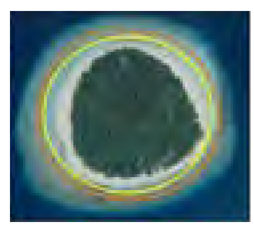
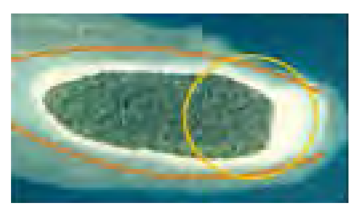
The main issue relating to the use sand bags as temporary structures is the sourcing of sand from the existing beach. While this practice is practical, the negative impacts on the sediment budget may be substantial and may exacerbate erosion elsewhere. The poor quality of bags used in some resort islands can also result in damaged empty bags being littered on to the reef.

Strategic Design Location Considerations for Maldivian Islands

Kench (2010) proposed the following with regards to temporary groynes and their location (Figure C14). This is accepted as appropriate strategic practice for the Maldives. Chapter B3 also should be viewed to provide alternative ideas on the approaches that could be adopted for building resilience into designs of groyne fields. Chapter E2 should also be reviewed for advice regards to beach monitoring.

Figure C 14 Strategic Design Locations for beach re-nourishment design in the Maldives

Temporary Groyne design – strategic considerations for maldivian islands

Description	Island "Type" or position in the Atoll
The use of temporary shore perpendicular structures (groynes) should only be permitted following examination and quantification of the shoreline processes and sediment fluxes. Structures should be designed (length and height) to trap less than 20 % of the annual alongshore flux of sediment (see Chapter B3). Structures should (if possible) be made from materials that are able to be relocated (e.g. sand bags – see Chapter C4). Where such structures are permitted, monitoring of island shorelines should occur to assess whether the structure is exacerbating island erosion.	(a)  (b)  (c) 

Ledgend

Zones within which the shoreline exhibits significant variation between seasons


Diretion and pathways of neashore currents

3.4.2.3 Beach Ridge Maintenance

Overview

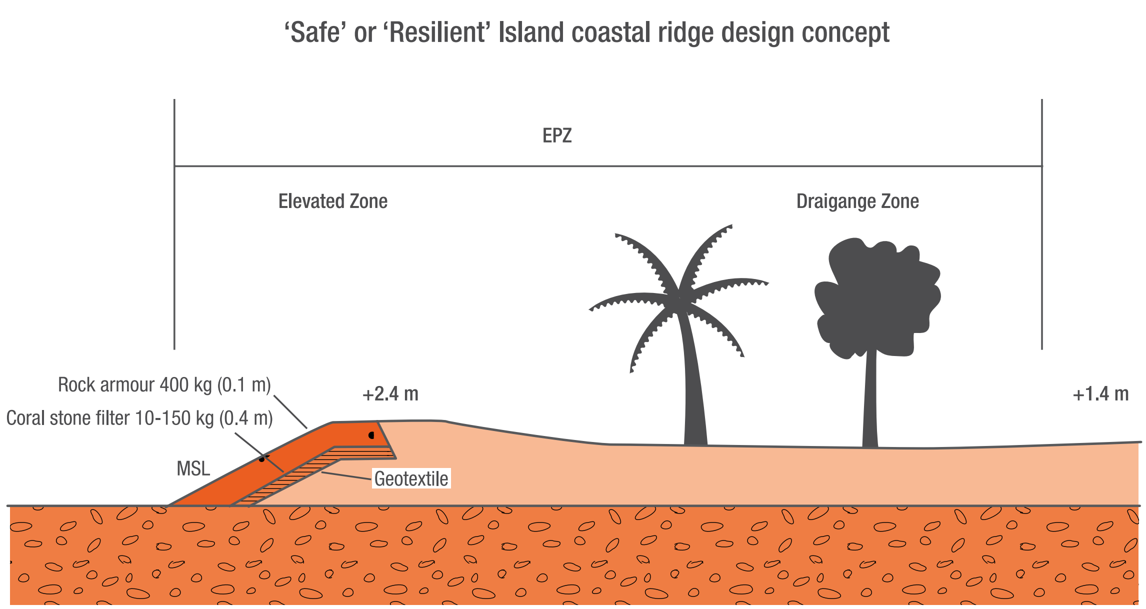
Ridges are a natural adaptation of the island coastlines to prevailing wind and wave conditions on an island. They are generally left untouched, especially in islands high wind and wave exposure. Ridges are treated as part of the coastal buffer zone and are usually used as an adaptation measure with land use setbacks and coastal vegetation retention.

There are significant variations in ridge height between the central and, northern and southern half of Maldives. The southern islands have some of the highest ridges particularly in Fuvahmulah (4.5 m) and S. Hithadhoo (3.6 m). Similarly, Kulhudhuffushi in the north has a ridge height of 2.6 m. The figures for central Maldives study islands are on average 1.6 m. The variation is likely to be caused by wave intensity and storm activity. Those islands exposed to strong swell waves and a strong prevailing SW monsoon wind often have the most pronounced beach ridges.

Artificial ridges have been used as an adaptation measure in the 'Safe Island' or 'resilient island' concepts of Maldives. The islands of Vilufushi and Viligilli, which were reconstructed as safe or resilient islands following the 2004 Indian Ocean Tsunami disaster, are reported to have 2.4 m high artificial ridges constructed from armour rock. The design incorporates artificial planting of coastal vegetation, drainage and construction setbacks as well, with a fixed width of 40 m. The design however involves hard engineered foreshore breakwaters due to their armour rock construction (see Figure C15).

Due to their variability, no formal design guidance can be provided. However, the use of coastal ridges as an adaptation measure is most crucial in northern and southern atolls and may drastically reduce the impacts of future coastal flooding from increasing abnormal climatic activity. If artificial constructions of ridges are required, the basic components of a ridge are its height, width, slope and sediment composition. Soft engineering will generally involve the use of lagoon sand to enhance the ridge.

Figure C 15 Safe or Resilient island coastal ridge concept (from Shaig et al 2011)



3.4.2.4 Submerged sand filled geotextile tubes

Overview

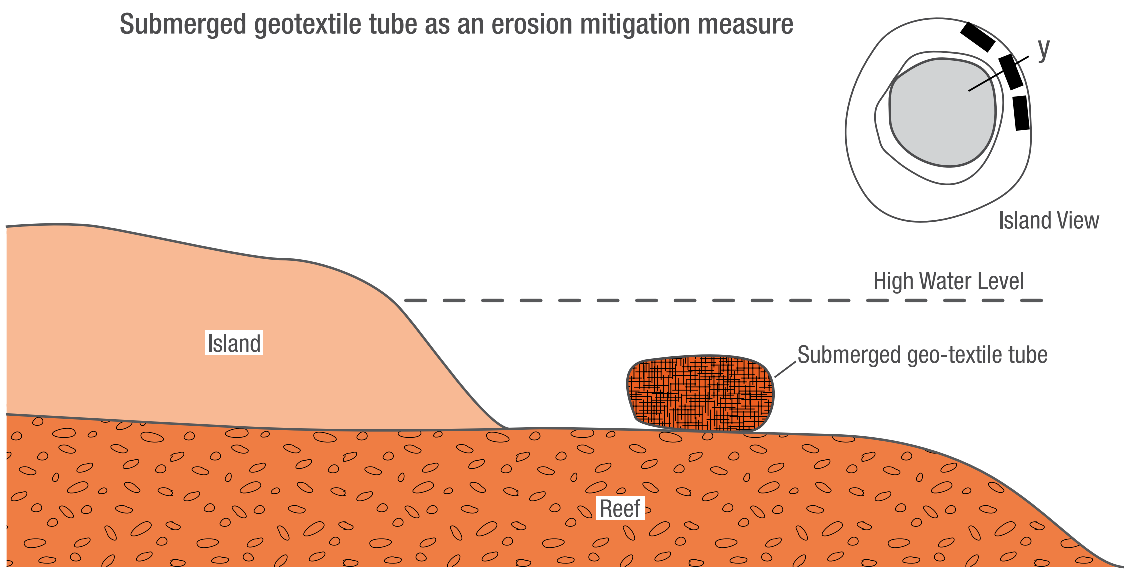
Submerged geo-textile tubes are a form of submerged breakwater but one which can be removed comparatively easily if no longer required. It has also been used as a measure to prevent sediment loss and to deep lagoon or reef slope after beach replenishment activity. The key advantages of geotubes are that it is easy to deploy, looks natural and can be removed. Examples of its use can be found in Shangri-La at Villigili and to some extent in B. Reethi Beach.

Design Guidance

The design involves placing sand filled geo-textile bags or tubes placed at a specific interval from the shoreline below high tide level. The bags are sewn from geotextile using a special sewing machine and filled using special equipment. Sand is usually placed using an excavator or dredger for larger projects. The tubes are placed using excavators or cranes mounted on a barge or sand bed (see Figure C16).

Engineering Guidelines

Figure C 16 Generic design of submerged geotextile tubes as a near shore structure



This method has not been widely adopted in Maldives yet. The reasons may be related to mix of costing, uses of specialized equipment and reliability. Most people interviewed are not aware of the durability of geo-textile material are concerned that it would break apart within a few years. The tubes require filling using sand which involves dredging. Unless there is a dredging project, this method becomes unattractive for resort islands and Government agencies funding beach protection measures in islands. Moreover, the environmental impacts are generally higher due to the requirement for dredging when compared to other material such as armour rock

3.4.3 Flood Prevention Structure Guidelines

3.4.3.1 Demountable Flood Barriers

It is recommended that the following guidance document is reviewed for specific details on flood demountable structures. It is believed that some techniques could be transposable into a Maldivian situation, though most probably of relevance to more urban set ups (e.g.: on Male island). The full set of techniques available may be found within the following report; "Environment Agency UK (2012) "Temporary and Demountable Flood Protection Guide" Project: SC080019 Published by: Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH www.environment-agency.gov.uk; ISBN: 978-1-84911-225-3.

3.4.3.2 Vegetation planting

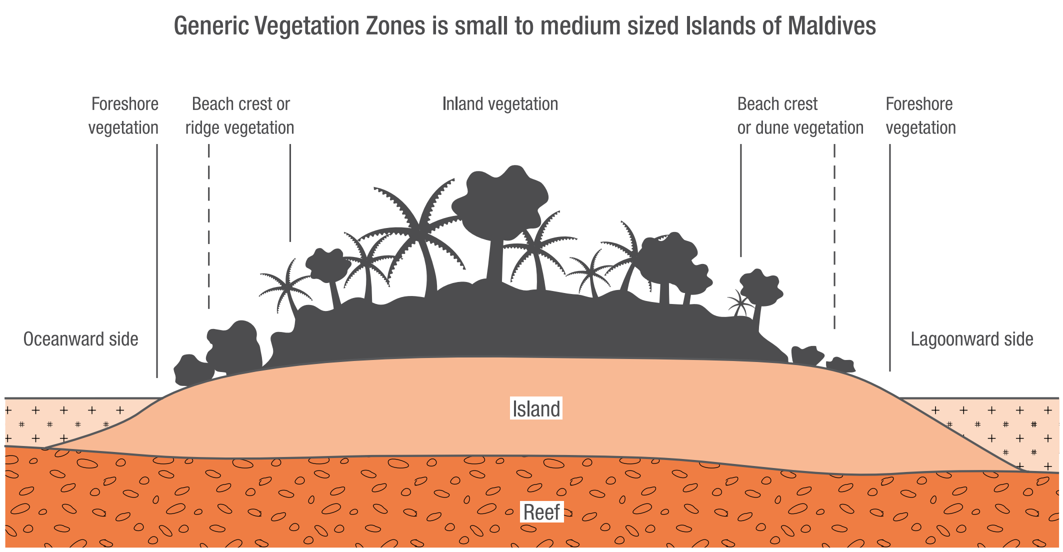
Overview

Coastal vegetation is known to play a major role in reducing the exposure and impacts of natural hazards in the Maldives. In the face of predicted intensity and frequency of natural hazards due to climate change, coastal vegetation may have a crucial role to play in the adaptation of small islands, particularly to coastal flood impacts and strong wind. Coastal vegetation has been retained in most islands as a traditional adaptation measure against strong wind, resulting salt spray and occasional coastal flooding. There appeared to be a strong relationship in the study islands between retention of coastal vegetation and intensity of wave and wind activity. In general, the following preliminary findings could be deduced.

The oceanward shoreline of islands on the western rim of Maldives, exposed to strong winds and salt spray during Southwest Monsoon, have a wider coastal vegetation system (see Figure C17). The exception to this pattern is when the island has been reclaimed or has a very high population density. Similarly, the oceanward shoreline of islands in the north Maldives, particularly on the atoll rim, has a wider coastal vegetation system. This could either be related to strong wave activity during NE monsoon or due the relatively large size of the islands. Islands in the central Maldives, which are less exposed to regular strong wave activity, have comparatively narrow coastal vegetation systems. This could either be related to the lack of need for a wide vegetation belt, relatively narrow width of islands and generally comparatively lower ridge.

There is no specific design for the retention or replanting of coastal vegetation, though it is vital that engineers and planners, intending to embark on a pilot project for coastal vegetative planting, are aware of the general vegetation zones on islands. These can be classified as: i) fore-shore vegetation; ii) beach-crest or dune vegetation; and iii) inland vegetation (see figure C17).

Figure C 17 Vegetation zones in small to medium sized islands in Maldives



Design Guidance

Vegetation transplanting, thatching and fencing may well be considered as a part of any scheme, no matter how small or large. Transplants for a small scheme over tens of metres may well be available at no cost from the local beach system, but schemes covering longer lengths of shoreline will probably need a commercial supply or the development of a managed nursery. Either way, supplies will be limited and work will have to be planned well in advance. Fencing or thatching supplies should be readily available at any location.

3.4.3.3 Artificial Reefs

Overview

Artificial reefs are currently being used primarily to enhance the reef as a tourism product rather that than as a mitigation measure against climate change or natural hazard mitigation. There have been proposals to create submerged breakwaters in island like B. Reethi Beach, K. Fun Island and Ha. Manafaru, but the projects haven't come through yet.

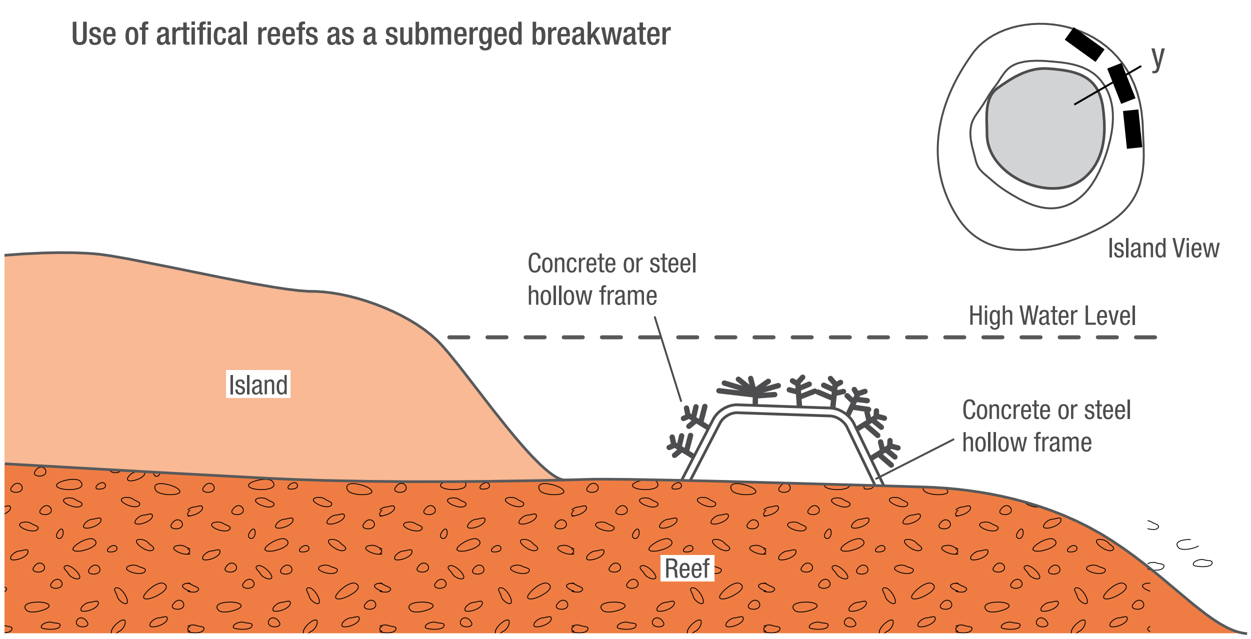
Design Guidance

The construction of base material generally needs to be from specially constructed concrete hollow blocks or steel frames (see Figure C18). Concrete blocks come in propriety designs such as the reef balls or as custom made blocks. The most commonly used material in Maldives is steel frames welded especially for the purpose. The shapes of the frame generally tend to be close to the profile of a breakwater. Coral recruits are collected from a nursery or nearby reefs and pasted onto the frame using special glue. The coral growth timing varies but generally taken more than 2-3 years to mature.

The survival of the coral depends on the site conditions. The most important aspect of the design is to identify the correct locations, depths and type of coral that would best survive in the conditions. This is a cheap and creative adaptation measure that can be readily applied to most islands of Maldives with the proper awareness and capacity building programmes.

More studies and pilot assessments should be undertaken to enable a better understanding and hence design of these structures on islands in the future.

Figure C 18 Generalized design for construction of artificial reefs as submerged breakwaters



3.5 Chapter C4: Material Standard Details (Hard Structure Measures)

3.5.1 Aggregate Material

3.5.1.1 References

The minimum standards for products specified in this Chapter shall be relevant BSI standards including but not limited to the following standards. Except as otherwise specified herein, it is proposed that contractors in the Maldives should attempt to perform work in accordance with specification codes and standards cited therein and to latest applicable addenda and supplements.

- BS 812 Testing aggregates;
- BS 882 Specification for aggregates from natural sources for concrete;
- BS 8110 Structural use of concrete;
- BS 5328 Methods for specifying concrete, including ready-mixed concrete;
- British Cement Association (BCA) Publications;
- 'Aggregates - Delivery and Storage';
- 'Testing Aggregates';
- 'Impurities in Concreting Aggregates'.

3.5.1.2 Products

Type A Coarse Aggregate Material

Granular material, free from harmful matter, well graded, passing a 75mm BS sieve and in any one layer only one of the following:

- Crushed hard rock or quarry waste (other than chalk);
- Gravel.

Type B – Coarse Aggregate Material

To be pea gravel free from clay, shale, organic matter and graded to the following limits (Table C4.1):

Table C 4.1 Seive size parameters

Sieve (mm)	**Size**	**Percentage passing BS sieves for graded Aggregate nominal size**		
		40 – 5mm	20 to 5mm	15 to 5mm
50.0		100	-	-
37.5		90 – 100	100	-
20.0		35 – 70	90 – 100	100
14.0		-	-	90 – 100
10.0		10 - 40	30 – 60	-
5.0		0 - 5	0 - 10	0 - 10

Engineering Guidelines

Type C – Fine Aggregate Materials

To be fine natural washed sand free of silt, clay, loam, friable or soluble materials or organic matter, graded within the following limits (Table C4.2):

Table C 4.2 Seive Size parameters (fine aggregates)

Sieve Size (mm)	Percentage Passing BS Sieves, overall limits
10.0	100.00
5.0	89 - 100
2.36	60 – 100
1.18	30 – 100
0.60	15 – 100
0.30	5 – 70
0.15	0 - 15

Source Quality Control

If necessary and as requested by the Engineer, the Contractor, at no extra cost to the Contract, is to source test and/or analyse the aggregate material in accordance with BS 882 and BS 812. If tests indicate materials do not meet specified requirements, change material or material source and retest. Provide materials of each type from same source throughout the Work unless agreed otherwise with the Engineer.

3.5.1.3 Execution

Stockpiling

Stockpile materials on site at locations designated by the Engineer Stockpile in sufficient quantities to meet Project schedule and requirements. Separate differing materials with dividers or stockpile apart to prevent mixing. Direct surface water away from stockpile site so as to prevent erosion or deterioration of materials.

Stockpile Clean-up

Remove stockpile, leave area in a clean and neat condition. Grade site surface to prevent free standing surface water or leave unused materials in a neat, compact stockpile as directed by the Engineer at the completion of the relevant portion of the Works. If a borrow area is indicated, leave area in a clean and neat condition. Grade site surface to prevent free standing surface water

3.5.2 Dredging and Reclamation

3.5.2.1 References

The Works shall generally be carried out in accordance with British Standards and other standards and references listed below except where specifically covered by this specification.

- BS 1377, Methods for Testing Soils;
- BS 6349 Maritime Structures Parts 1, 2, 4, 7.;
- BS 7755, Soil Quality. Terminology and Classification. Terms and definitions;
- Manual on the use of Rock In Coastal and Shoreline Engineering. CIRIA Special Publication 83, CUR Report 154;

Reclamation as defined under this specification comprises the following:

- The transport, placing, grading and testing of suitable excavated or dredged materials, to form the permanent reclaimed structures of the development;
- The transport, placing, grading of suitable materials to form any temporary reclaimed structures required by the Contractor to suit his own method of work;
- Any transport, placement, grading and testing of unsuitable excavated or dredged materials on specific land areas set aside for this material by the Engineer;
- Disposal of unsuitable material off site, when instructed by the Engineer.

3.5.2.2 Field Measurements

Survey control points are available in the proximity of the site. The Contractor shall satisfy himself of the accuracy of these survey control points prior to commencing any works. He shall report to the Engineer any discrepancies outside normal acceptable tolerances.

Any survey control points established by the Contractor shall be submitted to the Engineer for approval prior to erection. The Contractor shall, also prepare and submit to the Engineer for approval, all location diagrams of survey points showing the general locations with a schedule providing the following information:

- Station designation;
- Plan coordination (Eastings & Northings Maldives grid system);
- Level Values (to Global Mean Sea Level);
- Description.

The Engineer shall be informed by the Contractor in writing 24 hours in advance of any setting out operation and the Engineer shall be allowed a further 24 hours to satisfy himself that the setting out is within acceptable tolerances. The Engineer's approval will be given in writing.

The Contractor shall provide a robust protection system to the setting out points once they have been checked and approved.

3.5.2.3 Products

All materials and workmanship shall conform to this Specification, and shall be subject to inspection and testing as prescribed hereinafter. Materials shall be obtained from sources and suppliers approved by the Engineer. All materials to be utilised in the Works shall be submitted for approval one month prior to use, unless specified otherwise in the Contract.

The Contractor shall maintain a detailed record of all materials received on the Site or in his stores or storage areas associated with the Site and shall make such records available to the Engineer as required.

The workmanship, goods and materials shall be of the best available quality and shall be to the approval of the Engineer.

Where proprietary materials or equipment are referred to in the Specification or drawings by stating specific manufacturers or trade names, the intention is to establish the type and quality of materials required. The Contractor may substitute similar materials of alternative manufacture with the prior approval of the Engineer.

Prior to ordering or delivering any materials or manufactured items to the Site, the name or names of the manufacturer(s) and, where required by the Engineer, adequate samples, schedules and manufacturer's certificates of all the materials and goods shall be submitted to the Engineer for approval and in the case of rejection further samples shall be submitted until such are approved.

All proprietary materials shall be fixed or applied strictly in accordance with the manufacturer's printed instructions.

If instructed by the Engineer, samples of materials or goods shall be tested for compliance at the Contractor's expense in a laboratory designated by the Engineer. All materials or manufactured items that are liable to damage shall be delivered in the original package, containers, etc.. bearing the name of the manufacturer and the brand.

Materials or manufactured items shall be carefully loaded, transported, unloaded and stored in an approved manner, protected from damage and exposure to weather or dampness during transit and after delivery to the site. Damaged material or manufactured items shall not be used in the Works. Any material or manufactured items damaged during and after fixing in position shall be removed, repaired or replaced at the Contractor's expense.

3.5.2.4 Execution

Records

The Contractor shall maintain all necessary records for monitoring and controlling the Works including those specified in the Environmental Management Plan (EMP). All work statements shall be compiled in the form of monthly progress reports and submitted to the Engineer accordingly. In addition to any requirements elsewhere in the Contract monthly reporting shall also include, but not necessarily be limited to the following:

- Location of plant;
- Performance of plant;
- Details of any down time and the reasons for it;
- Material encountered;
- Weather including, wind, waves, sea state;
- Other environmental parameters as specified in the EMP;
- Any surveys of completed Works with measured volume(s).

The Contractor shall contact each of the Relevant Authorities responsible for utilities and services and shall maintain close liaison with them throughout the construction period. The Contractor shall establish the positions of all main services and utilities liable to interference by the Works prior to commencing any dredging and reclamation works and shall prepare a detailed drawing indicating the exact location and dimension of all the services. Trial holes shall be made to locate accurately buried services prior to commencing any dredging and reclamation works.

The Employer shall not be held responsible for damage to any utilities or services. The Contractor shall take precautionary measures to avoid damage to all underwater installations, such as pipe lines, cables, sewerage or drainage pipes etc.. The Contractor shall prevent his plant from operating too close to overhead high tension cables and he shall establish all necessary precautions for crossing under such cables.

The Contractor shall comply with all local, national and international Laws, Rules, Regulations and Orders in respect of shipping and navigation.

The Contractor shall immediately carry out any instructions of the Port/Maritime Authority, the Engineer or any other Relevant Authority with regard to berthing or manoeuvring any of his craft wherever berthed, lying at moorings or anchored within the jurisdiction of the Relevant Authority.

The Contractor shall conduct his operations in such a way as to cause as little inconvenience as possible to the shipping traffic in any area outside the Site Boundary or borrow area and the Contractor shall give prior notice of the commencement of any marine operations inside and outside the Site Boundary or any borrow area to the Relevant Authority and keep them informed of all plant and equipment movements outside the site boundary.

All plant and equipment employed by the Contractor shall be equipped with VHF radio telephone sets operating on international frequencies which shall be manned continuously whenever the vessels are at work.

The Contractor shall also provide VHF radio telephone communication between the dredging craft and the Contractor's site offices.

It shall be noted that it is obligatory under the laws of the Maldives to hold a valid license for a VHF radio telephone set.

In addition to any requirements elsewhere in the Contract, the Contractor shall provide, and maintain the necessary life-saving equipment in accordance with all Relevant Authority requirements and to the approval of the Engineer, around the site and on all items of floating plant and equipment. The equipment must be available for use at all times.

In addition to any requirements elsewhere in the Contract, the Contractor shall provide and maintain temporary moorings, fastenings, marker buoys, audible signals and lights as necessary to secure and mark the site boundary, his floating plant and equipment and such markers, signals and lights as the Engineer may consider necessary for the proper marking of the Works.

The Contractor shall remove the temporary moorings, fastenings, marker buoys, audible signals and lights at the end of the Works or when otherwise instructed by the Engineer.

All lights shall be placed or screened as necessary or as may be required by the Engineer so not to interfere with or be mistaken for any navigational lights or with or for any other signal lights. The Contactor shall provide the Engineer with a chart of the area to an agreed scale showing the location of any temporary mooring, fastening, marker buoy or light as soon as it has been laid or set. The Contractor shall at all times ensure that this chart is kept fully up-to- date.

Positioning and Tidal Registration of the Dredging Plant

All plant used for dredging and reclamation shall be equipped with an automatic positioning system to continuously monitor its position. In addition, a system shall be installed to continuously record the information from the automatic tide gauge.

Full records of the dredging and reclamation recorded information shall be kept and plotted on plans, and submitted as required by the Engineer.

Tide Gauge

An automatic tide gauge shall be installed on the Site. The gauge shall have a radio transmission link to the dredging and reclamation plant and a printer installed at a suitable location on the site. The gauge shall remain in operation throughout all periods of dredging and shall record and display results in metres above/below Global Mean Sea Level.

The Contractor shall, during the Contract period, regularly inspect, maintain and control the tide gauge to make sure the readings are correct. Malfunctioning equipment shall immediately be reported to the Engineer. The Contractor shall each month submit to the Engineer a table indicating for each tidal cycle, the maximum and minimum tidal level and the time these were recorded.

Monitoring Hydrographic Data

As a minimum and unless specified elsewhere in the Contract or by any other Relevant Authority, the Contractor shall, carry out the following monitoring activities:

Wind direction and speed measured at 4 equal intervals per 24 hour period.

Water sampling and measurement of ambient suspended materials in the water column is needed at intervals and locations as directed by the Engineer subject to any alternative requirements specified by the Relevant Authorities.

Baseline ambient suspended materials levels shall be determined at a site 1km to the east of the project Site Boundary. Samples shall be taken twice weekly. Where results are similar and approval is obtained from the Engineer, sampling may be reduced to weekly intervals. Where the results of any such tests differ or vary significantly, an additional monitoring point shall be established in agreement with the Engineer.

Samples shall generaly be taken at 1m below water level, 1m above bed level and at mid depth. Mid depth samples shall only be required in water over 4m deep. The Contractor shall ensure that sufficient samples are taken from each location to enable initial turbidity assessments to be made and further lab testing undertaken to accurately measure the suspended material levels.

The Contractor shall submit weekly to the Engineer results of all data from the monitoring activities above.

Engineering Surveys - Dredging

The Contractor shall undertake the following surveys to a method approved by the Engineer:

- Pre Dredged Bathymetric Survey – To be carried out prior to commencement of the dredging. A single or dual frequency recording echo sounder capable of resolving water depth to within 0.1m shall be used for this survey work. The echo sounder shall be capable of being adjusted for draft and speed of sound. A 3-component heave compensator shall be supplied.
- The echo sounder shall be calibrated at the start and end of each day's survey work by "bar check" (and/or other approved method) over the full range of water depth surveyed.
- Acceptance Survey – To be carried out upon completion of the dredging as defined in the Contractors programme to the extents indicated on the Contract Drawings with the intention of demonstrating to the Engineer's satisfaction that the dredging has been carried in accordance with the requirements of the Contract.
- A single or dual frequency recording echo sounder capable of resolving water depth to within 0.1m shall be used for this survey work. The echo sounder shall be capable of being adjusted for draft and speed of sound. A 3-component heave compensator shall be supplied.
- The echo sounder shall be calibrated at the start and end of each day's survey work by "bar check" (and/or other approved method) over the full range of water depth surveyed.
- Post Dredge Survey – Upon completion of the dredging Works the Contractor shall carry out a survey of all areas affected by dredging activities. The post dredge survey will be used for defining the scope and extent of Works carried out for the purposes of re-measurement, further mitigation Works and/or compensation issues. A single or dual frequency recording echo sounder capable of resolving water depth to within 0.1m shall be used for this survey work. The echo sounder shall be capable of being adjusted for draft and speed of sound. A 3-component heave compensator shall be supplied. The echo sounder shall be calibrated at the start and end of each day's survey work by "bar check" (and/or other approved method) over the full range of water depth surveyed.
- Additional Surveys -The Engineer may instruct the Contractor to undertake additional surveys and environmental monitoring as the Engineer deems necessary for the supervision of the Works.

Engineering Surveys - Reclamation

For land reclamation projects the Contractor shall undertake the following surveys to a method approved by the Engineer:

- Pre Reclamation Survey – To be carried out prior to the commencement of the Works and shall include areas to be reclaimed and those areas likely to be affected by the reclamation within the Site Boundary. Particular attention will be given to the identification of existing outfalls, pipes, drainage channels, marine structures, wrecks etc..
- Pre reclamation bathymetric survey measurements shall be taken at a maximum of 5m centres unless otherwise instructed by the Engineer or any other Relevant Authority.
- Post Reclamation surveys – The Contractor shall carry out settlement monitoring in accordance with the approved testing regime.
- Post Construction Surveys - To be carried out upon completion of the Works in accordance with the approved testing regime or as otherwise directed by the Engineer, shall include areas of the sea bed adjacent to the reclaimed structures to establish any settlement effects on the underlying sea bed material.
- Additional Surveys – The Engineer may instruct the Contractor to undertake such additional surveys and environmental monitoring as are deemed necessary for the supervision and control of the Works for the purpose of establishing monthly valuations.

Surveys - Methodology

The Contractor shall submit to the Engineer for his approval full details of the equipment and methodology to be adopted to undertake the above surveys. All surveys shall be carried out with a representative of the Engineer present unless otherwise agreed in writing.

For each of the surveys the Contractor shall provide the following:

- No. paper copies of the survey at scales to be agreed with the Engineer with bed contours at 0.5 m intervals;
- 1 electronic copy of the survey on CD ROM in AUTOCAD .dwg or .dxf files;
- Appropriate cross sections.

Diving and Diving Inspections

In addition to any requirements elsewhere in the Contract, the Contractor may provide professional divers for inspection of dredged slopes, protection to slopes and other submarine works. Where the Contractor proposes such divers, they shall have experience in similar dredging and reclamation works. The Contractor shall also provide all necessary diving facilities for any divers appointed the Engineer. The Contractor shall arrange for a competent linesman to be in attendance at all times during diving operations.

Before any diving is undertaken the Contractor shall supply to the Engineer's Representative two copies of the code of signals to be employed an have a copy of such code prominently displayed on the craft or structure from which the operations take place.

All diving operations shall be in accordance with all local, national and international standards such as Diving Operations at Work Regulations 1981 and all its amendments as published by the UK Health and Safety Executive and the publications of the UK Department of Energy, the Association of Offshore Diving contractors, the Employment Medical Advisory Service and the Diving Medical Advisory Council of the UK.

The Contractor shall provide a copy of these regulations to the Engineer for his sole use, together with any other codes he proposes to adopt for their approval by the Engineer.

3.5.2.5 Environmental Controls

Environment Controls - General

The Contractor shall ensure that the operation of his dredging and reclamation plant and his methods of operation are in compliance with all Relevant Authority requirements.

Unless specified elsewhere in the Contract, the Contractor shall put in place an Environmental Management Plan (EMP) including environmental monitoring and mitigation measures as agreed with the Engineer and in accordance with the guidelines and directives of any other Relevant Authority.

As a minimum, the EMP shall address the following items and include CVs of environmental specialists from within the in-house team or from appointed consultants responsible for the preparation and implementation of the plan.

- Environment monitoring and pollution controls cross referencing any mitigation measures that are listed in the EIA study for all aspects of the work;
- Sediment dispersion mitigation measures at the point of dredging;
- Pipeline transportation and discharge operations;
- Use of perimeter bunds to control suspended sediments;
- Methods for working material above water (shaping, grading, rolling);
- Use of spillways, lagoons, silt traps to control run-off (i.e. to reduce release of fines); Measures to deal with build-up of silt within and outside the site area;
- Any other mitigation measures.

Environmental Controls – Dredging and Reclamation

Unless specified elsewhere in the Contract, or as otherwise agreed with the Engineer or other Relevant Authority, the Contractor shall, as a minimum, measure on a daily basis the suspended solids content of the water column at the following locations, the results of these measurements shall be submitted to the Engineer within 24hrs, and recorded in a log book by the Contractor.

- A distance of 500m from any of the Contractors dredging plant;
- A distance of 500m from any Borrow Area (if required) or point of dredged material deposition;
- An offshore location at a distance of 500m from the Site Boundary;
- At any containment bund zone water run-off point;
- At any silt trap water run-off point;
- At any other location required by the Engineer or any other Relevant Authority.

The Contractor shall agree with the Engineer and any other Relevant Authority the methods for sampling the suspended solids content of the water at any of the required monitoring points.

The environmental limit on suspended solids content of the water column above background level is to be in line with Relevant Authority requirements.

In the absence of any such requirements, the following limits shall apply:

- A maximum suspended solids content of 10mg/litre above ambient at a distance of 500m from any dredging plant;
- A maximum suspended solids content of 10mg/litre above ambient at a distance of 500m from any borrow area boundary;
- A maximum suspended solids content of 100mg/litre above ambient during preparation and construction of the reclamation containment bunds and at locations agreed with the Engineer associated with material deposition as part of the reclamation Works;
- A maximum suspended solids content of 30 mg/litre or 10mg/litre above ambient (whichever is the lower) during general reclamation works at any containment bund zone water run-off point;
- A maximum suspended solids content of 30 mg/litre or 10mg/litre above ambient (whichever is the lower) at any silt trap water run-off point.

Where the results of any such tests indicate that the agreed limits have been exceeded the Engineer may instruct the Contractor to change his methods of working or to stop his operations temporarily until there is again compliance with the specified limits. Any additional costs resulting from a change in methodology or temporary cessation of operations, as a result of exceeding environment limits, shall be to the Contractors account.

Pipeline Monitoring

Unless specified elsewhere in the Contract, daily inspections of all floating and submerged dredging pipelines shall be undertaken, where any leaks or pipeline deterioration are found these shall be reported to the Engineer immediately.

Silt Accumulations on the Seabed

Unless specified elsewhere in the Contract, where any post construction survey indicates an accumulation of silt layers on the seabed within the Site Boundary and perimeter survey zones or at any other affected location, the Engineer may instruct the Contractor to undertake additional surveys to establish the extent. The results of any such surveys shall be submitted to the Engineer within 24 hours.

Where any silt layers on the seabed in excess of the limits set by any Relevant Authority or in the view of the Engineer are unacceptable are found, the Contractor may be instructed to remove the silt or undertake mitigation measures as necessary, any such measures shall be completed by the Contractor at his own expense by methods agreed by the Engineer and any other Relevant Authority.

Dredging Exclusion Zones

Dredging exclusion zones are areas of the Site to be protected from dredging works, except with the approval of the Engineer and/or other Relevant Authority

Pollution Control

In addition to any requirements elsewhere in the Contract or controls specified by any other Relevant Authority, the Contractor shall ensure that all necessary measures are taken to prevent the pollution of the environment by his plant and equipment for both dredging and reclamation works, including as a minimum:

- Avoidance of pollution of any waters, (surface or underground)
- Avoidance of pollution of any land
- Preservation of flora and fauna;
- Avoidance of nuisance of noise, vibrations and dust.

The Contractor shall demonstrate in his written Method Statement or EMP, as appropriate, his proposals to minimise environmental impact and satisfactorily address the following issues as a minimum.

- Equipment which leaks any fuel, lubricant or hydraulic fluid shall not be used;
- Equipment shall be maintained to ensure efficiency and to minimise emissions;
- Equipment shall be clean on arrival at site;
- Fuel and oil shall be stored away from watercourses, fully bunded and containers shall be
- maintained in a secure and clean manner;
- Refuelling or servicing of equipment shall be supervised and carried out in designated locations agreed with the Engineer;
- Appropriate oil absorbent and containment materials/ products shall be readily available on site at all times in case of fuel leak or spillage;
- Any spillage shall be immediately contained and removed from site to an approved location. The Engineer shall be promptly informed of any such spillage;

Environmental Control – Archaeology and Heritage

Unless specified elsewhere in the Contract, all fossils, coins, articles of value or antiquity and structures and items of geological or archaeological interest found on the site shall be placed under the care and authority of the Employer. The Contractor shall take all reasonable steps to protect such findings.

The Contractor shall immediately notify the Engineer of any such discovery, who shall issue instructions for dealing with it. All costs or delays associated with any such discovery shall be notified to the Engineer, for his consideration under the Contract.

3.5.2.6 Dredging Operations

Material to be Dredged

The Contractor shall satisfy himself as to the nature of the material to be dredged. The Contractor will be deemed to have:

- Visited the site;
- Examined any samples obtained during the course of the site investigation and all available site investigation records.

In addition to any requirements elsewhere in the Contract, if the Contractor considers it necessary, he shall carry out additional investigations and testing to enable him to accurately assess the nature of the material to be dredged and determine the most suitable type of plant and method of operation.

All costs associated with any clean-up operation arising from his activities shall be at the Contractors own expense and be undertaken in a timely and efficient manor to the satisfaction of the Engineer and any other Relevant Authority.

Tolerances

The Contractor shall carry out his dredging operations in accordance with the drawings or as otherwise directed by the Engineer.

Where specific dredged depths and finished profiles are indicated, the Contractor shall demonstrate in his acceptance survey that no part of the dredged area is above the levels indicated on the drawings.

The horizontal tolerance shall be +/- 500mm and the vertical tolerance shall be + 100mm and must not exceed 500mm below any specified depths/levels.

Over Dredging

In addition to any other requirements elsewhere in the Contract, where dredging in excess of the tolerances has taken place the Contractor may be instructed at the discretion of the Engineer to undertake mitigation works at his own cost in any such over dredge area to ensure the appropriate levels are obtained.

Dredging Adjacent to Existing or Intended Structures

Dredging will not be permitted in any exclusion zones marked on the drawings or in areas where in the opinion of the Engineer the stability of any adjacent structure might be adversely affected.

Where permitted dredging activities take place adjacent or near to the newly formed reclaimed structures, the seabed shall be finished to a profile such that bed contours are parallel to the plan alignment of the reclaimed fill material.

Adverse Weather Conditions

In addition to any other requirements in the Contract, dredging shall cease if in the opinion of any Relevant Authority or the Engineer, weather conditions are such as to render continued dredging operations hazardous to shipping, the environment, persons or property.

Testing of Dredged Material

In addition to any other requirements in the Contract, the Contractor shall, for the duration of the dredging works, be responsible for commissioning and ensuring the testing of dredged material is in accordance with the project requirements1. All testing shall be subject to the materials testing procedures identified in this materials specification.

Where any material samples tested indicate the presence of silt deposits within the Site Boundary, details of the location shall be brought to the attention of the Engineer.

Table C 4.3 Testing and Sampling Regime during Dredging Operations

Item	Purpose	Location	Number	Frequency	Testing
Pre-dredging material samples	Classification of proposed material for dredging and reclamation	Any designated dredging area within the Site or a Borrow Area Boundary	Samples to be taken at a maximum of 200m centres, unless otherwise agreed with the Engineer.	1m intervals over proposed dredged depth.	Particle Sieve Distribution (PSD) test, Shell Content test and Carbonate Content test on each sample, as per Clause 1.1.1. or BS 1377 as appropriate
Dredged material samples	Classification of proposed material for dredging and reclamation	From each dredger during dredging where possible, otherwise refer T6.1.	As per frequency or as otherwise directed by the Engineer or other Relevant Authority	Every 5000m3 dredged	
Seawater samples	Suspended solids	As per this Materials Specification	As per this Materials Specification	As per this Materials Specification or as otherwise directed by the Engineer or other Relevant Authority	Suspended solid content

3.5.2.7 Reclamation Operations

The Contractor shall carry out his reclamation operations in accordance with this Specification, the drawings and as directed by the Engineer.

The permanent reclaimed structures shall be formed from the appropriate fill materials described in this Section.

Suitable Fill Material (Permanent Reclaimed Structures)

Material classed as "suitable fill material" shall be free draining, fine to coarse sand containing less that 2% organic matter, gypsum or other salts and less that 8% silt and clay sized material. It should meet the following requirements:

- Maximum Particle size   250mm
- Percentage Passing   63 micron sieve   8% maximum
- Liquid Limit   Non Plastic

Fill found to be outside these limits shall be classed as "unsuitable fill material" for the reclamation of the permanent structures, unless otherwise approved by the Engineer.

Vertical Edge Structure Backfill

The material to be used for backfilling purposes for the construction of the vertical edge structures shall be free draining free from organic matter or other deleterious material. It shall not contain lumps over 150mm in greatest dimension, and not more than 15% larger than 70mm.

Suitable material shall be graded and stockpiled following excavation for inspection by the Engineer.

Material classed as "Vertical Edge Structures backfill material" shall be free draining, fine to coarse sand or rock containing less that 2% organic matter, gypsum or other salts and less that 8% silt and clay sized material. It should meet the following requirements:

- Angle of Friction   35 Degrees (Minimum)
- Unit Weight   2.0 kg/cm3
- Maximum Particle size   150mm
- Liquid Limit   Non Plastic
- D10 limit   2.0mm

Permeability test results to yield permeability greater than 5x10-4 m/s

The backfill material shall consist of filter materials composed of clean coarse sand and gravel or crushed stone conforming to the following requirements.

