

# DESIGN – TECHNICAL NOTE

JBA Project Code 2014s1358  
Contract Isle of Man Sea Defence Options  
Client Department of Infrastructure, Isle of Man Government  
Day, Date and Time 26/08/2014  
Author Alec Dane  
Subject Douglas Open Coast – Option DOCB2 – Xbloc Revetment



Project Title: Isle of Man Sea Defence Options			Sheet No: 1
Subject: Douglas Open Coast – Option DOCB1 – Xbloc Revetment			Calc No:
Job No: 2014s1358			Version:1.0
Developed By: Alec Dane	Date: 26/08/2014	Revised By: Alec Dane	Date: 03/12/2014
Checked By: Graham Kenn	Date: 02/12/2014	Approved By: Graham Kenn	Date: 04/12/2014

## 1 Aim

JBA have been commissioned by the Department of Infrastructure (DoI) to develop a number of technically viable solutions to address the still water level flooding in harbour environments and wave overtopping in open coast environments, at seven coastal sites across the Isle of Man.

This technical note covers the design assumptions, decision making process and methodology for the concept design of Option DOCB2, an option to place an Xbloc revetment in front of the existing sea defences in Douglas, to reduce wave overtopping to the hinterland. Douglas has been split into two distinct areas due to the differing wave overtopping mechanisms experienced. This design option covers an Xbloc revetment option fronting the Manx railway in the north of Douglas Bay. Xbloc is a proprietary concrete armouring system, considered to be the most technically efficient system in terms of reduction in overtopping and total material requirements, currently available on the market.

The scope of works does not include a formal options appraisal process. However a high level Multi Criteria Analysis will be undertaken with input from key stakeholders to help determine which option best satisfies the project criteria. The option proposed has been developed based on technical feasibility, engineering judgement, environmental impact, cost and consideration of the long term vision and key criteria determined by the project stakeholders.

## 2 Assumptions

The following assumptions have been used during the development of the concept design.

### 2.1 Datum

All elevation and depth measurements presented in the conceptual design of defence options will be presented in Douglas02 datum.

### 2.2 Baseline conditions

The coastal defences at Douglas are frequently overtopped by waves during a storm event. In order to design an option that efficiently reduces the risk of wave overtopping damage to the hinterland, it is important to look at the baseline conditions.

As stated above, the options proposed to reduce wave overtopping in Douglas have been split into two distinct sections, due to the differing wave overtopping mechanisms experienced. In the south of Douglas Bay, defence elevations are low, but are fronted by a large sand beach in places. Here, the wave overtopping occurs due to the run-up of broken waves exceeding the defence crest elevation, inundating the hinterland. However, in the north of the bay, wave overtopping occurs due to impulsive conditions. Here, the large vertical walls allow for large waves to break on the structures, causing jets of up-rush water to pass over the structure. This design option seeks to reduce the volume of wave overtopping in the north of Douglas Bay.

#### 2.2.1 Existing defence geometry

The existing defences are composed of a large vertical concrete wall fronted by a hard rock platform. There

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is very little beach protecting the toe of the wall, resulting in a large vertical face in contact with the still water levels.

Attribute	Dimension
Sea wall crest level	6.6mD02
Rock platform level	1.1mD02
Sea wall height	5.5m

Table 2-1: Existing defence geometry summary

## 2.2.2 Current wave overtopping risk

Based on baseline modelling of the existing defences, Douglas Section B is currently offered a 1 in 10-year level of protection against wave overtopping. However, by including an allowance for climate change up to the year 2115, that standard of protection reduces to less than a 1 in 5-year. This highlights the requirements for defence improvements, to provide protection to the road and property behind.

## 2.2.3 Current still water level flood risk

Based on the predicted extreme water levels from the Environment Agency Coastal flood boundary conditions for UK mainland and islands project<sup>1</sup>, a maximum SWL of 5.52mD02 for the 1 in 200-year event including an allowance for climate change is predicted. Based on this prediction, it is considered that there will be no risk of flooding caused solely by static water / tide levels over the open coast defences, as the impermeable defence has a crest elevation of 6.63mD02.

## 2.3 Design life and level of protection

The structure has been designed to achieve the following design standards:

- **Design life:** 100 years
- **Design storm event:** 1 in 200-year event (including climate change)

## 2.4 Climate change

By selecting a design life of 100 years, it is important to factor in the predicted effects of climate change. The latest UK Climate Projections (UKCP09) have been used to determine climate change allowance for:

- Still water levels;
- Wind driven waves; and
- Swell waves.