It shall be spread in lifts not exceeding 250 mm in un-compacted thickness, moisture conditioned to its optimum moisture content, and compacted to a dry density not less than 95 percent of the maximum dry density as obtained by Modified proctor compaction test (ASTM D 1557).

The backfill materials comprising the drainage layer immediately behind the retaining walls shall consist of filter materials composed of clean course sand and gravel or crushed stone conforming to the following grading requirements:

Sieve Size	Percentage Passing by Weight
2 ½ "	100
1 ½ "	80 – 100
¾ "	60 – 95
No.4	35 – 65
No. 8	25 – 50
No. 30	5 – 25
No. 200	0 - 3

Fill found to be outside these limits shall not used as backfill material to the reinforced concrete vertical edge structures as indicated on the Contract drawings.

Beach (lagoon) Sand

The Contractors attention is drawn to the requirements of this materials specification, where limits are placed for the classification of fill material to be used to form the beaches or lagoon areas.

Where such conforming materials are identified as part of any Borrow Area search, all technical information regarding the location, quantity and nature of such possible fill material obtained by the Contractor shall be made available to the Engineer.

Temporary Structures

Temporary structures erected by the Contractor to suit his method of work shall be constructed using medium to coarse sand or rock containing a target 5% silt and clay sized material, but not more than 8%, unless otherwise agreed with the Engineer.

Placement of Suitable Fill Material

In addition to any other requirements in the Contract, the Contractor shall remove all vegetation, organic material and debris from all seabed areas or landward beach areas to be reclaimed prior to placing any fill.

The disposal of all such materials off the site shall be carried out in accordance with all Relevant Authority requirements.

Unless specified elsewhere in the Contract or where approved by the Engineer and/or other Relevant Authority, containment bunds shall be mandatory for all reclamation areas. The method of placing the fill shall be approved by the Engineer including all pipeline routes and discharge points.

The Contractor shall control the deposition of material such as to avoid the concentrations of fine or shell material in localised areas or the formation of compressible areas of fill and shall conduct regular monitoring of materials, particle size distribution tests and other materials laboratory test results in accordance with this Specification to ensure the acceptance criteria are being met.

Where such test results indicate that accumulations of unsuitable fill material may be present or where the acceptance criteria are not met, the Engineer shall instruct the Contractor to undertake further investigation to establish the extent of such deposits. Where deposits of unsuitable fill in excess of 200mm total cumulative thickness are found, the Engineer may instruct the Contractor to remove the whole of the material and replace it with suitable material.

The Contractor shall include in his method statement, his methodology for meeting the required acceptance criteria, by way of trials or by other means, which shall be subject to the approval of the Engineer. This shall include details of the appropriate standards; frequency and spatial variation of monitoring, not withstanding the foregoing in-situ density testing.

Side Slopes and Temporary Revetments

The side slopes of the permanent structures shall be trimmed to the slopes shown on the drawings or as otherwise directed by the Engineer. The Contractor shall be responsible for protecting the reclaimed fill side slopes up until the completion of the subsequent permanent Works. Any temporary revetment proposed by the Contractor during this time shall be subject to approval by the Engineer prior to placement.

Tolerances

Fill material shall be placed to within +/-100mm vertically and to within +/- 100mm horizontally of the position and levels shown on the drawings. Material on slopes to be armoured with rock shall be placed to within 0mm and +200mm of the profiles indicated on the drawings.

Testing of Reclaimed Fill Material

In addition to any other requirements in the Contract, the Contractor shall do such monitoring, sampling, and testing of the placed materials as required to control his operations and ensure that he complies with this specification in all respects.

As a minimum, the Contractor shall adhere to the sampling and testing regime outlined in this materials specification, or as otherwise directed by the Engineer, adopting the test procedures as applicable in this materials specification. All test results shall be reported to the Engineer on a daily basis, together with plans showing location and level of samples taken.

The works will not be accepted as complete until all materials tests have been performed and the acceptance criteria have been met and approved by the Engineer as being in accordance with the requirements of this Specification.

Table C 4.4 Testing and Sampling after Initial Reclamation and Placement Activities

Item	Purpose	Location	Number	Frequency	Testing
Fill samples	Compliance of placed material	At point of placement	Every 2500 m3 placed, or as otherwise agreed with the Engineer		PSD test on each sample,
CPTs	General compliance of placed material	Finished surface of all areas behind vertical edge structures including under stockpiled/ surcharge materials	At 100 m centres behind the vertical edge structures	To 5m below base of vertical edge structures	N/A
CPTs	Compliance of placed material in areas of building construction	Finished surface of all areas behind vertical edge structures including under stockpiled/ surcharge materials	Minimum of 1 number, over each building plot area	To 5m below base of vertical edge structure	N/A
Borehole	Compliance of placed material	Finished surface of all areas behind vertical edge structures	1 per 25,000 m2 or min 3 per lagoon area	To 5m below base of vertical edge structure	PSD samples every 1.0m. and SPT tests every 1.0m
Trial pit	Compliance of placed material	Finished surface of all areas behind vertical edge structures	1 per 25,000 m2 or min 3 per lagoon area	To groundwater level	In situ density testing every 1m. plus 2 samples per pit for PSD & max dry density. In-situ or laboratory CBR tests as directed by Engineer.

Monitoring Backfilled Material Levels

As a minimum and in addition to any other requirements in the Contract, the levels of the backfilled material behind the vertical edge structures shall be monitored in accordance with the recommendations of this materials specification, or as otherwise directed by the Engineer, adopting the test procedures as applicable in this materials specification.

The monitoring commencement date and locations of each monitoring point shall be agreed with the Engineer. Should any settlement occur during the monitoring period, the Contractor shall rectify the levels by adding fill quantities as necessary or as directed by the Engineer, at no additional cost to the Employer. No acceptance of levels shall be issued during the initial three month monitoring period.

Sequencing Reclamation Works

The dredging and reclamation Works shall be sequenced to suit the other contracts which may be in process on the site.

3.5.2.8 Materials Testing

An independent laboratory, capable of performing the necessary tests listed herein shall be appointed by the Employer for the duration of the Works.

All samples taken for laboratory testing and in situ tests results will be given a unique number and clearly labelled. The label will also include information of the location of the test or where sample was taken as well as its source and placement location. This information and the test results will be stored in an electronic database by the laboratory and issued to the Engineer in an Excel format.

Table 3.5.3 Testing and Sampling Regime Post Construction

Item	Purpose	Location	Number	Frequency	Testing
Surface monitoring plates or gauges as appropriate	Settlement monitoring of placed fill	Finished surface of all reclaimed areas or under stockpiles or surcharge material as appropriate.	At 100 m centres behind the vertical edge structures	Weekly for 12 weeks and then monthly until three months after cessation of fill placement Works or as otherwise directed by the Engineer.	Topographic levelling of the settlement plates as per this materials specification

Stockpiles of Suitable Fill

The Contractor shall notify the Engineer of all areas where he proposes to stockpile suitable fill materials, submitting details of the proposed heights above the initial reclamation level(s). Prior to stockpiling any materials, the Contractor shall test the reclaimed area using CPT's in accordance with this materials specification and shall continue monitoring by installing settlement gauges in accordance with this materials specification, or as otherwise directed by the Engineer.

Overbuilding, where the Contractor builds up fill above final formation level and immediately distributes it as part of a continuous hydraulic filling operation will not be considered as stockpiling.

Interface with Infrastructure Works

Unless specified elsewhere in the Contract or otherwise directed by the Engineer, the Contractor shall comply with the following:

- The Contractor shall provide and maintain access to areas of the completed reclamation Works for the purposes of others to form trenches for laying pipes or cables.
- The Contractor shall take adequate measures to protect reclamation areas against erosion from precipitation during storms and shall cover and provide drainage if necessary. Damage arising from effects shall be reinstated to the Contractor's account.

The Contractor shall compile, record and maintain in appropriately organised logbooks all test results and test certificates related to the project, whether issued by the site laboratory or others.

Upon completion of the Works all files, logbooks and records shall be handed over to the Engineer and become the property of the Employer.

Any tests required or requested by the Engineer or any other Relevant Authority during the course of the Works that are not listed in this Section shall be carried out in accordance with appropriate and approved international standards and with the agreement of the Engineer.

Laboratory Test Equipment

Laboratory shall be assumed to be equipped to carry out the following tests in accordance with BS 1377 : 1990 Parts 1 to 9, as appropriate.

Soil Classification Tests:

Part 2 Determination of the moisture content, (oven drying method);

Part 2 Determination of the liquid limit using the cone penetrometer;

Part 2 Determination of the bulk density and dry density of soil particles;

Part 2 Determination of particle density -Method for clay, silt and sand sized particles;

Method for soils with particles up to gravel size

Part 2 Determination of the particle size distribution

- Standard method by wet and dry sieving;
- Standard method for fine-grained soils (pipette method);
- Standard method for fine-grained soils (hydrometer method) Part 3 Determination of the organic matter content;

Part 3 Determination of the total sulphate content of soil

Part 3 Determination of the sulphate content of ground water and of aqueous soils extracts

Part 3 Determination of the pH value.

- Standard methods (electrometric) and subsidiary method (colorimetric)

Soil Compaction Tests

Part 4 Determination of the dry density/moisture content relationship (4.5kg rammer method) and (vibrating hammer method)

Part 4 Determination of the maximum and minimum dry densities of granular soils

Part 4 Determination of the California Bearing Ratio

Soil Insitu Tests (Field Tests)

Part 9 In-situ tests for soils for engineering purposes

Reclamation and Material Testing Requirements

Unless specified elsewhere in the Contract, samples taken for materials compliance and classification shall undergo a sieve analysis carried out in accordance with BS 1377 Part 2. Based on the results the material shall be classified in accordance with this materials specification.

As a minimum, the Contractor shall conduct insitu density tests at the frequency stated in this materials specification, or where the Engineer has reason to believe areas of fill may not be sufficiently compacted the Engineer may direct the Contractor to carry out additional testing, that shall include:

In-situ density tests in accordance with BS 1377 Part 4 shall be carried out in representative locations and number as directed by the Engineer.

The maximum dry density test in accordance with BS 1377 Part 4 shall be carried out on representative samples of the soils used for the in-situ dry density tests.

The degree of compaction shall be assessed as the ratio of the insitu dry density measured against the maximum dry density on a sample taken from the same location, or the average of a number of tests from similar material if agreed by the Engineer.

Cone Penetration Tests - Static Cone Penetrometer

A static cone penetrometer designed and manufactured in accordance with ASTM-D3341 (1986), or other similar standard as the Engineer may direct, shall be used for cone penetration tests. The penetrometer shall consist of a standard cone and friction sleeve complete with sensing device. The following criteria shall apply:

The precision of the measurement shall not be worse than the larger of the following values:

- 5% of the measured value
- 1% of the maximum value of the range

Standard Penetration Tests

Standard Penetration Tests (SPT’s) shall be carried out in boreholes at 1.0 metre intervals or such other spacing as may be directed.

Standard Penetration Tests shall be carried out in accordance with BS 1377 1990. The Contractor shall ensure that a full head of water is maintained in the borehole during testing, and the Contractor shall ensure that the ground being tested is not disturbed by the boring and drilling operations. The material recovered from the split spoon after each test shall be retained as a sample for testing as directed by the Engineer.

California Bearing Ratio Tests

California Bearing Ratio Tests (CBR’s) shall be carried out on disturbed or undisturbed fill material samples taken at suitable intervals or locations as may be directed by the Engineer. Samples shall be compacted in a CBR mould to reflect the conditions that exist on site. CBR tests shall be carried out on the top 300mm of reclamation at the specified location.

California Bearing Ratio Tests shall be carried out in accordance with BS 1377 1990 Part 4 and 9 as appropriate. Where in-situ tests are instructed, one additional sample shall be taken for laboratory testing for results calibration purposes.

Settlement Monitoring

Settlement plates shall be 500mm x 500mm x 100mm thick precast concrete slabs fitted with a brass survey pin at the centre. The manufacturing tolerances are:

- On the thickness of 100mm + 2.5mm;
- On the linear measurement of 500m + 5mm.

Settlement gauges shall comprise a 500mm diameter steel plate connected orthogonally to a 50mm diameter steel tube of minimum wall thickness 3mm one metre long. Subsequent units of one metre tube can be screwed to the stem. The plate shall be horizontal and the stem and connection tube shall provide a true vertical relative to the plate. A PVC outer tube 100mm diameter will be provided in order to overcome any friction along the stem.

The settlement plates and gauges shall be monitored using precise survey equipment and related to an approved system of existing or temporary bench marks whose elevation is not influenced by reclamation operations. The Contractor shall include in his method statement, his methodology for the undertaking settlement monitoring that shall be subject to the approval of the Engineer.

Trial Pits

As a minimum, trial pits shall be carried out at the frequency recommended in this materials specification. The Contractor shall agree the locations of any trial pits with the Engineer.

If any subsequent materials tests show that the acceptance criteria stated in Clause 7 has not been obtained, the Engineer may instruct the Contractor to excavate additional trial pits at the Contractor's expense, for the purposes of completing additional materials tests, before a decision is taken about replacing and/or re-compacting the fill in any control section.

The Contractor shall excavate trial pits by hand or machine for examination of fill and to perform sampling and in-situ testing as required to a depth instructed by the Engineer. The trial pit shall commence at such a size that the plan area of the base of the pit shall be not less than 2.0m2. Appropriate shoring shall, safely and securely support the sides of the trial pits 1.5m or deeper. A heavy duty ladder in addition to a ramp-down of reasonable gradient shall be provided as a means of entry and exit to the trial pit.

The Contractor shall produce as-constructed drawings showing the location of trial pits.

Trial pits are to be logged by a suitably qualified engineering geologist/geotechnical engineer as approved by the Engineer. The Contractor shall ensure effective dewatering and shoring measures are in place at each trial pit location.

Routine Materials Sampling

As a minimum, the Contractor shall collect fill samples from the point of material discharge at the frequency recommended in this materials specification. Each sample shall be a true representative sample of material dredged and placed within the preceding 24 hours. The locations from where these samples shall be taken shall be agreed with the Engineer.

Additional Material Tests

In addition to the sampling and testing regime documented in this Specification, the Engineer may provide the Contractor within 24 hours of sampling a further schedule of laboratory tests to be carried out on any routine samples and those taken from any trial pits. The tests results shall be submitted to the Engineer within 24 hours.

Materials Testing Acceptance Criteria (Cone Penetration Test Results)

If the friction ratio (Rf) from any CPT test is greater than 2 per cent and the corresponding cone resistance less than that specified below for a total cumulative thickness of fill greater than 0.2m, the Contractor shall carry out additional CPTs in the near vicinity to identify, as closely as possible, the extent of such fill. Following its identification, the Engineer may instruct the Contractor to excavate such material and refill the area with suitable material at his own cost. Material to be excavated can be stockpiled and reused subject to the Engineer's approval.

CPT Test Results

The deposited material shall be placed so as to achieve the following criteria:

- At all depths except the uppermost 0.5m of reclamation from the final reclamation level; a minimum CPT cone resistance of 5 MN/m2.
- At all depths except the uppermost 0.5m of reclamation from the final reclamation level; a minimum SPT 'N' value of 12.

3.5.3 Erosion and Sedimentation Control – Rip-Rap

3.5.3.1 References

The minimum standards for products specified in this section shall be relevant BSI standards including but not limited to the following. Except as otherwise specified herein, perform work in accordance with specification codes and standards cited therein and to latest applicable addenda and supplements.

- BS 6349; Maritime Structures, Part 7; Guide to the Design and Construction of Breakwaters; 1991.

- "Manual on the use of Rock in Coastal and Shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154).
- BS 6906 Method of test for geotextiles;
- BS 12 Portland Cement;
- BS 146 Specification for blast furnace cements;
- BS 890 Specification for building lime;
- BS 1881 Testing Concrete;
- BS 3148 Methods of test for water for making concrete;
- BS 4027 Specification for sulfate - resisting Portland cement;
- BS 4721 Specification for ready mixed building mortars;
- BS 4887 Mortar admixtures.

3.5.3.2 Products

Stone

Stone for mortared rip-rap shall consist of field stones furnished in broad flat shapes to maximum extent practicable. All stones shall be hard, sound, durable, and highly resistant to weathering and shall be suitable as protection material for intended purpose.

Samples of the stone material proposed for use in the work shall be submitted to the Engineer for approval prior to its use in the work.

Stone Weight – Mortared Rip-Rap

Class A : The minimum weight of stone for mortared rip-rap shall range from 20kg (twenty) to 25kg (twenty) but limited to suit depth of grouted rip-rap.

Cement

Cement shall confirm to the relevant requirements of Section MS10 Cast-in-Place Concrete.

Sand

Fine aggregate shall be natural sand complying with the particular requirements of the following:

Fine Aggregate (Under 4.75mm)

• Soundness	AASHTO T104	10% MAX
• Organic	AASHTO T21	"Lighter than Standard"
• Clay Content	AASHTO T112	1% max
• Sand Equivalent	AASHTO T176	75 min

Water

Water added shall be the least amount which will yield a workable mix. Water shall conform to the relevant requirements of Section on Cast-in-Place Concrete.

Mortar

Mortar for Mortared rip-rap shall consist of 1: 3 cement:sand by volume. The compressive strength of the mortar shall be not less than 15N/mm2 measured in accordance with BS1881, Part 108.

3.5.3.3 Execution

The stones shall be wetted and hand-laid with the flattest face uppermost and parallel to the prepared slope, starting from the toe and progressing upwards. Stones shall be arranged in close contact, the largest being placed in the lower courses. Spaces between large stones shall be filled with smaller stones of suitable size.

The mortar bed shall be progressively spread ahead of stone placing. Stone faces in contact with the mortar shall be clean and free from any defects that will impair the bond with the mortar. Mortar shall be spaded and rodded between the stones until the voids are completely filled.

The completed work shall be cured for at least 7 days by a curing method approved by the Engineer. After the expiry of this period, the exposed surfaces shall be cleared of loose mortar and broken stone fragments.

3.5.4 Geotextiles and Impermeable Barriers

3.5.4.1 References

- BS 6349; Maritime Structures, Part 7; Guide to the Design and Construction of Breakwaters; 1991.
- "Manual on the use of Rock in Coastal and Shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154).
- BS 6906 Method of test for geotextiles

3.5.4.2 Definitions

Quality Control

This is defined as the measures, procedures, operations performed by the geosynthetics manufacturer to ensure quality products are produced. For example, Quality Control tests and certificates for geosynthetic materials used in these works.

Quality Assurance Consultant

The Quality Assurance Consultant (QAC) is the firm appointed by the Employer to assure that the geosynthetic materials and their placement used in the works comply with the Specification. The QAC shall have a representative on site namely the Quality Assurance Engineer (QAE).

Independent Testing Institute

This is a company, professional body or academic institute used by the Contractor and approved by the QAC to undertake certain test programmes relating to the implementation of this Specification. The independent testing house shall be United Kingdom Accreditation Services (UKAS) accredited in all appropriate test methods.

Conformance Tests

These are tests carried out by either an Independent Testing Institute or other approved testing body approved by the QAC to demonstrate conformance with the Manufacturer's quality control test certificates and the Specification. The actual cost of laboratory geosynthetics testing shall be paid directly by the Employer. All associated costs including; sampling, storage, packaging, courier charges etc.. shall be borne by the Contractor.

3.5.4.3 Products

Geotextile Filter Materials

Geotextile filter shall be chemically inert, mechanically robust and have long term sustainable tensile strength. The geotextile filter shall be installed as shown on the drawings and shall have properties equivalent to or superior to those specified in Table below. Samples of the geotextile shall be submitted to the Engineer for approval.

Table C 4.5 Geotextile Properties

Property	**BS Test**	**Requirement**			
		Type 1	**Type 2**	**Type 3**	**Type 4**
Type		Non-woven needle punched Geotextile in virgin polypropylene containing 1% carbon black UV inhibitor.			Thermally bonded nonwoven
Minimum Mean Thickness Under 2kN/m2	BS EN 964-1	3.9 mm	4.9 mm	6.0 mm	-
Maximum Mean Pore Size O90	BS EN ISO 12956	150 microns	110 microns	85 microns	150 microns
Min Mean Tensile Strength	BS EN ISO 10319	20 kN/m	35 kN/m	50 kN/m	8 kN/m
Min Mean Tensile Extension	BS EN ISO 10319	80%	75%	75%	28%
Max Mean Cone Drop Perforation Hole diameter	BS EN 918	6 mm	5 mm	2 mm	-
Minimum Mean CBR Puncture resistance	BS EN ISO 12236	3000 N	5000 N	9000 N	1500 N
Minimum mean CBR puncture displacement	BS EN ISO 12236	65 mm	65 mm	65 mm	-
Min Mean Coefficient of Permeability	BS EN ISO 11058	10.5 x 10-3 m/s	5.6 x 10-3 m/s	4.1 x 10-3 m/s	-

Quality Assurance

The Contractor shall be responsible for the quality of all furnished items and, shall develop and submit a Quality Programme for review. The programme shall cover those items related to manufacture, field supervision and the procedures to be followed. The programme shall define a system for identification of all materials through manufacture to delivery at the site and shall meet the general requirements of BS 5750 (ISO 9000). The monitoring system established by the QAE will include the following:

- Inspection of all geotextile manufacturing Quality Control certificates provided by the Contractor;
- Section of geotextile samples for conformance testing prior to installation, if required;
- Inspection of all geotextile conformance test certificates provided by the Independent Testing Institute;

The inspection of the installed geotextile including any repairs that may be required.

Manufacture

Geotextiles shall be manufactured from polypropylene or polyethylene fibres as specified and be in the form of permeable membranes. Geotextiles used for protection shall display the properties listed in Table above. The Contractor shall provide all of the test results detailed in Table above at least 5 working days before the geotextiles are delivered to site. Any missing test results will be obtained by the QAE at the Contractor's expense.

Delivery

Prior to delivery to site, the QAE shall agree a storage area for the geotextile. On delivery to site all rolls of geotextile shall be handled with care. The Contractor shall ensure that the handling equipment used does not damage the geotextile. Rolls of geotextile shall not be handled directly with an excavator bucket. The use of slings or similar is necessary. The rolls of geotextile shall be stored in such a manner that no damage occurs.

The Contractor is required to arrange for independent testing of a sample of the proposed geotextile. This should be completed before its delivery to site. All geotextiles that the Contractor proposes to use in the works require approval in writing by the Engineer. Any source of supply shall not be changed without the Engineer's approval. The manufacturer or supplier of each geotextile shall provide the following information for each separate consignment of each geotextile delivered to the site:

- Product name and grade/no;
- Name and address of producer/supplier;
- Batch or code number;
- Manufacturing characteristics and constituents including composition and type of constituent filaments, fibres, threads, films, tapes, etc.., and any additives used in the manufacturing process;

Method and manufacture

Proof that the manufacturer has carried out a magnetic test for broken needles as part of their manufacturing process;

Consignment number and delivery date

Each consignment shall be numbered and the delivery date recorded. A consignment is considered to be the number of rolls or packages delivered at one time.

Conformance Tests

Upon delivery of the rolls the Contractor shall provide the QAE with conformance test samples from rolls to be selected by the QAE. Sample sizes shall be 1.0m long by the roll width. A total of 3 no. sub-samples of equal size shall be obtained from each sample, 1 no. to be retained by the Contractor, 1 no. to be retained by the QAE, 1 no. to be sent to an Independent Testing Institute for testing.

3.5.4.4 Execution

Placing of Geotextile Filter Material (Subgrade Acceptance)

The sub-grade preparation shall be such that damage will not be caused to the geotextile either during installation or in service. The subgrade material shall be placed and compacted such that the geotextile is in continuous contact with the subgrade and the geotextile shall not be stretched or bridged over any hollows or humps. Additionally, the subgrade shall be smooth and free from rocks, cobbles and hard/soft spots which may, in the opinion of the QAE, damage or stress the geotextile. The Installer shall certify in writing that the surface on which the geo-membrane will be installed is acceptable prior to deployment of materials.

After the supporting subgrade has been accepted by the Installer it will be the Contractor's responsibility to maintain its condition and to indicate to the QAE any change in the supporting soil condition that may require repair work. The Contractor will ensure that the supporting soil is repaired prior to placement of the relevant panels of geotextile and overlying geo-membrane.

Installation

The Contractor shall supply a drawing or drawings showing the proposed position of all rolls, panels and seams of the geotextile to be installed on the works area. The Contractor shall only be able to commence installation after approval by the QAE. The Contractor shall provide adequate and acceptable measures for protecting the material at all stages of the work from all sources of potential damage, including weather conditions, until completion of the Contract. The programme of works submitted under the Contract shall indicate the period or periods during which each geotextile will be installed and covered by other components of the permanent works.

The Contractor shall submit a detailed Method Statement for the approval of the Engineer at least 7 days prior to installing any geotextile. This shall detail procedures for the installation and covering of that geotextile, including the method of holding it in place and jointing the adjacent rolls panels. The Contractor shall also submit Working Drawings, which shall include details of:

- The location and orientation of each panel;
- The location of all connections, joints, overlaps and pins;
- The allowances made for any shortening of the geotextile during fill coverage.

The layout of individual panels shall be such that the number of joints and overlaps is minimised as far as is practicable. Joints and overlaps shall not be permitted perpendicular to the direction of slope. Once installation has commenced, variations from the Method Statement and Working Drawings shall only be permitted with the prior approval of the Engineer.

Care shall be taken to avoid damaging the geotextile on removal of wrappings and during the installation process or at any other time. Any resulting damage, or any geotextile exposed to daylight for longer than the manufacturer's recommendations, shall be inspected by the QAE and the condition noted. Damaged lengths of geotextile shall be replaced with new material unless the QAE accepts repair by an approved method.

The geotextile shall be laid in a direction such that the work progresses generally downslope and/or down wind. When a geotextile is laid out on site, care shall be taken to prevent damage or disturbance by wind or dust. Where necessary, the geotextile shall be weighted or otherwise held in place by means which will not damage it. The works shall generally progress in incremental stages to ensure that no excessively large areas remain uncovered, and hence reduce the potential for damage by wind. The deployment of the beach sand layer on the upper layer of geotextile shall generally follow the geotextile/geomembrane deployment to ensure that no more than 10,000m2 remains uncovered in any individual working area.

On slopes, the geotextile rolls shall be securely anchored in an anchor trench and the geotextile then deployed down the slope in such a manner as to keep the geotextile panel in tension. Panels deployed down slopes shall be continuous.

The subgrade layer of materials on to which the geotextile is to be placed shall not have protrusions or sharp projections, which are likely to damage the geotextile during installation or in service. The method of installation shall ensure that the geotextile is in continuous contact with the surface on which it is to be placed and the geotextile shall not be stretched or bridged over hollows or lumps. Operation of construction plant directly on the installed geotextile will not be permitted.

All geotextiles shall be continuously sewn or thermally bonded. Spot sewing is not permitted. Geotextile shall be overlapped a minimum 75mm prior to sewing or 300mm prior to thermal bonding.

All sewing shall be done using polymeric thread with chemical and UV light resistant properties equal to or exceeding those of the geotextile.

The Contractor shall keep daily records of the progress of geotextile installation and covering by fill. Copies of these shall be submitted to the Engineer on the following working day. The daily record shall include the following details:

- Date;
- Area and location of formation;
    - Area and location of geotextile installation;
    - Area and location of geotextile covered by fill;
- Consignment reference of each roll or sheet;
- Levels and positions of installed geotextile;
    - Details and locations of any damage to the geotextile;
- Details and locations of any repairs;
    - Any variations from the Method Statement or Working Drawings.

The form of the daily records shall be agreed with the Engineer in the Method Statement.

Repair Procedures

Any damage (e.g. holes, tears, solvent spillage etc..) to the geotextile shall be repaired using a patch. A patch shall be cut from the same specified material. It shall be either sewn in place with a 75mm overlap or heat bonded in place with a 300mm overlap. Care shall be taken to remove any soil or other material that may have penetrated the damaged geotextile. Alternatively, the whole of the damaged area shall be replaced with a new panel.

3.5.4.5 Quality Assurance testing for Geosynthetics

Upon delivery of the geotextile rolls, the Contractor shall provide the QAE with conformance test samples from the rolls selected by the QAE. Sample sizes shall be 1.0m long by the full roll width. A total of 3 no. sub-samples of equal size shall be obtained from each sample, 1 no. to be retained by the Contractor, 1 no. to be retained by the Employer's Representative and 1 no. shall be sent to the Independent Testing Institute for testing.

The test samples shall be subject to the following conformance testing prior to installation:

PROPERTY	TEST METHOD
Nominal Thickness	ASTM D751/BS EN 964-1
Mass per unit area	ASTM D3776/BS EN 965
Puncture Resistance	BS EN ISO 12236

Quality Control and Conformance test data may be provided by using internationally recognised standards other than ASTM, with the written permission of the Engineer.

The Contractor will provide any assistance required by the Engineer to enable the recovery of samples for testing. The Contractor shall allow in his tender for the time taken to test materials and any subsequent work required by the Engineer to enable approval of materials prior to their incorporation into the works.

The testing shall be carried out at a minimum frequency of 1 per 5,000m2 per material type.

If the Engineer deems the materials proposed for use in the works by the Contractor to have failed an excessive amount of tests the Contractor will pay for the aforementioned testing and all associated costs. In addition following the non-conformance of a material, the Contractor will be required to supply a substitute material and test this for conformance to the above schedule, at his own expense.

3.5.5 Rock for Coastal Protection Revetments and Breakwaters

3.5.5.1 References

The works shall generally be carried out in accordance with British Standards and other standards listed below except where specifically indicated in this Specification.

- BS 6349; Maritime Structures, Part 7; Guide to the Design and Construction of Breakwaters; 1991;
- "Manual on the use of Rock in Coastal and Shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154);
- BS6906 Method of test for geotextiles.

Any differences between the requirements of this Specification and the Standards identified above shall be submitted to the Engineer for his ruling.

3.5.5.2 Setting Out and Levelling

Any survey control points established by the Contractor shall be submitted to the Engineer for approval prior to erection. The Contractor shall, also prepare and submit to the Engineer for approval, all location diagrams of survey points showing the general locations with a schedule providing the following information:

- Station designation;
- Plan coordination (Eastings & Northings (Maldives grid system);
- Level Values (to Global Mean Sea Level).

Table C 4.6 Geotextile parameters *The required values are absolute minimum values. They are not minimum average roll values (MARV's) or any other average.

PROPERTIES	TEST METHOD	REQUIRED VALUE
SPECIFICATION		
Material		Polypropylene
Mass Per Unit Area (g/m^2)	ASTM D3776/ BS EN 965	340 (MIN)
CBR puncture resistance (KN)	BS EN ISO 12236	3.0 (MIN)
Nominal Thickness @ 2kPA (mm)	ASTM D1777 BS EN 964-1/DIN 43855	3.9 (MIN)
Min mean Tensile Strength	BS EN ISO 10319	20kN/m
Min Mean Tensile Extension	BS EN ISO 10319	80%

Description

The Engineer shall be informed by the Contractor in writing 24 hours in advance of any setting out operation and the Engineer shall be allowed a further 24 hours to satisfy himself that the setting out is within acceptable tolerances. The Engineer's approval will be given in writing.

The Contractor shall provide a robust protection system to the setting out points once they have been checked and approved.

3.5.5.3 Products

Quality Control for Rock Material

Approval of Materials

In addition to any requirements elsewhere in the Contract, all materials, materials supplies and sources of material must be approved in writing by the Engineer prior to their incorporation in the works. Prior to any approval being given all of the following as required by the Engineer must be complied with as appropriate:

Provision of material samples to site and subsequent testing of the sample is needed for compliance with the relevant specifications and standards. Testing is to be carried out by an approved laboratory in accordance with this specification or as otherwise directed by the Engineer.

Works and material source inspections.

Source of Material

It is the responsibility of the Contractor to identify, propose, obtain and deliver all material necessary for completion of any rock armouring works that fall within his particular scope of works. The Contractor shall obtain the approval of the Engineer, for the source from which all materials will be obtained, prior to commencing any rock works. Any approval given by the Engineer will not relieve the Contractor of any of his obligations under the Contract and related Specifications or relieve the Contractor of his obligations and responsibilities under any Statutory Act or Regulation applicable to the construction and his method of working.

The Contractor shall ensure that all sources of materials are capable of producing the required quality and sufficient material quantities exist to complete the works in accordance with his intended programme, this Specification and the relevant construction drawings. The Contractor shall produce and submit evidence to support these requirements to the Engineer for his approval. Evidence may be in the form of:

- Boreholes or trial holes;
- Test blasts;
- Recent geological maps;
- Samples and test reports.

The Contractor shall be responsible for obtaining all permissions necessary for the extraction of natural resources (aggregates, rock, water etc.) and for the safe transport of all materials in compliance with the appropriate transportation regulations. The Contractor shall be responsible for all royalties, fees, charges etc. incurred in developing quarry sites.

Quarry Sites and Operations

In addition to any specific requirements elsewhere in the Contract and where the Contractor intends to utilise a new or existing quarry site, the Contractor shall, as a minimum, comply with the following:

Where applicable, all necessary permissions, to open, develop and operate a quarry or quarries for the sole purposes of carrying out the Works are obtained in writing before commencing operations. The Contractor shall ensure that any quarry is left in a safe, neat and tidy condition upon completion of the works. The quarry is operated in a safe, professional and approved manner at all times

Where applicable, and in addition to any other Contract requirements, all permissions specific to the use and transportation of explosives are obtained from the ROP and any other Relevant Authority

Storage of Materials

The Contractor shall ensure all materials are stored in such a manner so as to preserve their quality and condition for subsequent use in the works. The Contractor shall submit his proposals for stockpiling any rock material for the approval of the Engineer and shall, as a minimum address the following:

- Methods and procedures to reduce/prevent occurrences of air pollution attributable to wind blown dust and sand
- Proposed locations of any material stockpiles
- Methods and proposals for stockpiling different graded rock material
- Anticipated materials storage durations

Selection, Handling and Transport

The Contractor shall ensure all rock armour materials are selected, handled and transported in such a manner so as to preserve their quality and condition for subsequent use in the Works. As such, the Contractor shall, in his method statement(s) outline his methodology for selecting, handling and transporting any such rock for the approval of the Engineer and or other Relevant Authority and shall, as a minimum address the following:

Rock Quality Selection

- Proposals for assessing the geological conditions likely to affect rock quality, type, block composition or integrity

- Proposed blasting design to ensure production of suitable material;
- Proposed excavation procedure(s)
- Inspection, selection and rejection procedures
- Anticipated production rate(s) for grading, sorting and storing suitable material

Transport and Handling Procedures

- Proposed methods to demonstrate that all possible measures have been taken to prevent volumetric loss and segregation during transport, handling and placing
- Details of all plant proposed for transporting material, including marine plant
- Proposed transportation routes including land and sea options

3.5.5.4 Rock Quality

All rock used in the Works shall be hard, dense, sound, non-friable stone from sources approved by the Engineer.

The rock shall be free from cracks, holes, seams and other similar defects and shall not fracture when dropped through a height of not less than 1.5m onto a steel plate, or other hard service as agreed with the Engineer. It shall be resistant to disintegration and erosion by the action of air, water (fresh or seawater), wetting and drying, extremes of temperature and impact due to wave action or any other natural or climatic factors. It shall be free from dirt, clay or any organic matter and all holes drilled for blasting.

It shall be capable of being handled and placed without fracture or damage. Rock shall not contain visually observable or chemically detectable impurities in such quantities that these are damaging for the constructive application of the rock or for the environment in which the rock is to be placed.

Rock Descriptions

The Contractor shall provide detailed petrological descriptions of all rock types and test results from the proposed source for the Engineer's approval.

Shape

Rocks shall be of the size and shape within the limits specified in Table 2.1 and shall generally be equant in shape, and shall not be unduly elongated, flat or rounded.

The rock shall not contain more than 5% of stones with a length to thickness (L/d) ratio greater than 3, where the length L is defined as the greatest distance between two points on the stone and the thickness, d, as the minimum distance between two parallel straight lines through which the stone can just pass. The test shall be carried out in accordance with CIRIA Special Publication No. 83.

Prior to Commencing Work

Prior to commencing any rock armouring works the Contractor shall for each type of rock class, as a minimum and unless otherwise directed by the Engineer: -

- Provide a minimum of three test results for each test listed in the table below for three separate rock samples to the Engineer, proving the material conforms with the specified parameters
- Provide rock samples together with 200 x 250mm photographs of rocks, which are of a size similar to that of the rocks to be used in the works to the Engineer for his approval and obtain agreement on the colour and general appearance of the exposed rock
- Supply a control sample of not less than 10m3 or 10 rocks (whichever is the larger volume), or a similar sized sample of the works for approval by the Engineer, that shall be held on site as the control bench mark for approval of colour and shape
- Construct a 10m long full scale test panel of each revetment structure to the satisfaction of the Engineer, which demonstrates the Contractors proposed working methods meet the required Specification, standard and the visual appearance of the structure
- Accompany the Engineer and/or his representative to the quarry for the purposes of agreeing and inspecting any of the above.

Rock Material Properties

All rock shall have the following properties as a minimum:
References indicated thus:

Table C 4.7 Rock Properties

Test	Rock Properties	Limits	Standard/Ref	Frequency of Testing
1	Apparent Specific density (oven dry)	Minimum 2600 kg/m3	*	Every 1000t produced
2	Minimum Specific Weight (saturated surface-dry)	Minimum value - 2600 kg/m3 Average value – 2680 kg/ m3	*	Every 1000t produced
3	Water Absorption	Not more than 2%	*	Every 1000t produced
4	Resistance to Weathering Magnesium Sulphate Soundness	Not more than - 12%	BS 812 BS 6349	Every 2500t produced
5	Crushing Resistance 10% fines	Not less than 100KN	BS 812	1 sample per month
5a	Crushing resistance Franklin Point load index (IS50)	Not less than 4.0MN/m2	ISRM 1985	Every 2500t produced
6	Block Integrity Drop test	Not more than 5%	*	Every 2500t produced
7	Sizing l/d (Aspect ratio)	1.5 - 2.0 (refer Clause 3.2.3)	**	Every 1000t produced
8	Aggregate impact value	Not more than 25%	*	1 sample per month
9	Wet Dynamic Crushing Value	Not more than 20%	*	1 sample per month
10	QMW, Mill Abrasion Resistance, ks	Not more than 0.004	*	1 sample per month
11	Shape index (PR)	90% of rock 0.011 to 0.015 10% of rock 0.09 to 0.011 or greater than 0.015	*	Every 1000t produced
12	Methylene Blue Absorption test	Not more than 0.7	*	1 sample per month
13	Fracture Toughness, (KIC)	Not less than 1.4	ISRM 1988	1 sample per month
14	Grading	As per relevant rock class in Table 3.2 sampling by weight distribution.	*	Every 1000t produced

*refer to the "Manual on the use of rock in coastal and shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154, Table 21 and Appendix A1 and A2)

**refer to the "Manual on the use of rock in coastal and shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154, Table 18 and Appendix A1.5, A1.6, and A1.8)

Table C 4.8 Main Armour Rock Grading Requirements

Reference	Rock Grading Classification (kg)	Class Limits (CL) by weight (kg)				
		ELCL*	LCL*	UCL*	EUCL*	(W50)
Armour Grade A	3300 - 6600	2200	3290	6580	9870	4400 kg
Armour Grade B	3000 - 6000	2000	3000	6000	9000	4000 kg
Armour Grade C	1170 - 3900	780	1170	3900	5850	2600 kg
Armour Grade D	1000 - 3000	650	1000	3000	4500	2000 kg
Armour Grade E	700 - 2500	460	700	2300	3500	1550 kg
Armour Grade F	500 - 1650	330	500	1650	2500	1100 kg
Armour Grade G	400 - 1500	285	400	1500	2150	1000 kg
Armour Grade H	20 - 70	15	20	70	105	50 kg
Under Layer Type 1	200 - 750	150	220	720	1100	800 kg
Under Layer Type 2	50 - 950	1	50	950	1400	
Under Layer Type 3	25 - 550	5	25	550	800	
Under Layer Type 4	15 - 300	5	15	300	460	
Under Layer Type 5	10 - 200	2	10	200	285	
Quarry Run #	1 - 500	-	1	500	1000	250 kg
Foundation layer to Vertical Edge Structures (if required)	10 – 60	2	10	60	120	20 – 35 kg
Levelling course to Vertical Edge Structures (if required)	40mm single size rock	Layer thickness as shown on the construction drawings				

References indicated thus: * refer to the "Manual on the use of rock in coastal and shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154). ** refer to the Standard Gradings from T19 of the "Manual on the use of rock in coastal and shoreline Engineering" (CIRIA Special Publication 83, CUR Report 154)

Quarry run shall have a uniformly coefficient (D60/D10 > 3.0)

Rock Grading

Rock shall meet the following requirements in respect of grading

Anti-Scour Rock

Rock for the anti-scour layers shall meet the following requirements in respect of grading:

Table C 4.9 Anti-Scour Rock Grading Requirements

Reference	Rock Diameter mm (Single Size)	Layer Thickness (mm)
Anti-scour 1	100	Refer to Final Contract Drawings
Anti-scour 2	150	Refer to Final Contract Drawings

Sampling and Testing - General

As a minimum and unless otherwise directed by the Engineer, the Contractor shall adopt the sampling and testing regime for grading as described in Table 3.1 and Appendix A1 Clause A1.8 and A2 of CIRIA Special Publication 83, CUR Report 154 until such time that test results show the rock produced from a particular quarry face is consistently of a good and acceptable quality. After which, the frequency of testing for the rock from that particular face will be reviewed and an adjusted testing regime may be implemented to the satisfaction of the Engineer.

Any agreed and amended testing regime will remain in place until such time that that test results shows fluctuations or a detrimental change in rock quality or where directed by the Engineer, upon which the testing regime specified in Table above will be re-introduced. All test results shall be reported to the Engineer at agreed intervals, together with records indicating where samples have been taken from.

The works will not be accepted as complete until all materials tests have been performed and the acceptance criteria listed in Table above have been met and approved by the Engineer as being in accordance with the requirements of this Specification.

All non destructive strength tests and other relatively simple quality control procedures will be undertaken by the contractor in a site laboratory for the duration of the works. The Engineers approval may be withdrawn at any time, should any doubt about the performance of any external laboratories arise.

Tests which (due to their nature or the equipment required) cannot be carried out in any site laboratory shall be performed in a specialist laboratories.

The Contractor shall compile, record and maintain in appropriately organised logbooks all test results and test certificates related to the project, whether issued by the site laboratory or others. Upon completion of the works all files, logbooks and records shall be handed over to the Engineer and become the property of the Employer.

Any tests required or requested by the Engineer or any other Relevant Authority during the course of the works that are not listed in Table above shall be carried out in accordance with appropriate and approved international standards and to the agreement of the Engineer.

Rock Quality Testing

As a minimum and unless otherwise agreed with the Engineer, the Contractor shall, at his own cost, undertake the rock quality tests outlined in Table above.

Subject to the test results and if in the opinion of the Engineer, the rock varies in quality or appearance, the Engineer may request additional or more frequent testing be carried out that shall be completed by the Contractor at no extra cost to the employer.

Unsuitable Rock Material

Any rock delivered to site, that fails to meet the requirements of this Specification or does not comply with any control bench mark limits agreed on site shall be deemed 'unsuitable' and shall be removed from the site immediately and disposed of at an agreed location at the Contractor's expense, unless otherwise directed by the Engineer.

3.5.5.5 Execution

Surveys and Inspections

Unless specified otherwise in the Contract, the Contractor shall carry out the following surveys and inspections as part of the construction works to the satisfaction of the Engineer:

- A topographic ground profile survey prior to commencing the rock armouring work;
- A survey of the finished rock armour profile upon completion at intervals not exceeding 0m and at an interval of 1m across the profile.
- Detailed visual inspections of the whole of the rock armour works.

In addition to any requirements elsewhere in the Contract, for each of the surveys the Contractor shall submit to the Engineer for his approval, full details of the equipment and methodology to be adopted to undertake the above surveys. All surveys shall be carried out with a representative of the Engineer present unless otherwise agreed in writing. As a minimum, the Contractor should undertake the surveys in accordance with the following procedures, unless otherwise directed by the Engineer.

Measurements shall be carried out using a probe with a spherical end of diameter 0.5Dn50. For a land based survey this will be connected to a staff; for underwater survey it will be a weighted ball on the end of a sounding chain. Alternatively below 3 m below LAT the survey may be carried out by echo sounding.

- For each of the surveys the Contractor shall provide the following: -
- No paper copies of the survey plan area at scales to be agreed with the Engineer.
- 1 electronic copy of the survey on CD ROM in AUTOCAD .dwg or .dxf files.
- Cross sections at 10m intervals.
- Photographic evidence that has been verified by the survey team as a true and accurate record.

Diving Inspections

In addition to any requirements elsewhere in the Contract, the Contractor may provide professional divers for inspection of armoured slopes and other submarine works. The Contractor's divers shall have experience in similar construction works. The Contractor's facilities required for diving operations should also be available to divers appointed by the Engineer. The Contractor shall arrange for a competent linesman to be in attendance at all times during diving operations.

Before any diving is undertaken the Contractor shall supply to the Engineer's Representative two copies of the code of signals to be employed an have a copy of such code prominently displayed on the craft or structure from which the operations take place.

All diving operations shall be in accordance with all local, national and international standards such as Diving Operations at Work Regulations 1981 and all its amendments as published by the UK Health and Safety Executive and the publications of the UK Department of Energy, the Association of Offshore Diving contractors, the Employment Medical Advisory Service and the Diving Medical Advisory Council of the UK.

The Contractor shall provide a copy of these regulations to the Engineer's Representative for his sole use, together with any other codes he proposes to adopt for their approval by the Engineer.

Placing of Rock - General

The rock placement density and layer thickness coefficient shall be calculated based on the test panel results. The revetment layer thickness has been calculated based on a layer thickness coefficient of 1.0. The provisional quantity of rock required has been calculated based on a rock placement density of 1.60 t/m3. Where the test panel results for placement density vary from this figure by more than 0.1, the Engineer may adjust the layer thickness accordingly, with upper/top levels remaining fixed and lower levels being adjusted to match test panel results

The methods used for placing rock shall be subject to the approval of the Engineer. The Contractor shall:

- Ensure that no layer shall be progressed until the previous layer is checked and approved
- Ensure that the agreed visual quality is being achieved at intervals agreed with the Engineer, to the satisfaction of the Engineer
- As required by the Engineer, demonstrate that the target weight of rock placed of 1.6 t/m3 with a tolerance of -0.1 t/m3 is being achieved
- Ensure rocks are placed immediately after approval of a previous layer to maintain permitted tolerances and maintain continuity
- Ensure that effective interlocking of placed rocks within each layer and also between subsequent layers.

Placing of Breakwater Core Material

Breakwater core material should be placed in accordance with the following, unless otherwise directed by the Engineer: When directly on the seabed or on geotextile filters, the material shall be placed in such a manner as to avoid excessive disturbance and to ensure any geotextile filter is not ruptured

- To achieve a dense core;
- To achieve an even distribution of rock sizes.

Core placement shall not exceed 3m height prior to placing rock armour materials. The Contractor is responsible for the protection of placed and unarmoured core material during the works. Protection costs should be included in the rates

Placing of Breakwater Underlying Rock and Revetment Primary Armour

The rock armour should be placed in accordance with the following, unless otherwise directed by the Engineer:

- Rocks shall be placed in order to achieve effective interlocking so that each rock is securely held in place by its neighbours and shall be placed such that within the overall thickness of the layer, separate layers do not exist in the plane parallel to the slope of the underlying material.
- Rocks having one axis predominantly greater in length than other dimensions of the rock should be placed with the longer axis normal to the surface of the underlying layer with the short axis up slope.
- All outer layer armour rock and underlayer rock in excess of 1500 kg mass shall be placed individually, tipping and dumping of such rocks will not be permitted. Where outer layer armour rock is to be placed below 1 m below LAT, the Contractor may propose an alternative method, subject to the specified placement criteria within this

Clause being maintained and to the agreement of the Engineer.

- Armour rock shall be placed in such a way to achieve a resulting structure well keyed, densely packed and of the specified dimensions.
- Underlayer rock less than 1500 kg mass may be deposited by end tipping from trucks or by individual placing and dressed as appropriate to achieve a resulting structure well keyed, densely packed and of the dimensions specified. The maximum drop height of underlayer material shall be limited to 1.5m.

The Contractor shall be responsible for the order of placing rock within the revetment and for protecting the works such that any detrimental effects caused by adverse weather or otherwise are minimised. Reinstatement of damaged areas of rock armour occurring during the works shall be the responsibility of the Contractor.

- Placing shall commence at the toe and proceed upwards towards the crest of the rock armoured slopes.
- Armour rock shall be placed to achieve a minimum "three-point support" and be stable to the lines and levels shown on the drawings.
- The surface of the armoured slope shall present an angular uneven face to the sea to achieve a maximum energy dissipation of waves.
- The finished rock armour shall be placed to thickness shown on the drawings and to the tolerances agreed upon.
- Smaller pieces of rock shall not be used to fill interstices, or to prop larger rocks in order to achieve the required profile.
- Any void below finished profile level in excess of mean rock size shall be filled with appropriate stone or stones.

Placing of Bedding and foundation Layers

Graded bedding and foundation layers shall be placed in accordance with the following, unless otherwise directed by the Engineer: -

- Bedding and foundation layers may be placed by bottom opening grab or skips or by any other method subject to the approval of the Engineer.
- Handling, transportation and deposition of the material at the specified location shall be carried out in a manner such that segregation of the material does not take place.

Tolerances on Placing Rock Armour.

In all cases the dimensions and levels shown on the drawings represent the minimum cross sections and plan locations. Notwithstanding any accumulation of positive tolerances on underlying layers, the thickness of the layer shall not be less than 80% of the nominal thickness when calculated using mean actual profiles. The tolerances on two consecutive mean actual profiles shall not be negative. The tolerance for placing rock above LAT and final crest level shall be +300mm to zero from the levels shown on the drawings.

- The tolerance for placing rock below LAT shall be +400mm to zero.
- The deviation from nominal line of the crest shall be +250mm seaward to zero
- The maximum deviation of the toe of the rock armour slope shall be +500mm to zero.
- The tolerance on deviations from slope of the rock armour shall be +600mm to zero.

Tolerances on Placing Core Material

- The vertical tolerance on placing core material shall be +/- 200mm
- The horizontal tolerance on placing core material shall be +/- 200mm
- Tolerances on Placing Foundation Rock. The thickness of the layer shall be within 75 mm of the thickness specified on the drawing such that the overall average thickness of the layer is not less than that specified on the drawing.

Allowance for Settlement

The Contract may determine and allow for settlement of the breakwater and revetment by placing all rock layers in thicknesses that are greater than that specified on the drawings or as otherwise directed by the Engineer.

Where settlement occurs and the resulting profile of the armour is outside the permitted tolerance, the Contractor shall make good the settlement by undertaking remedial works to the satisfaction of the Engineer, at the no additional cost to the Employer.

3.5.6 Beach Creation

3.5.6.1 References

The Works shall generally be carried out in accordance with British Standards and other standards and references listed below except where specifically indicated by this specification.

- BS 1377, Methods for Testing;
- 6349 Maritime Structures Parts 1, 2, 4, 7.
- BS 7755, Soil quality. Terminology and classification. Terms and definitions
- Manual on the use of rock in coastal and shoreline engineering. CIRIA Special Publication 83, CUR Report 154.

3.5.6.2 Products

Beach creation construction work shall commence only when the Engineer's approval is given to the Contractor in writing. All materials, materials supplies and sources of material must be approved in writing by the Engineer prior to their incorporation in the works. The beaches shall be constructed from suitable materials meeting the requirements of this and all relevant supporting project Specifications.

Suitable Beach Sand Material

Sand for beaches shall be a free draining naturally occurring marine sand of silicate or carbonate origin with an apparent mean specific density (saturated surface dry) of at least 2200 kg/m3. The material shall not contain more than 0% organic matter, gypsum or other salts and not more than 1% clay, silt or other material deemed unsuitable by the Engineer with a maximum of 2% shells and shall meet the following grading limit requirements:-

Table C 4.10 Grading Limits for Beach Sand Material.

Grain Size	% passing (lower limit)	% passing (upper limit)
10	100	94
6.3	100	93
5	100	92
3.35	100	89
2	98	80
1.18	93	68
0.6	76	33
0.425	65	4
0.3	48	0
0.15	2	0
0.063	0	0
0.01	0	0

The Contractor is responsible for identifying appropriate beach sand material and source locations both inside and outside the Site Limits.

In addition to any requirements elsewhere in the Contract, if the Contractor considers it necessary, he shall carry out additional investigations and testing to enable him to accurately assess the nature of any material to be dredged and determine the most suitable type of plant and method of operation. All such additional technical information regarding the location and nature of possible borrow material obtained by the Contractor shall be made available to the Engineer.

Prior to commencing the beach creation works, the Contractor shall provide full details of his proposals for undertaking the works and submit a minimum of five (5) representative material samples from each specific source location for approval by the Engineer. As a minimum, the details and samples shall include:

- Information relating to the source (location, maps, charts, history etc..);
- Petrographic description;
- Colour;
- Physical properties;
- Typical particle size distribution curves;
- Details of any proposed treatment (e.g. screening, washing, etc..);
- Details of any chemical contamination;
- Organic matter content details;

Where marine and/or offshore sources are proposed the Contractor shall ensure that all necessary licences, permits, approvals etc.. are obtained to the satisfaction of the Engineer and any other Relevant Authority prior to the extraction and transport to site of any beach sand material and shall provide written confirmation of the same.

Where the Contractor proposes to dredge beach sand material from any source he shall undertake his works in accordance with the Specification for Dredging and Reclamation, as agreed, and to the satisfaction of the Engineer.

The Contractor shall carry out sufficient investigations and shall satisfy the Employer and the Engineer as to the availability of appropriate material, confirming that sufficient volumes exist and that it complies with this Specification and all relevant environmental controls, as agreed with the Engineer, prior to the submission of any proposals for approval by the Engineer and any other Relevant Authority.

The Engineer shall have the right at any reasonable time to make inspections of any source location proposed by the Contractor at the start of the Contract or at any period during the Contract. The Contractor shall provide suitable access to each site for the Engineer.

Unsuitable Beach Sand Material

Unsuitable Beach Sand material is material that falls outside the acceptance criteria stated above.

The Contractor shall include in his method statement, his proposed methodology for handling and disposing of unsuitable fill material(s), which will be subject to the approval of the Engineer.

3.5.6.3 Materials Sampling and Testing

As a minimum, the Contractor shall be responsible for ensuring that testing is carried to meet the requirements of this and all related supporting Specifications. Sampling and testing of materials shall be undertaken in accordance with BS 1377: 1990 Parts 1 to 4 as appropriate. These tests are to be carried out at the project testing laboratory that has been approved by the Engineer.

Beach Sand Testing

The Contractor shall undertake the following tests in accordance with MS02 Dredging and Reclamation as appropriate and to the following standards, unless otherwise agreed with the Engineer.

- BS 1377:1990 Part 2 Determination of particle density;
- BS 1377:1990 Part 2 Determination of the particle size distribution (PSD);
- BS 1377:1990 Part 3 Determination of the organic matter content;
- BS 1377:1990 Part 3 Determination of the total sulphate content of soil;
- BS 1377:1990 Part 3 Determination of the sulphate content of ground water and of aqueous soils extracts;
- BS 1377:1990 Part 3 Determination of the pH value;
- BS 1377:1990 Part 2 Shell content test for selected fill.

As a minimum, the Contractor shall collect material samples at the frequency recommended in Table below. Each sample shall be a true representative sample of material sourced and placed. The locations from where these samples shall be taken shall be agreed with the Engineer.

beach fill material is acceptable, the Engineer may consider relaxing the frequency of the PSD compliance testing regime to a minimum 2 samples per 100m of beach, where appropriate.

All samples taken for laboratory testing and in situ tests results will be given a unique number and clearly labelled. The label will also include information of the location of the test or where sample was taken as well as its source and placement location. This information and the test results will be stored in an electronic database by the laboratory and issued to the engineer in an excel format.

The Contractor shall compile, record and maintain in appropriately organised logbooks all test results and test certificates related to the project, whether issued by the site laboratory or others. Upon completion of the works all files, logbooks and records shall be handed over to the Engineer and become the property of the Employer.

Table 3.5.10 Testing and Sampling Regime for Beach Sand.

Test	Purpose	Location	Frequency
PSD and density tests	Compliance of placed beach sand material	As agreed with Engineer within each nominated section of beach.	A minimum 10 samples per 100m section of beach, (where all testing is insitu), or, A minimum 5 samples per 100m section of beach, (where testing is undertaken on stockpiled material ahead of placement)
Organic matter	Compliance of placed beach sand material	As agreed with Engineer within each nominated section of beach.	A minimum 6 samples per 300m or as otherwise directed by the Engineer.
Shell content test	Compliance of placed beach sand material	As agreed with Engineer within each nominated section of beach.	A minimum 6 samples per 300m or as otherwise directed by the Engineer.
Chemical tests	Material monitoring	As agreed with Engineer within each nominated section of beach.	A minimum 3 samples per 300m or as otherwise directed by the Engineer.

Where beach sand material has been stockpiled prior to its inclusion in the permanent works, the Contractor may propose to undertake some materials compliance testing of the beach sand material from such stockpiles ahead of material placement on the beach areas. Where such materials sampling and testing is proposed by the Contractor, the Engineer may consider a relaxation in the PSD and density testing regime on the placed beach sand material on a volumetric pro-rata basis, up to a maximum 50% limit (Refer Table above).

Where any such materials PSD compliance testing is producing consistent and valid test results, and if in the opinion of the Engineer, the quality and appearance of the

Any tests required or requested by the Engineer or any other Relevant Authority during the course of the works that are not listed above shall be carried out in accordance with appropriate and approved international standards and to the agreement of the Engineer.

In addition to the sampling and testing regime documented in this Specification, the Engineer may provide the Contractor within 24 hours of sampling a further schedule of laboratory tests to be carried out on any routine samples. The Contractor shall perform these tests and submit the results to the Engineer within 24 hours.

3.5.6.4 Execution

Surveys and Inspection

The Contractor shall carry out the following surveys and inspections as part of the construction works to the satisfaction of the Engineer: -

- A topographic and bathymetric bed/ground profile survey prior to commencing the beach creation works;
- A survey of the finished beach sand profile shall be carried out at intervals not exceeding 50m and at an interval of 1m across the profile at the completion of the works and at 3 months after cessation of Beach Sand placement works for the purposes of monitoring settlement.
- Detailed visual inspections of the whole of the beach creation works, upon completion of the works;
- For each of the surveys the Contractor shall provide a) No paper copies of the survey at scales to be agreed with the Engineer; b) 1 electronic copy of the survey on CD ROM in AUTOCAD .dwg or .dxf files; c) photographic evidence that has been verified by the survey team as a true and accurate record.

3.5.6.5 Placing of Beach Sand - General

The Contractor shall include in his method statement, his methodology for placing the beach sand material that shall be subject to the approval of the Engineer and any other Relevant Authorities.

As a minimum, the Contractor shall remove all vegetation, organic material and debris from the beach areas to be created prior to placing any beach sand.

The Contractor shall control the deposition of beach sand material so as to avoid the concentrations of fine or shell material in localised areas and shall conduct materials monitoring in accordance with this Specification to ensure the acceptance criteria are being met.

Where any test results indicate deposits of unsuitable fill material may be present, the Engineer may instruct the Contractor to undertake further investigation to establish the extent of such deposits. Where deposits of unsuitable fill in excess of 100mm total cumulative thickness are found, the Engineer may instruct the Contractor to remove the whole of the material and replace it with suitable beach sand material.

3.5.6.6 Tolerances

The permissible tolerances of the finished beach sand material fill shall be -100mm to +200mm above the specified levels, measured as soon as practicable after completion on any area of beach creation works.

3.5.6.7 Allowance for Settlement

The Contract may determine and allow for settlement of the beach sand by placing all beach sand layers in thicknesses that are greater than that specified on the drawings to the agreement of the Engineer.

If after a three month period from completion of any beach creation works, settlement of the beach sand material is identified and the resulting beach profile, as a consequence of settlement, is outside the permitted settlement tolerance of 100mm, the Contractor shall make good the settlement by undertaking remedial works to the satisfaction of the Engineer, at the no additional cost to the Employer. Settlement observations shall exclude the natural effects of wind and wave action on the resulting beach profile (i.e. erosion and accretion).

3.5.7 Reinforced Concrete Vertical Edge Structures

3.5.7.1 References

This Specification shall be read in conjunction with the following documents.

- BS 6349; Maritime Structures, Part 1 (2000) and Part 2 (1988);
- BS 8002: Code of Practice for Earth Retaining Structures;
- BS 8110: Design of Reinforced Concrete Structures;
- BS5628: Use of Masonry.

3.5.7.2 Products

All Quay Wall construction work shall commence only when the Engineer's approval is given to the Contractor in writing. The Contractor shall submit two copies of certificates for all material supplies and material sources to be used in construction of any Quay Wall structure to Engineer for his approval at least 14 days prior to their incorporation in the works. The Quay Walls shall be constructed from suitable materials meeting the requirements of this and all relevant supporting project Specifications as appropriate.

3.5.7.3 Execution

Setting Out and Levelling

The Contractor shall be responsible for the setting out and survey control of the Quay Wall construction works. The Contractor shall identify any survey control points to be established and shall submit any such proposals to the Engineer for approval prior to their erection, providing the following information:

- Plan coordination (Eastings & Northings JTM (Maldives grid system);

- Level Values (to Global Mean Sea Level – if known at atoll location).

Environmental Controls

The Contractor shall ensure that the operation of his plant and methods of working are in compliance with all Employer and any other Relevant Authority requirements with regard to environmental and pollution controls.

As a minimum and unless otherwise agreed with the Engineer, the Contractor shall adopt and implement the environmental controls specified in Clause 4 of Section MS02 Dredging and Reclamation that are applicable to the construction works covered by this Specification. Any discrepancies with regard to the scope of these controls in relation to these works shall be submitted in writing to the Engineer for his ruling.

Foundation Trenches to Walls

The Contractor shall submit his proposals for forming the foundation trenches to the Quay Walls that shall be subject to the approval of the Engineer. Any foundation trench shall be excavated and to the lines and levels shown on the drawings and shall be finished so as to prevent loose material migrating into the trench.

In-situ concrete works shall not take place on any section of work until the overall verticality and position of adjacent cast Vertical Edge structures has been checked and approved by the Engineer, ensuring the tolerances specified in this document have been met.

Placing of Backfill Material to the Wall Structures

The Contractor shall include in his method statement, his methodology for placing the backfill material that shall be subject to the approval of the Engineer.

3.5.7.4 Monitoring of Structures

As a minimum and in addition to any other requirements in the Contract, the levels of the Vertical Edge Structures shall be monitored during and after completion of the works in accordance with the recommendations of Table below, unless otherwise directed by the Engineer.

The monitoring commencement date and locations of each monitoring point shall be agreed with the Engineer. All monitoring results shall be recorded, compiled and submitted to the Engineer at weekly intervals, unless otherwise directed by the Engineer.

Table C 4.11 Level Monitoring Regime

Item	Purpose	Location	Number	Frequency
Surface monitoring of wall structure	Settlement monitoring of permanent works	On completed coping beam or top block as appropriate	At 10m intervals, unless otherwise directed by the Engineer.	Weekly for 12 weeks and then monthly until three months after cessation of wall construction works or as otherwise directed by the Engineer.

Screeding rails will be set up and the trench prepared in 10m lengths for the inspection of the Engineer who will examine the excavation for clean lines and sample the trench bottom. Any soft areas shall be excavated by the Contractor and made up with foundation material.

The Contractor shall measure and survey any finished trench to the satisfaction of the Engineer prior to placing any foundation material. Upon receipt of the Engineer's approval, the Contractor shall immediately proceed to place the foundation material.

Vertical Edge Structure Construction

The Contractor shall include in his method statement, his methodology for placing the in situ concrete to form the Vertical Edge Structures that shall be subject to the approval of the Engineer.

The Contractor shall adopt the recommendations and requirements of the supporting project specification document for structural concrete, as appropriate or as directed by the Engineer.

3.5.7.5 Tolerances

The tolerances specified in Table below – Construction Tolerances shall apply to all Reinforced Concrete Wall Vertical Edge Structures construction works:-

Table C 4.12 Construction Tolerances

Description	Tolerance
Finished Foundation Layer	+/- 5mm
Blinding Concrete Layer	+/- 5mm
Vertical Alignment	+/- 10mm

3.5.7.6 Surveys and Inspections

As a minimum, the Contractor shall carry out the following surveys and inspections as part of the construction works to the satisfaction of the Engineer. The Contractor shall conduct his surveys and measurements by means of traditional survey equipment and hard soundings or staff with an end plate for underwater surveys.

- A local bathymetric bed/ground profile survey prior to commencing work
- A survey of the finished foundation trench profile shall be carried out at intervals not exceeding 10m immediately before construction of the Vertical Edge Structures activities commence
- As-built measurements shall be carried out and recorded for in situ reinforced concrete panel cast in position
- A Final survey of the finished Vertical Edge Structures shall be carried out at intervals not exceeding 10m along its entire length checking the longitudinal and vertical alignment, after the period of level monitoring has ceased, or as otherwise directed by the Engineer
- Checks will be carried out along the entire structure length by diving inspections and photographic records as appropriate at 3 month intervals over the first 12 months after the lagoons have been infilled with water.

For each of the surveys the Contractor shall provide the following: -

- No paper copies of the survey at scales to be agreed with the Engineer.
- 1 electronic copy of the survey on CD ROM in AUTOCAD .dwg or .dxf files.
- Photographic evidence that has been verified by the survey team as a true and accurate record.

3.5.8 Concrete Formwork

3.5.8.1 References

The minimum standards for products specified in this section shall be relevant British standards including but not limited to the following. Except as otherwise specified herein, perform work in accordance with specifications, codes, and standards cited therein, and latest applicable addenda and supplements. Copies of these items shall be kept available on site for the Engineer's inspection.

- BS 5975 : 1982 Falsework
- BS 8110 The Structural Use of Concrete - Part 1, Design and Construction.
- UK Structural Design Standards specified herein can be substituted by standard listed in "CIRIA Special Publication 35 - Structural Design Standards : Selected National and International Title and Sources", provided that request for substitution is made and reviewed by the Engineer before use in the project.

3.5.8.2 Products

Formwork shall conform to the shape, lines, grades and dimensions of concrete as required by the drawings and shall be constructed of approved timber or metal, in which all bolts and rivet heads in contact with concrete are counter-sunk. The supporting structure shall be of sufficient strength to carry the concrete without deflection and the tolerances of the concrete when stripped shall be in accordance with those specified under the appropriate specification section.

The formwork shall be designed and constructed so that it can be tightened at joints to avoid offsets, fins and mortar joints. The Contractor shall ensure that the pattern left by formwork on exposed surfaces is to the approval of the Engineer. The Contractor shall design and construct his formwork such that the forms shall be straight, free from distortion and shall leave, after stripping, a regular pattern on the surface of the concrete and he shall submit to the Engineer for approval, details of the formwork he proposes to use.

Representative samples of the material proposed for temporary and permanent formwork shall be supplied by the Contractor for the Engineer's approval.

The Contractor shall provide all necessary bracing to the supporting structure to ensure lateral stability of the formwork.

Form Materials

Temporary formwork shall be constructed of materials approved by the Engineer. They shall be positively anchored to the structure and the joints between them shall prevent bleeding of cement paste from the concrete.

- Plywood or metal formwork of suitable surface quality as approved by the Engineer shall be used to achieve the following classes of concrete finishes:
- Concrete surfaces to take waterproof liquid coating.
- Concrete surface to take plaster.
- Horizontal concrete surfaces to take waterproof sheet membrane.
- Concrete surface to take paint in surface location or exposed after construction.
- Concrete to be rendered or topped.

Plywood formwork shall be used for all external faces which are to receive applied liquid waterproofing provided the joints are grout tight to the approval of the Engineer.

Formwork shall be oiled or greased to prevent adhesion of mortar. Oil or grease shall be of non-staining mineral type, applied in a thin film, before reinforcement is placed. Mould oil is to be removed before the application of waterproofing. Form oil is to be compatible with finish applied to concrete.

Where ply formwork is to be used this should be exterior grade ply bonded with a waterproof adhesive sheets well fixed to backing to avoid absorption of water and nailed with at least 10 nails per sqm over the whole area. The edges of the sheets should be joined on the same backing board for a smooth joint.

Steel formwork for the construction of exposed external walls shall be insulated or left in place at least 7 days.

Re-use of boards is to be agreed with the Engineer and be to his approval.

Formwork Accessories

Include for all formwork accessories as implied necessary to complete the full and correct works including for ties, form release agent, anchor slots, nails, spikes, bolts, waterstops etc..

The material for ties passing through the concrete requires the approval of the Engineer.

Controlled Permeability Formwork (CPF)

Controlled Permeability Formwork allows the controlled escape of air and some of the mix water to the surfaces of concrete elements cast against formwork material. Generally this results in an increase in surface cement content and reduction in water/cement ratio in the outer 20mm of the surface. The resulting surface has increased surface strength, reduced permeability and porosity and release agents are not required leaving the finished surface uncontaminated with residues.

CPF consists of three essential components, a filter medium, a drainage layer and structural support formwork. Generally the filter and drainage layer are formed from a composite fabric. Any CPF proposed by the Contractor shall comply with the following:

- The filter medium shall prevent the loss of fines from the concrete;
- As a minimum, the filter medium shall have independent third party certification and have a current BBA certificate (or approved equivalent).
- The CPF filter medium shall be tested as recommended by the BBA (or approved equivalent) and certified by them to:
    - Have a compression of less than 10% under a pressure of 200 kN/m2
    - Have a minimum water retention capacity of 0.35 litre/m2;
    - Have a minimum water retention capacity of 0.35 litre/m2;
    - -Result in bleed water from the medium which is free from cement and fine aggregate particles

The CPF shall not affect the finish of the cast concrete such that it is nonconforming with:

- Use of the CPF shall comply with the manufacturers technical guidelines;
- Unless otherwise directed, CPF liner materials shall be retained in-situ during the curing period.

3.5.8.3 Execution

Erection – Formwork

Use forms for all concrete, except as otherwise permitted by the Engineer. Design and construct concrete forms to withstand all forces, including construction live loads imposed upon them during placing and curing of concrete, and with adequate bracing to hold them within specified tolerances for lines and grades shown on drawings

Permanent props for all blocks, beams, slabs and walls shall be steel with adjustable height to allow fine movements for precamber and levelling. The propping for the formwork must be separately considered and may be removed according to the stripping times set out in Section 3.6. The permanent props to carry the structural member after formwork is removed must remain in place until the concrete has sufficient strength to carry the construction loading, or until the Engineer approved removal. It is possible that in some cases the construction live load will be greater than the final working load, and in others that de-propping too early may lead to unacceptable deflections.

The setting out and the dimensions of the finished formwork shall, unless otherwise specified on the drawings or other specification section, be within the tolerance given below

Conditions	Tolerances
On dimensions of 3000 mm and over	6mm
This tolerance must not be cumulative On dimensions below 3000 mm	4mm
On dimensions of cross sections of Members and slab thicknesses	4mm
Top beams and slabs	+/- 5mm in level
Plumbness of columns and walls	+/- 6mm per storey height But 13mm in full height
For the positions of reinforcement	=/- 3mm

For a minimum of one hour prior to concrete placement, wet forms continuously with water to swell forms in order to prevent leakage of concrete matrix and to minimize absorption of concrete matrix water by form materials. Care must be exercised to prevent a build-up of water at base of forms. Particular care must be taken where concrete directly abuts cork bound boards. Before form materials can be re-used, surfaces that will be in contact with freshly cast concrete shall be thoroughly cleaned, damaged areas repaired and projecting nails withdrawn. Re-use of form material shall be subject to the approval by the Engineer. Align joints and make watertight. Keep form joint to a minimum. Obtain approval before framing openings in structural members which are not indicated on the drawings.

Joints and Edges

All joints in formwork shall be close-fitting to prevent bleeding of cement paste from the concrete. At construction joints formwork shall be tightly secured against previously cast or hardened concrete to prevent the loss of grout or the formation of steps or ridges in the concrete. Formwork shall be constructed to provide straight and true angles, arises or edges. Where chamfers are called for, the fillets shall be accurately sized to provide a smooth and continuous chamfer.

Formwork panels shall have true edges to permit accurate alignment of their sides and to provide clean lines at construction joints and shall be fixed with joints either vertical or horizontal, unless otherwise specified. The type and treatment of any lining (plywood, metal, plastics, etc..) to the forms shall be appropriate to the concrete finish required.

Where holes are needed on forms to accommodate projecting reinforcement or fixing devices care shall be taken to prevent loss of grout. Special care shall be taken when de-moulding in order not to break off the edge of the concrete adjacent to the projecting reinforcement.

3.5.9 Concrete Reinforcement

3.5.9.1 References

The minimum standards for products specified in this section shall be relevant British standards including but not limited to the following. Except as otherwise specified herein, perform work in accordance with specification codes and standards cited therein and to latest applicable addenda and supplements.

- BS 2640 Specification for Class II oxy acetylene welding of carbon steel pipework for carrying fluids;
- BS 4449 Specification for carbon steel bars for the reinforcement of concrete;
- BS 4482 Specification for Steel wire for the reinforcement of concrete productivity;
- BS 4483 Specification for steel fabric for the reinforcement of concrete;
- BS 4486 Specification for hot rolled and processed high tensile alloy steel bars for the pre-stressing of concrete;
- BS 5896 Specification for high tensile steel wire and strand for the pre-stressing of concrete;
- BS 6399 Code of Practice for dead and imposed loads;
- BS 6744 Specification for stainless steel bars for the reinforcement and use in concrete;
- BS 7123 Specification for metal arc welding of steel for concrete reinforcement;
- BS 8110 Structural use of concrete;
- BS 8666 & Specification for bending dimensions and scheduling of;
- BS EN ISO 4066 Reinforcement for Concrete;
- BS ISO 14654 & Fusion bonded epoxy coated carbon steel bars;
- BS ISO 14656 reinforcement of concrete;
- BRE Digest 258 The durability of steel in concrete;
- BRE Digest 263 Mechanism of protection and corrosion;
- BRE Digest 325 Concrete Part 1 – Materials;
- BRE Digest 326 Concrete Part 2 – Specification and Quality Control.

3.5.9.2 Products

Reinforcement

- High yield steel deformed reinforcing bars used for the work shall have a minimum yield stress of 420 N/mm2 (Hot Rolled).
- Mild steel reinforcement shall be of plain round bars with minimum yield stress of 250 N/mm2.
- High yield steel threaded reinforcement bars used for the work shall have a minimum yield stress of 420 N/mm2 (Hot rolled).
- Welded Wire Fabric shall conform to BS 4483.

Site fabricated mesh reinforcement.

The reinforcement shall comply with the relevant British Standards as given below:

Mild steel, plain rolled bars	BS4449
High yield steel hot rolled deformed bars	BS4449
High yield steel, cold worked deformed bars	BS4449
Fabric reinforcement, indented or deformed	BS4483

Deformed bars shall have a Type 2 bond classification.

Bends in reinforcement shall have a substantially constant curvature. Where the temperature of the steel is below 5 oC, special precautions may be necessary such as reducing the

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speed of bending or, with the Engineer's approval, increasing the radius of bending.

Where it is necessary to bend reinforcement projecting from concrete, care should be taken to ensure that the radius of bend is not less than that specified in BS 8666 and BS EN ISO 4066.

No welding of reinforcement should be carried out without the Engineer's approval.

Bundle and tag reinforcement with suitable identification to facilitate sorting, transporting, storing and placing at the site.

All reinforcement bars shall be cut and bent to shape as per the approved bar bending schedule. All bars shall be tagged showing the corresponding bar number as shown on the relevant Bar Bending Schedule.

Dowel Bars

Where shown on the Drawings, dowel bars shall be de-bonded with an approved de-bonding compound or proprietary dowel bar sleeve. The Engineer may require the Contractor to demonstrate the efficiency of the method of de-bonding by carrying out the test described below.

The average bond stress on de-bonded bars cast into concrete specimen and subjected to pull out tests at 7 days shall not exceed 1.4MN/sq.m and the total movement of the dowel bar relative to the concrete shall be not less than 0.25mm at the stress. The concrete specimens shall be 150mm x 150mm in section and 450 mm long and made with the same mix proportions as used in the Works. The number of tests will be at the Engineer's discretion.

Compressible Caps shall be securely fixed and shall permit free movement of one end of the bar.

Dowel bars shall be rigidly supported so that they are correctly aligned.

Fabrication

- Fabricate concrete reinforcing in accordance with BS 8666.
- Weld reinforcement in accordance with British Standards.
- Galvanized and Epoxy Coated Reinforcement: Clean surfaces, weld and re-protect welded joint in accordance with manufacturer's instructions.
- Locate reinforcing splices not indicated on drawings, at point of minimum stress. Review location of splices with the Engineer.
- Use Nylotron Mandrels on the bending machine during fabrication of epoxy coated reinforcement.

3.5.9.3 Execution

Inspection

Examine work prepared by other trades to receive work of this section and report any defects affecting installation to the Contractor for correction. Commencement of Work will be construed as complete acceptance of preparatory work by others.

Placing of Reinforcement

The Contractor shall supply and incorporate in the work all such steel reinforcement including tie wire, support and spacer bars and the like whether shown or not shown on the drawings which are necessary to complete the work, all to the satisfaction of the Engineer.

Bar Schedules

The Contractor shall include for all necessary chairs and spacers, and his price and rates for steel thus shown shall include for these.

Protections Handling and Storage

The Contractor shall ensure that reinforcement left exposed in the Permanent Works shall not suffer distortion, displacement or other damage. When it is necessary to bend protruding mild steel reinforcement aside temporarily, the radius of the bend shall not be less than four times the bar diameter. Such bends shall be carefully straightened before concrete placing continues, without leaving residual kinks or damaging the concrete round them.

All reinforcement will be properly stored under impermeable cover to avoid contact with the ground, moisture, dust and salts and to avoid distortion once bent to shape.

Cutting and Bending

The Contractor shall cut reinforcement to length and bend it to the shape shown on the schedules within the dimensional tolerances given in BS 8666. Bars shall be bent cold by the application of slow steady pressure. Hooks or right angle bends shall be formed where called for by the schedules and to the dimensions and tolerances specified in BS 8666. In the unlikely event of temperatures below 5°C, in certain locations during the winter months, the rate of bending shall be reduced if necessary to prevent fracture of the steel.

High tensile bars shall not be bent after placing in the Works.

Bending, tack welding or cutting reinforcement in field in any manner other than as shown on drawings is prohibited.

Construction Joints

Reinforcement shall be continuous through construction joints unless otherwise indicated on drawings.

Splices

No splices shall be made in the reinforcement except where shown on the Drawings or agreed by the Engineer.

The splice lengths of all reinforcing bars which have to be spliced shall, unless otherwise shown on the drawings, be in conformity with the following:

- Plain round bars (50 diameters) minimum
- Deformed bars (45 diameters) minimum
- Fabric (30 diameters minimum, but overlap measured between outermost wires of each sheet not less than pitch of secondary)

Couplers

- The Contractor may use mechanical couplers in areas other than shown on the drawings to ease congestion with the written approval of the Engineer.
- The Contractor is to submit to the Engineer for approval drawings showing position of all mechanical couplers used on project.
- Threaded reinforcement may be joined by the use of mechanical couplers.
- Coupled joints to be in accordance with the recommendations in BS 8110 for threaded connections. Where couplers are to be used these are to be staggered.

Fixing

All reinforcement shall be placed accurately in position and securely fastened in place to prevent displacement during the placing of the concrete. Particular care shall be taken to ensure that the protective cover to reinforcement specified on the drawings is obtained by the use of approved plastic tipped steel chairs for lower reinforcement and cranked bars for upper reinforcement.

Unless otherwise agreed by the Engineer, all intersecting bars shall either be tied together with 1.6mm diameter black annealed mild steel and the ends of the wire clipped short or turned into the body of the concrete, or shall be secured with a wire clip of a type agreed by the Engineer.

Spacer blocks shall be used for ensuring that the correct cover is maintained on the reinforcement. Blocks shall be as small as practicable and of a shape agreed by the Engineer.

Wires cast into the block for tying in to the reinforcement shall be 1.6mm diameter annealed mild steel. Special provisions shall be made where special finishes are required and exposed spacer blocks not permitted.

Reinforcement shall be rigidly fixed so that no movement can occur during concrete placing. Any fixings made to the formwork shall not be within the space to be occupied by the concrete being currently placed.

Checking

Before concrete is cast, check all reinforcement after it is placed to insure that reinforcement conforms to Contract Documents and approved shop drawings. Such checking shall be done only by qualified experienced personnel. In addition, the Engineer shall be notified at least 24 hours prior to concrete placement and given opportunity to schedule site visit to observe completed reinforcement and formwork before concrete placement.

Delay

Where there is delay in depositing concrete after the placement of the reinforcement the Engineer may require the Contractor to restore the reinforcement to a satisfactory condition and may require protection of same from further corrosion.

Mesh Fabric

Sheets of steel mesh fabric reinforcement shall overlap each other by at least twice the wire spacing in the direction of the lap or as shown on the Drawing's and shall be securely fastened at the ends or edges.

Welding

Reinforcement shall not be welded except where required by the Contract or agreed by the Engineer. If welding is employed, the procedures shall be as set out in BS 2640 for gas welding or BS 7123 for metal arc welding. Full strength butt welds shall only be used for steel complying with BS 4449. If high yield deformed bars are to be welded they shall have a carbon equivalent of the steel less than 0.51% and a nitrogen content less than 0.007%

Projection bars

Ends of bars which are left projecting for any period exceeding 4 weeks shall be painted with a heavy coat of neat cement grout which shall be removed prior to continuation of concreting.

Contact Between Dissimilar Metals

Where concrete members contain galvanised or stainless steel reinforcement or embedded items as well as ordinary uncoated mild or high-yield steel reinforcement then contact between dissimilar metals shall be prevented, if necessary by inserting electrically insulating material between them. Starter bars shall be protected from wind blown dust, sand and sea salts.

Cover

The required cover specified in this materials specification is the nominal cover. Nominal cover is the design depth of concrete cover to all steel reinforcement, including links (stirrups). The sizes of spacers and the dimensions of all reinforcement shall be based on this nominal cover. The fixing of reinforcement and formwork shall also be such as to maintain the nominal cover.

The actual concrete cover to all steel reinforcement shall not be less than the required nominal cover minus 5mm.

Where reinforcement is located in relation to only one face of a member (e.g. a straight bar in a slab) the actual concrete cover shall be not more than the required nominal cover plus:

5mm on bars up to and including 12mm size
10mm on bars over 12mm up to and including 25mm size,
15mm on bars over 25mm size.

Unless shown on the drawings concrete cover to all reinforcement shall be a minimum as follows:

- ACI 305 Hot Weather Concreting;
- ASTM C 87 Effect of organic impurities in fine aggregate on strength of mortar;
- ASTM C 142 Clay lumps and friable particles in aggregates;
- ASTM C 227 Potential Alkali reactivity of cement - Aggregate combinations (Mortar bar method);
- ASTM C 289 Test for potential reactivity of aggregates (chemical method);
- ASTM C 232 Bleeding water test;
- BS 12 Portland cement;
- BS 812 Testing aggregates;
- BS 882 Aggregates from natural sources for concrete;
- BS 1014 Specification for pigments for Portland Cement;

Table C 4.13 Concrete Mix Requirement for Marine Concrete

Description		Cover mm	Min cement content (kg/m3)	Max water cement ratio
Marine Concrete	Precast Concrete	100	370 - 400	0.40
Marine Concrete	Insitu Concrete	100	370 - 400	0.40
Ground Contact	Precast Concrete	75	320 - 400	0.42
Ground Contact	Insitu Concrete	100	320 - 400	0.42

The design of reinforced concrete works will incorporate suitable design details to ensure wind borne salts and contaminants are least likely to become trapped and adequate drainage exists to ensure the removal of water and sea spray. The following maximum serviceability limit state crack widths have been used in the design of the reinforced concrete;

Table C 4.14 Values- Limiting Crack Width

Location	Limiting crack width	
	Permanent Load	Transient Load
Direct exposure to sea water	0.15	0.2
Elsewhere	0.25	0.3

Permanent load = dead load+50% live load

Transient load = dead plus full live load

3.5.10 Cast "in place" Concrete

3.5.10.1 References

This Specification shall be read in conjunction with the following documents.

- BS 1305 Batch type concrete mixers;
- BS 1377 Method of test for soils for civil Engineering purposes;
- BS 1881 Testing concrete;
- BS 3148 Methods of tests for water for making concrete;
- BS 3892 Pulverised fuel ash;
- BS 4027 Sulphate-resisting Portland cement;
- BS 4550 Part 2 Methods of testing cements - chemical tests;
- BS 5075 Part 1 Accelerating admixtures, retarding admixtures and water;
- BS 5328 Part 1 Guide to specifying concrete: Part 2 Method for specifying concrete mixes; Part 3; Specification for the procedures to be used in producing and transporting concrete; Part 4 Specification for the procedures to be used in sampling, testing and assessing compliances of concrete.
- BS 6100 Glossary of building and civil Engineering terms;
- BS 6349 Maritime Structures, Part 1 (2000) and Part 2 (1988);
- BS 8004 Foundations;
- BS 8007 Design of concrete structures for retaining aqueous liquids;
- BS 8110 The structural use of concrete DD 147 Method of test of curing compounds for concrete;

- D11/D901/Rev.0 Page 3 of 48 03300 Cast-in-Place Concrete;
- BS 8500 -1 and 2 Concrete Complementary Standard to BSEN206-1;
- BRE Digest 357 Shrinkage of Natural Aggregates in Concrete;
- BRE Digest 330 Alkali Aggregate Reactions in concrete.

Exposure Zones

Exposure zones applicable to structural concrete works shall be defined as follows:

Severe Exposure Zone

Severe exposure conditions are defined as those locations in the tidal zone and where structural concrete will come into contact with sea spray. This will generally apply to Marine Concrete above 1.0 m below Lowest Astronomical Tide (LAT) within 50m of the sea/land interface unless otherwise indicated on the drawings.

Concrete designated for use in 'severe exposure zones' will be labelled with the letters "SE".

Normal Exposure Zone

Normal exposure conditions are defined as those locations away from the tidal zone and where structural concrete is unlikely to come into contact with sea spray. This will generally apply to Concrete above 6.0m above LAT located more than 50m from sea / land interfaces (such as sea walls, revetments and beaches) unless otherwise indicated on the drawings.

Concrete designated for use in 'normal exposure zones' will be labelled with the letters "NE".

3.5.10.2 Products

Prior to starting work the Contractor shall submit to the Engineer for his approval details of the proposed sources of all materials he proposes to use for making concrete. No concrete shall be placed in the Permanent Works until the Engineer has approved the materials of which it is composed. Approved materials shall not thereafter be altered or replaced by other materials without the consent of the Engineer.

As a minimum and unless otherwise instructed elsewhere in the Contract, two copies of Certificates verifying that the materials comply with this Specification shall be submitted promptly by the Contractor at the following intervals:

- Coarse aggregates - each 400 m3 delivered or weekly for each grading of coarse
- aggregate, whichever is more frequent;
- Fine aggregates – each 250 m3 delivered or weekly, for each grading source, whichever is more frequent;
- Cement - each consignment/delivery;
- Water - at commencement of work, then weekly;
- Admixtures, curing compounds and other materials - each consignment. Where certificates are not available for admixtures, technical data sheets shall be submitted instead.