Within UKCP09 estimates for sea level rise are provided under low, medium and high emissions scenarios. Within the three scenarios the estimate is further refined by 5<sup>th</sup>, 50<sup>th</sup> and 95<sup>th</sup> percentile confidence ratings. In simple terms this should be interpreted as the relative likelihood of the projected change being at, or less than, the given change. For this study it is proposed that the medium emissions scenario is considered and that the 95<sup>th</sup> percentile confidence rating is used. This gives a projected sea level rise of 650mm by the year 2115 for Douglas.

UKCP09 acknowledges the difficulty in predicting changes in wind speeds over the next 100 years and concludes that there will be a negligible increase in wind speed. Therefore, the wind driven wave component of the numerical modelling has no direct increase in wave intensity due to climate change. However, as a result of the increased still water levels from relative sea level rise, there will be an indirect increase in wind driven wave height. As a result of the larger depth of water at the coastal defence toe, larger waves will be able to travel inshore before breaking, creating a higher intensity wave climate in the year 2115.

For changes in swell waves, UKCP09 gives a prediction of the change in annual maximum wave height for the year 2115 of up to **1.0m** for the UK. It should be noted that wave height increases could be limited by

<sup>1</sup> Coastal flood boundary conditions for UK mainland and islands, Project: SC060064/TR2: Design sea-levels. Environment Agency, Feb 2011.

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the water depth at the study location and therefore the full 1.0m increase is not applicable for all scenarios. The 1.0m allowance has therefore been applied to offshore swell wave conditions, which was subjected to wave transformation modelling to determine the change in wave height at each individual site.

## 2.5 Hydrodynamic data

The hydrodynamic data, used to design the open coast defences to a 1 in 200-year standard of protection in 2115, has been sourced from three primary sources:

1. **Extreme sea levels** - The Environment Agency Coastal flood boundary conditions for UK mainland and islands project<sup>2</sup>, which developed a consistent set of design sea levels for Scotland, England and Wales.
2. **Extreme winds** – Calculated using established methods in BS6399
3. **Extreme swell waves** - The extreme wave conditions were adopted based on the Environment Agency's *Coastal flood boundary conditions for UK mainland and islands* project<sup>3</sup> which developed a consistent set of design swell wave conditions around Scotland, England and Wales.

These three sources of data were combined using joint probability analysis to create the hydrodynamic input conditions for the design of these defences for any given return period.

## 2.6 Performance standards

For coastal defences, the performance standards can typically be split into two areas, the still water level performance and wave overtopping performance.

### 2.6.1 Performance standard 1 – still water level flood risk

As discussed above, the current defences are offering in excess of a 1 in 200-year level of protection in 2115 against still water level flooding. Hence this design option will not seek to raise the impermeable defence level to address still water level flood risk

### 2.6.2 Performance standard 2 – wave overtopping risk

Two thresholds have been used to limit the volume of overtopping that is deemed acceptable for the concept design options:

1. The first lower threshold was established for a common coastal storm event, considered to have a 1 in 1-year return period, based on a joint probability assessment.
2. The second higher threshold will be established for the design storm event, considered to have a 1 in 200-year return period, based on a joint probability assessment. During this event it is considered that general public use of the pavement and road immediately behind the structure will be discouraged and only trained personnel will be operating within the vicinity of the structure.

Table 2-2 below summarises the guidance for vehicles and pedestrians provided within the European Wave Overtopping Manual (EurOtop).

Table 2-2: Limits for overtopping for vehicles (source: EurOtop<sup>4</sup>)

Hazard type and reason	Mean discharge	Max volume
	q (l/s/m)	V <sub>max</sub> (l/m)
Driving at low speed, overtopping by pulsating flows at low flow depths, no falling jets, vehicle not immersed.	10 - 50 <sup>5</sup>	100 – 1,000

<sup>2</sup> Coastal flood boundary conditions for UK mainland and islands, Project: SC060064/TR2: Design sea-levels. Environment Agency, Feb 2011.

<sup>3</sup> Coastal flood boundary conditions for UK mainland and islands, Project: SC060064/TR3: Design swell-waves. Environment Agency, Feb 2011.

<sup>4</sup> Pullen, T., Allsop, W., Bruce, T., Kortenhaus, A., Schuttrumpf, H & van der Meer, J (2007) 'Wave overtopping of sea defences and related structure: Assessment manual'. Accessed from [www.overtopping-manual.com](http://www.overtopping-manual.com)

<sup>5</sup> Note: These limits relate to overtopping defined at highways.

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Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets.	0.01 – 0.05 <sup>6</sup>	5 – 50 at high level or velocity
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 of frightened, able to tolerate getting wet, wider walkway	0.1	20-50 at high level or velocity

The following twofold tolerable discharge thresholds have been proposed for all concept options on open coast environments:

- 1 in 1-year event – <0.1l/s/m
- 1 in 200-year event – <10l/s/m.

These tolerable discharges are such that all structures will be considered safe for pedestrian access during the more regular storm event, while vehicular and emergency staff will be safe to inspect defences during the less frequent, higher magnitude storm.

By adopting a twofold approach to acceptable overtopping levels, the new defence options considered for the sites have a dual purpose of preventing the frequent overtopping caused by common storms while providing structural and overtopping protection during rare events. By incorporating dual overtopping targets the crest height of all structures can be minimised, reducing both construction cost and visual impact.

## 2.7 Ground conditions

No geotechnical or ground condition information has been made available as part of this study. Therefore, all designs of defence structures have been progressed assuming poor ground conditions e.g. low bearing capacity. This should provide a conservative approach to the development of the concept design. The levels presented in the drawings represent finished defence levels, so would require consideration of potential settlement which would be taken into account during detailed design.

## 2.8 Structural design

A full structural design has not been included within this study as the scope of works did not include geotechnical investigation or analysis. All designs will be reviewed by a structural engineer to confirm that the design principles adopted are acceptable.

## 2.9 Services information

No detailed services information was provided as part of this study and a services search is not included within the scope of works. However, the location of more critical services has been identified by DoI. These critical services were considered in the development of the concept design options and have been highlighted on concept drawings and in hazard inventories. If the project progresses to outline and detailed design it will be essential that a full service plan is developed.

## 2.10 Environmental impact

This commission does not include any formal Environmental Impact Assessment or Landscape Visual Impact Assessment. If the project progresses to outline and detailed design, a more in depth study of the environmental impacts will be required.

## 2.11 Reinstatement and finish details

The development of landscape and architectural enhancements are outside the current project scope of works. It is assumed that following construction the surrounding area will be re-instated to a condition similar to the present. However, during the detailed design stage further architectural and landscape

<sup>6</sup> Note: These limits relate to overtopping defined at the defence, assumes the highway is immediately behind

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enhancements could be considered.

## 2.12 Contaminated land

No information regarding the location of areas of contaminated land has been provided as part of this commission. Therefore all design options have been developed with the assumption that none of the areas are subject to contaminated land constraints. An invasive contaminated land survey should be undertaken at all locations prior to detailed design to enable detailed assessment of suitable construction techniques and options for removal or re-use of excavated material.

To progress concept design options as part of this study the following have been assumed:

- No investigation of contamination issues at individual development sites; and
- Development flood defence options may require some contaminated land treatment depending on the result of the investigations.

## 2.13 Tie in details

Tie-in details between old and new defences have been considered at a conceptual level. The key consideration has been to develop an option that does not create an area of outflanking or weak point, where overtopped water can bypass the defences and flood the hinterland. Careful consideration of the connection between the existing and new defences will be required during the detailed design phase.

## 3 Standards, guidance & reference documents

All design assumptions have been developed using the following reference material:

- BS 6180 1999: Barriers in and about buildings, code of practice
- BS EN 206-1:2000 Concrete – Part 1: Specification, performance, production and conformity
- BS EN 12620:2002 Aggregates for concrete
- BS EN 6349-1-1:2013, Maritime works, General, Code of practise for planning and design.
- CIRIA (2010), The use of concrete in maritime engineering – a guide to good practise
- Cobb, F (2009), Structural Engineers Pocket Book (2<sup>nd</sup> Edition)
- DEFRA (2009) UK Climate Projections 09
- Delta Marine Consultants (2011), Xbloc - Guidelines for Xbloc Concept Designs
- Environment Agency. (2010). Fluvial Design Guide
- HR Wallingford (2007), EurOtop, Wave Overtopping of Sea Defences and Related Structures: Assessment Manual
- US Army Corp of Engineers (2002), Coastal Engineering Manual

## 4 Design development

The following provides a brief summary of how the key design elements were selected.

### 4.1 General form of defence

This design option acts to dissipate the wave energy arriving at the coastline by placing a permeable structure in front of the existing sea wall. This has been achieved through the design of an Xbloc armour revetment.