Cement

The cement to be used throughout the work shall be Portland Cement obtained from manufacturers approved in writing and shall be as described under one of the following headings:

- Ordinary Portland Cement (OPC), CEM 1 Class 42.5.
- Low heat Ordinary Portland Cement (OPC), ASTM type IV;
- Cement complying with either BS EN 197-1, BS 8500-2 or ASTM C150 Type I but containing not less than 7% and not more than 12% proportion by weight of tri-calcium aluminate (C3A).
- Cement complying with BS EN 197-1 or ASTM CI50 Type II but containing not less than 5% and not more than 9% proportion by weight of tricalcium aluminate (C3A). In either case the cement shall not contain more than 2.7% proportion by weight of sulphur trioxide (SO3).
- Sulphate Resisting Portland Cement (SRPC), ASTM type V
- Cement complying with either BS 4027 or ASTM C150 Type V, but containing not more than 4% proportion by weight of tricalcium aluminate (C3A).

Additional Requirement

In addition to the requirements above for cement to be used in permanent Works the following limits shall apply:

- Acid soluble alkali level measured as (Na2O + 0.658 K2O) shall not exceed 0.6% by weight;
- MgO shall not exceed 6.0%;
- Heat of hydration at 7 days in accordance with ASTM C-186 shall not exceed 290 kJ/kg;
- The fineness (specific surface) in accordance with BS 4550 shall be less than 320 m^2/kg;
- Loss on ignition shall be less than 2.5%;
- Insoluble residue shall be less than 0.75%;
- SO3 shall be less than 3.5%;
- Chloride levels shall be less than 0.05%.

Cement Delivery and Marking

Cement shall be obtained from a manufacturer or supplier approved by the Engineer and shall be delivered directly to the site whether in bulk or in sealed bags.

- Type of cement
- The number and date of the standard conforming to

- The net weight of cement contained therein
- The name, trade name of the manufacturer
- The country of origin
- The date of manufacture.

Cement Storage

Cement in bags shall be stored in a suitable weatherproof structure of which the interior shall be dry and well ventilated at all times. The floor shall be raised above the surrounding ground level by at least 100mm and shall be so constructed that no moisture rises through it.

Each delivery of cement in bags shall be stacked together in one place. The bags shall be closely stacked but shall not be stacked against an outside wall. If pallets are used, they shall be constructed so that bags are not damaged during handling and stacking. No stack of cement bags shall exceed 3m in height. Different types of cement in bags shall be clearly distinguished by visible markings and shall be stored in separate areas of the store.

Bulk cement shall be stored in weatherproof purpose-built silos which shall bear a clear indication of the type of cement contained in them. Different types of cement shall not be mixed in the same silo. Cement stored in silos shall be adequately protected against rain, humidity and dewfall. Silo charging and discharging points shall be properly sealed. Silo aeration equipment shall, if necessary, incorporate de-humidifiers. Cement silo charging pipes shall be clearly marked with the cement type. Precautions shall be taken to reduce the effect of solar radiation on the temperature of the silos.

The Contractor shall provide sufficient storage capacity on Site to ensure that his anticipated programme of work is not interrupted due to lack of cement.

The temperature of cement shall not exceed 65°C at the time of incorporation within the mix, subject to adequate controls being in place to control the temperature of the fresh concrete, all to the satisfaction of the Engineer.

Cement Sampling and Testing

All cement used in the Permanent Works shall be tested in accordance with the relevant standard and as otherwise required by this specification or any other supporting specification or at the discretion of the Engineer. Such tests shall be undertaken by the manufacturer or the Contractor in an accredited laboratory acceptable to the Engineer.

All cement-testing shall be in accordance with BS 4550 Part 1 for sampling, BS 4550 Part 2 for chemical tests and BS 4550 Part 3 for physical property tests, except for the following tests, where ASTM test methods shall be used:

- Method C204 - Fineness by air-permeability
- Method C151 - Soundness, autoclave expansion
- Method C186 - Heat of hydration.

As a minimum and unless otherwise directed by the Engineer, the following routine tests shall be carried out monthly or after each delivery (whichever is more frequent) for assessing cement quality before it is approved for use in the works:

- Fineness
- Setting time
- Loss on ignition
- Compressive strength

Aggregates for Concrete

General Requirements

- Aggregates for concrete shall conform to the requirements for fine and coarse aggregates in BS 882 and ASTM C33-93 as appropriate.
- Aggregates subject to high drying shrinkage such as quartz shall not be used.
- Fine and coarse aggregates shall conform to each specific set of requirements set out in the following sub-clauses:
- Aggregate shall be clean, hard, and durable and shall not contain iron pyrites, iron oxides, mica, shale, coal or other laminar, soft or porous materials or hollow shells.
- Aggregates shall not contain any inclusions of materials likely to cause staining or otherwise to disfigure finished concrete surfaces.
- Aggregates which do not comply with the associated specifications or standards may be mechanically washed in clean fresh water to remove clay, silt, salts and adherent coatings and other impurities to obtain compliance.

Gradings

As a minimum requirement, fine aggregate shall conform to BS 882 Table 5. The grading shall not cross from one side of the envelope to the other between any three adjacent grading points. In order to achieve an acceptable grading it may be necessary to blend materials from more than one source. Grading percentage by weight passing sieve no. 100 shall not exceed 10% for natural sand and 15% for crushed rock.

- Coarse aggregate shall be supplied in the nominal sizes specified and shall be graded in accordance with BS 882 for single sized aggregates. A coarse aggregate shall be rounded or irregular as defined in BS 812, Part 1.
- 40mm coarse shall be graded from 40mm to 20mm and be produced by a combination of single size gradations. A maximum 10% should be retained on the maximum size of sieve, and not more than 20% should pass through the minimum size of sieve.

- 20mm coarse shall be graded from 20mm to 10mm and be produced by a combination of single size gradations. A maximum 10% should be retained on the maximum size of sieve, and not more than 20% should pass through the minimum size of sieve.
- 10mm coarse shall be graded from 10mm to 5mm and be produced by a combination of single size gradations. A maximum 10% should be retained on the maximum size of sieve, and not more than 20% should pass through the

  minimum size of sieve

Requirement	**Test Methods**		**Permissible Limits**	
	BS 812	ASTM	Fines	Coarse
1. Clays lumps and friable particles		C 142	max. 1%	max. 2%
2. Fines, 75 micron sieve		C 33	max. 3%	max. 1%
3. Organic impurities	(BS 1377 Test 8)	C40 / C87	max. 0.1% (BS) lighter than standard (C40)	lighter than standard (C40)
4. Water absorption	Part 109	C 128/ C 127	max. 2.0%	max. 2.0%
5. Specific gravity (apparent)		C 128/ C 127	min. 2.55	min. 2.6
6. Flat shell content in aggregate fraction Between 20mm & 40mm Between 10mm & 20mm Between 5mm & 10mm Between 2.36mm & 5mm Finer than 2.36mm Hollow shells	Part 106		max. 10% none none	max. 5% max. 10% max. 15% none
7. Particle shape Flakiness index Elongation index Elongation/ flakiness factor	Part 105.1 Part 105.2 See note 1		max. 10%	max. 25% max. 25%
8. Acid soluble sulphates (SO3) (See also clause 3.2.6)	Part 118		max. 0.4%	max. 0.4%
9. Acid soluble Chlorides(Cl) (See also clause 3.2.6)	Part 117, Appendix C		max 0.06%	max. 0.03%
10. Soundness. (Max loss in 5 cycles % weight). Magnesium sulphate MgSO4, or Sodium sulphate Na2SO4	Part 121	C 88/C 88	max. 15% max. 10%	max. 15% max. 10%
11. Mechanical strength 10% fines value or Impact value Los Angeles Abrasion	Part 111 Part 112	C131/C535		min 100 kN max. 25% max. 25%
12. Drying shrinkage	Part 120		max. 0.05%	max. 0.05%

Physical, Chemical and Mechanical Properties Requirement

The limits for physical, chemical and mechanical properties of aggregates for concrete and the test method to ensure compliance shall be as summarised in Table below.

Table C 4.15 Limits for Physical, Chemical and Mechanical Properties of Aggregates for Concrete

Note 1. Not more than 5% of particles shall have ratios (w:b:l)* greater than 1:2:3 (flakey) and 1:1:3 (elongate) when tested by visual inspection of 100g of sand under a microscope, for reinforced structural concrete works. This test is not required for unreinforced concrete. w:b:l - width : breadth : length.

Alkali Reactive Minerals

No part of the aggregates shall contain any mineral known to have a potential to cause alkali silica, alkali silicate, alkali carbonate, or any other damaging chemical reaction between alkalis and aggregates. The Contractor shall demonstrate to the Engineer's satisfaction that the matrix will be stable and not liable to excessive internal expansion due to alkali-aggregate reaction.

Delivery and Storage of Aggregates

Aggregates shall be delivered to Site in clean and suitable vehicles. Different types or sizes of aggregates shall not be delivered in the same vehicle. Aggregates shall be stored on a hard, dust-free surface and shielded from dust and the direct rays of the sun. If a dust-free environment cannot be achieved re-screening and washing of aggregates with clean water shall be carried out prior to their use.

Aggregates of each grade and type of material shall be kept separate until batched. Segregation of the particles within each aggregate stock-pile shall be prevented. Stockpiles shall be protected against contamination from soil, evaporate salts, vegetable matter or other deleterious material.

The floors of bins shall be constructed from a minimum 75mm thick mass concrete slab (or similar and approved) and shall be laid to fall to the outer edge or provide a free draining apron.

Testing Aggregates

The Contractor shall deliver to the Engineer samples containing not less than 5 kg of any aggregate which he proposes to use in the Permanent Works and shall supply such further samples as the Engineer may require. Each sample shall be clearly labelled to show its origin and shall be accompanied by all the information called for in BS 882.

At the discretion of the Engineer, the full range of tests listed in this specification and any other supporting specification will be carried out by the Contractor in a laboratory acceptable to the Engineer to determine compliance of the aggregate material and source.

The acceptance tests carried out by the Contractor shall generally be on three representative samples (each of approximately 8kg weight) of fine and coarse aggregates taken in the presence of the Engineer from a stockpile of at least 5 tonnes. Total numbers of tests required for acceptance are summarised in Table below

Minimum Number of Acceptance Tests required for Aggregates.

Table C 4.16 Minimum Number of Acceptance Tests required for Aggregates

Test	Fine Aggregates	Coarse Aggregates
Water Absorption	3	3*
Flakiness Index	3	3*
Shell Content Determination	3	3*
Test for Shell Content	3	1
10% Fines Test or Aggregate Impact Value	3	3*
Gradings	3*	3 on each nominal size
Chloride Content	3*	3*
Sulphate Content	3*	3*
Soundness	-	3*
Petrographic Examination	As required, minimum of 1	As required, minimum of 1
Clay, silt and dust determination	3	3
Organic impurities	3	3

Note * One test on each sample- Testing shall also be carried out to establish the relationship between Quantab

Routine Testing

The Contractor shall carry out routine testing of aggregates for compliance with the Specification during the period in which concrete is being produced for the Permanent Works.

Unless specified elsewhere in the Contract, or where instructed differently by the Engineer, the following routine tests shall be executed at a frequency not less than that indicated in Table 3.5.17 below – Frequency of Routine Aggregate Testing.

Table C 4.17 Frequency of Routine Aggregate Testing

	Test	Frequency	Remarks
1	Flakiness index	Weekly	Reducing to monthly when stable.
2	Elongation index	Weekly	Reducing to monthly when stable.
3	Angularity No.	Weekly	Reducing to monthly when stable.
4	Organic impurities	Weekly	Reducing to monthly when stable.
5	10% fines	Weekly	Reducing to monthly when stable.
6	Sulphate soundness	Weekly	Reducing to monthly when stable.
7	Others	Monthly	Reducing to as required by Engineer if stable

In addition to the above routine tests, the Contractor shall carry out the following tests at the frequencies stated, unless otherwise agreed with the Engineer:

- Moisture content: As frequently as may be required in order to control the water content of the concrete as required by the Specification, but at least daily.
- Chloride content:. As frequently as may be required to ensure that the proportion of chlorides in the aggregates does not exceed the limit stated in the Specification, but at least daily.

The Contractor shall take account of the fact that when the chloride content is variable it may be necessary to test every load in order to prevent excessive amounts of chloride contaminating the concrete. For this purpose the Contractor shall use the rapid field test (Quantab test). In the event of disagreement regarding the results of the field test, the chloride content of the aggregate shall be determined in the laboratory as described in BS 812 (the Volhard test).

Water for Concrete

Water shall be clean and free from salt, organic matter and other impurities to the satisfaction of the Engineer. It shall be tested in accordance with BS 3148 or ASTM C94.

Water used for mixing and curing of concrete shall have a pH value in the range of 7 to 9 and the soluble solids shall not exceed the following limits:

- Total dissolved solids 2000 mg/l;
- Chlorides (NaCl) 600 mg/l;
- Sulphate (SO3) 500 mg/l;
- Alkali Carbonates and Bicarbonates 1000 mg/l.

The total chloride and sulphate content of the water shall be included in the assessment of the total chloride and sulphate content of the proposed mix. As a minimum and unless otherwise directed by the Engineer, water shall be sampled and analysed at approximately one-week intervals.

Water for concrete making shall be kept shaded from the sun and appropriate measures shall be taken to ensure that the water temperature is kept as low as possible. Where flaked or crushed ice is added to the water for concreting, it shall have completely melted prior to its inclusion in the concrete mix.

Water used for curing purposes shall be within 5°C of the placed concrete temperature.

Admixtures

The Contractor shall obtain the Engineer's approval prior to the use of admixtures in each mix. The suitability of admixture shall be verified by trial mixes. Admixtures shall be stored to avoid deterioration and segregation. Admixtures shall be used strictly in accordance with the manufacturer's instructions unless directed otherwise by the Engineer. Neither calcium chloride nor any admixture containing chloride shall be used. Both the amount of admixture to be added and the method of use require the approval of the Engineer, for whom the following data shall be provided:

- The chemical name(s) of the main active ingredient(s) in the admixture;
- Whether or not the admixture contains chlorides;
- The typical dosage and detrimental effects of under-dosage and over-dosage;
- Whether or not the admixture leads to the entrainment of air when used at the manufacturer's recommended dosage;
- Long-term and short-term effects of the admixture on concrete, and the effect of different types of cement and aggregate;
- Storage life and any special storage requirements
- Safety precautions in handling;
- Availability of on-site technical service.

Admixtures shall comply with one of the following British Standards:

- BS1014, BS3892 or BS 5075 as appropriate.

Dosing

Admixtures shall be introduced into the mix by means of acceptable automatic dosing equipment in accordance with the manufacturer's instructions. This equipment shall be maintained daily and a measuring cylinder suitable for checking the calibration shall always be available. The Contractor shall ensure that the batch plant has an accessible outlet pipe to enable these calibration tests to be carried out.

Submittals for Consent

In all cases the Contractor shall provide the following for the Engineer's consent:

- The location of concrete within the works to contain admixture and a clear statement of the purpose that the admixture is expected to fulfil;
- Full manufacturer's data sheets, including` certificate of compliance with` relevant` standards. The chemical names of the main ingredients, alkali content details, storage` and handling requirements and anticipated shelf life will be stated.
- Details of any possible side effects;
- Details of the detrimental effects that can occur should added quantities be greater or less than those required;
- Details of the compatibility with other admixtures;
- Details on the method of packaging, handling, transporting and storage;
- Full details on the quantity to be used by weight of cement or binder or volume of concrete;
- Confirmation that the admixture contains no chloride.

Fibres

Fibres may be added to the concrete mixture for the purpose of providing improved resistance to scaling and spalling in areas of severe exposure, such as marine splash zone and tidal environments. Submitted products shall be supported by satisfactory certification to confirm the product characteristics to the satisfaction of the Engineer.

Fibres must be composed of virgin polypropylene and may either be monofilament or fibrillated, providing the fibres do not adversely affect the capillary absorption qualities of the concrete mixture. i.e. their use does not increase the capillary index (ci) above the value obtained from any such test requested by the Engineer on a control mixture.

Optimal dosage in terms of the effects on workability, strength and capillary properties shall be determined by:

- Making comparative trial mixes and tests of similar mixtures both with and without fibres, to the satisfaction of the Engineer;
- Results of Pre-cast Concrete Ring Test(s) to ASTM x
- In addition to the above, the following shall be adhered to:
- Strength tests on standard laboratory specimens of fibre concrete shall be in full compliance with the standard mixture strength requirements.
- Slump tests of fibre mixes shall be at least 50mm and the concrete shall be highly mobile when vibrated.
- The capillary Index (Ic) determined from capillary suction tests of fibre concrete carried out on three specimens from three individual filed cured cube specimens at 7 days age shall be in accordance with this specification.

Concrete Mixtures

The grades of concrete are shown on the Drawings by reference to the 28-day characteristic cube compressive strength in N/m2 and, followed by the nominal size of the coarse aggregate in millimetres - for example C40-20.

Design of mixes shall be undertaken by the Contractor and shall comply with the requirements of BS EN 206-1 and BS 8500 as appropriate, and shall observe the recommendations of CIRIA Guide to the Construction of Reinforced Concrete in the Arabian Peninsular.

The Contractor's mix proposals for each mix require the Engineer's approval. Existing data provided as evidence of satisfactory previous performance shall, as a minimum, include details and data relating to workability and water/cement ratio.

During any production of concrete for either pre-cast or in-situ works, the Contractor shall inform the Engineer of all changes in sources of materials or cement content. Trial mixes shall be made initially as well as before any substantial change is made. No changes shall be made without the

Grade	Agg size mm	Binder kg/m3 Max	Ash % target	Silica Fume min / max (%)	Max W/C ratio	Halide content kg/m3 max	Coarse Agg. % min.	Free water l/m3	Ic produ ction max	Pore space % max
C45-20 SE	20	400	30	5 / 7	0.37	0.7	50	125	tbc	tbc
C45-40 SE F	40	400			0.38	0.7	50	-	tbc	tbc
C40-20 UW	20	400	30		0.4	1.0	45			
Blinding	20	250								

Engineer's approval.

Based on the results of the tests on the trials mixes, the Contractor shall submit two copies of the full details of his proposals for mix designs to the Engineer, including the type and source of each ingredient, the proposed proportions of each mix and the results of the tests on the trial mixes. Indicative mix designs are given in Table below – Indicative Concrete Mixes

Table C 4.18 Indicative Concrete Mixes

Cement (binder) Content

- Binder content is the sum of cement, ash and additives.
- The binder content of structural concrete shall not be less than 330 kg/m3 m unless directed otherwise as agreed with the Engineer.
- A cement content in excess of 400 kg/m3 m shall not be used without the specific
- approval of the Engineer.

Water/Cement Ratio

- Free water/cement ratio shall be as defined in BS EN 206-1: 2000.
- For Marine structures and water retaining structures the maximum free water/cement ratio shall be 0.4 or as otherwise indicated in Table abve – Indicative Concrete Mixes unless otherwise agreed with the Engineer.
- For structures in contact with soil within the capillary rise zone the maximum free water/cement ratio shall be 0.42 unless otherwise agreed with the Engineer.
- For structures in contact with soil above the capillary rise zone the maximum free water/cement ratio shall be 0.45 unless otherwise agreed with the Engineer.

Air Content

The average allowable air content of the fresh concrete (other than those from air-entraining agents) shall be no more than 2%.

Halides

Halides content is the sum of fluorides, chlorides, bromides and iodides within the total concrete mix. Where initial tests indicate negligible quantities of fluorides, bromides and iodides, Halide content can be taken as chloride content.

Maximum Temperature Rise

The maximum temperature rise on 1m3 specimen of all concrete grades shall not exceed 30 oC. Initial placement temperature shall not exceed the levels stated in Clause 2.12.7, unless otherwise agreed with the Engineer.

Performance Testing of Trial Mixes

As a guide and unless specified elsewhere in the Contract performance verification tests shall be performed as follows:

- For the initial approval of each mix design prior to concreting works;
- Severe exposure conditions – every 10,000 m3;
- Other concrete – every 25,000 m3.

The following verification tests are also required at the trial mix design stage and periodically during production to verify the mix design:

- Halide content of ingredients and calculated total for mix.
- Fresh slump, fresh density, fresh placement temperature, slump loss over 60 minutes,
- measured at 10 minute intervals.
- Temperature rise on a 1 m3 sample over 60 hours.
- Temperature of concrete at deposition.
- Hardened density of laboratory and field cured specimens at 7 and 28 day periods.
- Compressive strength tests of laboratory and field cured specimens at 7 and 28 day periods

Segregation and Bleeding Tests

The proportions of the ingredients of the concrete, including the water, shall be so chosen that the concrete will be workable enough to be fully compacted and not be prone to segregation or bleeding.

The mix shall be such that there will not be excess water on the top surface after compaction. It may be necessary to reduce the water content of batches at the top of deep lifts to compensate for water gain from the lower levels, but this should be avoided by designing the mix, checking with preliminary trials and accurately controlling the mix proportions throughout the work.

Trial mixes shall be tested in accordance with ASTM C232-90 (bleeding test). Segregation or bleeding shall not be greater than 1.5% for concrete generally and 0.5% for concrete with micro silica.

Durability Tests

The following tests shall be carried out on all trial mixes and as a minimum on every 1000 m3 of concrete produced, unless otherwise agreed with the Engineer:

Chloride Permeability to AASHTO T-277

Table C 4.19 Limits for Chloride Permeability

Type of Concrete	Maximum Charge Pass (Coulombs) Age 28 days

Unreinforced concrete	4,000
Microsilica concrete	1,000

Water Permeability to DIN 1048

Table C 4.20 Limits for Water Permeability

Type of Concrete	Maximum Penetration (mm) Age 28 days
Concrete Generally	15 mm
Microsilica concrete	8 mm

Initial Surface Absorption to BS 1818 Part 5

Table C 4.21 Limits for Initial Surface Absorption

Type of Concrete	Minimum ISA Age 28 days; 10 minute test
Concrete generally	0.4 ml/m^2/sec
Microsilica concrete	0.2 ml/m^2/sec

30 Minute Absorption to BS 1818 Part 122

Table C 4.22 Limits for 30 Minute Surface Absorption

Type of Concrete	30 Minute Absorption (28 Days)
Concrete generally	3.0%
Microsilica concrete	1.5 %

Strength Testing of Trial Mixes

For each mix of concrete the Contractor shall prepare three separate batches of concrete using the materials which have been approved and the mixing plant which he proposes to use for the Permanent Works. Six test cubes shall be cast from each batch.

The making, curing and testing of all test cubes shall comply with the requirements of BS 1881 part 116. The workability test of the concrete carried out in accordance with BS 1881 shall be recorded for a range of mixing temperatures and at various times after mixing. The mixing temperature shall be the temperature after the water has been added. Slump control graphs shall be prepared for use on site.

Three cubes from each batch shall be tested for compressive strength at 7 days and the remaining three at 28 days.

The density of all the cubes shall be determined before the cubes are crushed.

The target strength of the mix shall be approved if the mean strength at 28 days of the set of nine cubes from the mix (three cubes from each of the three separate batches) exceeds the Characteristic Strength plus 11.5 N/mm2.

3.5.10.3 Execution

Batching and Mixing

The quantity of cement, the quantity of fine aggregate and the quantity of the various sizes of coarse aggregate shall be measured by weight except that aggregates may be measured by volume for concrete of Grade C20

A separate weighing device should be provided for weighing the cement. Alternatively, the cement may be measured by using a whole number of bags in each batch.

The amount of water should be measured, by volume or weight. Any solid admixtures to be added should be measured by weight but liquid or paste admixtures may be measured by volume or weight.

The batch weights of aggregate shall be adjusted to allow for a moisture content typical of the aggregate being used. The accuracy of the measuring equipment shall be within 3% of the quantity of cement, water or total aggregates being measured and within 5% of the quantity of any admixture being used. All measuring equipment shall be maintained in clean, serviceable condition.

The mixer should comply with the requirements of BS 1305 where applicable. The mixing time should not be less than that used by the manufacturer in assessing the mixer performance. For mixes of low workability or high cement content the Engineer may direct that the mixing time be determined by tests to ensure that maximum strength is achieved.

Plant used for making concrete shall be free from any concrete or mortar containing either high alumina or super-sulphated cements. Calibration of the batching and mixing plant shall be carried out at intervals agreed with the Engineer.

Ready Mixed Concrete

Concrete shall only be mixed at a mixing plant approved by the Engineer.

Unless specially authorised by the Engineer, the concrete shall be mixed and the water added to mixer at the depot. No additional water shall be added at any stage from batching to placing. When the Engineer is asked to authorise dry batching, he will require to be satisfied that appropriate steps will be taken to ensure the quality, consistency and strength of the concrete as placed and that the water will be added to the dry ingredients under properly controlled conditions.

Truck mixer's mixing performance when tested in accordance with BS 3963 shall be within the limits of Table 5 of BS 1305. The drum of the truck agitator or truck mixer shall be completely clean and empty before it is filled with concrete. Trucks shall not be loaded in excess of the manufacturer's rated capacity, which shall be displayed on the vehicle in terms of the volume of mixed concrete. Concrete shall be discharged from the trucks within thirty minutes after the introduction of the water to the cement unless longer time is authorised by the Engineer. This will not normally be allowed, except in exceptional circumstances.

The actual batched weight of cement, water and coarse and fine aggregates, the time of introduction of the water and the mixing temperature after water has been added shall be recorded on each delivery ticket by the supplier. When concrete is wet batched no water shall be added after batching. The supplier's test certificate as appropriate of BS 5328, giving the results of tests on aggregates for workability and strength, shall be submitted by the Contractor to the Engineer at weekly intervals.

Calibration of the Ready Mix Plant shall be carried out at regular intervals and calibration certificates of the plant shall be submitted to the Engineer.

Transport of Concrete

In addition to the guidelines of the above document, the concrete shall be compacted and in its final position within 45 minutes of the introduction of cement to the aggregate unless a longer time is agreed by the Engineer. Precautions shall be taken to ensure that the loss of slump due to temperature rise during transport, pumping and placing does not exceed 25 mm.

Containers used for transporting concrete made from Portland Cements shall be free from any concrete or mortar containing either high aluminium or super-sulphated cement.

Concreting works

Preparation and Permission to Concrete

As a minimum, and in addition to any requirements elsewhere in the Contract, prior to the commencement of concrete works the Contractor shall provide the Engineer with fully detailed proposals of the method of placing, compacting, finishing and curing the concrete.

The method statements, which shall be subject to the approval of the Engineer, shall cover all principle types of concrete elements, e.g. Foundations, walls, columns, beams, slabs etc..

The concrete-mixing plant, mixers, pipelines, pumps chutes and transport equipment shall be shaded and painted white. Pump lines and other surfaces shall be kept cool by insulating them or by covering them with hessian and kept damp by spraying with water.

Surfaces on which concrete is to be placed shall be moist but free of standing water at the time of concreting. This shall be achieved by spraying the forms and reinforcement prior to placing concrete. Shading shall be provided to prevent solar heat gain of forms and reinforcement.

The Contractor shall give the Engineer at least 24 hours written notice before concreting to allow time for final inspection and approval.

Placing and Compacting Concrete

No concrete shall be placed if its bulk delivery temperature is over 33qC. When the air temperature is expected to reach 35qC or higher, the Contractor shall schedule operations to place and finish concreting during the hours that the temperature will be below 35qC. When the overnight temperature is not expected to fall below 35qC, then concreting may be permitted after sunset subject to the provisions of this section.

In the event that conditions become such that these requirements cannot be met, concreting shall be suspended immediately and not resumed until the requirements can be met again. Under such circumstances, additional precautions may have to be taken to avoid the temperatures being exceeded on future pours.

During concreting and throughout the first stage of hardening, the concrete shall be protected from the harmful effects of sunshine, drying, winds, rain or running water.

The requirements of BS 8110 Part 1 Clause 6.5.2 shall be met and also:

- When directed by the Engineer, the Contractor shall demonstrate the efficiency of the proposed methods of placing and compaction on a trial section. When a trial section has been approved by the Engineer, this section shall be maintained as a control for the duration of the contract. The trial section may become part of the permanent works if appropriate.
- Concrete shall not be placed or compacted by any method which causes segregation, undesirable finish or defective structural quality. It shall not be moved into position by rakes or vibrators. The thickness of concrete placed at one time shall not exceed the amount which can immediately be compacted with the means available. This is unlikely to be more than 500mm.
- Adequate measures shall be taken to avoid displacing reinforcement and other embedded items.

Adequate staging or other facilities shall be provided so that compaction can be carried out without either operatives or plant adversely affecting the reinforcement or concrete that has already been placed.

Concrete shall not be subjected to disturbance between 4 hours and 24 hours after compaction except with the agreement of the Engineer.

The number and size of the vibrators shall be such as to ensure thorough compaction of the entire volume of concrete being placed. They shall be either the immersion type with a frequency of not less than 100 Hertz when operating submerged in concrete or the exterior type with a frequency of not less than 50 Hertz. The vibrators shall be applied systematically at such intervals and for such periods that dense, compact, homogeneous concrete is produced and segregation and voids do not occur. Immersion vibrators shall be withdrawn sufficiently slowly to prevent the formation of voids and shall not be placed against reinforcement.

Poker vibrators shall not be applied to external faces of shuttering to aid compaction of beams, columns etc.

All equipment shall be kept free from coatings of hardened concrete and shall not be wetted during use.

Concreting Near Joints

Concrete shall be placed continuously up to all joints. Particular care shall be taken in the placing of the new concrete close to joints to ensure such concrete is fully compacted with a vibrator where possible.

Immediately prior to recommencement of concreting at a joint, the surface of the existing concrete shall be free from laitance and shall be roughened so that the edges of the largest aggregate are exposed but not disturbed. This surface preparation shall be undertaken when the concrete has set but not hardened fully. Laitance shall be removed by spraying with a fine spray of water and/or brushing with a stiff brush.

Where this joint preparation is impracticable, sand blasting or a needle gun shall be used to remove the surface skin and laitance; hacking of hardened surfaces shall be avoided. The joint surface shall be cleaned immediately before the fresh concrete is placed against it and shall be thoroughly wetted to reduce absorption of water from the fresh concrete. Surplus water shall be drained/removed prior to concreting.

Height of Concrete Delivery

Concrete shall not be dropped from a height exceeding 1.5m. Any trunking or chutes used shall be kept clean. Concrete shall not be pumped through aluminium alloy conduits.

Concreting Against Ground

Where it is specified that concrete shall be placed directly in contact with the ground the ground surface shall be lined with polythene sheeting prior to concreting.

Concrete for Walls

The concrete in each section between joints or corners shall be placed in successive pours working away in both directions from the centremost panel of that section. The minimum interval between placing adjacent panels shall be 3 days unless directed otherwise.

Under Water Concreting

Concrete shall only be placed underwater by means of a tremie pipe or approved pumping methods. The bottom of the pipe shall remain embedded in the concrete during placement operations.

Underwater concrete shall be designed to flow underwater a distance of at least 60% of the proposed spacing of the tremie or pumping pipes with a final surface slope no greater than 1:8.

The target slump of such a mix shall be between 125mm and 200mm. Concrete designated for underwater construction will be labelled "UW".

Temporary Stop-ends

If a delay of more than thirty minutes occurs during concreting, the work shall be completed against a temporary stop end. If the location of the joint is not satisfactory for a construction joint the concrete shall be cut back to a satisfactory location.

For deep lifts a temporary stop end may be formed in 'steps' subject to the approval of the Engineer.

Deep Lifts

For lifts exceeding 2.5 metres the Contractor shall submit his proposals for the Engineer's approval. Particular attention shall be paid to the factors mentioned in BS 8110 Part 1 Clause 6.5.2.

Curing of Concrete

The method of curing shall provide an effective means of preventing premature drying of the concrete and the effects of plastic shrinkage and settlement and shall ensure that the concrete has satisfactory durability and strength, the minimum of distortion, freedom from excessive efflorescence and will not cause by its shrinkage early age (i.e. during curing) cracking in the structure.

Methods of curing and protection shall comply with the guidelines given in ACI 305R-91, together with the additional requirements contained within the following paragraphs:

Concrete shall be cured for a minimum of seven days. For concrete incorporating cement replacements such as GGBFS, PFA or Microsilica, this period shall be increased to 10 days minimum. If a change in curing method is made during this period, it shall only be done after the concrete is 3 days old.

Unless an alternative method has been approved by the

Engineer, wet curing techniques shall be adopted either by ponding, immersion, spraying, fogging or with wet hessian combined with reflective impervious sheeting.

Approved white pigmented curing compounds may be applied to supplement the use of wet hessian and polythene, subject to the approval of the Engineer. Use of curing compounds alone will not generally be approved. Curing compounds will not be permitted on surfaces to which further concrete or a surface finish is subsequently to be bonded.

The hessian and polythene shall be left in place for at least a further 7 days following curing to reduce the rate of drying of the concrete surface.

Where structural members are of considerable depth or bulk, additional measures may be required. Under such circumstances, the method of curing requires the approval of the Engineer. It may be necessary to insulate the concrete so that it is maintained at a suitable temperature, or so that the rates of evaporation of moisture from the surfaces are kept to appropriate values, or both.

Un-formed Surfaces

Within ten minutes of placing and compaction, the un-formed surfaces of the concrete shall be completely covered with reflective polythene sheeting with substantial close fitting taped laps. The polythene sheeting may be raised a short distance above the concrete so that it does not mark the surface. At the edges of the pour, the polythene shall drape over the forms and it shall be securely fixed to prevent billowing due to the wind.

Within three hours of placing and compaction the polythene shall be quickly removed and replaced with wet hessian laid onto the concrete surface. The polythene shall then be replaced and secured as above.

The polythene sheeting and hessian may be temporarily removed for surface finishing of the concrete.

The hessian shall be kept continuously damp during the curing period. Inspections shall be carried out at intervals not exceeding 6 hours. Alternate wetting and drying of the concrete will not be permitted. The Contractor shall maintain a register of the inspections throughout the curing period. This shall note for each pour the time of the inspection, the condition of the hessian, the condition of the polythene sheeting and any remedial action necessary. The records of the inspections shall be made available to the Engineer.

Protective measures shall be maintained throughout the curing period to shade the concrete from direct sunlight and protect it from the wind by the use of wind breaks.

Formed Surfaces

Formwork shall be shaded and continuously wetted to prevent high temperatures accelerating the curing. As soon as possible, forms shall be loosened to enable curing water to run down inside them. Within half an hour of stripping, formed surfaces shall be covered by wet hessian and reflective polythene and then treated in accordance with the requirements above for un-formed surfaces.

Protecting Concrete

Concrete shall be protected against damage from thermal shock, physical shock, overloading, movement and vibration. Particular care shall be taken during the curing period.

Concrete which shall remain exposed after completion of work shall be protected against damage from dirt, rust marks and other disfiguration.

No traffic shall be allowed on any concrete surface until it is hard enough to resist damage by such traffic.

Dimensional Tolerances

The concrete work shall be constructed to an accuracy which shall permit the proper assembly of components and installations and shall be compatible with the finish. The accuracy of the work shall be within the tolerances stated on the Drawings or specified elsewhere and in the absence of any other requirements, shall comply with the following Table.

Table C 4.23 Tolerance Limits on Concreting Works

Element	Tolerance
All setting out dimensions	+/- 5mm
Sections of concrete members	+/- 5mm
Foundations	
Surface against ground (underside)	+5/ -100mm
Top surfaces of bases, walls and piers	+5/-20mm
Floor slabs	
Surface level (5m straight edge)	+/- 5mm
Surface level to datum	+/-10mm
Columns and walls	
Plumb in element height	+/-5mm
Cross diagonal distortion in element height	+/-10mm
between adjacent columns	
Plumb in full structure height	+/-20mm

Dimensions and position of openings	+/- 5mm
Bolt pockets	
Position (mean of set)	+/-15mm
Position (to mean, measured at surface of foundations)	+/- 5mm
Inclination of bolt pockets	1:100
Position of embedded items	+/- 5mm

Notes: The thickness of a slab shall not be less than 95% of the nominal thickness specified. Where stated on the drawings, slabs shall be laid to the specified falls.

Compliance of concrete with Specifications

Provided that the specified materials have been used and the concrete has been properly made and handled, concrete will be judged by the strength of the hardened concrete, in comparison with the specified characteristic strength together with the cement content.

Sampling and testing of concrete shall comply with BS 1881, Parts 1 to 6, together with further specifications referred to herein. The Contractor shall afford access to the Engineer to witness all tests. The testing laboratory requires the approval of the Engineer. It shall be capable of carrying out every concrete test required by this Specification at the frequency specified and all equipment shall be kept in good working order and calibrated at regular intervals.

The Engineer may arrange for independent concrete testing to verify the results obtained by the Contractor's laboratory. Such testing shall not relieve the Contractor of his responsibilities for testing under the Contract.

Sampling To test for workability

One sample shall be taken at the point of placing for each 10 m3 of concrete batched or for readymix concrete, each truck load delivered. For each 50 m3 of concrete produced, an additional sample shall be taken for comparison purposes at the point of batching.

Sampling to test for strength

At least one sample shall be taken from each mix (OPC or SRC) of concrete each day and an additional sample for each 20 m^3 or 20 batches of structural concrete, whichever is the lesser.

Additional samples will be required of all mixes until concrete production has been shown to be to the Engineer's satisfaction.

Testing Workability

- Each sample shall be tested for workability.
- For each sample the temperature of the concrete shall be measured and recorded with the time the test was performed.
- For each mix of each grade the equivalent slump measured by the cone test shall be determined by trial mixes. Control shall be maintained by measuring the slump at the point of placing.
- The tolerance on acceptance will be +/- 25mm or +/- one-third of the target/control value, whichever is the greater.

Testing the Strength

A standard 150mm cube shall be made from each sample required by Clause 2.11 and stored and tested at 28 days in accordance with BS 8500.

One additional cube for testing at 7 days shall be taken from each sample until the concrete production has been shown to be to the Engineer's satisfaction.

Reporting the Results of Tests

The report of the tests for strength shall embody the information required by Clause 1.4 of BS 1881: Part 4, 1970, together with the information about the workability required by Clause 2.4, 3.4 or 4.4 of BS 1881: Part 2, 1970, and the information listed below:

a. Name of Contractor
b. Identification of mixer or ready mix supplier and depot.
c. Grade of concrete.
d. Type of concrete.
e. Section of work represented by sample.
f. Density of cube (kg/m3)

Compliance

Compliance with the strength shall be determined if:-

a. The average strength of each group of 4 consecutive test cubes for each mix exceeds the specified characteristic strength by not less than 3.0 N/mm2 or MPa and is not less than 8.5 N/mm2 or MPa below the mean strength determined for all previous test results for the mix.
b. Each individual result exceeds 95% of the specified characteristic strength and is not less than 16.0 N/mm2 or MPa below the mean strength determined for all previous test results for the mix.

Action to be taken in the event of non-compliance

a. The action to be taken in the event of non-compliance shall be determined by the Engineer, and may range from qualified acceptance to rejection and removal of all or part of the concrete cast between the previous set of 4 cubes and the next set of 4 cubes.

The Contractor shall provide at his own expense all records, samples, including core samples, tests and their results as may be required by the Engineer, whether the concrete has been finally accepted or not.

3.5.10.4 Finishes

Samples

Where directed by the Engineer in writing, full-scale reinforced concrete samples shall be built by the Contractor to demonstrate quality and finish for the Engineer's approval.

Such samples shall incorporate junctions, joints and applied finishes, unless otherwise agreed with the Engineer. Subject to agreement with the Engineer, such samples may be incorporated in the permanent works. Subsequent finished work shall not be inferior to the samples, which shall be used as models. The remainder of the work shall adopt the same methods as the sample construction.

Finishes to Formed Surfaces

All forms shall be well made and not liable to move or allow grout-loss. They shall be true to shape and free from defects likely to detract from the appearance of the finished concrete.

Whatever method the Contractor uses to obtain each finish, the same method (including the formwork, the release agent and the curing procedure) shall be used for the whole of each separate building or item of construction.

In the event of front runs evident upon removal of formwork, these should be carefully removed without delay with any additional remedial work carried out.

Type	**Finished Appearance**
Type A: Rough Finish	This finish is obtained by the use of properly designed formwork or moulds of closely-jointed panels formed from approved materials. Surfaces will be imprinted with the grain of timber boards and any mould or panel joints. Small surface blemishes caused by entrapped air or water may be expected. The surface should be free from voids, honeycombing and other large blemishes. The holes left for formwork bolts shall be filled. Fins and irregularities projecting more than 3mm shall be cleaned off.
Type B: Normal Finish	This finish is obtained by the use of properly designed forms of closely-jointed wrought boards, plastic, steel or other suitable material, provided that the surfaces shall be free from the imprint of the forms. Small blemishes caused by entrapped air or water may be expected, but the surface should be free from voids, honey-combing or other large blemishes. The holes left for formwork bolts shall be filled. Fins and other projections shall be removed and all blemishes filled with a cement and fine aggregate paste. Care shall be taken in the choice of any release agent used, to ensure that the finished concrete surface is not permanently stained or discoloured.
Type C: Superior Finish for exposed works	This finish can only be achieved by the use of high quality concrete and by using properly designed forms having a hard, smooth surface. The concrete surfaces should be smooth with true, clean arises. Only very minor surfaces blemishes should occur and there should be no staining or discoloration from the mould oil or curing agent. Fins and other projections shall be removed and all blemishes filled with a cement and fine aggregate paste that matches the colour of the original concrete. The surface shall be free from the imprint of wood grain. The material for the form shall be provided in large sheets and arranged in an approved uniform pattern: joints between sheets shall be arranged to coincide with architectural features; all joints between sheets shall be accurately aligned in the plane of the sheets. Visible bolt holes are not allowed.

For exposed finishes, fins and irregularities projecting more than 3mm shall be removed; the positions of formwork ties shall be to the Engineer's approval and the holes left shall be filled with a cement and fine aggregate paste to match the colour of the original concrete.

Types of Finish

Where details of the required finishes are not specified separately, the following definitions listed in the Table below Concrete Finishes (Unformed Surfaces) shall apply.

Table C 4.24 Concrete Finishes (Formed Surfaces)

Other Types of Finish

These shall include any finish different from A, B and C that requires the use of special forms or linings, the use of a different concrete mix near the surface, grinding, bush hammering or other treatment. If any of these special finishes is required it shall be fully specified on the Drawings.

Whichever method the Contractor uses for obtaining each finish, the same method shall be used for the remainder of the work.

Remedial treatment to the finish of the concrete, additional to that specified above, requires the approval of the Engineer.

Finish of Uniformed Surfaces

The finish of unformed surfaces shall be tamped, floated, trowelled or brushed as defined below and shown on the Drawings.

Table C 4.25 Concrete Finishes (Un-formed Surfaces)

Type	Finished Appearance
TF - Tamped	Tamped surfaces shall be formed by levelling and tamping the concrete to produce a uniform plain or ridged surface, surplus concrete being struck off by a straight edge immediately after compaction. It is also the first stage of the following finishes:
FF - Floated	Floated shall be a uniform surface which has been worked no more than is necessary to remove screed marks by hand with a wood float or by power float of a type approved by the Engineer. The surface shall not be floated until the concrete has hardened sufficiently.
ST – Steel Trowelled	Steel trowelled shall be a hard, smooth finish free from trowel marks formed with a steel trowel under firm pressure. Trowelling shall not commence until the moisture film has disappeared and the concrete has hardened sufficiently to prevent excess laitance from being worked to the surface. If laitance is brought to the surface it shall be removed.
BR - Brushed	Brushed shall be formed by first producing a floated finish and then, before the concrete has hardened, by drawing a wire broom over the concrete surface at right angles to the traffic flow to give an average texture depth of 1mm.

Plastic Cracking

If plastic shrinkage cracking occurs, the construction affected shall be rectified and the Contractor shall take all necessary steps to prevent a recurrence. Rectification method and results shall be subject to the approval of the Engineer.