Xbloc is a precast concrete proprietary armour unit developed by Delta Marine Consultants (DMC) in 2003. Unlike armourstone, the stability of Xbloc is dependent on both the mass of the unit and the interlocking of adjacent units. This makes them a more effective form of armouring slopes per unit mass of armour material. Double layer systems have been shown to allow unwanted movements of units in the upper layer, consequently, Xbloc has been designed to be used in a single layer. Xbloc has to be placed on a predefined grid, however, the orientation is allowed to vary randomly unlike other monolayer armour units.

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Figure 1 - Xbloc armour unit (DMC, 2011)<sup>7</sup>

Placing an Xbloc primary layer on top of the existing armour also has the added benefit of weighing down the existing armour which has been said to be mobile during a storm event, due to the rock being inadequately graded.

## 4.1.1 Defence crest level, crest width and slope

A defence crest level of 6.10mD02 has been proposed for the rock armour revetment. This has been defined by an iterative process using the EurOtop overtopping tool and engineering judgement. The initial design of this revetment considered a full suite of revetment crest elevation, widths and slopes which were all tested against a range of wave height and water level combinations that comprises a 1 in 200-year event including an allowance for climate change and a 1 in 1-year event again including an allowance for climate change. The primary aim of this modelling was to determine the worst case combination for anticipated overtopping volumes. This initial modelling provided a guide for the general defence geometry appropriate for this location. In this case, the greatest reduction in overtopping rates were seen for a crest elevation equivalent to just below the existing sea wall with the front slope, sloping a 1:1.4.

The Design Input Statement set out limits for overtopping and are again presented here, <0.1 l/m/s for a 1 in 1 year event and <10 l/m/s for a 1 in 200 year event. Using the iterative overtopping process, defence crest widths were varied at 100mm increments to identify the required width of crest to achieve these tolerable overtopping limits. This iterative process showed that a crest width of 9m was sufficient to reduce the overtopping to those set out above.

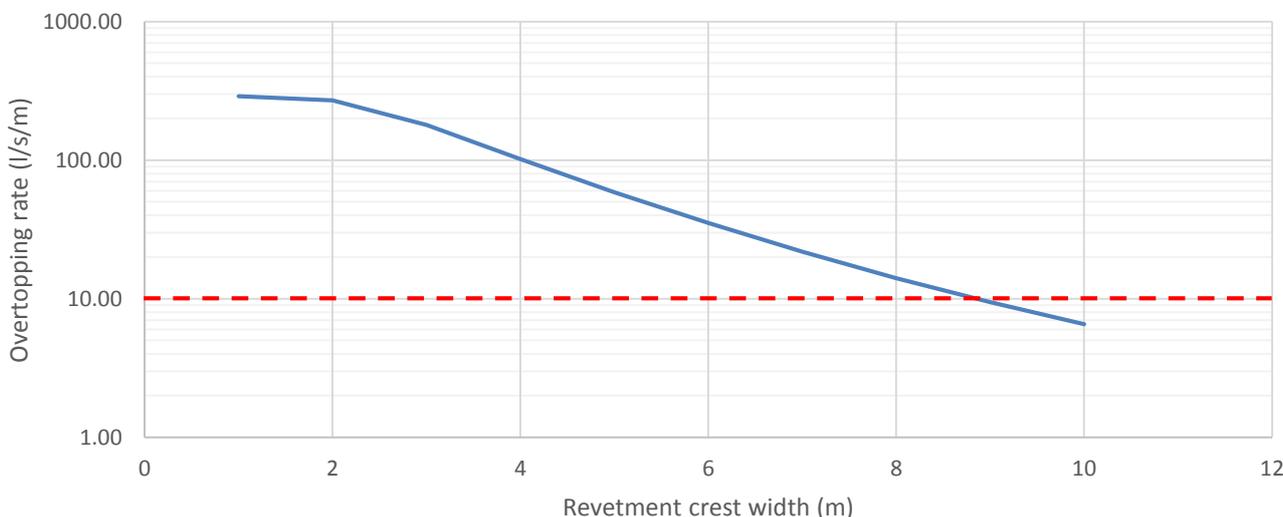
<sup>7</sup> <http://www.xbloc.com/projects/breakwater-lng-terminal-nw-australia/item679>

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## Optimisation of revetment crest width (1 in 200-year event)