Random drying Shrinkage Cracking and Plastic settlement Cracking

If any cracking of the concrete occurs in an uncontrolled manner, the construction affected shall be rectified and the Contractor shall take all necessary steps to prevent a recurrence. Rectification method and results shall be subject to the written approval of the Engineer. Such measures may include, but not be limited to:

Construction Joints

Construction joints, including stop ends and crack-inducing joints, shall meet the followingrequirements:

- Construction joints shall be at right angles to the member and shall have neat, clean lines. Formed joints shall be plain unless a key or surface rebate is specifically detailed on the drawings or called for by the Engineer.
- Where kickers are required they shall be placed integrally with the floor slab; this may necessitate a special design for the formwork. Kickers shall have a height of not less than 70mm and not more than 170mm above the floor slab or above any splay. Concrete in kickers shall be of the same mix as the main member. The concrete shall be vibrated or rammed into place and prepared as for other joints.
- Joints in columns and walls shall only be formed about 15mm above the soffits of suspended floors, at floor levels, or at the tops of kickers which shall not be less than 75mm. There may be a joint between haunches or column capitals and the column.
- Joints in other locations may be allowed at the discretion of the Engineer.
- Horizontal joints in exposed walls or columns shall be formed within a re-bate.
- In certain circumstances the Engineer may limit the number of joints allowed in a vertical member in accordance with the requirements of the design.

Location

The location of construction joints not shown on the drawings shall be subject to the Engineer's approval. The Contractor's proposals shall be based on the following guidelines:

- The number of construction joints shall be kept as few as possible consistent with reasonable precautions against the effects of shrinkage; their location shall take due account of shear and other stresses. Joint lines shall be arranged so that they coincide with features of the finished work and meet the requirements of any added finishes, screeds, etc..
- Vertical joints in walls generally shall not be spaced at intervals greater than 6m and in no case shall be more than 10m. Where, however, a wall changes direction by at least 60o, the overall spacing of joints may be increased to 10m subject to the length of pour in either leg of the wall being no more than 5m. Where possible joints shall be positioned at least 2m away from corners.
- Joints in beams and slabs if required shall be between the quarter and third points of the span unless otherwise directed by the Engineer. It is preferable that no joints are formed in end bays.
- Joints in ground slabs should be aligned with column or grid lines whenever practicable and diamond-shaped or circular separations shall be provided around columns.

Workmanship

Work at construction joints shall be in accordance with BS 8110 Part 1 Clause 6.12. The recommendations for joints to transfer tensile or shear stresses shall be followed. Roughening of the joint surface shall be carried out sufficiently to remove the outer mortar skin

Crack Inducers

Crack-inducers in ground slabs shall be fixed where shown on the drawings and used in accordance with the manufacturer's recommendations. Crack-inducers in reinforced concrete walls shall be used only after the Engineer's approval.

Joints, fillers and Sealants

Sealants

- Hot applied sealants shall comply with AASHTO M282
- Cold applied sealants shall be polysulphide based sealants complying with BS5212. In addition to the manufacturer's certificate of compliance with BS 5212 a certificate shall be provided confirming that the 5 second reading on the Shore Hardness Scale a, as measured by a meter in accordance with BS 2719, is less than 20o for a cured sample 7 days after mixing. The difference between the Shore Hardness measurement at 7 days and the measurement after the BS 5212 heat aging test shall not be more than 5o.
- For joints in kerbs and joints other than in pavements, gunning grades of two part polysulphide sealant complying with BS 4254 may be used.

Preformed Expansion Joint filler

Preformed filler shall comply with AASHTO M213.

Waterbars and waterstops

Waterbars and waterstops shall be of approved type with eyelets.

Dowel Bars

Materials

Unless specified otherwise, dowel bars shall be straight, round, smooth, marine grade stainless steel bars complying with BS 6744; the free end shall be sawn and free from burrs or other irregularities.

Bond-Breaking

Where shown on the Drawings, dowel bars shall be de-bonded with an approved de-bonding compound or proprietary dowel bar sleeve. The Engineer may require the Contractor to demonstrate the efficiency of the method of de-bonding by carrying out the test described below.

The average bond stress on de-bonded bars cast into concrete specimens and subjected to pull-out tests at 7 days shall not exceed 1.4mN/ m2 and the total movement of the dowel bar relative to the concrete shall be not less than 0.25mm at this stress. The concrete specimens shall be 150mm x 150mm in section and 450 mm long and made with the same mix proportions as used in the Works. The number of tests will be at the Engineer's discretion.

Compressible Caps

Caps shall be securely fixed and shall permit free movement of one end of the bar.

Workmanship

Dowel bars shall be rigidly supported so that they are correctly aligned.

3.5.11 Pre-Cast Concrete

3.5.11.1 References

This Specification shall be read in conjunction with the following documents.

- BS 8110: Design of Reinforced Concrete Structures
- BS 6349: Maritime Structures, part 1 (2000) and part 2

(1988)

3.5.11.2 Products

Certification

In addition to any requirements elsewhere in the Contract, two copies of test certificates for each consignment of materials to be used in the concrete and for any reinforcement shall be supplied by the Contractor to the Engineer as required by this and any supporting specification document at least 10 days prior to commencement of concreting works.

This requirement may be waived in the case of standard proprietary units, or where auto-control methods of testing cement or other materials manufactured on a continuous basis may be acceptable, subject to the approval of the Engineer.

Uniformity

Where the visual appearance of the unit is especially important (e.g. coloured architectural units) the cement and aggregate shall be obtained from the same source throughout the casting period for the units concerned. Where the manufacturer cannot satisfy the Engineer at the outset that a continuous supply of uniform aggregate is assured, sufficient aggregate for the entire quantity of units concerned shall be obtained and stockpiled by the manufacturer before casting commences.

Moulds

Except where a particular material is specifically excluded within this or any other supporting Specification, acceptable materials for mould construction may include timber (plywood), steel, GRP, polypropylene or concrete as appropriate, and shall be subject to the approval of the Engineer.

3.5.11.3 Execution

Design

Except where the design had been carried out by the Engineer, the manufacturer or Contractor shall design the pre-cast concrete units from the information supplied by the Engineer in accordance with BS 8110.

The design and detailing of lifting points, bearings or other special items associated with any pre-cast unit shall be in accordance with BS 8110.

In all cases, the manufacturer or Contractor shall prepare detailed drawings of the units and shall be responsible for the accuracy of these drawings. The detail drawings shall clearly indicate all inserts, anchors, openings, lifting devices, centre of gravity and weight of each unit. Identification marks of units shall be related to a key plan copies of which shall be supplied to the Engineer.

Reinforcement shall be provided if the unit is overstressed at any stage during handling, erection, temporary propping and permanent fixing.

All lifting eyes, bolts, cast-in sockets or other lifting or handling devices shall be designed to carry the maximum load which could occur at the point of attachment during lifting, handling or erection plus an impact allowance of at least 100%.

Devices for fixing the units in position in the structure or for connecting units to each other shall be designed for the maximum load occurring during the life of the structure or as specified by the Engineer. The manufacturer or Contractor shall ensure that all such devices are located and embedded in the units in accordance with the maker's specifications or, where these do not exist, with established Engineering principles. Embedded items shall be stainless steel.

Before commencing production the Contractor shall supply the Engineer, and receive approval of, two copies of the manufacturer's design calculations and drawings. The Engineer will verify the correct interpretation of his requirements but will not necessarily verify the dimensions. He will mark one copy of the calculations and drawings with his comments and return them to the Contractor. Upon approval, an additional copy of each of the final drawings of the units shall be supplied to the Engineer.

Design of Concrete Mixes

In addition to any requirements elsewhere in the Contract, two copies of certificates of test results showing the suitability of any designed mixes as required by Section MS10 Cast-in-Place Concrete shall be submitted by the Contractor to the Engineer for his approval.

Casting

Pre-cast units shall be cast in an approved manner in one complete operation. All pre-cast units shall be vibrated and top surfaces shall be finished with vibrating screeds or plates to ensure the surface is properly 'sealed' unless otherwise agreed with the Engineer.

Construction Joints

Construction joints will not normally be permitted in a pre-cast unit. Where the shape of the units is such that casting in more than one operation is unavoidable, the manufacturer shall provide details of his proposals for the location and form of the construction joints for approval by the Engineer.

Mould Construction

Moulds shall be robustly constructed, closely jointed and free from surface defects that will affect the required pre-cast unit finish. Moulds shall be accurately dimensioned and designed such that moulds can be easily taken apart and reassembled.

Joints shall be caulked as necessary to prevent leakage of ‘fines’ material from the mix. All moulds shall be adequately braced or strengthened on the outside to prevent bulging or distortion during the compaction of the concrete.

Dimensional Tolerances

The tolerances given below apply to pre-cast units in their fully finished condition and the manufacturer or Contractor shall make provision in the design of the mould for shrinkage during curing and for the surface finishes specified.

Generally the tolerances of pre-cast units will be considered in relation to three centre lines or axes of the unit. Each of these centre lines or axes will normally, but not necessarily be perpendicular to the plane of the other two.

Unless specified otherwise each point of a surface, edge or corner of the units shall be not more than the following distance from its true position in space relative to these three centre lines or axes as shown on the drawings.

- 3mm for points not more than 500mm from any centre line or axis
- 5mm for points more than 500mm but not more than 3m from any centre line or axis
- 10mm for points more than 3m from any centre line or axis.

In defining straightness, the following tolerances on allowable deviation from the intended line shall apply:

- Units up to 3m length +/- 6mm
- Units 3m to 6m length +/- 9mm
- Units 6m to 12m length +/- 12mm

These limits define the tolerances on straightness and squareness and when any one of these tolerances is exceeded, or the combined effects of two or more cause any tolerance to be exceeded, the unit concerned shall be rejected.

Fixing, fittings and all cast-in items are to be in their true position relative to the centre line or axes to within 5mm.

Any or all of the above requirements may be varied by the Engineer if the accuracy of the face edge, corner or cast-in item is not suitable for structural reasons or for reasons of appearance or for the proper assembly of the unit or other adjacent units or components.

Curing

Curing by high pressure steam, steam vapour or other accepted curing process may be employed to accelerate the hardening of the concrete and to reduce the minimum curing time defined in this materials specification, provided the manufacturer obtains the prior approval of the Engineer to his proposal methods.

Cutting

No unit shall be cut, drilled or chased without the prior approval of the Engineer.

Handling, Stacking and Transporting

The Contactor’s proposals for handling, stacking and transporting of pre-cast units shall be subject to the approval of the Engineer.

The sides of the moulds may be struck after 24 hours provided the concrete has cured to the satisfaction of the Engineer. The Contractor shall take all necessary precautions to protect ‘struck’ concrete from the effects of more rapid cooling and moisture loss.

In no circumstances shall a pre-cast unit be moved, struck or propped until the strength of concrete has met any specified durability test limit, reached a minimum strength of 25N/mm2 or 3 times the maximum compressive stress to which it may be subjected through any such handling and placement, unless otherwise agreed with the Engineer. Moving, striking or propping shall be carried out carefully so that no shock force or vibration occurs which could damage the concrete.

Lifting shall always be carried out by means of the designed lifting points with the unit hanging in the manner for which it was designed.

When stacking pre-cast units, care shall be taken to ensure units are not overstressed. Stacking shall be managed such that units will be used in the permanent works in order of age. Pre-cast units stacks shall be shielded from the direct rays of the sun and wind effects.

Pre-cast units shall not be moved from storage until they are at least 21 days old and the concrete has attained a minimum strength of 95% of the required 28 day characteristic strength based on a minimum 3 cubes test results.

Pre-cast units shall not be used in the permanent works until the 28 day characteristic strength determined by tested cubes have shown satisfactory results, unless otherwise agreed with the Engineer.

Protection

The pre-cast units shall be adequately protected at all stages of manufacture, handling and storage and also during and after erection on site.

Where the finished appearance of the unit is especially important e.g. for coloured architectural units, care shall be taken to ensure that any protection materials themselves do not cause staining of the exposed faces of the units.

Where necessary, projected reinforcement shall be well coated with cement, grout or other approved material to prevent rust staining of exposed surfaces.

Marking

Units shall be indelibly marked during manufacture in a position which will not show on the finished elevations with the following details as a minimum:

- The location or identification symbols shown on the detail drawings and the erection key plan;
- The date of casting;
- The way up for handling, transporting and building in;
- The lifting points.

Repairs

The Contractor shall keep a fully detailed record of any repairs carried out to each unit.

A copy of this shall be provided to the Engineer not later than 7 days before delivery of the unit to site.

Inspection and Testing

Inspection

The Engineer shall be afforded the facilities to inspect the materials and the workmanship at any state during the manufacture of the pre-cast concrete units and he shall have the right to reject any materials or units which do not meet the specified requirements.

Testing of Concrete

The concrete shall be tested in accordance with the requirements of Section "Cast-in-Place Concrete".

Erection

Notwithstanding any requirements stated in accompanying specification documents, all precast units shall be erected to the lines and levels shown on the drawings.

The units shall be lifted, and supported in their final position both temporarily and permanently, in such a way that they will be stressed only in a manner for which they were designed.

The units shall be adequately braced and supported during erection to ensure proper alignment and safety and such bracing or support shall be maintained until there are adequate permanent connections.

Dimensional Tolerances in Erection

Pre-cast elements shall be subject to the following tolerances, unless specified elsewhere. Each unit shall be erected or located such that each surface edge or corner of a unit shall be not more than the following distance from its true position in space relative to the main setting out lines and datum level of the structure:

- 8mm for units not more than 1m overall in any direction
- 10mm for units more than 1m but not more than 6m overall in any direction
- 15mm for units more than 6m overall in any direction

In addition to the above, each surface edge or corner shall not be more than 5mm from its true position in space relative to the corresponding surface, edge or corner of the adjacent unit or units.

Any or all of the above requirements may be varied by the Engineer if the accuracy of the position of the units is not suitable for structural reasons, for reasons of appearance or for the proper assembly of the unit or other adjacent units or components.

Erection Mock - Up

Where units are to be erected together to form a larger unit a mock-up for trial of erection methods and suitability of tolerances shall be provided and erected, to the satisfaction of the Engineer.

3.6 Chapter C5: Practical Construction Guidance

3.6.1 Overview

The engineers task is to produce a solution that is technically sound, cost effective and that can be built without undue difficulty or danger. This should be based upon techniques that can be practically achieved within the atoll environment in the Maldives and within specified timescales. The main message regarding building climate resilience into coastal protection measures is simplicity of design which is often the key to a successful scheme in the Maldives. It is important for designers to foresee and avoid practical problems that may occur in building a coastal protection structure on an island. This is because often difficulties can arise necessitating cooperation between the designer and the contractor to produce solutions. Some problems may be better dealt with by re-designing elements of a scheme rather than making major alterations to the proposed method of construction (i.e.: see Option 2 in Chapter B3). This Chapter is therefore as relevant to the designer of a coastal protection scheme s to those building them.

The following sub-sections outline some of the special factors that need to be taken into account when building climate resilience into coastal protection structures, over and above the normal considerations for any normal construction project.

3.6.2 Access to the Site

Access to many sites in the Maldives is not only challenging (depending on access through reef systems) but also expensive to get to in many instances. With regards to access along the beachfront on many islands, it is important to carry out some initial reconnaissance prior to the project starting, to ensure that good access is possible for the equipment and materials needed for the project. In addition, finding adequate space for the safe storage of materials is key. Access routes also need to ensure minimal environmental impact or damage.

Access from the sea may be difficult if an island does not possess a harbour of sufficient draught for dredgers to operate from. The construction of a temporary jetty may be a solution from the reef edge to be able to allow site equipment to be brought onto the island.

Standard procedures in operation for dredging apply and are not altered in this Chapter.

3.6.3 Construction Plant and Methods

The suitability and availability of plant is an important factor in the efficiency of building coastal protection defences in the Maldives. This issue needs to be taken into account both during the design phase and when planning the construction programme.

The machinery and equipment to unload rock from barges onto islands is often not available in the Maldives and all exists overseas. Therefore the construction phase of developments is costly and often takes time as machinery needs to be hired for the job. Purchasing this machinery is not often undertaken as there can be many months "window" between projects that need this equipment (eg: "caterpillar excavator machinery is not used every week). An agreement needs to be reached with Sri Lanka or India to have a suitable supply of machinery "on stand-by" which maybe accessed by Maldivian contractors at suitable rates.

3.6.4 Sourcing Local Materials

Importation of rock/material from India is common. However there are restrictions imposed from the Indian Govt on vessels entering Indian ports that are 10 years old or more. This impacts significantly on Maldivian contractors being able to import rock from Indian Ports. There is also a key problem regarding Maldivian companies being able to get the appropriate level of Professional Indemnity insurance cover to use boats for importing rock. It is understood that some leniency (3 months PI cover "grace") is now being permitted on Maldivian import of rock. This needs to be reviewed and formalised through GoM intervention.

When a new harbour is created, often the dredged material is almost always used for land reclamation. Nothing is used for beach recharge elsewhere on the island. If not enough material is created for reclamation, it should be the role of the EIA to identify alterative sediment "reservoirs" for sourcing materials (borrow areas identified by local consultation).

3.6.5 Contract Documentation

Maldivian contracting procedures need to be reviewed to ensure that climate uncertainty is incorporated into the content of a contract. There appear to be many examples of local contractors having to "rush through" a project due to time constraints imposed on them by developers and / or financiers. Climate factors are not precise (as defined clearly in Chapter C1 and C2 and a number of uncertainties are inevitable when a contractor is forced to cost for the coastal protection project.

Currently, the process is quite routine and reflects international normal procedures. Following the detailed design of a project and receipt of planning approvals from the GoM, the project and tasks are documented to facilitate tendering and construction. Contracts are generally structured so that the delivery of the completed project at a specified time and cost is the responsibility of the contractor. As such, the contractor accepts the legal, financial and managerial obligations of the project. The common problem in the Maldives is that is essential that the contractor not only has a good understanding of construction contracts to ensure the sound management and operation of a project but also aware of the variances that occur between islands within the same atoll (i.e.: one design for one island is unlikely to be effective and work on a neighbouring island. Similarly, it is equally important that the engineers who assist in the formulation of the contract document have a good understanding of both climate resilience, coastal dynamics and construction contracts to ensure the document is not deficient in some technical or legal aspect (i.e.: climate resiliency), or prove to be burdensome to the contractor and ultimately the project.

Most Maldivian contracts for dredging and land reclamation follows standard government and large engineering consulting firms contract documentation which is often used on almost all projects with the inclusion of a section on *Technical Specifications (or Standards)* prepared exclusively for each project. Contracts are generally structured so that payments to the contractor are based on one of the following three methods (or a combination):

- Lump Sum – pay an agreed fixed sum of money for the completion of a project conforming to the plans and specifications.
- Unit Price – pay an agreed sum of money for each unit of work completed on a project (e.g. dredging charged at cost per cubic metre rate).
- Cost Plus Fee – reimbursement of all costs plus additional management fee. This is used where the scope of the work cannot be well defined. It is more difficult to control the contractor and is less popular than Lump Sum and Unit Price Contracts.

With regard to this Guidance Manual, careful consideration needs to be given to the unique factors which affect work in the coastal zone and in particular, the variances that may arise due to the onset of climate change. It is realistic to assume that in the coming decade that an increased frequency of downtime and delays in construction project schedules will occur in the Maldives due to numerous environmental influences such as:

- increased frequency of unfavourable wave conditions;
- strong or unfavourable currents occurring between islands ("kandus" – McCue 2000);
- stronger winds;
- elevated water levels and/or flooding
- increased frequency of intense rainfall events leading to drainage issues.
- increased sedimentation rates infilling dredged excavations or removal of deposited sediments (beach replenishment) during the contract period.

In the Maldives, other special conditions may also apply, such as navigation or vessel passage allowances, which can cause significant delays in project schedules.

GUIDANCE MANUAL NOTE 12

The Guidance Manual identifies the need for the GoM to consider a review of contract specifications to consider climate change risk, which is currently omitted from all contracts. It is the responsibility of both the developer and the contractor to consciously identify each of these risks which may reflect on a particular project and then decide the level of risk sharing to be borne by both the developer and the Contractor.

If the developer decides, for example, that all climate change related risks should be borne by the Contractor, in which case the tendered prices are likely to be higher to reflect the greater proportion of risk to which the Contractor is expose. The implication of this for the Maldives is potentially fewer island reclamation projects and the need to reconsider some major project development on outer islands.

PLANNING GUIDELINES

PART D

Future design and implementation of coastal protection structures will be able to confer resilience to climate change with planning

As a result, contract documentation itself needs to become climate proof. It needs to provide for agreements as to how risks will be shared between GoM and the contractor to account for climate change vagaries.

It is therefore proposed that future contract documents include the following "potential downtime" aspects for more detailed assessment and agreement PRIOR to any contract being accepted by either party:

- extremes in operating conditions, e.g. waves, winds;
- latent conditions, e.g. rock, soft sediments, debris, discovery of unexpected sites or artefacts of cultural significance;
- climate change conditions, e.g. results of storms – sediment scouring and deposition, damage to partially constructed works, or to equipment etc..

4 PART D: PLANNING GUIDELINES

4.1 Chapter D1: Updating Existing Environmental Regulations

4.1.1 Overview

Coastal protection confers climate change resilience by reducing the risk inherent from coastal erosion, tidal inundation and coastal flooding. That means that coastal risk areas are those currently at risk and those additional areas that are likely to be at risk in the future as sea level continues to rise unless the impacts of sea level rise can be effectively mitigated. The project field mission (CTL Consult Ltd 2012 c) identified a number of shortcomings to existing practices for the building of coastal protection structures, namely:

1. Inadequate feasibility assessment increasing the risk that structures will not preform to their design level.
2. Poor engineering design often utilising common designs at all locations without determining whether structure design matches specific need.
3. Poor construction standards so that built structures do not perform to their design performance standard or duration.
4. Inadequate maintenance that reduces the durability and functional lifetime of a structure.
5. In adequate drainage of reclaimed land that can in itself create flooding problems and/or exacerbate flooding.
6. Uncritical "sign-off" at construction completion to ensure that the engineering design has been followed.

Without planning to address these shortcomings it cannot be assured that future design and implementation of coastal protection structures will be able to confer resilience to climate change. The existing EIA process for the Maldives includes procedures that, if followed, would address and improve the planning process for coastal protection construction and address these shortcomings. A more rigorous application of the EIA process could also link the construction of coastal protection structures more closely with aspects of land-use regulations (see Chapter D2) and existing or future building codes thereby ensuring a more integrated process for building climate change resilience into planning.

Every project is designed with some assumption about the climate in which it will function. The conventional way is to assume that the climate of the past is a reliable guide to the future. This is no longer a good assumption. Thus design criteria must be based on probable future climate that is climate change over the life of the project. Accordingly, EIA of projects and activities should consider not only the effects of the project on the environment, but also the impacts of impending climate-related changes on the project or activity (i.e. the impacts of the environment on the project).

This Chapter is focussed on identifying how climate change could become indoctrinated and instilled into the **existing EIA process** in the Maldives. It identifies a number of stages required to do this. If agreed by stakeholders, this should be set against specific clauses of the existing EIA regulations (2007). Once this is achieved, the outcomes of embedding climate change principles within the EIA process could be extended to be also introduced into other regulations and codes, e.g. land-use planning regulations and building codes.

Building climate change analysis into the EIA process has been considered by a number of previous projects. The following text is based on the recommendations made by the project: *"Adapting to a changing climate in the Caribbean and South Pacific regions – Guide to the integration of climate change adaptation into the Environmental Impact Assessment (EIA) Process"*[11]. (see Appendix 2). These stages have been modified to be focussed on climate change resilience and the engineering of coastal protection structures.

4.1.2 Including Climate Resiliency into the Environmental Impact Regulations (2007)

The integration of climate change considerations should be undertaken within the existing environmental impact assessment framework, with little modification to existing processes and procedures. When considering the impacts of climate change, the EIA process evaluates a project's potential environmental risks and impacts in its area of influence; identifies and evaluates potential impacts from the proposed project on the project's area of influence; examines project alternatives; identifies ways of improving project selection, siting, planning, design, and implementation by preventing, minimizing, mitigating, or compensating for adverse environmental impacts, and enhancing positive impacts; and includes the process of mitigating and managing adverse environmental impacts throughout project implementation.

The following represents a key "preamble" to the proposed update to the EIA Regulations to address climate resiliency for coastal protection structures:

- Environmental Impact Assessment (EIA) is mandatory for development projects in the Maldives under the Environment Protection and Preservation Act of the Maldives (Law No: 4/93). Under this Act, a uniform set of procedures for EIA was adopted in 2007 in the form of Environmental Impact Assessment Regulations (2007).
- In the Maldives, all environmental management and protection, including EIA, is the responsibility of the Environmental Protection Agency (EPA). The EPA is a legal regulatory entity, working under the supervision of a governing body under the Ministry of Environment and Energy (MEE).
- Whereas some developments with less significant environmental impacts can pass through the EIA regulations without a full EIA study, coastal protection schemes12are identified in the Regulations (Schedule D) as necessitating a full EIA study.
- With climate change projected to have a measurable effect on the environmental impacts of coastal protection developments, it is important to assess these impacts in combination with climate change effects. This is necessary in order to provide a realistic assessment of environmental impacts of a coastal protection project over its operational lifetime.
- The following text is presented for use as supplemental guidance to the existing EIA Regulations in order to guide EIA practitioners and developers in the inclusion of climate change effects in assessment of environmental impacts in coastal protection developments.

4.1.3 Proposed Appendix Update to EIA Regulations

4.1.3.1 Coverage of this Appendix

This Appendix covers all Development Proposals which

GUIDANCE MANUAL NOTE 13

This Guidance Manual presents a simple way to incorporate climate change into the existing environmental regulatory structures in the Maldives. This is needed as at present in the EIA process, it is an implicit assumption that the impacts of developments are "static" through the planning horizon. However, projections indicate that climate change will increasingly affect certain aspects of the environment over time and thus this "static" model becomes less valid in some cases. As such, it is proposed to build in estimates of climate change into the assessment of impacts in order to accommodate projections and "climate proof" the EIA process so that future coastal protection selection and their designs become as robust as possible.

[13] http://www.caricom.org/jsp/projects/macc%20project/accc.jsp

[14] For the purposes of this Appendix, 'coastal protection structures' is deemed to include any form of hard or soft engineering intervention and includes harbour, jetty and overwater structures

include coastal protection schemes identified in Schedule D of the EIA Regulation: construction / dredging harbours, construction of jetties, construction of marinas, sea defence structures and beach nourishment. In addition, this Appendix covers any Development Proposal included in Schedule D which involves construction of coastal protection as part of the Development Proposal.

4.1.3.2 Aim of this Appendix

At present the EIA process, elaborated in the Regulations, does not incorporate climate change. There is high vulnerability associated with the shoreline in the islands of the Maldives. Projections for climate change suggest that this coastal vulnerability will increase in the future. The consequences of this are two-fold: (i) the design of coastal protection structures must consider these future conditions in their design (this is covered by the Performance Standards for Coastal Protection Schemes – see Part C (Chapter 1), (ii) the environmental impacts of coastal protection schemes must include climate change effects.

For any identified environmental impacts caused by a project, the effect of climate change over the planning horizon on these impacts shall be identified, quantified as much as is possible and documented. Climate change may exacerbate the identified impacts of a project over the planning horizon, or in some cases it may reduce the impact over time. In EIA's covered by this Appendix, Development Proposal impacts are to be considered within the projected scenarios of climate change over the stated planning horizon.

As a theoretical example, for demonstrative purposes, it may be that a Development Proposal (involving coastal protection with a 30 year planning horizon) involves an impact on a small coastal wetland area through partial disruption of natural rainwater drainage or infiltration rates. In present day conditions, this development impact does not affect the functioning of the wetland system or the constituent flora and fauna. However, climate change projections suggest that rainfall intensity will reduce over the coming decades and contribute to increased desiccation of the wetland. Consequently, during the planning horizon, the reduction of infiltration (natural drainage patterns) caused by the Development Proposal, exacerbated by the reduction in rainfall projected by climate change, may lead to a loss of integrity and functioning of the wetland. As such, the impact of the Development Proposal, coupled to climate change effects on the wetland would be deemed to be significant and thus could halt the Development Proposal, necessitate re-design or require mitigation (such as addition of a wetland rainwater infill culvert).

4.1.3.3 Inclusion of climate change

For Development Proposals covered by this Appendix, the following interpretations shall apply to the EIA regulations:

- In part II ("Project Planning"), section 4 (1) where it states that "sound project planning takes into account all policies and regulation" this should now include climate change effects and impacts and building resilience in the coastal zone.
- In part II ("Project planning"), section 9 (2) it states that "The Environmental Impact Assessment on a Development Proposal shall ensure that all environmental parameters have been addressed and their consequences recognised and taken into account in the project design". This statement is interpreted to include changes in the environmental impacts due to projected climate effects over the planning horizon of the project (i.e.: no substantive change but a qualification statement is needed).
- In part III ("Application for an Environmental Decision Statement"), section 7 (2), paragraph 2 it states that "during the scoping meeting the main environmental issues related to the development proposal shall be discussed between the Ministry and the proponent or his / her designate and the Terms of Reference will be agreed upon by the proponent and the Ministry". The term "main environmental issues" in this statement is interpreted to include the effects of climate change. The Terms of Reference agreed at the scoping meeting shall include the tasks that seek to better understand effect of climate change on the Proposed Development. These tasks will need to be undertaken unless a fully justified and conclusive case can be made by the proponent that the effects of climate change will have no effect the potential impacts of the project.

4.1.3.4 Contents of an initial environmental study or an EIA study

For Development Proposals covered by this Appendix, the following interpretation shall be used of in the contents of an EIA study (Schedule E):

Description of the Natural Economic and Human Environment sub-section, under "*Other attributes of the locality*" a description as quantitative as possible shall be included on the projected climate change and impacts on all the relevant aspects identified in this sub-section.

Assessment of Direct and Indirect Environmental Impacts shall involve consideration of the best available projections on climate change and include an assessment of the effect of climate change on the magnitude / frequency / severity of each of the identified the impacts of the Development Proposal over the planning horizon. Development proposal impacts shall be considered in combination with project climate change impacts.

Evaluation of Alternatives Including No Development Option sub-section, shall include one or more development options which involve alternative coastal protection schemes. If the Development Proposal is proposing use of a "hard" coastal protection scheme then at least one alternative should involve a "soft" engineering schemes through which an same performance standard and can be achieved. Reference to procedures set out in Part C of the Coastal Protection Guidelines is a required action here.

Selection of the Preferred Alternative and Mitigation Measures sub-section shall consider the coastal protection resilience that is provided by Development Proposal and the alternatives and also the overall climate change resilience provided by the Development Proposal. Overall climate change resilience includes not just the physical protection offered by proposed coastal protection schemes but also other dimensions relevant to the local people and situations such as demographic, economic, natural resource sustainability and cultural values and ties. The discussion of the preferred option should include justification of the selection based on at least (i) cost, (ii) coastal protection performance and (iii) coastal resilience. The consideration of overall coastal resilience and the effect of the Development Proposal on overall resilience should involve public consultation with both island-level governmental and local people affected by the Development Proposal.

Environmental Monitoring Plan sub-section shall include monitoring of impacts of the project which are affected by climate change (as per Part F of the Coastal Protection Guidelines).

4.1.3.5 Schedule I – Review of initial environmental examination study or EIA study

For Development Proposals covered by this Appendix, the following interpretation shall be used of in the Review Form (Schedule I):

2. **Policy and Legislative Framework** shall consider conformity to climate change.

5. **Impact Prediction** shall consider climate change and ensure that all impacts have been addressed, methods used to consider climate change are clearly described and limitations defined.

6. **Alternatives to the Proposed Development** shall ensure that appropriate, realistic and valid possible alternatives that provide adequate performance standards have been considered, including "soft" approaches where possible. In addition, it shall consider the validity of the process for selection of the preferred alternative (see Part C of the Coastal Protection Guidelines).

8. **Monitoring** shall ensure that all impacts of the project affected by climate change are monitored and that monitoring parameters of climate change related impacts are relevant and nationally appropriate.

4.1.3.6 Schedule M – Format of Environmental Monitoring Reports

The Format of Environmental Monitoring Reports (Schedule M) shall include in the Final Report in the section "*comments, recommendations and conclusions from the monitoring period*" an analysis of the extent to which climate change has affected the predicted impacts of the development as identified in the EIA over the lifetime of the project.

4.2 Chapter D2: Updating Existing Land Use Planning Regulations

4.2.1 Overview

Embedding a rigorous analysis of climate change and its impacts within the EIA process, as outlined in Chapter D1, shall help significantly to ensure that the design and completion of coastal protection structures is made with recognition of the needs and demands of climate change resilience. The overall planning process, which should direct and steer how engineering interventions are instigated, should be based on established principles designed to ensure that rigorous measures are applied to the planning process.

The intention of this Chapter is not to provide a summary of existing Land Use Planning regulations (LUP), instead, a tailored focus on how roles and responsibilities of key organisations within GoM (namely the Ministry of Energy and Environment -MEE) need to improve to ensure these Guidelines are adopted and mainstreamed into land use planning within the Maldives.

Details specifically linked to the Environmental Protection Zone (EPZ) are presented separately in Chapter D4.

GUIDANCE MANUAL NOTE 14

This Guidance Manual promotes the use of Vulnerability Assessment within land use planning for Maldivian islands. The VA should determine erosion/ inundation areas (using specialist advisors with expertise in physical coastal processes).The outcome shall be clearer understanding hazards and their nature and erosion/ inundation area assessments that would comprise of assessing extreme coastal water levels, better understanding current mean sea level heights on each island (critical) and from this, undertake inundation modelling and mapping exercises. The outputs (maps etc) shall be used within future revisions and update to island land use plans.

4.2.2 Recommendations for MEE input into existing LUP regulations

The Ministry of Environment and Energy (MEE) are statutory consultees to the Land Use Planning (LUP) which is the responsibility of the Ministry of Housing and Infrastructure. LUP is important as it sets the spatial planning strategy for islands and provides the context within which EIA works.

In the context of climate change and resilience, the oversight of the LUP by the MEE should be focussed a robust evaluation of "Vulnerability Assessments" (VA) that identify the areas of islands that are under threat from erosion and/or inundation as a key stage that must precede the choice of management interventions. This assessment should consist of drawing up a vulnerability report using indicators (hazards, stakes, risk perception, policies and management measures taken). This would then clearly report, for each island, measures of damage that could be caused by the hazard should it take place and thereby inform the likely coastal protection requirements.

The climate change criteria that should be used for this assessment is set out below. A template for coastal protection evaluations and appraisals is also included in Appendix 3.

4.2.2.1 Identifying coastal threats

Current planning and design for engineering of coastal protection structures should, as part of the EIA process, take into account the dynamics of existing coastal processes and island dynamics and evaluate their consequences as part of the impact assessment within EIA. These performance standards do not seek to replace the approaches and methodologies that achieve that purpose. Rather the measures outlined below seek to ensure that the intensification of coastal threats that will arise as a consequence of climate change are accounted for in the planning and design of coastal protection structures for the Maldives.

4.2.2.2 The impact of climate change

Climate change is projected to have a significant impact on the coastal zones of all Maldivian islands, especially through sea-level rise and intensification of storm activity. This increasing coastal risk will occur over a long timeframe and significant changes are generally not projected to be experienced until 2030 or later. However, land-use planning decisions have long-term implications and most urban development cannot easily be relocated. Thus it is important that the planning of coastal protection structures for climate change resilience is instigated now. Maldivian islands already experience flooding largely arising from storm activity leading to surges that increase run-up on beaches and/or overtopping of existing structures. In addition some astronomical high tides raise sea level such that low lying areas can flood – this is often exacerbated where there are gaps in existing coastal protection structures, for instance, to facilitate drainage of rain water. However, the implications for the islands of the Maldives from climate change are that these events are likely to become exacerbated by a progressive worsening of coastal threats as detailed below.

- Coastal erosion:

  i. Increased water levels will accelerate coastal erosion.

  ii. Sediment transport patterns may be altered by shifts in wave direction triggering changes to the form and location of shorelines.

Performance outcomes	Acceptable outcomes
1. Development in an erosion inundation prone area (i.e.: within the Environmental Protection Zone)	
Development is to be located outside the part that is in the erosion/inundation prone area (i.e.: EPZ)	Development is: Located outside an erosion/inundation prone area. Redevelopment that intensifies the use of a site and mitigates increase in risk to people and property from adverse erosion/inundation impacts. Planned against the practical design life of the development in the context of future erosion/inundation threat. Compatible with the installation and maintenance of on-site erosion/ inundation control structures.
Coastal-dependent development is to mitigate any increase in risk to people and property from adverse coastal erosion/inundation impacts.	Development: installs and maintains coastal protection works to mitigate adverse impacts to people and property from coastal erosion/inundation at the location, or locates, designs and constructs relevant buildings or structures to withstand coastal erosion/inundation impacts.
	Note: The following information should be provided to demonstrate compliance with this performance outcome: assessment of the erosion/inundation hazard at a property scale; plans showing the intended location, materials and method of construction for any structures; a report certified by a registered professional engineer that demonstrates this performance outcome will be achieved.
Development within an “urban” locality 9or as defined by an Island Council) is located outside a medium coastal hazard area unless: it does not result in an increase in the intensity of development on the site, or; it is consistent with a relevant adaptation strategy prepared for the area to address coastal hazard risks, or a risk assessment demonstrates that development avoids any increase in risk to people or property from coastal hazard impacts.	Development: is located outside the medium coastal hazard area, or consistent with a relevant adaptation strategy, or is located, designed, constructed and operated to avoid adverse coastal hazard impacts (including impacts on the development’s on-going operation) as demonstrated by a risk assessment prepared to support the development proposal.
Development for essential community service infrastructure is to be located, designed and constructed to ensure it is able to function during and after a recommended storm-tide inundation event.	Essential community service infrastructure is: located in an area that is above the recommended storm tide event level (RSTEL), or located and designed to ensure any components of the infrastructure that are likely to fail to function or may result in contamination when inundated by storm tide inundation (e.g. electrical switchgear and motors, water supply pipeline air valves) are: located above the RSTEL, or designed and constructed to exclude storm tide intrusion/infiltration. Development maintains existing natural environmental features to mitigate impacts from storm-tide inundation and permanent inundation due to sea-level rise.

Development is located, designed and operated to avoid adverse impacts on areas of high ecological significance; or where avoidance is not feasible, impacts are minimised and an environmental offset is provided for any residual impacts if the development is for: urban or rural residential purposes within an urban locality; or development associated with a port or airport; or low impact tidal water intake or discharge infrastructure for development on land; or extraction purposes within a key resource area	Measures are incorporated as part of location and design to protect and retain identified ecological values and underlying ecosystem processes within and adjacent to the development site to the greatest extent practicable. An environmental offset is provided for any permanent, irreversible loss of identified ecological values in the area of high ecological significance caused by the development.

iii. Low-lying areas are more likely to be permanently inundated.

iv. Increased storm activity will escalate the severity of coastal erosion events.

- Storm-tide inundation:

i. Sea-level rise will increase the severity of storm-tide inundation and will cause inundation to occur further inland.

Increased storm intensity will add to the magnitude of storm-tide events and the extent of inundation.

4.2.3 Recommended performance standards for LUP

As part of their consultation of LUP, MEE shall take into account the following performance outcomes to inform their response mindful of the likely requirements that LUPs may impose for coastal protection structures. The following Table D1 possesses a similar style to the performance outcomes table set out in Chapter C1.

Table D 1 Proposed future adoption of Land Use Performance Outcomes for the Maldives

The following Table D2 outlines that for any development that is subject to an actual development "commitment" (i.e.: a permit is accepted etc.), the following should be adhered to as part of the LUP performance standard.

Table D 2 LUP criteria for committed developments in the Maldives

For development subject to a development commitment
Planning period equivalent to expected asset life of the development as outlined in table D3
Projected sea-level rise of amount outlined in table D4, based on expected asset life
Adoption of the 100-year average recurrence interval extreme storm event or water level
Increase in storm intensity by 10 per cent by 2100 (relative to maximum potential intensity) due to climate change

Table D 3 Assessment factors for determining flood/ erosion prone areas and storm-tide inundation areas.

type of development	planning period (based on anticipated asset life
Short-term tourist accommodation	25 years
Residential dwelling, prefabricated structures	25 years
Residential dwelling, concrete structure	40 years
Utility infrastructure	35 years
Industrial building	30years

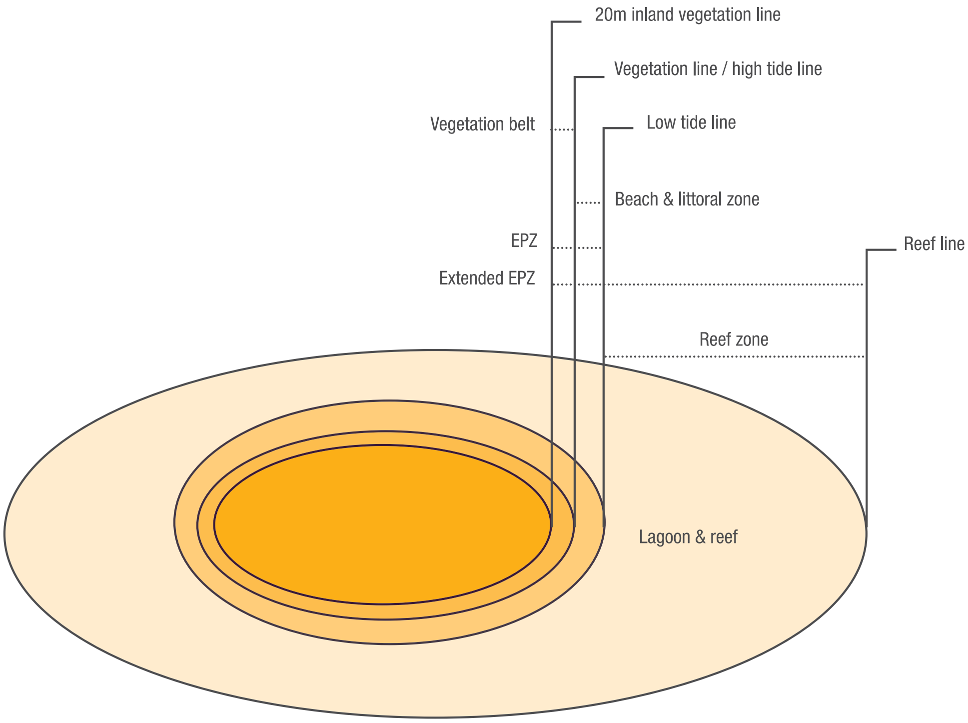
Table D 4 Planning period for development to be defended by coastal protection structures.

End year of planning period	projected sea level rise relative to 2000 baseline
Year 2030	0.2 metres
Year 2040	0.3 metres
Year 2050	0.4 metres
Year 2060	0.5 metres
Year 2070	0.6 metres
Year 2080	0.7 metres
Year 2090	0.8 metres

GUIDANCE MANUAL NOTE 15

For the purposes of this Guidance Manual, it is recommended that The Ministry of Tourism ensure that the TRDR will comply to, or pay due cognisance of, the updated EIA Regulations (see Chapter D1) AND that all tourism development contracts comply to the engineering guidance set out in PART C for any tourism development that requires any coastal protection structures.