	Threshold Value	Value
Crest Elevation (mD02)	-	6.10
Crest Width (m)		9.00
Overtopping Rate 1:1 (l/m/s)	0.1	0.14
Overtopping Rate 1:200 (l/m/s)	10	9.5

Table 4.1: Defence configuration and overtopping rates for DOCB1

It should be noted, that this defence configuration does not conform to the tolerable threshold for the more regular 1 in 1-year storm ( $<0.1$  l/s/m). In order to meet this threshold, the crest width would have to be in the order of 12m which would be a considerable capital scheme. An overtopping rate of 1 l/s/m is suggested as being acceptable for a well shod, trained member of staff to access the land behind<sup>8</sup>. Given the north of Douglas Bay’s relatively less busy promenade, the DoI could consider this overtopping threshold acceptable for the more regular storm event. However, the lack of conformity to the design standard should be noted and considered when evaluating other options in the appraisal. It is important that the DoI understand the implications of accepting this higher overtopping rate and the need to plan for area cordoning during the storm event.

It should be noted that the EurOtop guidance suggests that the model is only suitable for the development of concept design options. Physical modelling is recommended for detailed design stages, if control of overtopping volumes forms one of the key design criteria.

### 4.2 Armour sizing

The following summarises the Xbloc design process (further details can be found within the calculation sheet). The Xbloc armour units have been sized using the ultimate limit state, or the upper limit for the structural stability of the proposed defence components. This limit state has been used to ensure that the Xbloc will withstand 200-year wave conditions in combination with 200-year extreme sea-levels, including the effects of climate change to the year 2115. The overall likelihood of an event of this magnitude occurring will have a probability greater than 200 years, incorporating a preliminary level of safety into the critical design elements. This has ensured any structures will withstand wave conditions with an extremely low

<sup>8</sup> Pullen, T., Allsop, W., Bruce, T., Kortenhaus, A., Schuttrumpf, H & van der Meer, J (2007) 'Wave overtopping of sea defences and related structure: Assessment manual'. Accessed from [www.overtopping-manual.com](http://www.overtopping-manual.com)

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recurrence interval.

- Xbloc sizing calculation used: Xbloc - Guidelines for Xbloc Concept Designs (Delta Marine Consultants, 2011).
- Significant wave height ( $H_s$ ): 1 in 200 year ultimate limit state wave height plus climate change transformed to the structure toe = 2.56m
- Period ( $T_m$ ): 1 in 200 year plus climate change wave period = 7.10s
- Still Water Level (SWL): 1 in 200 year water level including climate change = 4.92mD02
- Concrete density: 2.4t/m<sup>3</sup>
- Slope Angle ( $\alpha$ ): 1 in 1.4 (36°) has been selected to represent a stable slope while attempting to limit the total required volume of concrete and through best practice guidance from DMC (2011).

Using the above input parameters within the Xbloc calculation (Xbloc guidance) a required armour unit volume ( $V_{x,req}$ ) = **0.335m<sup>3</sup>**. Xbloc guidance states that for units placed on a low-crested structure, a safety factor of **1.5** should be applied on the armour unit volume. Using the recommended safety factor, produces a required armour unit volume ( $V_{x,req}$ ) = **0.503m<sup>3</sup>**. Xbloc armour units are produced in standard sizes, so by selecting an armour unit size above the required volume, results in a designed Xbloc armour unit volume of ( $V_{x,des}$ ) = **0.75m<sup>3</sup>**. This equates to an armour unit mass of ( $M_{x,des}$ ) = **1.8t**, and an armour unit height of ( $D_{x,des}$ ) = **1.31m**. Further detailed analysis and specification should be undertaken during the detailed design phase, subsequent to physical modelling on the stability of the armour units.

## 4.2.1 Intrinsic properties of concrete for Xbloc armour units

The properties of the concrete for the armour units are suggested below based on guidance from EN 206-1:2000:

- **Density:** A typical concrete density of 2.4t/m<sup>3</sup> has been selected for the Xbloc armour units. DMC (2011) recommend using concrete densities within a range of 2.35-2.5t/m<sup>3</sup>.
- **Grade:** C25/C30
- **Exposure class:** XS3 for concrete in a tidal, splash and spray zone
- **Aggregate diameter:** 20-40mm selected in accordance with EN 12620:2002
- **Workability:** Slump class S2 (50-90mm)

## 4.2.2 Armourstone filter layer

The permeability of the structure has a direct impact on the structural stability of the armour units. With a greater permeability, wave energy can be dissipated through a larger armour unit depth and reduce the development of interstitial pore pressures that can result in the expulsion of armour units. In order to increase the permeability, it is essential to provide an adequate filter layer. Xbloc guidance recommends use of a **0.06-0.3t** armourstone filter layer of minimum **0.8m** thick for a primary unit size of 0.75m<sup>3</sup>.