Year 2100	0.9 metres



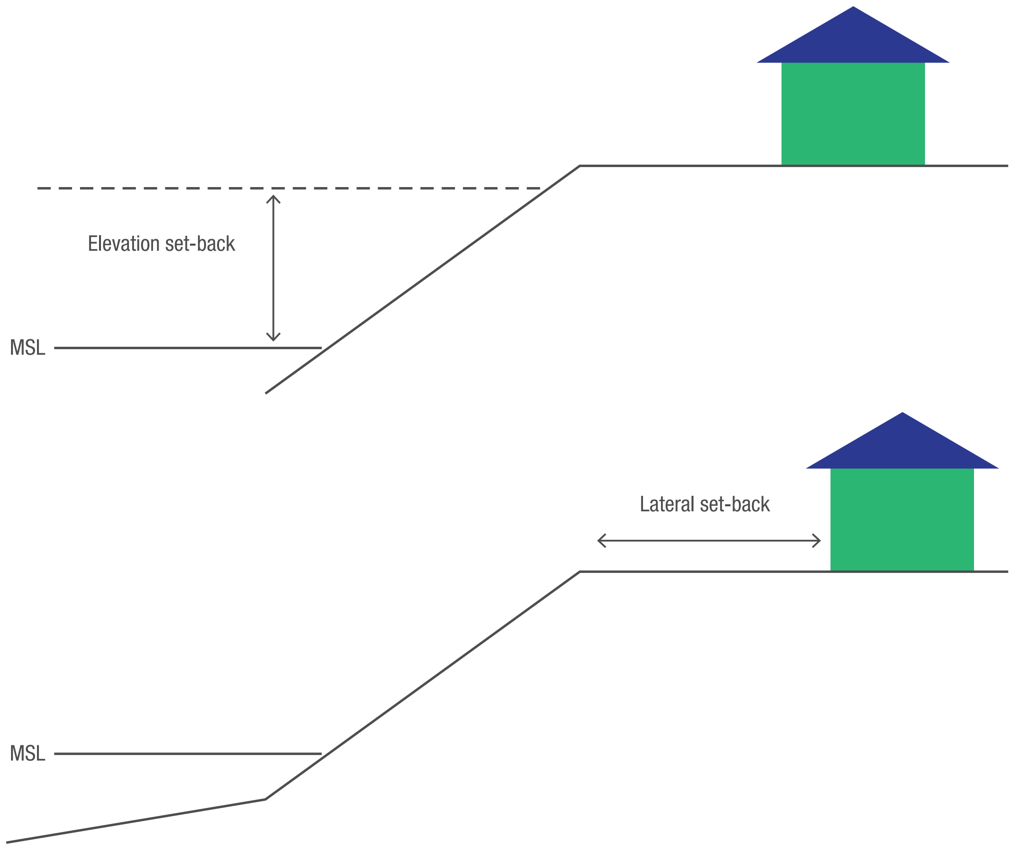
NB: Note that sea level rise is not predicted to rise on a linear trajectory, but on an exponential trajectory. By using a linear rise of sea level, a 'safety' margin to cover the current high uncertainty of predictions is built into planning process

A Registered Professional Engineer with expertise in physical coastal processes may determine the area subject to flooding risk and/or erosional pressures relevant to the proposed coastal protection structure by undertaking a storm-tide inundation assessment consistent with above tables.

Where a relevant flood/erosion prone areas and/or storm-tide inundation assessment referred to above has not been completed in relation to a proposed development, the coastal risk area is taken to be all land between high water mark and a minimum default storm tide event level of 1.5 metres above the level of highest astronomical tide (HAT) for all development in the Maldives.

4.3 Chapter D3: Updating the Tourism Resort Development Regulations

This Chapter provides no specific recommendations to alter the existing Tourism resort Development Regulations (TRDR). Part A has already explained that issues relating to climate resilient updates to the TRDR are addressed through the recommended revisions to the EIA Regulations, set out in Chapter D1.



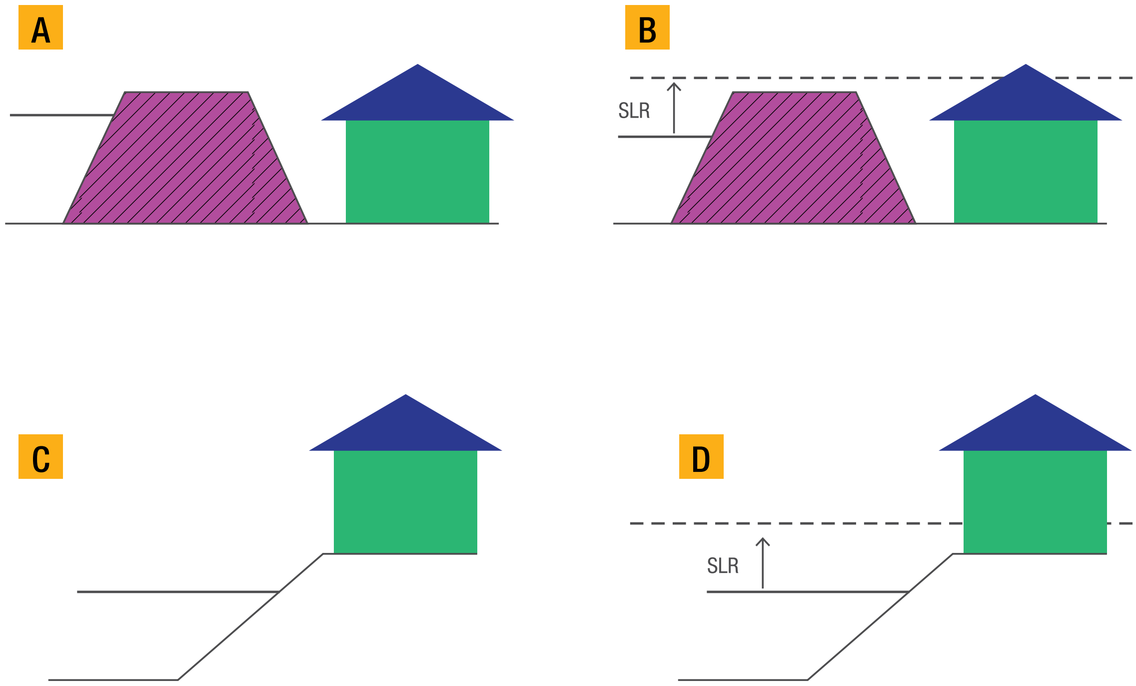
Elevation seetback (top) to cope with coastal flooding and lateral setback (bottom) to cope with coastal erosion

It should be made mandatory that tourist developers (as part of the EIA process) are to review the following sections of this Guidance Manual prior to any contracts being prepared for construction:

- dredging and land reclamation (see Chapter C3.1, section 3.3.3);
- beach replenishment (see Chapter 3.2, section 3.4.1);
- harbour development including quay walls and breakwater development) (see Chapter C3.1, section 3.3.4);
- coastal erosion protection measures (hard and soft) (see

Chapter C3.1 and C3.2 sections 3.3.5 and 3.4.2 respectively);

- access improvement and creation of access to islands (reef entrance channels, jetties) (see Chapter C3.1, section 3.3.6);



In the event of a flood event in excess of design standard, vertical setbacks lead to shallower, less extensive flooding

- over-water structures (see Chapter C3.1, section 3.3.7).

4.4 Chapter D4: Advisory Update to Current Set Back Policy

The intention of this Chapter is to take into consideration the recommendations set out in Chapters D1 and D2 and provide recommended revisions to strategic standards for set-back in the Maldives.

4.4.1 Current Guidance on Setback in the Maldives

A key issue regarding island planning and compliance to land use regulations relates to enforcing setback criteria. Current setback regulates for a 20m "green buffer" within the EPZ. Guidance currently states that, within the EPZ:

"A minimum of 20m wide Environmental Protection Zone, consisting of vegetation should be provided around the outer periphery of the island between the beach and rest of the island. (see Figure D1 below).

Figure D 1 Representation of the concept of EPZ in the Maldives (from Riyan et al 2011).

It also states that:

"EPZ's can be excluded from areas where the land use is for harbour frontage or for commercial use" and " Prior to the implementation of the 2005 Land Use Guidelines, if any building works has started on the EPZ, the works can be completed, but no additional building works should commence on the EPZ".

The 20m ruling appears, however, to only be implementable

GUIDANCE MANUAL NOTE 16

In the context of coastal resilience, it is worth noting that having a fixed width of setback will actually lower climate change resilience by promoting a false sense of security to planners and communities alike. This is because the width of the setback has no basis in the fact of actual reality in the local island situation (i.e.: it is an imposed width based on no baseline information of relevance to that island.

Consequently, this Guidance Manual proposes that set back should be based on locality specific hazard mapping as part of the planning and design of coastal protection structures and assessed through the EIA process. Say that hazard mapping should be a feature of future land planning and until that time apply Shaig (2011) should be applied (see Guidance Note 15).

if hard defences are constructed to surround an island, otherwise there is limited space for any degree of urban planning on islands. The set back after the 2004 tsunami was extended to 40m though distance was unenforceable on most smaller islands (no space for desalination plants or any support infrastructure, hence the policy is unenforceable).

The challenge that exists for these islands is that planning law effectively ends at the toe of the beach. There is no current delimitation of a "baseline" for measurements and the reef platform (i.e.: its size, shape, juxtaposition with the island, aspect to prevailing environmental conditions) is not considered as part of the current LUP regulations. It is critical that planning seeks to (in the future) encompass the whole system from the outer reef edge to the centre as this will significantly alter the risk and threat to islands from storm surges etc.. and hence the demands on coastal protection.

4.4.2 Proposed Guidance Revision within LUP Regulations

It is proposed that current EPZ regulations needs to be re-considered with regard to fixing "distances" as many islands do not have the luxury of having a 20m "inland vegetation line". In addition, there appears to be no differentiation between islands that already have hard engineering structures circling the island or not.

4.4.2.1 Proposal 1 – set temporal and elevation setbacks

There are two types of setback that could be incorporated into the EPZ. This may dictate a minimum distance from the shoreline for new buildings or infrastructure facilities (as it does in the EPZ – 20m) but it also may state a minimum **elevation above sea level for development**. Another factor that should be considered in determining a setback is time; it is important to know rates of change over time in order to set strategic planning over time scales. Elevation setbacks are used to adapt to coastal flooding whilst lateral setbacks deal with coastal erosion (see Figure D2). The benefit of "elevation type setbacks are that they are more easily implementable on small islands where lateral setbacks are impossible.

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This Guidance Manual proposes that set back distances should be based on locality specific hazard mapping as part of the planning and design of coastal protection structures and assessed through the EIA process. In addition, hazard mapping should be a feature of future land planning (updates to the DIRAM work for islands and application of the Vulnerability Assessment work – see Chapter D2). Until that time, the following criteria should be applied (taken from Shaig 2011):

1. Ocean side island coastlines on atoll rim islands requires a wider width than the lagoon ward side.
2. Islands in high wind and wave energy zones (particularly the western rim islands) generally require wider than normal setbacks due to heavy salt spray and potential for seasonal flooding. The minimum recommended setback width for ocean side island coastlines should be increased to at least 30 m in all islands and 50 m in high exposure islands. In addition, newly accreted beach which temporarily become stable should not be considered as permanent land or developed for at least 5 years. This applies to all types of islands including inhabited, resort and Industrial islands.
3. For resort islands, the fixed width of 5m is inadequate for islands on atoll rims. Instead, appropriate widths should be reviewed based on findings from EIAs or subsequent additional studies undertaken by the resort (following the template example in Appendix 3)."

Figure D3 demonstrates the potential benefit to the enforcement of "elevation" related setback regulations in the EPZ. These could provide higher levels of protection (see sub-diagram C and D) when compared to hard defence works, on many Maldivian islands, the sole adoption of a national setback ruling within the EPZ (without some intervention approach in parallel) is unlikely to be a sustainable option for many developers/communities.

MONITORING MAINTENANCE & EVALUATION

PART E

Coastal protection structures are monitored to determine if they are liable and performing to their design function and standards

construction (see sub-diagram A and B). For example, if a water level in excess of the design standard occurs (i.e. extreme north east monsoonal storm event), then the elevation set back will result in shallower and less extensive flooding of developed areas that would occur if hard defences were employed instead.

Figure D 3 Figure D3. (taken from Linham 2010) – Differing flood impacts after failure of structural defences and setbacks.

4.4.2.2 Proposal 2 – Setback variances depending upon different coastal protection measures

Where hard structures exist, it is proposed there is need for a setback distance to be set behind it, unless it has purposely been built to a lower level. Some factor could be built in for spray and/or extreme overtopping.

Where no defences occur, though soft structure measures are proposed (as defined by the flow chat in Chapter B4), a setback could be a feature of the schemes future design and should therefore be determined by its design standards (see Chapter C3.2), which would be evaluated and assessed as part of the EIA process (see Chapter D1). It is postulated that spray and extreme overtopping estimates could be the determinate for any associated set back on larger Maldivian islands.

Where there are no engineered (hard or soft) coastal protection structures then set back can be advocated as a form of coastal protection in itself as it provides effectively a buffer between built structures (assets) and SLR and/or inundation events from storms and surges. The amount of setback should be planned on hazard mapping so will vary from island to island and site to site *(see Appendix 5; Project 5C2 which outlines a good approach to adhere to for the Maldives to help update the DIRAM reports and to consequently map coastal hazard zones for different levels of inundation).*

Similarly, for tourist islands the setback should be planned based on the design of the coastal protection. Here overtopping and spray are more likely factors as tourist island planners often try to design beaches with a direct access to accommodation and so the "natural vista" is not affected. On such islands, larger setback distances are required to address the risk of wave / water level encroachment during monsoonal storm events.

4.4.2.3 Proposal 3 – Setting Development Exclusion Zones

Control of development in the EPZ could be achieved by defining a linear exclusion zone along the whole of an administrative "unit", or simply by specifying development "exclusion zones" which is perhaps more appropriate to a Maldivian situation. Setback distances (or reclamation heights) need to be based on historic erosion rates or coastal overtopping heights (extreme water levels) rather than adopting arbitrary distances which do not truly represent the threat from erosion or coastal flood inundation.

It is recommended, therefore, that "elevation" setbacks are set within the EPZ (defined reclamation height – to be determined for each island as dictated by the field data collection exercises undertaken from the Land Use Plan exercise - Component 1 - or subsequent EIA data collection programmes). As some islands have no topography thus any form construction is unsustainable and therefore becomes untenable. Maybe worth saying that has systematic connotations to some low-lying islands. These should then be incorporated within pre-existing land use planning regulations (EPZ) and new national Building Codes for the Maldives (new building codes being set for the country into 2013). The adoption of the current 20m lateral setback figure should be qualified within the existing regulations.

It is important to stress that the arbitrary 20m distance is qualified by specific factors such as coastal typology (Island A, B or C as stated by Kench 2010), the presence of physical defences and the influence of coastal processes. The lateral distance also needs to appreciate what built assets (and the owners of such) that now fall within the EPZ. Policy text therefore needs to be prepared that addresses this aspect (compensation etc..) plus also when significant modifications to property/assets are needed now it resides within the EPZ. Retrospective planning applications need to considered within this text. Clarity is also needed on Island Council responsibilities/regulators to ensure that building standards and planning permissions on property within the EPZ adhere to the building standards set for the EPZ.

5 PART E: MONITORING, MAINTENANCE AND INFORMATION

5.1 Chapter E1: Monitoring Coastal Protection Schemes

5.1.1 Performance Monitoring (Overview)

It is important that once built coastal protection structures are monitored to determine that they remain viable and are performing to their designed function and performance standards. This Chapter outlines how monitoring should be designed in the Maldives (as part on new contracts) to ensure that climate resilience is taken into consideration.

Monitoring of the performance of a project is important from both a client, consultant and contractor perspective. The client pays for a project to be undertaken based on a clear set of outcomes and levels of quality assurance. Usually the contract documentation will provide performance clauses relating to the design and construction phases of a project including a 6 to 12 month monitoring period for which the responsibility of the project performance is held by the design engineer and the contractor. During this period, any inadequacies in the project are rectified by the engineer and/. or contractor. Chapter C4 should be reviewed to ensure that climate resilience is incorporated into future contract clauses

Performance monitoring is a tool used in quality assurance and can be a useful mechanism for improving design and construction methods. Performance monitoring may include:

- biological monitoring for a project's impact on water quality (see Chapter E3);
- beach and dune surveys for effectiveness of erosion control;
- breakwater surveys for subsidence or rock displacement;
- general workmanship.

The following sub-sections focus specifically on the coastal protection related schemes that have been addressed in Part C (Chapter C2 – design criteria).

5.1.2 Monitoring of Land Reclamation Schemes

As a minimum and in addition to any other requirements in the Contract, the levels of the backfilled material over the footprint of the reclaimed area shall be carried out using the recommendations set out in TableE1 below. The monitoring commencement date and locations of each monitoring point shall be agreed with the Engineer. Should any settlement occur during the monitoring period, the Contractor shall rectify the levels by adding fill quantities as necessary or as directed by the Engineer, at no additional cost to the Employer. No acceptance of levels shall be issued during the initial three month monitoring period.

Table E 1 Recommended performance monitoring for land reclamation schemes in the Maldives

Item	Purpose	Location	Number	Frequency	Testing
Surface monitoring plates or gauges as appropriate	Settlement monitoring of placed fill on reclaimed land	Finished surface of all reclaimed areas or under stockpiles or surcharge material as appropriate.	At 100 m centres behind the seaward structural extremities of the reclaimed area.	Weekly for 12 weeks and then monthly until three months after cessation of fill placement Works. Monitoring will then be carried out on a quarterly basis until the engineer is satisfied that all settlement has now taken place.	Topographic levelling of the settlement plates detailed below

With regards to testing and sampling regime (post construction), settlement plates shall be 500mm x 500mm x 100mm thick precast concrete slabs fitted with a brass survey pin at the centre. The manufacturing tolerances are:

- On the thickness of 100mm + 2.5mm
- On the linear measurement of 500m + 5mm

Settlement gauges shall comprise a 500mm diameter steel plate connected orthogonally to a 50mm diameter steel tube of minimum wall thickness 3mm one metre long. Subsequent units of one metre tube can be screwed to the stem. The plate shall be horizontal and the stem and connection tube shall provide a true vertical relative to the plate. A PVC outer tube 100mm diameter will be provided in order to overcome any friction along the stem.

The settlement plates and gauges shall be monitored using precise survey equipment and related to an approved system of existing or temporary bench marks whose elevation is not influenced by reclamation operations. The Contractor shall include in his method statement, his methodology for the undertaking settlement monitoring that shall be subject to the approval of the Engineer.

5.1.3 Monitoring/Inspection of Coastal and Harbour Structures

The scope of these Monitoring/Inspection guidelines includes, but is not limited to, the following:

- Steel Structural Components;
- Reinforced Concrete Components;
- Concrete Components;
- Timber Components;
- Fendering and Berthing Ancillaries;
- Steel sheet Pile Walls.

Harbour structures comprise both open piled and solid face structures. These items requiring inspection and testing may be grouped under the following headings and features that will require inspection are listed for each structure type:

5.1.3.1 Reinforced Concrete & Precast Concrete Structures

The following provides an indication of the common causes of structural deterioration in reinforced & precast concrete structures. The visual symptoms are noted in parenthesis for each cause of deterioration:

- Microbiological growth; - (discolouration/ growth on material surfaces);
- Thermal expansion – (cracking);
- Chemical attack, ASR, ACR, ALWC and similar; - (efflorescence deposits, leaching, sulphate attack, cracking, spalling);
- Fire damage – (soot, charring, discolouration, structural damage);
- Excessive loading – (cracking, bulging of walls, hogging or sagging of beams/floor slabs, popouts, loosening/ movement of component members);
- Abrasion/ Erosion – (cracking, spalling, disintegration);
- Corrosion – (discolouration on material surfaces/rebar corrosion, disintegration). Note that spalling of concrete over corroding rebar or strands is the most common problem with reinforced concrete, particularly in a marine environment;
- Design/ Construction defects – (cracking, pop-outs, voids, loosening/ movement of component connections, bulging walls, hogging or sagging of beams/floor slabs, removal (or lack) of stability members;
- Protective coating breakdown – (flaking paint, discolouration on material surfaces);
- Ill-considered or incompatible alterations – (removal of stability members e.g. cross bracing, infilling wall panels, etc.;
- Damp and water penetration – (discolouration/ growth on material surfaces);
- Water ponding problems - (puddles, leaks);
- Outdated services – (abandoned pipework, disused cables);
- Damage from impact – (cracking, spalling, holes, loosening/ movement of component connections, dents).

5.1.3.2 Structural Steel and steel framed components

The following provides an indication of the common causes of structural deterioration in structural steel and steel framed components. The visual symptoms are noted in parenthesis for each cause of deterioration:

- Accelerated Low Water Corrosion (ALWC);
- Microbiological growth - (discolouration/ growth on material surfaces);
- Chemical attack – (corrosion/rust);
- Thermal expansion – (buckling);
- Fire damage - (soot, charring, discolouration, structural damage);
- Excessive loading – (hogging or sagging of beams, buckling, loosening/movement of component members, welding and bolt failures and omissions);
- Design/ Construction defects - (hogging or sagging of beams, buckling, loosening/movement of component members, welding and bolt failures and omissions);
- Corrosion - (disintegration, rust);
- Protective coating breakdown – (flaking/cracked paint);
- Ill-considered or incompatible alterations - (removal of stability members e.g. cross bracing, infilling wall panels, cutting holes in members for pipes or other objects to pass through, etc.;
- Outdated services – (abandoned pipework, disused cables);
- Damage from impact – (movement of component connections, dents, buckling);
- Concrete fireproofing on steel members;
- Falling object danger (concrete chunks) and loss of structural strength;

5.1.3.3 Timber Components

The following provides an indication of the common causes of structural deterioration in timber components. The visual symptoms are noted in parenthesis for each cause of deterioration:

- Microbiological growth - (discolouration/ growth on material surfaces);
- Material decay - (timber rot, insect infestation, wood swelling, discolouration, mouldy/musty smells);

- Thermal expansion (warping);
- Chemical attack - (swelling);
- Fire damage - (soot, charring, discolouration, structural damage, disintegration);
- Excessive loading – (cracking, warping, loosening/ movement of component members);
- Design/ Construction defects – (cracking, loosening/ movement of component connections);
- Soil related damage – (cracking, heave);
- Ill-considered or incompatible alterations – (removal of stability members e.g. cross bracing, infilling wall panels, etc.);
- Damp and water penetration – (timber rot, swelling);
- Potential damage as a result of damage/deterioration of adjacent buildings – (Cracking, loosening/ movement of component connections, e.g. lack of lateral restraint);
- Damage from impact – (cracking, holes, broken members, loosening/ movement of component connections, dents);
- Fenders and Support Chains and Holding down bolts;

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in Fenders and Support Chains and Holding down bolts.

- Microbiological growth - (discolouration/ growth on material surfaces);
- Excessive loading – (loosening/movement of component members, welding and bolt failures and omissions);
- Protective coating breakdown – (flaking paint, discolouration on material surfaces);
- Rusting – (discolouration, flaking, laminations);
- Damage from impact – (loosening/ movement of component connections, dents).

5.1.3.4 Bollards and Mooring Hooks

The following provides an indication of the common causes of structural deterioration in bollards and mooring hooks. The visual symptoms are noted in parenthesis for each cause of deterioration:

- Microbiological growth - (discolouration/ growth on material surfaces);
- Excessive loading – (loosening/movement of component members, welding and holding down bolt failures and omissions, cracking and loss of section for concrete members);
- Protective coating breakdown – (flaking paint, discolouration on material surfaces);
- Corrosion – (discolouration, flaking, laminations)Damage from impact – (loosening/ movement of component connections, dents).

5.1.3.5 Grating, Handrails, Access Ladders and Stairs

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in gratings, handrails, access ladders and stairs.

- Fire damage – (soot, charring, discolouration, structural damage);
- Excessive loading – (cracking, bulging of walls, buckling, loosening/movement of component members);
- Protective coating breakdown – (flaking/cracked paint);
- Corrosion – (discolouration, flaking, laminations);
- Damage from impact – (loosening/ movement of component connections, dents).

5.1.3.6 Pipework and Supports to Services

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in pipework and supports to services.

- Microbiological growth – (Discolouration/ growth on material surfaces);
- Excessive loading – (buckling, deflection, loosening/ movement of component members);
- Damage from impact – (movement of component connections, dents, buckling);
- Protective coating breakdown – (flaking/cracked paint);
- Corrosion – (discolouration, flaking, laminations)Damage from impact – (loosening/ movement of component connections, dents);
- Insufficient or incorrect support members.

5.1.3.7 Steel Sheet Pile Wall

Steel Sheet Pile Walls are classified as forming jetties, quay wall, berthing and mooring dolphins or forming coastal revetments. A visual survey and coating survey should be carried out on the following areas of the Steel sheet pile wall:

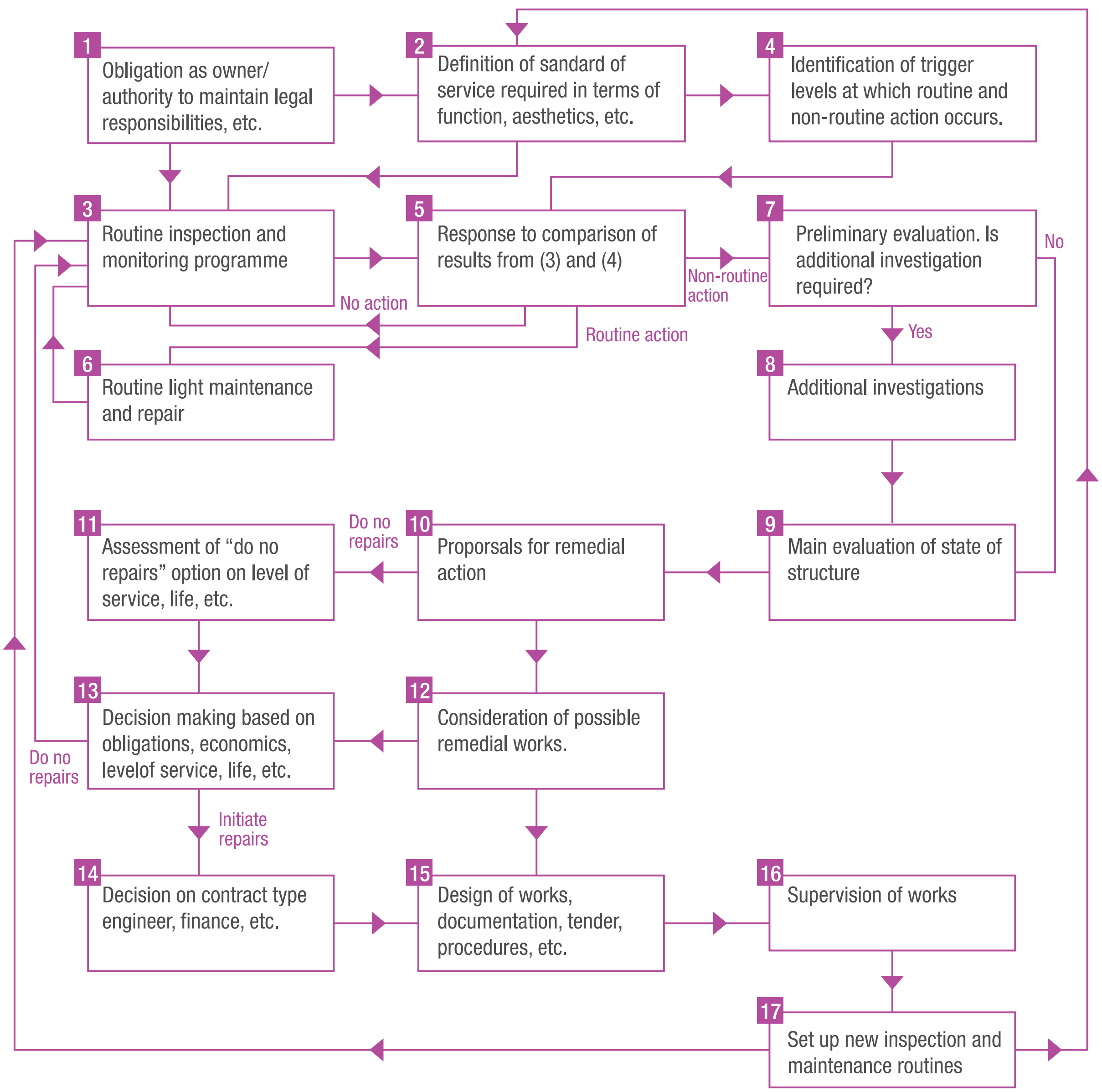
- Accelerated Low Water Corrosion (ALWC);
- Microbiological growth - (discolouration/ growth on material surfaces) ;
- Chemical attack – (corrosion/rust);
- Thermal expansion – (buckling);
- Corrosion - (disintegration, rust);
- Impact and abrasion damage, commonly resulting in damaged joints and holes, with subsequent loss of fill. Note that the excessive settlement is called sink holes, and frequently indicate that the sheet pile wall has corrosion or impact damage above or below water resulting in loss of fil;.
- Fire damage - (soot, charring, discolouration, structural damage);
- Excessive loading – (hogging or sagging of beams, buckling, loosening/movement of component members, welding and bolt failures and omissions);
- Design/ Construction defects - (sagging of anchor rods (tie backs), failure of anchor walls causing movement of the front face of the steel sheet pile wall, buckling,

loosening/movement of component members, welding and bolt failures and omissions);

- Excessive settlement of paved area behind steel sheet pile wall – (undulations on ground level, ponding of water, damage to paved area surface);
- Corrosion - (disintegration, rust);
- Protective coating breakdown – (flaking/cracked paint);
- Ill-considered or incompatible alterations - (removal of stability members e.g. cross bracing, infilling wall panels, etc.;
- Outdated services – (abandoned pipework, disused cables).

5.1.3.8 Cope Beam

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in cope



Monitoring Maintenance & Evaluation

GUIDANCE MANUAL NOTE 18

For the purposes of this Guidance Manual, the "decision tree" highlighted in Figure E1 could be adapted for immediate use in the Maldives. It could be used to determine a monitoring and inspection schedule for the build of a coastal protection structures for all islands. It will help to determine the scope of work through construction and post-construction phases. A worked example of such a schedule is shown at Appendix B for possible adoption as a "performance monitoring standard for the Maldives.

beams. For a steel sheet pile wall the cope beam is generally made from in situ reinforced concrete.

- Microbiological growth; - (discolouration/ growth on material surfaces);
- Excessive loading – (cracking, hogging or sagging of beams, loosening/movement of component members);
- Design/ Construction defects – (cracking, pop-outs, loosening/ movement of component connections, hogging or sagging of beams;
- Spalling of concrete over corroding reinforcement;
- Damage from impact – (significant cracking greater than 100mm in length and wider than 10mm, spalling, holes, loosening/ movement of component connections, dents).

5.1.3.9 Access Ladders

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in access ladders. The ladders can either be constructed from steelwork or GRP elements.

- Microbiological growth - (discolouration/ growth on material surfaces);
- Fire damage – (soot, charring, discolouration, structural damage);
- Excessive loading – (cracking, bulging of walls, buckling, loosening/movement of component members);
- Protective coating breakdown – (flaking/cracked paint);
- Corrosion – (discolouration, flaking, laminations)Damage from impact – (loosening/ movement of component connections, dents);
- Inspection of structures in vicinity of waterline shall be performed at low tide to ensure maximum coverage.

5.1.4 Monitoring of Coastal Revetment and Breakwaters

Coastal Revetments are classified and inspected as part of the structural inspection. Coastal Revetments usually comprise of either concrete, rock or masonry structures. These items requiring inspection and testing may be grouped under the following headings and features that will require inspection are listed for each structure type:

5.1.4.1 Rock Armour Elements

The following provides an indication of the common causes of structural deterioration in rock armour elements. The visual symptoms are noted in parenthesis for each cause of deterioration:

- Microbiological growth - (discolouration/ growth on material surfaces);
- Abrasion/ Erosion; (scouring, missing/loose blocks);
- Damage from impact (souring, missing/loose blocks);

5.1.4.2 Armour Units and Masonry Structures

The following provides an indication of the common causes of structural deterioration in armour units and masonry structures. The visual symptoms are noted in parenthesis for each cause of deterioration:

- Microbiological growth; - (discolouration/ growth on material surfaces);
- Abrasion/ Erosion – (cracking, spalling, disintegration, scouring);
- Damage from impact – (cracking, spalling, holes, loosening/ movement of component connections, dents).

5.1.4.3 Revetment Toe Structure

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in revetment toe structures.

- Abrasion/ Erosion – (cracking, spalling, disintegration, scouring);
- Design/ Construction defects – (cracking, popouts);
- Soil related damage – (cracking, heave, subsidence).

5.1.4.4 Capping Beam

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in capping beam. This is generally used as a precast concrete capping beam or wave wall placed on the summit edge of a coastal revetment. This is distinguished separately from capping beams from steel sheet pile wall structures that are made from in situ concrete.

- Microbiological growth; - (discolouration/ growth on material surfaces);
- Thermal expansion – (cracking);
- Chemical attack, ASR, ACR, ALWC and similar; - (efflorescence deposits, leaching, sulphate attack, cracking, spalling);
- Fire damage – (soot, charring, discolouration, structural damage);
- Excessive loading – (cracking, bulging of walls, hogging or sagging of beams/floor slabs, popouts, loosening/ movement of component members);
- Abrasion/ Erosion – (cracking, spalling, disintegration);
- Corrosion – (discolouration on material surfaces/rebar corrosion, disintegration). Note that spalling of concrete over corroding rebar or strands is the most common problem with reinforced concrete, particularly in a marine environment;
- Design/ Construction defects – (cracking, popouts, voids, loosening/ movement of component connections, bulging walls, hogging or sagging of beams/floor slabs, removal (or lack) of stability members;
- Protective coating breakdown – (flaking paint, discolouration on material surfaces);
- Ill-considered or incompatible alterations – (removal of stability members e.g. cross bracing, infilling wall panels, etc.;
- Damp and water penetration – (discolouration/ growth on material surfaces);
- Water ponding problems - (puddles, leaks);
- Outdated services – (abandoned pipework, disused cables);
- Damage from impact – (cracking, spalling, holes, loosening/ movement of component connections, dents).

5.1.4.5 Access Stairs and Handrails

The following provides an indication of the common causes and the symptoms in brackets of structural deterioration in access stairs and handrails. The stairs are generally constructed from precast concrete stair units with infill concrete panels. Reference should be made to section on Precast Concrete and Reinforced Concrete

- Fire damage – (soot, charring, discolouration, structural damage);
- Excessive loading – (cracking, bulging of walls, buckling, loosening/movement of component members);
- Protective coating breakdown – (flaking/cracked paint);
- Corrosion – (discolouration, flaking, laminations);

- Damage from impact – (loosening/ movement of component connections, dents).

5.1.4.6 Outfalls and Manholes

The following provides an indication of the common causes of structural deterioration in outfalls and manholes. The visual symptoms are noted in parenthesis for each cause of deterioration. The outfalls can either be concrete (Reference should be made to section on Precast Concrete and Reinforced Concrete), steel (Structural Steel and steel framed components or HDPE outfall pipelines:

- Microbiological growth - (discolouration/ growth on material surfaces);
- Protective coating breakdown – (flaking/cracked paint);
- Damage from impact – (movement of component connections, dents, buckling).

5.1.5 Planning and Scheduling Monitoring

Monitoring is only effective if it is planned in an appropriate and timely manner. Figure E1 gives a decision-tree for the planning and scheduling of monitoring for coastal protection structures.

Figure E 1 Decision Tree to help plan for monitoring and inspection scheduling for coastal protection schemes in the Maldives

Appendix 4 is produced to assist in standardising the monitoring of all coastal protection structures. It is recommended that this template is considered as part of a planning and scheduling review of all coastal and marine contracts that MEE (or GoM) are considering letting tenders for into 2013 and onwards.

5.2 Chapter E2: Maintaining Coastal Protection Schemes

5.2.1 Overview

Maintenance of coastal protection projects in the Maldives is strongly driven by economics (e.g. cost to replace/ repair versus cost to maintain), design life of the project, consequences of failure and aesthetics (type of island where the defence is location – tourist or inhabited island). Coastal conditions in many of the islands are abrasive, corrosive, subject to extremes of natural conditions and forces, as well as attack by marine and terrestrial organisms. These conditions are predicted to become more noticeable and severe in the coming decades. Neglecting maintenance of coastal protection schemes, especially with the onset of climate change, will lead to deterioration of the facility and ultimately its failure to perform its designated tasks.

Within the Maldives, the maintenance of coastal protection projects and facilities can generally be classified into three categories:

- built-in maintenance:
- routine maintenance:
- event-driven maintenance.

In some circumstances (particularly "eco-resort islands", there may be no requirement for specific maintenance allowances. This may be the case where the project design life is of short duration (e.g. temporary groynes found on Ihuru island – see Figure E2) or where the cost to rehabilitate or replace is more economical than maintenance measures.

Figure E 2 Temporary "sand bag" groyne on Ihuru Island

GUIDANCE MANUAL NOTE 19

For the purposes of this Guidance Manual, it is proposed that EPA should coordinate this activity and ensure that the information collected for the database or GIS (that is not already another agency's remit), becomes their responsibility. This means they should ensure that data collectors are trained to gather the information effectively, that they centralise the data at EPA, ensure quality assurance, keep backups, and are the gatekeepers to distributing the data through the National GIS (NGIS) or other portals and direct how the information is used in mapping or statistics.

5.2.2 Built-in maintenance

This is a preventative maintenance method adopted during the construction phase of a project. Material selection and protective techniques (see Chapter C2 and C3) are important criteria reflecting on both the initial capital outlay and maintenance of a coastal protection project. Built-in maintenance methods are generally employed on projects where the design life of the project is of significant duration and the costs can be justified (i.e.: a land reclamation scheme to increase the size of an island such as Thilafushi which is amongst the largest artificial islands in the Maldives and has become an industrial zone).

These systems usually require some form of ongoing monitoring and routine maintenance. However, the routine maintenance is considerably less than that of a similar project without built-in maintenance. This type of maintenance can be effective for the Maldives to help address climate resiliency of coastal protection structures and to extend the life of a facility, where the design life is controlled by material or structure durability. Therefore, allowing for future modifications in the event of climate changes also comes under this heading, e.g. ensuring foundations and design of a seawall can accommodate height increase. Several other examples of built-in maintenance on coastal protection projects include the following:

- cathodic protection of steel piles (see Chapter C4, Section 3.3.4.3);
- impressed current protection of concrete reinforcement (see Chapter C4; Section 3.5.11);

- selection of larger than required grain size for beach

Priority[3]	Item	Potential Source	Status	Notes
BACKGROUND				
H	Coastline	NGIS	complete data	Includes unique island numbers synthesise this with any classification of island type or shape
M	Lagoon	NGIS	complete data	
H	Reef	NGIS	complete data	
M	Buildings	Lands and Surveys http://ngis.gov.mv/lis/	Only land Parcels; covers many islands but not comprehensive.	Land Parcels are proxy for buildings at present
M	Roads	NGIS	Patchy coverage from several sources	
M	Bathymetry	Mapping of the Maldives and Climate Change study/ Admiralty	For SE N Male Atoll have LIDAR and water column depth.	Derivation of bathymetry contours (to minimise the data burden) and extension of this nationwide would be advantageous but costly. Digitisation of existing Admiralty Charts could be cheaper option.
L	Airports/ seaplane ports	NGIS	No dataset at present	Useful for islands where these are, but otherwise of minor interest.
H	High or Mean Water Mark	NGIS	No data at present.	Current mapping of island outline interpreted from remote sensed imagery with no knowledge of tide status.
H	Land Elevation	NGIS	No data at present	No known surveys of land elevation data, Would need to be at least 20cm vertical resolution and better if possible.
M	Satellite imagery	Various	Various resolutions, dates and sources of data.	Useful as a detailed backdrop for islands. Interactively using Google Earth would be helpful for IC , but should be wary of using snapshots as legitimate mapping due to copyright issues.
M	Administrative data	NGIS	These can be derived from the coastline layer above. Some data on atoll boundaries exist	Atoll boundary data does not appear to be properly georeferenced.
GENERAL PHYSICAL DATA				
H	Storm surge direction	DIRAM reports	Data in report form, need to apply classification to islands	General directions splits country into three but useful first classification
H	Tsunami threat	DIRAM reports	Data in report form, could not obtain GIS data.	
H	Tidal information		Little data exists	
H	Rainfall		Rainfall stations exist in GIS form	Acknowledge difficult to represent the high temporal volume/low spatial distribution data on mapping but could be useful for other reports. Encouraging IC to look at forecast more systematically would be useful.
H	Flooding hazard	DIRAM report	Data in report, could not obtain GIS data	Map shows zones of potential hazard from flooding events Hazard zones have been identified by DIRAM for selected islands

Priority[3]	Item	Potential Source	Status	Notes
H	Cyclone	DIRAM report/ International websites	no GIS data available – forecast and historical data online	Need a reliable source online of historical and forecast data. Hazard zones have been defined (DIRAM) for selected islands
H	Swell and Udha	DIRAM report	Little data exists in useable form. Several research projects (Kench et al , 2006; Young, 1999; DHI, 1999; Binnie, Black and Veatch, 2000)	Historical pattern could be obtained from IC, but needs careful verification of times. Hazard zones identified by DIRAM for selected islands
L	Marine vegetation	Mapping of the Maldives and Climate Change study	data for SE N Male Atoll	may be other vegetation surveys but likely to be patchy and use different classification schema.
M	Land vegetation	DIRAM, selected studies	Some coastal vegetation mapped for DIRAM, no GIS data available.	Vegetation could be split into general survey of habitats, important and exotic species, and coastal planting schemes or surveys
MANAGEMENT DATA				
H	Coastal Segments	Coastal protection database	Only sample versions as part of this project	The coastal protection database documents the status of these segments from initial surveys, but there is a need to identify these for each island and use GIS to map linear representations of them.
SHORELINE PROTECTION MANAGEMENT				
H	Coastal Segments Status	Coastal Protection database	Not collected at present	For each coastal segment look at present shoreline situation (perceived beach changes, sediment sizes, shoreline change evidence, wave approach direction, littoral drift direction, sediment sources, boat wake erosion). Can also look at selecting possible future shoreline management approaches and for each approach document specific planned measures. Can look at short term and medium term trends for each factor,
H	Island Based Data	Coastal Protection database	Not Collected at present	Logging community responses to what they perceive as key vulnerabilities, development plans and existing resilience status.
H	Coastal Assets	Coastal Protection database & Coastal Adaptation Survey or CAS (Shaig 2011)	CAS only has documented 50 islands and only formal structures.	Coastal protection database should consolidate existing data with locally gained survey data, which would be able to include both informal and soft option structures, and be able to monitor both existence and status of such assets. Data should include construction, function and structure, status (state of decay) and where possible, photographs or other media records.

Priority[3]	Item	Potential Source	Status	Notes
H	Set back	MLSA	No set back data appears to exist	Some guidelines need to be made for setback, whether a universal figure or different for each type of coast. Reports suggest a "built environment" and other setback limit. A GIS layer taking this from high or mean water mark would be useful for each island and can be easily generated from island outline data from NGIS.
M	Beach Profiling	Coastal Protection Database	No Systematic monitoring known	Can view this as part of coastal segment identification and if needed monitoring, but at a visual interpretation level rather than detailed measurement.
M	Historical coastal erosion	DIRAM	selected data do exist, but no GIS data available	For DIRAM report islands, coastal erosion trends have been mapped. Further work could be completed based on aerial photography and satellite data archives, with the proviso of knowledge of tide status when imagery captured.
ACCESS DATA				
H	Harbours and Jetties	Selected reports / Coastal Protection database	Some data in reports; need Georeferenced CAD data at least to be useable.	Would need more sophisticated mapping of major ports with infrastructure, but harbours can be integrated within Coastal Protection Database.
L	Marine navigation features	Admiralty chart, survey	No data made available	Includes lights, buoys, navigation marks, wrecks, mooring zones, speed restriction zones
H	Bridges and causeways	NGIS/Coastal protection database	At present only causeways identified as land features are mapped.	Detailed maps of bridges and causeways would be useful for location, but the Coastal Protection database should be able to attribute the construction material et al, and condition for asset management.
CRITICAL FACILITY DATA (RISK MANAGEMENT)				
M	Land use	DIRAM	Land use data exists for some islands. GIS data not made available.	Consolidation is needed of existing land use studies at a parcel level placed in NGIS
H	Critical Facilities	NDMC DIRAM	No list of critical facilities known, although DIRAM report did identify them for selected islands – no GIS data made available	Agreement on what to call critical facilities and survey of all islands done locating these. Should include communication towers, administration, emergency services, water, electricity and waste management facilities,
OTHER USEFUL DATA				
L	Hotels	Tourism Authority	List of hotels, no point location map or detailed maps of hotels made available.	mapping of resort locations and outlines would be useful at National scale monitoring and strategic planning, and in terms of relating coastal protection measures to responsible parties.

Priority[3]	Item	Potential Source	Status	Notes
L	Biodiversity monitoring	MEE	Unknown	Assists when planning new coastal protection, land reclamation and access assets to know impact on special sites and general environmental quality.
L	Fisheries protected/ priority areas	Department of Fisheries	No data known (http://fishagri.org/?a=news&sdx=101&i=7)	Location of these might influence planning and design of coastal engineering structures
L	Marine Protected Areas	Department of Environment	No data made available	Location of these might influence planning and design of coastal engineering structures
L	Dive sites	Ministry of Tourism/ http://www.mpaglobal.org/index.php?country_id=462&conv_code=&site_code=&action=searchResults&submit=Go	Web site of MPA shows dive site names but not location	Location of these might influence planning and design of coastal engineering structures. Generally not expecting dive sites to be around residential islands.
L	Public beach/ Recreational facilities	Ministry of Tourism/ MLSA	No data made available	Location of these may be involved in any planning application considerations.
M	Land Ownership/ cadastre	MLSA	the LIS has parcel data but ownership not public	Useful for development planning applications, and identifying private owners affected by any planned coastal protection.
H	Existing Reclaimed land	MLSA	Did not see an explicitly defined dataset	Boundary of reclamation, some typology based on construction method, date created.
PLANNING DATA				
M	Reclamation plans	MLSA / LUP?	Plans exist for some islands, and detailed plans for individual reclamation schemes	Data should be in GIS ready format and able to be overlaid with other data to see plans. Where possible the plans should be as geographically accurate as possible rather than schematic.
L	Development Application and Control	MLSA	Unknown	Understanding local plan applications, approvals and control features useful. Coastal protection issues should be part of control procedure and vice versa, knowledge of locations of applications can help assess threats to any coastal protection or exposed shorelines.
L	Mooring Zones	???	Unknown	Useful to demarcate as part of management plan for coastal protection (to avoid deterioration of some sites.

5.3 Chapter E3: Information Management: Data Storage, Sharing and Future Use

5.3.1 Overview

replenishment (see Chapter C4, Section 3.5.6).

5.2.3 Routine maintenance

This involves regular monitoring of the completed project and being pro-active in the prevention of deterioration by providing maintenance on a routine basis. Routine maintenance also includes projects such as maintenance dredging, mechanical beach cleaning and storm water trash rack cleaning. Routine monitoring or inspection includes periodic measurements of the performance of cathodic protection systems, inspection of paint systems, beach surveys for sand replenishment projects, dune stabilisation projects, breakwater inspections and hydrosurveys for dredging programs, etc..

Maintenance is undertaken or implemented when the monitoring identifies the requirement for maintenance. The proposal to establish a Maldives Coastal Asset Database (see Chapter E3) is critical to this and also this can be effectively be used to monitor climate change impacts on coastal protection measures and the surrounding environment.

5.2.4 Event-driven maintenance

This is perhaps most specific to the purpose of these Guidelines as it involves maintenance or repair following storm events. For example, replacement of dislodged rocks from a breakwater following a storm or, in some instances, repeat replenishment of an islands beach after a major monsoonal storm has passed. This action is undertaken in addition to routine maintenance to ensure that repair of any damage or necessary maintenance is carried out immediately, rather than to address the maintenance or repair at the next programmed routine inspection. Unforeseen maintenance may occur where inappropriate planning, design or construction methods have been employed or when unforeseen events occur. For example a concrete mix may be incorrectly specified during the design process or the curing process may be inadequately controlled resulting in cracking and exposure of reinforcement to chloride attack. Unforeseen maintenance can be avoided when due care is exercised. The future adoption of the materials standard (Chapter C4) should reduce these risks if it is adhered to effectively in the Maldives.

The cataloguing of coastal assets and the emergence of problem areas is an important way to develop a framework from which climate resilience and coastal protection issues can be presented. It also helps to provide the platform to help facilitate the implementation of this Guidance Manual ensuring they effectively target the main problems to help provide clarity and signposts to help in future adherence of national building (engineering) and quality (management) standards for coastal protection.

When offering guidelines for better coastal protection to national and island administrations, improved information management will give them the knowledge for better asset identification, monitoring and management. There is currently limited availability of high quality information for coordination and cooperation between different sectors to achieve integrated responses to coastal problems. However, a database of what is known, and where information as it becomes available can be stored, can assist decision making that relies heavily on the ability to appreciate and understand the complex nature of interlinked spatial and non-spatial information. In turn, this would allow Island Councils and national government to improve their overview of coastal defence assets and perceptions of vulnerability and resilience on islands to aid reporting and strategic planning. This information in turn could also strengthen the EIA process and provide support for Land Use Planning and other statutory planning instruments (see Part D).

This Chapter presents an information management framework that covers these issues for which national and island administrations would be responsible but from which data can be aggregated to be of use at atoll and national levels. While the design and data input is designed around use by national and island administrations, both this database and the wider information management should be coordinated and controlled at a national level by EPA. While data will often be resourced from other agencies (e.g. land cadastre from the Maldives Land and Survey Authority - MLSA), the output and quality of products and ensuring timely, accurate data are available for decision making should rest with a relevant central body like the Environmental Protection Agency (EPA). This should sit comfortably with national and island administrations being appropriately

END NOTE

For the first time, the Republic of the Maldives has a Guidance Manual to help formulate improved decision making on designing and constructing Climate Risk Resilient Coastal Protection in the future. This Manual is very timely as climate change predictions suggest that the Maldives will be experiencing increased coastal pressures from intensive rainfall, storm surges, swell waves, all aggravated through sea level rise and alterations in weather patterns. Since 2006, more than 90 inhabited islands have been flooded at least once, and 37 islands have been flooded regularly or at least once a year.

The Guidance Manual is produced to help increase climate change resilience by initiating:

a. **Planning guidelines that provide;**

- Qualifying explanation to the requirements of existing EIA and land use planning regulations.

b. **Engineering guidelines that cover;**

- Performance standards to integrate climate change design into coastal protection structures.
- Performance standards to include required material specifications to "climate proof" coastal protection structures.

c. **Guidelines for the monitoring, maintenance and information needs for coastal protection structures**

The success of the Guidance Manual will be judged on actual outcomes on the ground. As a result, the onus now lies on all Maldivian stakeholders (regulators and developers) to act in partnership to make this happen. It is designed to be a "living" Guidance Manual and that requires regular planned updates when new data and knowledge on island hydrodynamics and climate change impacts becomes available.

A concerted effort is now needed (initially by the Government of Maldives) to ensure that this takes place and that new information is added to the Manual to help fine tune the performance standards presented within it.

APPENDICES

resourced in GIS data and mapping capability for them to monitor and plan at the local level as well.

5.3.2 Needs of an information management system

The information required for ensuring climate resilience is incorporated into improved coastal protection design can be summarised as:

1. Wider understanding of physical island-wide vulnerability to sea level rise (occurrence of natural threats such as tsunami or storm surge) covered by the Performance standards for coastal protection (Part C, Chapter C1 and C2);
2. Vulnerability/Resilience perceptions (see Part D, Chapter D2);
3. Asset documentation and visualisation of current status (assets including coastal defences, features related to access to islands, or addressing land shortage issues). Additionally look at maintaining an archive of past and present assets;
4. Asset Management (understanding extent of resources, materials, monitoring of state and effectiveness);
5. Strategic Planning – coastal protection in relation to national priorities (reclamation schemes, safe island concept, land use planning);
6. Land Development Planning – coastal protection in relation to development application for house extension or building, service provision and building codes (see Part D, Chapter D2);

All these needs would be required at different administrative levels (island council, atoll council and state department) although the types of information and its detail may vary.

5.3.2.1 Data needs

Table E2 is designed to outline the metadata requirements for the database system. The table identifies the dataset with its potential source and status (coverage, quality or plans for development) and any associated notes. A simple prioritisation of how important data are (and to assist in designing any roadmap for completion) is given in the left column (H= High Priority, M = Medium, L= Low).

Several of the regional datasets where internet data are available could be linked through the Maldives Climate Change Portal (currently at http://mccp.maldicore.com/map/ but not publicised).

5.3.3 Hardware and software issues

Establishing a database to include the information outlined in Table E2 requires consideration around hardware/software resourcing of data providers and users, the responsibility for activities and issues related to updating of data and monitoring programmes, as well as how the data and activities listed here fit with the developing NGIS government initiative.

The MEE is a founding member of the NGIS and has access to concurrent ArcGIS licenses through a government network in Male, so they are already sufficiently provisioned for any mapping work associated with coastal protection. For other stakeholders, who do not necessarily require direct access to the ArcGIS software, provision of mapping and analysis can be completed through the proposed database and geographical information could be supplied to these stakeholders using Google Earth KML/KMZ format files from either the NGIS or MEE. MS Access can be used as a data entry facility for a database.

Table E 2 Metadata Requirements.

5.3.4 Data flow

Some of the activities related to coastal protection are conducted by several agencies and there needs to be a strict method for capturing this information. For works (e.g. reclamation and coastal protection asset construction), the national and island administrations should have knowledge of this and either enforce the constructors to document the data, or conduct an "as built" survey themselves on completion. If possible, it would be better as a contractual obligation on behalf of the contractor or consultant to supply in agreed standard format prior to sign off. An example of this is in coastal protection works:

1. EPA – works on protection from coastal erosion;
2. MHI – works with reclamation schemes, build government jetties;
3. Private concerns – build local retaining walls, access assets (jetties, slipway);

4. Community projects – to do temporary or soft options (planting schemes, beach renovation, rubble walls).

Similarly for biodiversity or physical survey, EPA should be a conduit for such work going on and can enforce that relevant data is passed back to them for assimilation into applicable GIS datasets. The national level should be responsible for quality assurance of any data, ensuring that standards are kept to, errors minimised and data are cross-comparable across the whole state.

5.3.5 Updating regime

The database should be seen as an active tool that can document changes in both the coast itself and the assets and other features related to it. While most agencies should be responsible for updating their information (e.g. the Department of Meteorology will frequently collect rainfall data), the data itemised for the coastal protection database itself will require an updating regime managed by EPA. Table E3 identifies an indicative list of survey updates and their frequency of update:

Figure E 3 Figure E3 – Survey type and frequency

Survey Type	Interval/ Timing	How to update
New Reclamation	On completion	"Retire" old segment and asset data, Remap section renumbering segment (new numbers) and identifying and numbering any new shoreline assets.
New Coastal Asset	Every Year	Print out existing map, Walk the entire coastline, note any changes. Use also for looking at condition of existing assets. Alternatively document the new asset when built, but this would still require a monitoring regime. Refresh photographs if signs of decay found.
Segment monitoring	2 years	Look at completing a full review every two years of coastal segments documenting physical changes
Community perceptions	2 years?	Look at revisiting the perceptions about resilience and vulnerability to chart changes.
Critical Facilities	1 year	Review the list of critical facilities annually (if no other agency is updating the list for the island).

5.3.6 Piloting a Climate Resilient Database

Appendix 3 outlines a series of recommended next steps. One of these is to prepare a demonstration database to capture new information on coastal protection assets, their performance and links to environmental assets and features. The underlying recommendation of the database will be to design a monitoring program to help establish island base-line conditions, which should commence prior to any construction is undertaken (or proposed on an island) and should continue during the lifetime of the coastal protection structure to ensure it maintains at least a minimum level of performance. This includes monitoring both biological and physical parameters before a project commences, during all the phases of a project and for the design life of the structures that are built as part of the project. Appendix 3 should be considered to help assist with the design of any future monitoring programme.

APPENDIX 1: KEY REFERENCES

CAROCOM (2009) "Adapting to a changing climate in the Caribbean and South Pacific regions – Guide to the integration of climate change adaptation into the Environmental Impact Assessment (EIA) Process"

CDE Consulting (2011) Climate Change Research Strategy - Integration of Climate Change Risks into Resilient Island Planning in the Maldives Project Final Draft Version 7

CTL Consult Ltd (2012a) "Report 1 – Inception Report Mission 1", UNDP Maldives.

CTL Consult Ltd (2012b) "Report 2 – Preliminary Coastal Development Standards", UNDP Maldives.

CTL Consult Ltd (2012c) "Report 3 and 4 – Field Visit Findings and Coastal Resilience Guidance Outline Structure", UNDP Maldives.

CTL Consult Ltd (2012d) "Report 5 - Recommended Updates to Maldives Land Use and Environmental Regulations, UNDP Maldives.

DIRAM (2008). Detailed Island Risk Assessment in the Maldives. Natural Hazards and Physical Vulnerability Report. UNDP Maldives.

Govt of Maldives (2007) The Environmental Impact Assessment Regulation

Govt of Maldives (2008) Land Use Planning and Building Act (Draft)

Govt of Maldives (2008) Maldives National Building Code Handbook

Hay E (2006) Republic of the Maldives Climate Risk Profile for the Maldives Report Prepared by John E. Hay New Zealand April, 2006.

IIED (2009) "Assessing the coasts of Adaptation to Climate Change" – A Review of the UNFCCC and estimates.

Linham, M. M., and Nicholls, R. J., (Zhu, X (Ed)), 2010. Technologies for Climate Change Adaptation – Coastal Erosion and flooding. GEF and UNEP – TNA Guidebook Series. 150pp.

McCue (2000) "Appreciating coastal problems on small tourist islands - examples from the Maldives". Paper presented to the International Tourism and the Natural Environment Symposium, University of Brighton, 23-25 October 2002.

NIWA (2012) Geospatial framework for climate change adaptation in the coastal zone Cook Islands Coastal Calculator: User Manual Prepared for Ministry of Infrastructure and Planning, Cook Islands.

RIMES, 2012. Development of High-Resolution Regional Climate Model for the Maldives through statistical and dynamic downscaling of global climate models to provide projections for use in national and local planning- Report No. 4: Climate change scenarios and their interpretation for Maldives. 53pp

Riyan Consultants (2011) Integration of Climate Change Risks into Land Use Planning

Shaiq, A (2011). Survey of Climate Change adaptation Measures in the Maldives. Report prepared for Integrated Climate Change Risk into Resilient Island Planning in the Maldives Project. Ministry of Housing and Environment and UNDP Maldives.

Shaig A *(2009)* Climate Change Vulnerability and Adaptation Assessment of the Maldives Land and Beaches

Shaig, A (2009). Coastal Erosion Data Synthesis Report. Prepared for the Maldives Environmental Management Project (IDA Credit: 4427-MV) and the Environment Protection Agency, Ministry of Housing, Transport and Environment, Republic of Maldives, 15 p.

Oriental Consultants Ltd (2012) Final Technical Standard and Design Manual July 2012

Vention C (2009)Cost Benefit Study of Disaster Risk Mitigation Measures.

APPENDIX 2: STAGED APPROACH TO BUILDING CLIMATE RESILIENCE INTO EIA PROCESSES (EXAMPLES FROM THE CARIBBEAN AND PACIFIC)

The following steps (taken from CARICOM 2009) have been considered within the decision process to update the existing environmental regulations (2007) for the Maldives (see Part D). The steps have reviewed and absorbed into the existing regulations to ensure that climate resilience is taken into consideration for future EIAs that need to address coastal protection into existing processes.

Stage 1 – Defining project and alternatives

Objective: Clearly describe the proposed project, identify alternatives to project and approaches to implementation.
Information needs: • Project information: plan(s), design(s), costs, expected benefits • Project scope: spatial and temporal boundaries • Site information: location, environment, hazards, development and social setting
Process: Prepare project description and information on the site(s) identified, as per requirements of review agency, with natural hazard-related information added, as necessary.
Responsibility: Client/proponent

At the very least, all impact assessments should consider the 'no project' alternative (i.e. what the impacts would be if the project were not carried out) AND one technically feasible alternate (if no technically feasible alternate can be identified this MUST be justified). Any concerns or issues affecting local communities should be identified. As a minimum, the following information should be included in the initial project definition and description:

- Environmental
    - Minimise visual impacts on existing foreshore
    - Wind, wave current effects
- Technical
    - Geotechnical site investigation and materials testing
    - Construction Programme
    - Construction Cost; (capex)
    - Scour
    - Potential future dredging requirements
- Buildability
    - Availability of Contractor's plant and equipment
    - Proposed method of construction
    - Availability of materials
    - Approval from Maldives Authority (Not sure correct Department)
- Social Environment
    - Minimise noise/vibration and disruption to adjacent properties (mostly commercial/ warehouses).
    - No disruption to operation of any third party organisation.
- Health and Safety
    - Minimise construction and operational Health and Safety issues as far as reasonably practicable
    - Construction activities affecting current vessel movements

The risk associated with inadequate, or incorrect, feasibility studies is the possibly that the structure will not perform its desired function adequately and the structural integrity may be compromised well before the specified design life of the structure. This may in turn lead to deterioration or structural failure than would normally be expected. , This has the potential to increased maintenance costs or remediation work. With the expectation of climate change and its associated uncertainties in relation to physical drivers, some assessment of the "future feasibility" needs to be taken into account with the planned lifetime of the structure (e.g. increased sea levels).

Stage 2: Preliminary Vulnerability Assessment (Qualitative Analysis)

Objective: Preliminary identification of significant hazards and hazard impacts to inform EIA screening and scoping (stages 3 and 4).

Information needs:

- Prevalent hazards in project's zone of influence-frequency, distribution and magnitude. Climate scenarios. Factors influencing hazard occurrence. Disaster history.
- Characteristics of the project-the site, structures and processes Understanding of vulnerability to hazard impacts.

Process:

- Using existing information and expert knowledge, estimate frequency or probability of hazard events [initial hazard identification]
- Estimate severity of impacts on project components and zone of influence [initial assessment of vulnerability

Climate change should be addressed during the initial project screening process. During initial screening of the project, the project team should identify and evaluate potential impacts from climate change on the project's area of influence. At this stage a Qualitative Analysis should be undertaken – that is one that is subjective and based on best professional judgement. The following questions should be considered during screening, and answered more fully during project evaluation/preparation:

1. What are the relevant climate change impacts that may affect the project?

   Effective integration of climate change considerations requires that project-relevant short-medium-and long-term climate change impacts be identified using appropriate climate prediction models and climate change "scenarios." A distinction is made between climate scenarios – which describe the forcing factor of focal interest to the Intergovernmental Panel on Climate Change (IPCC) – and non-climatic scenarios, which provide socio-economic and environmental "context" within which climate forcing operates. A "risk management" approach should be utilised to develop appropriate climate change scenarios that are relevant for the life-span of the proposed project. In addition, the use of the range of outcomes, rather than a single projection, can give the EIA analyst the opportunity of judging the probable ranges of impacts on the project – and of the project on future resources, society and environment in the affected area.

2. What, if any, project elements are likely to be affected significantly by climate change?

   This question should be addressed initially as part of the screening process using the process for "Estimating Frequency or Probability of an Event" and "Estimating Severity of the Impacts". This evaluation will identify project and ecosystem components that are at high risk/impact from climate change.

Stage 3 - Initial Screening

Objective: Determine, based on information provided, whether: a) the project is likely to have a significant effect on the environment and b) climate change impacts are likely to have significant effects on the project, and therefore require further study.

Information needs:

Initial project description and output of preliminary vulnerability assessment.

Process:

Using information from preliminary vulnerability assessment, assign appropriate category based on frequency, probability and severity of impacts.

Responsibility:

Reviewing agency.

It is essential that potentially significant impacts from climate change that may affect project siting and/or design be identified at the beginning of an assessment through the preliminary evaluation process, and be taken into account in determining the appropriate type and scope of through environmental screening into one of three categories according to the nature and extent of potential climate change impacts:

Category A for significant impacts - A proposed project is classified as Category A if it is highly likely to have (i) significant adverse environmental impacts that are sensitive, diverse, or unprecedented; or (ii) the anticipated short-to mid-term impacts from climate change are highly likely to result in significant adverse social, economic, structural or environmental impacts. These impacts may affect an area broader than the sites or facilities subject to physical works. An EIA for a Category A project: (i) examines the project's potential negative and positive environmental impacts, compares them with those of feasible alternatives (including the "without project" situation), and recommends any measures needed to prevent, minimize, mitigate, or compensate for adverse impacts and improve environmental performance; and (ii) identifies short-, medium- and long-term climate change impacts from appropriate models or climate change scenarios, evaluates social, economic, structural or environmental impacts arising from climate change, identifies and evaluates appropriate adaptation planning and management mechanisms, and recommends any measures needed to adapt to (prevent, minimize, mitigate) or compensate for adverse climate change impacts.

Category B for limited impacts - A proposed project is classified as Category B if: (i) its potential adverse environmental impacts on human populations or environmentally important areas including wetlands, forests, grasslands, and other natural habitats – are less adverse than those of Category A projects, or (ii) the anticipated short- to midterm impacts from climate change are likely to result in social, economic, structural or environmental impacts that are less adverse than those of Category A projects. These impacts are site-specific; few if any of them are irreversible; and in most cases mitigatory and climate change adaptation measures can be designed more readily than for Category A projects. The scope of EIA for a Category B project may vary from project to project, but it is narrower than that of Category A EIA (e.g. a "focus report"). Like a Category A EIA it: (i) examines the project's potential negative and positive environmental impacts and recommends any measures needed to prevent, minimize, mitigate, or compensate for adverse impacts and improve environmental performance, and (ii) identifies short-, medium- and long-term climate change impacts from appropriate models or climate change scenarios, evaluates social, economic, structural or environmental impacts arising from climate change, identifies and evaluates appropriate adaptation planning and management mechanisms, and recommends any measures needed to adapt to (prevent, minimize, mitigate) or compensate for adverse climate change impacts.

Category C for minimal or no impacts - A proposed project is classified as Category C if it is likely to have minimal or no adverse environmental impacts, or minimal anticipated short-, medium- or long-term impacts from climate change. In such circumstances a detailed EIA report is seldom required. The EIA Administrator and/or the project proponent records in the Project Document that summarises the project description: a) the key environmental issues (including any resettlement, indigenous peoples, and cultural property concerns); b) anticipated project relevant climate change scenarios in the short- medium-, and long- term; c) the project category and the type of EIA needed; d) and proposed consultation with project-affected groups and local non-governmental organizations (NGOs), including a preliminary schedule of consultations.

Stage 4 - Scoping (Category A and Category B Study)

Objectives: Identify and agree upon the critical issues to be addressed in the EIA and the information and analyses required for inclusion in the environmental assessment report to determine acceptability and feasibility of the project.

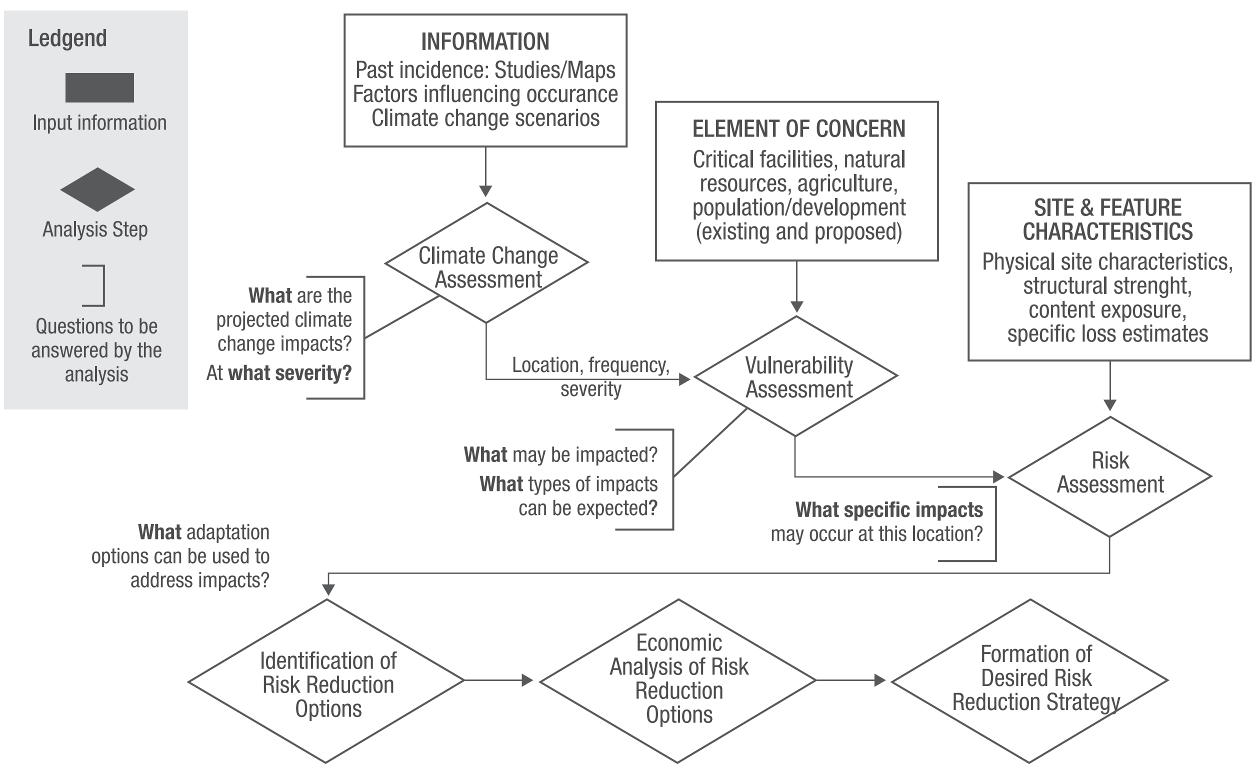
Information needs:

Baseline data on project site, existing detailed hazard maps and assessments

Significant hazards and potential impacts on project and zone of influence/ project boundaries identified in screening

Information on relevant legislation and institutions

Climate change assessments



Process:

Identify information needs regarding significant hazards and vulnerabilities. Specify analyses that must be conducted to complete project assessment. Agree on the terms of reference/scope of work for the impact assessment.

Responsibility:

Reviewing agency

In instances where climate change impacts are likely to result in significant impacts, the EIA team identifies and prioritizes significant impacts for assessment. This initial stage in the EIA process (termed. "scoping") should include agreement on the following aspects:

Project Description and Definition of Spatial Boundaries - the definition of the project and its area of influence;

Definition of Other Project Boundaries - the identification of temporal boundaries affecting project activities (including time frame for climate change impacts that are to be evaluated), and the identification of regulatory, administrative and customary aspects affecting the project or project activities

Baseline Environmental Setting - data to be collected and monitored for the identification of ecological, climatic, cultural and social features relevant to the spatial and temporal boundaries of project activities;

Project-Relevant Climate Models - the identification of appropriate climate predictions relevant to the spatial and temporal boundaries of project activities;

Project-Relevant Climate Change Scenarios (Impacts) - project relevant "downscaled" climate change scenarios (for high risk/impact valued ecosystem components) relevant to the proposed project or development - as identified in Step 2. As applicable to the project, the identification of climate change impacts should be assessed in regard to:

a) Biodiversity and Wildlife

b) Ecosystems and their Goods and Services (Agriculture, Forestry, Fisheries, Aquaculture, Coastal Zones and Marine Ecosystems)

c) Hydrology and Water Resources

d) Soils and Land Resources

e) Human Settlements (including buildings and structures), Energy and Industry

f) Insurance and Other Financial Services

g) Human Health

h) Socio/economic Development.

A key factor affecting public acceptability of and support for any proposed development is the level and nature of public consultation that has been undertaken and the amount of public input obtained in the project design. Scoping normally requires public consultation to determine the utility value attached to affected ecosystem features. The EIA process should ensure transparency in all decision-making, provide timely, adequate and accurate information to the public, and provide access to the public to all relevant documents that are not confidential. There will be instances (especially with private sector development) where information may not be fully disclosed and is protected by law to ensure confidentiality in order to protect a legitimate economic interest, protect location of valuable cultural property, intellectual property rights, issues affecting international relations and national defence.

Stage 5 - Assessment and Evaluation (Category A and Category B Study)

Objective: Fully assess and characterise significant natural hazards, their potential impact on the project and potential effects on those hazards introduced by the project.

Information needs:

Baseline data

Hazard studies and maps indicating past incidence (caution re:

climate change historical data)

Factors influencing hazard occurrence

Climate change scenarios

Process:

Establish baseline

Predict impacts

Evaluate management, mitigation and adaptation options

Select preferred alternative

5. Determine feasibility

Responsibility:

Client/Proponent to undertake assessment, including detailed vulnerability assessment (Quantitative Analysis), using specialists (natural hazards, engineering, social), as appropriate.

Upon the completion of scoping, an assessment and evaluation (EIA study) should then be undertaken of:

- the impacts of the project and project activities on the existing environment (i.e. in the absence of climate change considerations);
- the impacts of the project and project activities on social and economic development;

- the impacts of the project and project activities on community values.

This evaluation constitutes the usual assessment process undertaken for an EIA, and serves to establish the assessment "baseline" against which climate change considerations will be evaluated. Once the baseline assessment has been undertaken, an assessment and evaluation should be undertaken of the impacts of climate change on the project and project activities, which should include an assessment and evaluation of identified climate change impacts (see Stage 2) relevant to:

a) Biodiversity and Wildlife

b) Ecosystems and their Goods and Services (Agriculture, Forestry, Fisheries, Aquaculture, Coastal Zones and Marine Ecosystems)

c) Hydrology and Water Resources

d) Soils and Land Resources

e) Human Settlements (including buildings and structures), Energy and Industry

f) Insurance and Other Financial Services

g) Human Health

h) Socio/economic Development.

At this stage in the process a detailed Quantitative Analysis (see Figure 2) should be undertaken that uses environmental variables represented by numbers or ranges, often accomplished by numerical modelling or statistical analysis. A "model" of the Terms of Reference for undertaking a detailed vulnerability assessment of climate change is provided in Appendix C.

Figure A 1 Detailed climate change impacts evaluation.

The detailed vulnerability assessment may require the development of project relevant climate change scenarios (i.e. "downscaled" scenarios) and should also address "cumulative impacts" and result in:

- The identification of impacts that need to be addressed;
- A quantification of their significance; and
- A determination as to whether appropriate management, mitigation or adaptation measures be established through an environmental management plan (including the climate change adaptation program - see Stage 6 below). The management, mitigation and adaptation options should emphasis re-design and relocation as viable options.

The assessment should also be undertaken on a scenario where there is no project (i.e., status quo), in other words, how would the natural environment behave in the absence of human-made intervention? Costs associated with appropriate management, mitigation and adaptation measures have implications for project viability. Accordingly, the assessment should include an evaluation of the economic implications of such measures to provide a meaningful indicator to decision-makers. This economic evaluation should include a costs/benefits analysis of alternative management, mitigation and adaptation options (see Stage 7).

Stage 6 - Environmental Management Plan (Climate Change Plan)

Environmental management plans that are developed as part of the EIA process are not designed to normally address the impacts of climate change. Accordingly, a Climate Change Adaptation Program should be developed as part of the EIA process to address significant impacts from climate change that will affect the project (including project activities and project area of influence) and define adaptation measures that will be established to address climate change impacts on the following (as relevant to the project and project activities):

a) Biodiversity and Wildlife

b) Ecosystems and their Goods and Services (Agriculture, Forestry, Fisheries, Aquaculture, Coastal Zones and Marine Ecosystems)

c) Hydrology and Water Resources

d) Soils and Land Resources

e) Human Settlements (including buildings and structures), Energy and Industry

f) Insurance and Other Financial Services

g) Human Health

h) Socio/economic Development.

Adaptation planning and management regimes have been broken down into four principal types of strategy for adapting to the effects of climate change, namely:

- Strategy A - Prevention of Loss, Tolerating Loss (Enhancing the Resilience of Natural Systems), and Spreading/Sharing Loss
- Strategy B - Changing Use or Activity
- Strategy C – Relocation
- Strategy D – Restoration

Stage 7 – Cost-Benefit Analysis

A cost benefit-analysis should be undertaken to determine the economic viability of proposed adaptation measures. A cost-benefit analysis is a conceptual framework for the evaluation of investment projects. It differs from a straightforward financial appraisal in that it considers all gains (benefits) and losses (costs) regardless of to whom they accrue (although usually confined to the residents of any country). A benefit is then any gain in “utility”; a cost is any loss of utility as measured by the “opportunity cost” of the proposed project. In practice, many benefits or damages are not readily estimable in monetary terms (e.g. destruction of community ties). Costs will be measured in terms of the actual money costs of the project.

Stage 8 – Monitoring programme

The EIA team should develop the “Climate Change Monitoring Programme” that is established as part of the climate change adaptation program. Such a program should be designed to monitor:

- climate patterns affecting the project area;
- climate change impacts on key social, economic and environmental indicators.

The results from the monitoring program will assist in the development of a database to guide, evaluate and refine adaptation measures and will be required for project evaluation activities.

Stage 9 - Project Appraisal

Objective: Determine viability and acceptability of project against established criteria.

Process:

- Technical review by responsible authority against established criteria.
- Approval or rejection of project.
- Responsibility: CDB or responsible authority (national-level).

A project appraisal of the natural hazard components of an EIA must confirm that:

- all potentially significant hazards, as identified in the EIA scoping, have been analysed using appropriate methodologies;
- appropriate and sufficient management, mitigation and/or adaptation measures have been identified and incorporated into project design for all potentially significant impacts identified in the detailed hazard and vulnerability assessments; and
- it is technically, financially and administratively feasible to implement the necessary natural hazard risk management measures in the proposed project.

A sample project appraisal/review checklist that includes natural hazard considerations is included in Appendix D.

Stage 10 – Implementation and Monitoring

The project proponent is responsible for ensuring that the project is developed in accordance with the provisions of the "Environmental Management Plan," "Climate Change Adaptation Program" and "Climate Change Monitoring Program" that comprise part of the EIA. The EIA Administrator shall ensure that regular reports are submitted by the project proponent outlining the results of any monitoring that has been undertaken. The EIA Administrator should also consult with the National Climate Change Focal Point (established under the United Nations Framework Convention on Climate Change) to:

- monitor any changes in climate that may impact upon project implementation; and
- provide guidance to the project proponent on any changes that may be required to the monitoring programme.

APPENDIX 3: SAMPLE COAST PROTECTION PROJECT APPRAISAL/REVIEW CHECKLIST

The following represents a good example of a project appraisal checklist that could be adopted in the Maldives for coastal protection project scheme evaluations.

1. DESCRIPTION OF THE DEVELOPMENT, THE LOCAL ENVIRONMENT AND THE BASELINE CONDITIONS

1.1 Policy, Legal and Administrative Framework: The adherence to national policies and legislation where necessary should be clearly outlined in the report.

> **1.1.1** The regulations, standards, policies and guidelines applicable to project should be referred to and reference to those applicable made in the report. The terms of reference for the environmental impact assessment should be included and made available.

1.2 Description of the development: The purpose of the development should be described as should the physical characteristics, scale, design and where appropriate a description of the production process should be included.

> **1.2.1** The purposes and objectives of the development should be explained.
>
> **1.2.2** The design and size of the development should be described including diagrams, plans or maps.
>
> **1.2.3** The nature of the production processes intended to be employed in the completed development should be described with the appropriate layouts and the expected rate of production outlined.

1.3 Baseline conditions: A description of the affected environment as it is currently and as it could be expected to develop should be presented.

> **1.3.1** Local land use plans, guidelines and policies should be consulted and the other data collected to assist in the determination of the baseline conditions (biological and social) i.e., the probable future state of the environment in the absence of the project, taking into account natural and man-induced fluctuations and human activities.
>
> **1.3.2** From this information a description of the project without the proposed development must be documented in the report.
>
> **1.3.3** Include historical background in terms of climate conditions, and anticipated climate change scenarios and impacts affecting the area of the proposed development.

1.4 Environment description: The area and location of the environment likely to be affected by the development proposals should be described.

1.4.1 The environment expected to be affected by the development should be indicated with the aid of a suitable map of the area – for example does the study area fall within a Conservation Area/ Protected Area/ vulnerable area. Include hazard and/or vulnerability maps.

1.4.2 The affected environment should be defined broadly enough to include any potentially significant effects occurring away from the immediate construction site. For example the dispersion of pollutants,etc.

1.4.3 The boundaries of the development site should be defined and its location clearly shown on a map.

1.4.4 The uses to which this land will be put should be described and the different land use areas demarcated.

1.4.5 The duration of construction, operational and where appropriate, decommission phase should be estimated. Climate change impacts should be determined for each phase of the project.

2. IDENTIFICATION AND EVALUATION OF KEY ENVIRONMENTAL (INCLUDING CLIMATE CHANGE) & SOCIO-ECONOMIC IMPACTS

2.1 Identification of Environmental Impacts: Methods should be used which are capable of identifying all significant impacts of the project on the environment and identifying significant impacts on the project from climate change.

2.1.1 Impacts (including climate change impacts) should be identified using a systematic methodology such as a matrix, consultations etc..

2.1.2 A brief description of the impact (including climate change impacts) identification method should be given, as should the rationale for using them.

2.2 Definition of environmental impacts: Potential impacts of the development on the environment as well as the potential impact from climate change on the development should be investigated and described. Impacts should be broadly defined to cover all potential effects on the environment, and all potential climate change impacts on the development and surrounding area.

2.2.1 An exhaustive list/matrix should be compiled including all:

i) the direct effects and any indirect, cumulative, short, medium and longterm permanent and temporary, positive and negative effects of the project, and

ii) the direct climate change impacts and any indirect, cumulative, short, medium and long-term permanent and temporary, positive and negative impacts from climate change on the project.

2.2.2 The above types of effects should be investigated and described with particular regard to identifying effects on or affecting biodiversity, soil, water, air, climate landscape, material assets, human health risk and the interactions between these.

2.3 Assessment of socio-economic and environmental impact significance: The expected significance that the projected impacts will have for society and the environment should be estimated. The climate change models used for the assessment should be identified. The sources of quality standards, together with the rationale, assumptions and value judgments used in assessing significance should be fully described.

2.3.1 The significance of an impact should be assessed, taking into consideration national and international quality standards where available.

2.3.2 Where mitigating or climate change adaptation measures for impacts have been proposed, the significance of any impact remaining after mitigation or appropriate adaptation measures should be described.

2.4 Prediction of environmental impact (including climate change impacts) magnitude: The likely impacts of: (a) the development on the environment; and (b) climate change on the development, should be described in exact terms wherever possible.

2.4.1 The magnitude of the predicted impact should be identified. Where possible predictions of impacts should be expressed in measurable quantities with ranges and or confidence limits as appropriate.

2.4.2 The methods used to predict magnitude should be described and be appropriate to the size and importance of the projected impact.

2.5 Definition and identification of potential socio-economic impacts: The effect of the development on the socio-economic characteristics of the project area should be investigated and described. This should also include the prediction of impacts that the project will have on the socio-economic characteristics of the area to be developed and the extent to which this may be affected by climate change impacts.

2.5.1 The socio-economic characteristics of the existing location should be identified.

2.5.2 The impacts of: (a) the proposed project; and (b) climate change, on the socio-economic environment should be analysed including the use of land, the main economic activities (tourism etc..), and the social level within nearby communities, employment levels and existence of archaeological and historical sites.

2.5.3 These impacts should be categorized in terms of being positive or negative

3 **ALTERNATIVES**

Feasible alternatives to the proposed project should have been considered. These should be outlined in the Report, the socio-economic and environmental implications of each presented, and the reasons for their rejection briefly discussed, particularly where the preferred project is likely to have significant adverse environmental impacts or is likely to be severely compromised by prevailing and projected environmental issues.

Alternative sites should have been considered where these are practicable, available and cost-effective to the developer. The main environmental advantages and disadvantages of these should be discussed and the reasons for the final choice given.

Where available, alternative processes, designs and operating conditions should have been considered at an early stage of the project planning and the socio-economic and environmental implications of these investigated and reported where the proposed project is likely to have significant adverse environmental impacts.

The analysis of alternatives should include the “no-action” alternative.

4 MITIGATION AND ADAPTATION

4.1 Mitigation Measures: All significant adverse impacts of the project on the environment and vice versa should be considered for mitigation. Evidence should be presented to show that proposed mitigation measures will be effective when implemented.

4.1.1 The mitigation of all significant adverse impacts should be considered and where practicable, specific mitigation measures should be put forward. The cost of the mitigation action should be assessed and included in the Report.

4.1.2 It should be clear to what extent mitigation methods will be effective when implemented. Where the effectiveness is uncertain or depends on assumptions about operating procedures, climatic conditions etc.., data should be introduced to justify the acceptance of these assumptions.

4.1.3 Any unmitigated impacts should be indicated and justification offered as to why these impacts were not mitigated for.

4.1.4 In the case of beneficial impacts it should be demonstrated how these can be maximized.

4.2 Commitment to mitigation: developers should be committed to, and capable of, carrying out the mitigation measure and should present plans of how they propose to do so.

4.2.1 There should be a clear record of the commitment of the developer to the mitigation measures presented in the Report. Details of how the mitigation measures will be implemented and function over the time span for which they are necessary should be given.

4.3 Adaptation measures: All significant climate change impacts affecting the project should be considered in the formulation of appropriate adaptation measures. Evidence should be presented to show that proposed adaptation measures are consistent with any adaptation policy or program being implemented at the national level, and will be effective when implemented.

4.3.1 The implementation of appropriate adaptation measures to address all significant adverse impacts should be considered and where practicable, specific adaptation measures should be put forward. The cost of the adaptation measures should be assessed and included in the Report.

4.3.2 It should be clear to what extent adaptation measures will be effective when implemented. Where the effectiveness is uncertain or depends on assumptions about operating procedures, climatic conditions etc.., data should be introduced to justify the acceptance of these assumptions.

Task / Objective	**Monitoring/Inspection Scope of Work**	**Comments**
Harbour and Coastal Structures		
Agree Final Scope of Work	The Contractor will agree with the relevant Government department the survey basis and scope, agree methodology, the information to be obtained and the data model requirements. Obtain approval in principle for additional input from specialists, if required. Brief survey team(s), boat/equipment operators and specialists, if required. The Contractor will identify and agree any change in scope of works with the relevant Government department prior to undertaking the works. Agreement will be sought on price together with a revised programme for acquisition of data and completion of the services.	This can be set out through discussions and meetings.
Data Gathering & Desk Study	Identify and collate all available as constructed drawings and reports. This may include; specifications, design reports, operation & maintenance manuals; health and safety files; risk assessments; construction photographs; piling records; geotechnical considerations/ designs and underlying geology; load cases; mooring and berthing assessments; topographic surveys, site investigation surveys; services searches; and adopted design standards. Copy and organise A3/A4 extracts for annotation during on-site surveys. Identify and collate all relevant data relating to historic inspections and/or monitoring of assets. To include damage reports; design/ construction details of repairs/ replacements; ongoing maintenance and operating procedures; diving survey factual reports; and cathodic protection systems, where installed. Gap Analysis to identify missing data requirements from previous reports and databases.	All required data/archive files identified to be gathered on site and copied. Any data missing to be identified and alternative sources/scope agreed with Government representative.

Task / Objective	Monitoring/Inspection Scope of Work	Comments
Site Access Procedures	Prepare and submit written notification for approvals, where necessary, to gain access to assets in advance of carrying out Visual Inspections. Notification will include contact details, names and telephone numbers at Employers offices, port and other relevant authorities. Confirm where access is forbidden and/or restricted. Confirm hazard/chemical/fuel risks, if any, and establish emergency contacts to ensure communication functions. Confirm requirement for site induction for Contractor's inspection team with responsible parties. The Employer will be expected to provide contact details in the Scope of Services. Obtain tide tables and forward weather forecasts for planned Inspection period. Where tide tables are not available, the Contractor will inform the Employers Representative and agree an alternative approach (such as interviewing local residents and/or identifying other information sources). Access the structure by a suitable means.	Contacts on site to be identified. Site inductions to be arranged with contacts on site and undertaken on arrival to the site
Asset Description and Extents	Record the location of all notable features using GPS, paper sketches/ photographic records or similar. Common/ significant defects will be described and commented on, but a record of obviously minor defects will not be recorded. Features to be noted will include, but not be limited to, the following: Change in asset type, both hard and soft engineering structures. This is to include damage, missing elements, settlement behind harbour walls, loss of 'three point contact' of rock armour, slumping rock armour; Outfall structures, condition of outfall pipe, scouring or loss of bed supports; Position of piers/ piles/ columns particularly relating to harbour passenger ferry terminals; Access ladders; Access steps and safety handrails; Significant defects including impact damage and loss of support.	Performing actual inspection works
Swim around and Splash Zone Visual Survey	Survey full structure from high water mark to edge of house reef, or defined zone of the structure. Visually survey all structural elements. Look for obvious signs of damage or distress, such as missing members, bulging, cracking, impact damage and other obvious deterioration.	Performing actual inspection works.
Topside Survey	Visual survey of the structure from the high water mark to the deck level. Look for obvious signs of damage or distress, such as missing members, bulging, cracking, impact damage and other obvious deterioration.	Performing actual inspection works.

Task / Objective	Monitoring/Inspection Scope of Work	Comments
Defects/ Dilapidation Survey	The following defects and structural deterioration should be identified during the survey: **Discolouration/growth on material surfaces** Look for any evidence of discolouration on materials in which a material has lost its original colour, due to a damaging process directly affecting it, like water penetration (with or without permanent coloured stains) or sun radiation, and not because of something that covers it (deposited matter, e.g. paint, salt or dirt). Identify any signs of biological growth material (thriving micro-organisms), that is living matter thriving on the building material surface). **Material decay** For timber structures the inspection should look for any signs of the wood swelling or changing colour and also if there is any evidence of mouldy or musty smells present Also check for any signs of damage due to insect infestation **Chemical attack** When visually inspecting the structures for chemical attack the following defects should be noted: Any evidence of efflorescence deposits mainly in concrete, brick, paving and mortar. This will be evident in cracks appearing in concrete structures. Leaching, this will be evident in cracks appearing in concrete structures; Sulphate attack which can affect the concrete in harbour wall construction and can cause it to expand/crack; Degradation caused by acids or bases; Alkali aggregate reactions in concrete which can cause expansion leading to spalling; **Thermal expansion** Visually inspect materials for any noticeable changes in size of any components which can involve: Buckling of metal components including piled supports to access bridges and harbour passenger piers; Cracking of concrete. If there are no flexible expansion joints installed between precast concrete 'L' or 'T' wall sections, cracking will develop at these joints over time with expansion and contraction of the concrete elements; Warping of timber elements including fenders and the timber elements of harbour passenger piers. **Fire damage including;** Includes typical fire damage to elements such as timber fenders or harbour passenger piers. Surveying the degree and extent of damage from Odour; Burn; Soot; Water.	All required data/archive files identified to be gathered on site and copied. Any data missing to be identified and alternative sources/ scope agreed with Company representative.

Appendices

Excessive loading on Harbour Wall Structures

Most of the harbour wall structures observed during the Island Visits were either the tradition sand bag form of construction or the new introduced precast reinforced concrete 'L' wall and 'T' wall structures. The excessive loading could either be caused by poor design, lack of free draining material directly behind the walls leading to an increase in the out of balance water pressure or excessive crane or vehicle loading directly behind the wall.

Look for any evidence of:

Cracking of precast concrete wall units caused by excessive bending moments or shear forces,

Buckling of piled supports of harbour passenger piers,

Bulging. This would be noticed in the traditional sand back form of construction by 'line of sight' survey along the length of the harbour structure. In precast concrete wall structures this would be noticed by individual adjacent precast elements being out of alignment.

that may be caused by excessive loads being placed on a structure

Coastal Revetments, Onshore and Offshore Breakwaters and Rock Groynes

Armoured slopes with rock armour stones missing and visible on the seabed;

Slumping of the rock armour slope below water level, this could be caused by scour or inadequate toe structures;

Loss of 'three point contact' of rock elements leading to movement and slumping of blocks

Evidence of scouring of material at the toe of rock armour including missing rock armour stones;

Evidence of loss of the fine material (from behind the rock armour, or similar revetment) through the rock armour layer.

Abrasion/erosion

Look for and identify any signs of degradation to materials caused by erosion/abrasion on structures which can include the following:

Bright/exposed metal on metallic elements including support piling elements;

Cuts/loss of surface material in concrete and exposure of aggregate and reinforcement;

Loss of surface material in timber which could result in 'necking' of the timber elements at water level. This is particularly relevant to any piled bridge support structures, outfall support structures and piled supports for harbour passenger piers.

Corrosion/Erosion/Missing elements

As part of the visual survey, assess the extent of surface corrosion and estimate, for each type of component the following:

Extent of corrosion damage to steel sheet pile and tubular pile pier support elements particularly in the splash zone;

Change in beach profile;

Retreating coastal hinterland;

Damage and missing elements of offshore breakwaters;

Damage and missing elements of rock groyne structures;

Damage and missing elements of sand bag construction rock groyne elements;

Erosion/removal of rubble coastal protection structures. During the Island Visits it was noticed that some of the coastal protection measures were formed from 'end tipped' building rubble incluing brick and block and concrete elements;

Erosion of soft coastal erosion measures.

Design/construction defects

The following signs should be included when identifying any construction defects:

Slumping of rock armour revetment and breakwater structures due to settlement of the backfill material, inadequate toe detail, incorrect geotextile specification, lack of 'three point contact' of armour units due to unsatisfactory construction supervision;

Slumping of rock armour revetment and breakwater structures due to incorrect rock armour sizing or inadequate rock slope to meet the design environmental conditions on site;

Damaged/missing elements of sand back offshore and nearshore breakwater structures due to inadequate facing slope to meet the environmental conditions on site;

Increased coastal flooding directly behind rock revetment structure due to not correctly detailing the facing slope to meet the environmental conditions on site;

Cracks in precast reinforced concrete 'L' wall and 'T' wall elements due to bad reinforcement detailing and insufficient concrete cover;

Cracks in precast reinforced concrete 'L' wall and 'T' wall elements due to incorrect concrete mix design, inadequate water/cement ratio or inadequate curing and enhancement admixtures

Bulging of harbour walls and coastal rock structures due to vehicle and craneage loadings directly behind the structures not considered in the design

Missing or severed members due to not following the load path correctly during the detailed design

Cracking between adjacent precast concrete 'L' wall and 'T' units caused by poor detailing and not using a flexible joint between adjacent units. The flexible joint should also be covered with a suitable marine grade sealant.

Settlement of material leading to lack of support below reinforced concrete slipway structures due to using inadequate backfill material comprising compressible material, shells or any other detritus material.

Climatic/atmospheric effects

Look for any signs of climatic/atmospheric effects on the structures including:

Damage from strong winds/storms

Flood damage on the coastal hinterland

Damage caused by increased cracking of drier soils

<u>Protective coating breakdown</u>

The visual survey of coatings is to assess the effectiveness and condition of the various protective coating systems of the structure.

Visually assess the overall condition and effectiveness of the various coating systems. Describe the type of coating systems for the components inspected. Note specific location of moderate to excessive coating failure. Estimate, for each component, the following:

Average percent breakdown of the coating

Extent of coating damage

Soil related

The visual survey will look for any signs of soil related damage involving:

Vibration due to vehicle loadings or crane loadings on roadways directly behind revetment and harbour wall structures

Heave of backfill material structures due to using inadequate backfill material comprising compressible material, shells or any other detritous material.

Ground slip directly behind coastal revetment structures due to settlement of the backfill material, inadequate toe detail, incorrect geotextile specification, lack of 'three point contact' of armour units due to unsatisfactory construction supervision ,

Tree roots causing damage to armour stone and concrete coastal structures

Subsidence due to inadequate backfill material or coastal flooding

Ill-considered or incompatible alterations

As built structural drawings should be used as reference during the visual survey in order to identify where there are variations to the structural design. Variations may include the following:

Poor or inadequate construction supervision;

No monitoring during the 12 months following construction;

Poor or inadequate Change control'

Poor or inadequate Quality Control on site;

Poor or inadequate materials testing during construction including backfill material, concrete slump and cube tests, geotextile testing;

Poor or inadequate logging on site of all materials testing certificates for delivered material including rock armour, geotextile, timber elements, etc.

Damage from impact

Visually assess structures for any signs of damage from impact which can include:

Vessel impact on harbour wall structures;

Impact damage from seabourne detritus material on nearshore and offshore breakwaters;

Impact damage from seabourne detritus material on coastal revetment structures;

Vessel impact causing damage or missing members for harbour passenger piers

Delamination

Areas of concrete showing no deterioration should be struck in several places with hammer blows to confirm there is no delamination occurring. Concrete that is hard or spalling should be struck with hard hammer blows and an effort made to pry pieces off with a screw driver or other simple hand tool to dislodge concrete if possible

Diving Inspections of Harbour Structures

Divers will inspect the piles for any signs of damage, (refer to Contractors Site Specific Risk Assessments), to allow estimate of void volumes or materials loss. Divers should check for the following:

Damaged or missing sections of vertical timber support piles;

Damaged or missing sections of horizontal bracing timber elements;

Damaged or missing timber connections;

Reduction in section size of the timber member due to long term degradation. This will include probing the timber members with a screwdriver, or similar, to confirm the structural strength of the timber members.

Every 20 piles on a timber jetty (or similar structure) divers will dig a short distance ((minimum depth of 10 inches (250mm)) beneath the existing sea bed level and record timber dimensions at this depth.

Measurement of pile metal thickness will be carried out using a Cygnus thickness meter ((accuracy of +/- 1/25th inch (1 mm)). This instrument will work efficiently above and below water and functions without the need to remove protective paint coating prior to taking measurements. Removal of marine growth will be required. (Sheet piling measurements will be taken at the return where the in-pan meets the out-pan, tubular pile measurement will be taken at quarter points around the circumference, or as otherwise agreed with the Employers Representative.

Divers will measure steel thickness at every second pile, and all piles at 3 feet (1 m) above MLWS, at MLWS, at Chart Datum level and thereafter at 3 feet (1 m) intervals vertically to the intersection with the seabed. It is good practice to clear the seabed to a depth of 8 inches (200 mm) and measure the thickness at seabed minus 4 inches (100 mm).

Divers will look for the effects of side wash scouring or damage caused by the effects of vessel bow thrusters.

Where the distinctive 'orange bloom' of biological activity attributed to Accelerated Low Water Corrosion (ALWC) or Microbial Induced Corrosion (MIC) is observed, the Employers Representative will be informed and extra readings will be recorded on instruction.

Revetment and Breakwater structures		
Diving Inspections of Revetment and Breakwater structures	Divers will inspect rock armour slopes for signs of the following: Armoured slopes with rock armour stones missing and visible on the seabed; Slumping of the rock armour slope below water level; Evidence of scouring of material at the toe of rock armour including missing rock armour stones; Evidence of loss of the fine material (from behind the rock armour, or similar revetment) through the rock armour layer. Divers will look for the effects of side wash scouring or damage caused by the effects of vessel bow thrusters	A CCTV recording of the diving survey will be provided accompanied by a factual report highlighting the key findings from the survey. These findings will be interpreted by the Contractor in their Inspection Report.

Appendices

4.3.3 Any significant climate change impacts that cannot be adequately addressed through appropriate adaptation measures should be indicated and justification offered as to why suitable adaptation measures were not provided for these impacts.

4.3.4 In the case of beneficial impacts it should be demonstrated how these can be maximized.

4.3.5. Commitment to adaptation: developers should be committed to, and capable of carrying out the proposed adaptation measure and should present plans of how they propose to do so.

4.3.6 There should be a clear record of the commitment of the developer to the adaptation measures presented in the Report. Details of how the adaptation measures will be implemented and function over the time span for which they are necessary should be given.

5 MONITORING

5.1 Monitoring programme: Developers should include a detailed monitoring plan and present how they intend to implement this plan.

5.1.2 A detailed environmental and climate change monitoring plan should be described outlining the reasons for the costs associated with the monitoring activities.

5.1.3 The plan should clearly state the institutional arrangements for carrying out the work, the parameters to be monitored, methods employed, standards or guidelines to be used, evaluation of results, schedule and duration of monitoring, initiation of action necessary to limit adverse impacts disclosed by monitoring, format and frequency of reporting.

5.2 Environmental management and training: Developers should include a detailed management plan for all stages of the development.

5.2.1 The developer should include a detailed management plan outlining how the environment and any significant impacts from climate change will be managed or addressed during the implementation of both the construction and operational phases of the project.

5.2.2 The training programme for employees of the facility should be outlined.

5.2.3 The plan should also include any institutional needs for implementing the recommendations of the EIA report.

6 PUBLIC / COMMUNITY INVOLVEMENT

6.1 The public should be actively involved in the EIA process using appropriate methods of garnering public opinion, including local knowledge of past events. The public should be provided with full information concerning any anticipated climate change impacts affecting the development.

6.1.1 Where applicable, the Non-Governmental Organisations (NGOs) and citizens within the community in which the project is proposed to be implemented should be formally contacted in writing and be informed of the project. Comments should be sought from all parties who will be affected by the proposed action.

6.1.2 The methods employed to obtain public/community input should be described and assessed for appropriateness depending on size of audience, expertise required and issues and concerns should be documented in accordance with the guidelines for Public Participation.

7 COMMUNICATION OF RESULTS

7.1 Layout: The layout of the Report should enable the reader to find and assimilate data easily and quickly. External data sources should be acknowledged.

7.1.1 There should be an introduction briefly describing the project, the aims of the environmental assessment and how these aims are to be achieved.

7.1.2 Information should be logically arranged in sections or chapters and the whereabouts of important data should be signalled in a table of contents or index.

7.1.3 Unless the chapters themselves are short, there should be chapter summaries outlining the main findings of each phase of the investigation.

7.1.4 When data, conclusions or quality standards from external sources are introduced, the original source should be acknowledged at that point in the text. Full reference should also be included either with the acknowledgment, at the bottom of the page or in a list of references.

7.1.5 Where climate change models and scenarios are used, the source of such models and scenarios should be identified. The risk management regime used to address any scientific uncertainty should be identified.

7.2 Presentation: Care should be taken in the presentation of information to make sure that it is accessible to the non-specialist.

7.2.1 Information should be presented so as to be comprehensible to the non-specialist. Tables, graphs and other devices should be used as appropriate. Unnecessary technical or obscure language should be avoided.

7.2.2 Technical terms acronyms and initials should be defined, either when first introduced into the text or in a glossary.

7. 3. Emphasis: Information should be presented without bias and receive the emphasis appropriate to its importance in the context of the environmental report.

7.3.1 Prominence and emphasis should be given to potentially severe adverse impacts as well as to potentially substantial favourable environmental and climate change impacts.

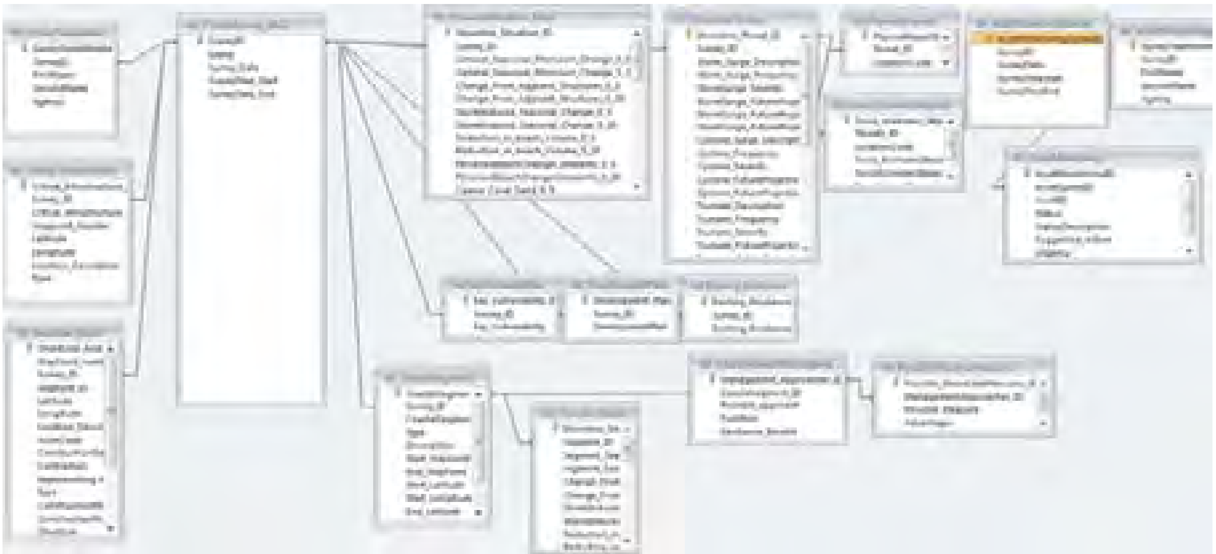
7.3.2 The Report should be unbiased. Adverse impacts should not be disguised by euphemisms or platitudes.

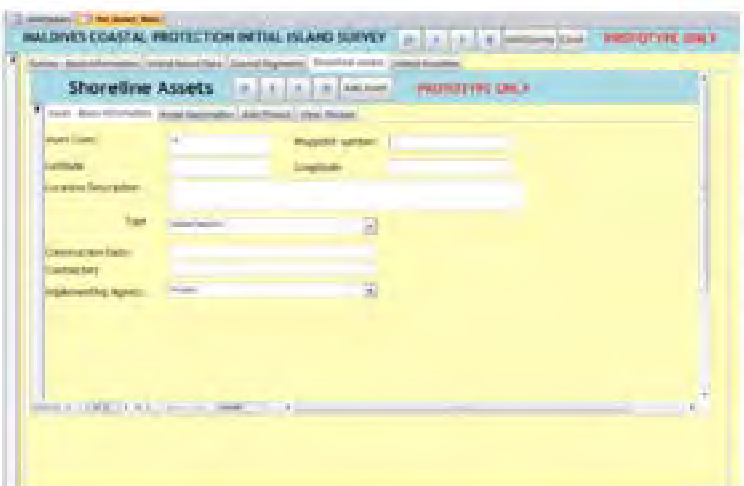
7.4 Executive Summary: There should be a clearly written executive summary of the main findings of the study and how they were reached.

7.4.1 There should be an executive summary of the main findings and conclusion of the study. Technical terms, lists of data and detailed explanations of scientific reasoning should be avoided.

7.4.2 The summary should cover all main issues discussed in the Report and contain at least a brief description of the project and the environment, a brief summary of anticipated significant climate change impacts affecting the development, an account of the main mitigation and adaptation measures to be undertaken by the developer and a description of any significant residual impacts.

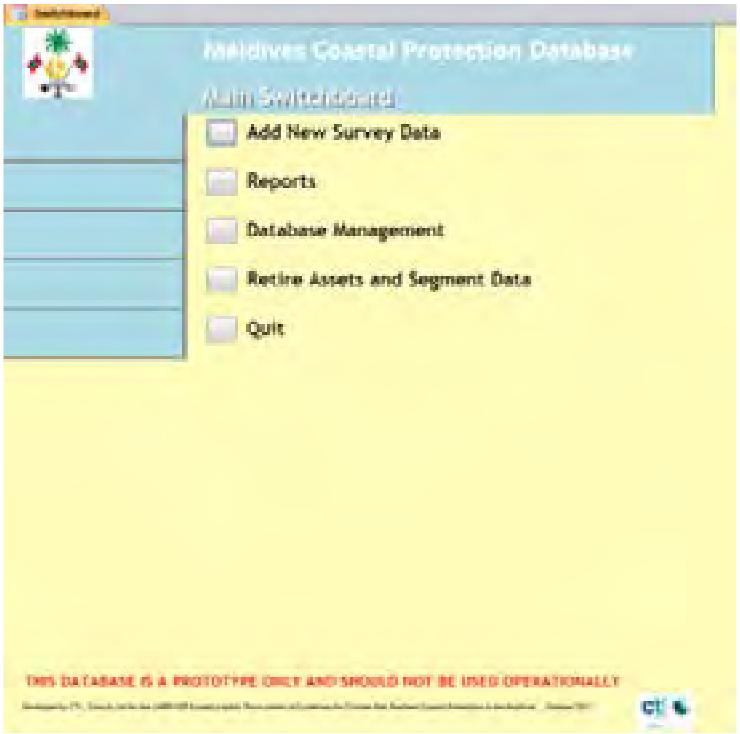
7.4.3 A brief explanation of the method by which these data were obtained and an indication of the confidence which can be placed in them should also be included.





This shows one of the detailed survey sheets. For ease of entry, the data are split into tabs which could be accessed left to right. In this case, the Shorelines Assets have been selected and basic information about its location and construction are entered. Separate tabs for description and photos are also available.

Example of a data entry form (critical Infrastructure) showing use of drop down boxes for easy selection.



APPENDIX 4: SAMPLE INSPECTION AND MONITORING SCHEDULES

The following is an example of an inspection and monitoring schedule, designed specifically for harbour and coastal protection structures. It is recommended that a similar inspection schedule is devised and included with all new developer contracts to adhere to.

Appendices

APPENDIX 5: NEXT STEPS AND ADDITIONAL WORK

5A) Summary of Proposed Project Interventions

The following projects / interventions have been identified for MEE to consider for adoption. Where possible, a link to the latest (2013) MEE Work Plan has been identified to assist in budgetary allocations.

PROPOSED PROJECT INTERVENTION	Links to MEE 2013 Work Plan ID code	Indicative Budget (as set in MEE 2013 Work PLan)
Project 1 - Creation of an interactive PDF version of the Guidelines produced and translation;	(ID: 50 and 130)	MVR 30,000 and MVR 77,100
Project 2 - Training on the use of the new guidelines for different Island Councils (through a new Coastal Forum) (March 2013)	ID: 154-158	MVR 2,590,560
Project 3 – Integrating Databases – taking forward the CTL advice in Report 4) and linking it to the Climate Risk Database plus also the ICCRIP protocol monitoring work *(see 5B below for details).*	Linked to ID: 122 and 1761	MVR 2,814,450 (ID: 122 only)
Project 4 – Pilot Testing the design of new schemes (Kulhudhuffushi, Thinadhoo, Thulusdhoo)	ID: 142-146	40,092,000
Project 5 – Setting up the “proxy measures” needed to establish a future “Coastal Monitoring Calculator” for different island shapes and sizes *(see 5C below for details)*	Not specified directly in Work Plan	
Project 6 – Integrating the Guidelines into University Course Design – specific reference to Planning, Engineering and Environmental Management syllabus content (input of Ministry of Education needed).	Not specified directly in Work Plan though a similar approach is identified for renewable energy (see ID: 191).	
Project 7 – Study of options and approaches to help initiate “Private Public Partnerships” for coastal protection schemes and long term management/monitoring/maintenance of harbours/structures etc. etc. (place economic responsibilities on private sector in coming years).	Not specified directly in Work Plan	

5B) Project 3 - Demonstration Database

To demonstrate the capability of using databases as a solution for information management to fill gaps in coastal protection knowledge, a prototype database has been created. Some data needed for coastal protection management cannot be sourced from other agencies or available mapped information, and needs to be entered and controlled at the local level by the Island Council, and quality controlled, validated and aggregated by EPA in Male. It is recommended that development of this database is seen as a high priority, focusing especially on asset identification (soft/hard, formal/informal) and coastal segmentation.

Needs for the coastal protection database include the following:

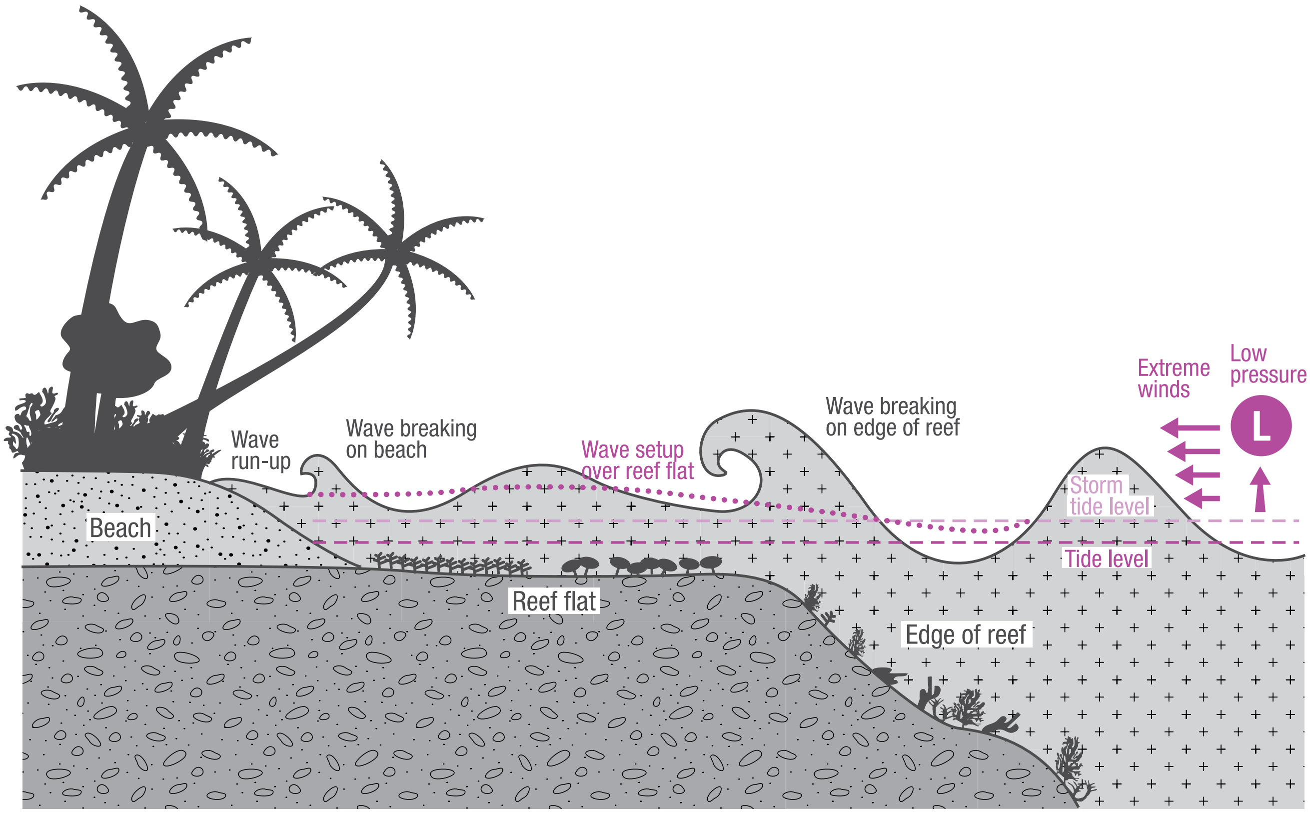
1. Ability to assess the status of the coastline (especially erosion and accretion) around each island. The coastline can be separated into broadly discrete units or segments that have different characteristics (e.g. beach, hard rock, protected channel coastline) and will need different approaches to coastal protection.
2. Ability to asset manage the various coastal protection features (hard and soft, formal and informal) around each island.
3. Ability to be integrated with GIS applications, especially for synthesis within the National GIS.

5B1) Design requirements

1. A simple easy to use database with forms for data entry using drop down menus with pick lists, where possible.
2. A series of reports that are self-generating or can be adapted by the user to relate to the time, location and other parameters easily.
3. Flexibility in the design to allow new options for pick lists to be entered easily.
4. Database to store information about:
   a. The segments of discrete coastline; their physical status and plans.
   b. The coastal shoreline assets (access, mitigation and land use expansion):
      i. Their construction and materials,
      ii. Their status and level of repair.
   c. Critical facilities (unless it can be shown that NDMC or another agency can create this data).
5. Reporting possible through:
   a. Summary reports of coastal segments, critical facilities and assets for each island,
   b. Inventory reports showing coastal segments and assets in detail (showing for example construction and current status),
   c. Monitoring reports showing how coastal segments and assets have changed in various periods,
   d. Descriptive reports of island status showing general physical considerations and local perceptions of risk, vulnerability and resilience,
   e. Aggregated reports to atoll and national level of above to show summaries that could include total assets on each island, pivot tables showing total lengths of different asset types, relative perception of resilience

or risk across islands, summaries of potential risk at atoll level,

f. Historical reports of past management, construction and status,



g. Creation of attribute tables showing coastal segments, critical facilities and assets that can be joined to GIS data (e.g. linear features of coastal segments and assets).

6. Database structured so it can cope with various scenarios:

Appendices

a. To be used at IC, AC and national level

Parameter:	Width of reef flat

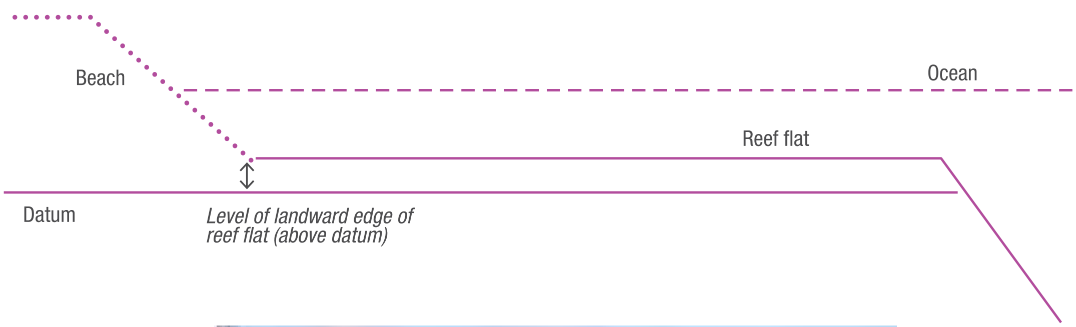
Description:

Width of reef or sand flat from reef edge to the toe of the beach / seawall or shoreline beach rock outcrop. Measured using Google Earth or from survey information (if available).

Parameter:	Level of landward edge of reef

Description:

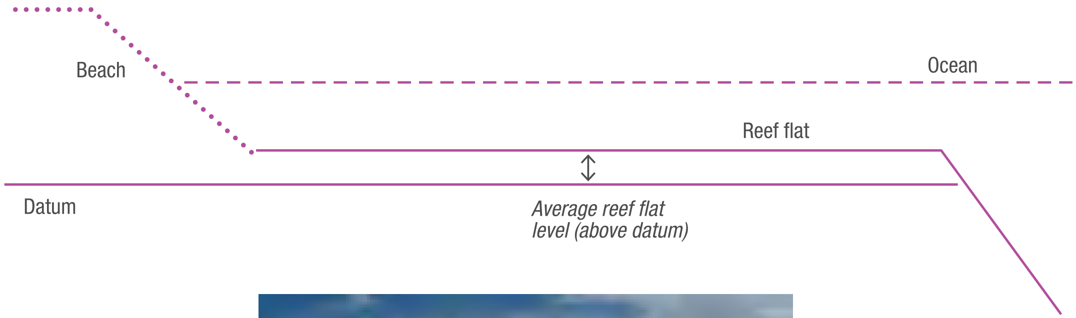
The level of the reef flat at the toe of the beach / seawall or seaward edge of beachrock outcrop The level must be relative to the vertical datum being used. Accurate levels needs to be measured by survey for the specific location.



Parameter:	Average reef flat level

Description:

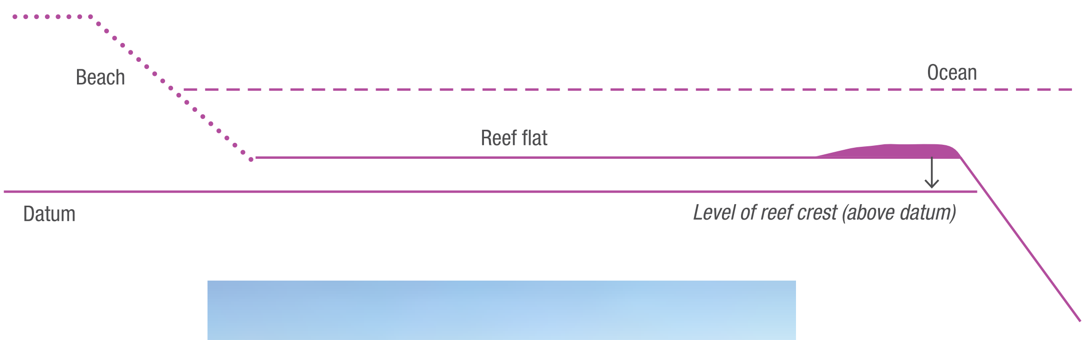
The average level of the fringing reef flat if levels are relatively consistent over its entire width. The level must be in metres relative to the vertical datum. Accurate levels need to be measured by survey for the specific location as this parameter has an important bearing on the size of wave conditions reaching the shoreline.



Parameter:	Reef crest level

Description:

The level of the reef crest at the seaward edge of the reef. The level must be relative to the vertical datum used. Accurate levels need to be measured by survey. However, an approximation could be made based on comparison with tide levels on a particular day.

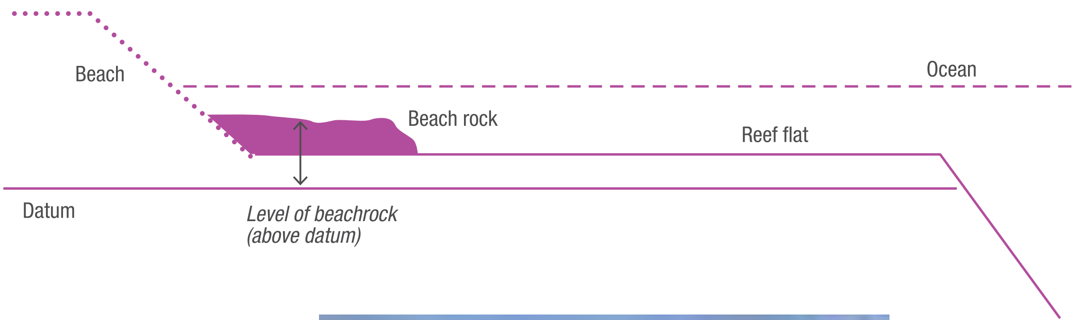


Appendices

Parameter:	**Level of the top of any beachrock**

Description:

The level of the top surface of any significant outcrops of beachrock or other significant structures such as wharfs at the shoreline. The level must be relative to the vertical datum used. Accurate levels need to be measured by survey. However, an approximation could be made based on comparison with high tide levels on a particular day.

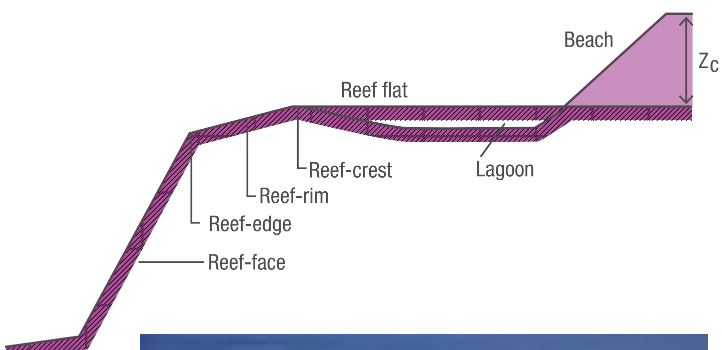


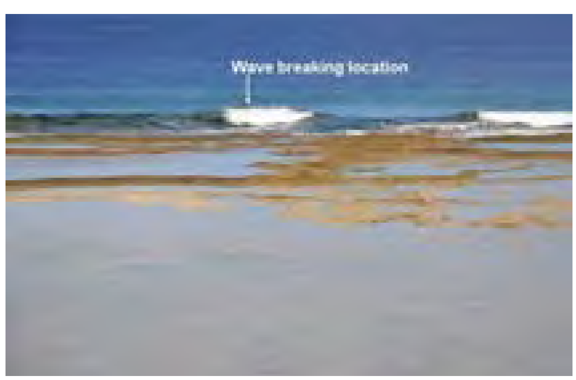
Parameter:	**Wave breaking location**

Description:

The position on the reef edge where wave breaking occurs. If wave breaking occurs over a narrow part of the rim of the reef, greater wave set-up will occur than if the larger waves break significantly further seaward and the smaller waves. Wave breaking options include;

- Reef edge
- Reef rim





Parameter:	Angle of reef face slope

Description:

The slope of the outer edge of the reef face. The steeper the reef face, the greater the wave set-up. The average slope can be estimated from nearshore bathymetric survey information. An estimated can also be made using Google Earth based on:

1. Measuring the distance from the edge of the reef to the change in colour indicating the approximate base of the reef face.
2. Assuming this change in colour is approximately 15 m water depth.
3. The slope of the reef = Distance / Depth (15).

Parameter:	Reef flat characteristics

Description:

The height of waves that reach the shoreline over the reef flat on the ocean side is influenced by the type of material that is found across the reef flat surface. Options are set out below. For the ocean side reef the selection will be generally be between:

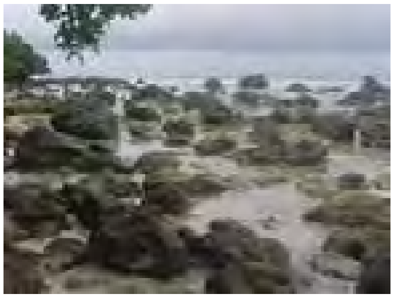
75-100% sand

75-100% smooth rock or coral pavement

75-100% seagrass or algal turf

Smooth rock or coral pavement with 50-100% coral rubble

Appendices



10%-25% live coral or dead uneroded coral or tall (> 30cm) boulders

75%-100% live coral or dead uneroded coral or tall (> 30cm) boulders

Beach / seawall characteristics

Parameter: **Shoreline type**

Description:

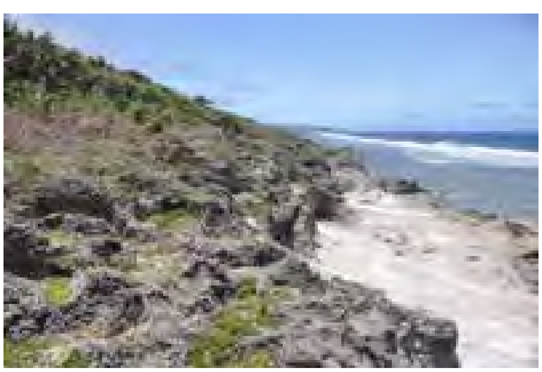
The beach / seawall characteristics determine how much:

1. wave run-up occurs (beach, sloping limestone platforms, revetment (sloping seawalls)
2. overtopping occurs (seawall structures).

Select from:

Sand beach

Coral rubble beach



Sloping limestone platform

Limestone cliff

Revetment (sloping) seawall

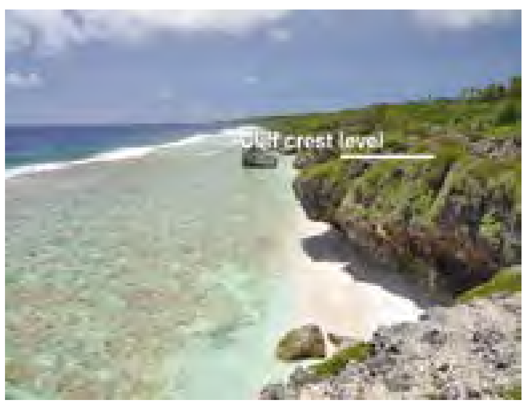
Vertical seawall

Parameter:	Beach / cliff / seawall crest level

Description:

The beach / cliff seawall crest level determines how much:

3. wave run-up occurs (beach / revetment (sloping seawalls), or
4. overtopping occurs (vertical cliffs, seawalls) .



Appendices

Parameter:	**Beach / seawall (revetment) slope**

Description:

The slope of a beach or revetment (sloping) seawall influences how much wave run-up or overtopping occurs. It is expressed as 1: x where x is the horizontal distance for a 1 m change in vertical level.

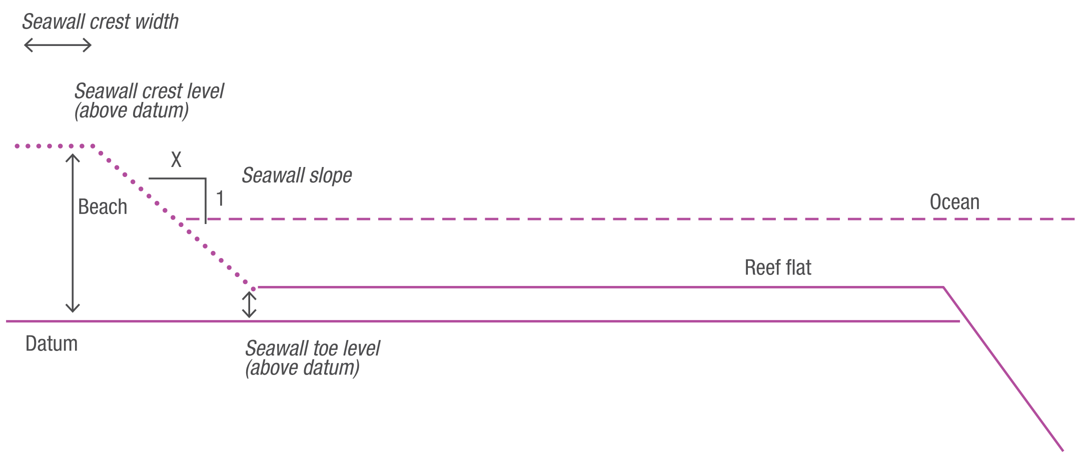
Beaches: Any slope can be entered

Revetments: The slope selected should be between 1:1 and 1:5.

The slope is calculated either by:

1. The horizontal distance (H) between seawall crest and toe divided by the vertical difference (D) between the seawall crest and toe = D / H
2. If survey data is available by using the X, Y coordinates of the seawall crest and toe to establish D and H.

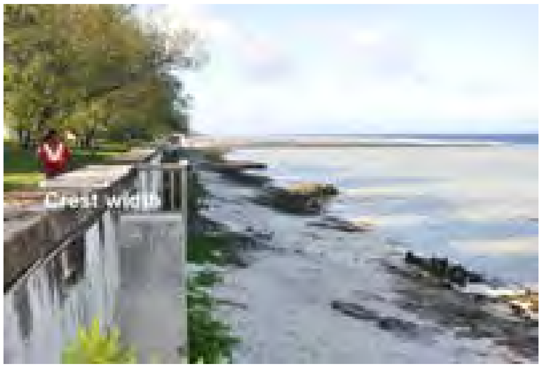
The slope can be calculated automatically using one of the tools in the "Help" section of the coastal calculator.



Parameter:	Seawall crest width

Description:
The width of the crest of the seawall (metres) influences how much wave overtopping occurs.

The crest width makes little difference in overtopping rate for:
- Concrete or solid seawall structures (it has more influence with seawalls built from rock or concrete armour units).
- Crest widths less than 1 m.



b. To allow archiving of old data while keeping up with new assets and reclamation schemes.

c. Flexible enough to accommodate local conditions that may not be universal to all islands.

5.3.6.1 5B2) Demonstration database attributes

The demonstration database is developed using Microsoft Access 2007 (.accdb file extension). It needs no other software to run. It uses a small amount of additional internal Visual Basic programmes which requires security warnings to be ignored to enable them. Several features of the database allow for ease of entry and usage:

1. A menu for users to get to data entry, reports and database management and which protects other elements of the database from inadvertent tampering.
2. Use of forms for data entry with, where possible, drop down pick lists available to simplify typing and standardize data.
3. Colour coding of data boxes has been used to help guide users –
   a. White boxes are for data entry only
   b. Greyed boxes are for information only
   c. Orange boxes are to allow no data entry but for users to make choices (e.g. to search for a particular asset).
4. A final database would attempt to match the order in which data are entered to that of any survey methodology or paper

Parameter:	Revetment crest wall

Description:

A vertical wall at the top of a sloping revetment seawall can significantly reduce the volume of wave overtopping.

A simple approach is adopted that takes account of the presence of a crest wall and adjusts overtopping volume. This does not take account the height of the crest wall, just its presence.

Appendices

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