## 4.2.3 Core

The design specifies a semi-permeable core to allow some dissipation of energy through the core. Suitably graded material should be selected with both the required permeability and economic feasibility in mind. Where it may be suitable to place a more impermeable core, the depth of the filter layer may be increased to allow for a reduction in the permeability. These options should be considered during the detailed design phase.

## 4.3 Structure toe and foundation level

The Xbloc revetment has been designed to be placed directly on to the existing rock platform to reduce the risk of scour at the structure toe. The design specifies the use of a rock armour toe, due to the reduced stability of Xbloc armour units on flat slopes. An Xbase armour unit has been included underneath the main structure slope to key the units into one another.

The stability of the leading edge of the toe armour is likely to be reduced due to reduced friction between

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interlocking layers (Environment Agency, 2013). These rocks are more vulnerable to movement due to the absence of support from the seaward side. In order to mitigate this potential failure mechanism, the design specifies using the largest rocks as the keystone (a minimum of 4.5 tonnes).

## 4.4 Defence crest form

The 1.5 safety factor on the armour unit mass has been applied due to the relatively low freeboard in relation to the wave height. Due to the stability of the armour units being dependent on the slope and the interlocking between units (and not their mass), the stability is greatly reduced on the horizontal crest. In order to reduce the likelihood of the expulsion of units on the revetment crest, an armourstone crest has been applied. The mechanism for the stability of armourstone is primarily the unit mass and consequently will be more stable during large overtopping events. The rock has been graded at **3-6t** to ensure stability through calculations of the required armour mass on low-crested structures (CIRIA (2007), The Rock Manual (page 631)).

## 4.5 Tie in details

It is proposed that the structure will run for the full length of the existing vertical sea wall structure. The exact location of this tie in cannot be confirmed at this design stage. During detailed design, it is recommended that multiple sections are analysed to identify the exact location of the defence tie in.

## 4.6 Access for the public

By providing a physical barrier between the pavement and the beach, it is necessary to provide designated access routes for the public to access either side. This access could be achieved through placing stainless steel access steps at strategic locations. The best method for achieving this access should be developed during a latter design stage.

## 4.7 Public safety

Public safety has formed a key consideration during the concept design development phase. The main risks associated with this option are the issues surrounding the future public usage of the structure. The public should be discouraged from climbing on the rock structure as there is a risk of injury. It is suggested that signage is used as a means of warning. In addition, it is recommended that stainless steel access steps are provided over the defence, to allow members of the public to access either side of the structure.

In addition, by offering a lower standard of protection or allowing a higher tolerable threshold during the regular storm event, the risk of public interaction with water overtopping the defence is higher than if it conformed with the intended design standards. If this option is progressed, the DoI should implement a storm action plan to control these risks, to prevent pedestrians encountering the overtopped water.

For further information on all the risks considered, mitigated or reduced please refer to the Designers Hazard Inventory.

## 5 Technical risks summary

The following are considered to represent the key risks highlighted during the development of this concept design.

### 5.1 Unknown ground conditions

Due to the unknown ground conditions it is possible that the current design will require modification in order to achieve structural and geotechnical stability.

### 5.2 Integrity of the sea wall

While the seawall face seems to be in reasonable condition, the placement of rock armour and concrete armour units onto the existing structure represents a technical risk. Care should be taken to not drive plant on the landward side of the wall, minimise any required excavations and take care when rock is placed in direct contact with the existing defences. All attempts to prevent loading to the sea wall should be made.

The 100 year design life of the coastal defence is dependent on the structural integrity of the existing defences, as this new structure forms part of a composite coastal defence. This design assumes that the existing sea wall will not be allowed to deteriorate further as this may undermine the newly proposed

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superstructure. It is recommended that a full asset inspection be undertaken prior to detailed design, to quantify the residual life of the structure and allow for the development of more tailored remediation measures.

## 5.3 Tie-ins with existing defence

The tie-ins have been considered at a conceptual level but will require careful consideration during detailed design.

## 5.4 Pavement closure during a storm event

The higher tolerable thresholds offered by the wall mean that the pavement area behind the defence will be unsuitable for public pedestrian access during the regular storm event (1 in 1-year). Consequently, DoI should provide emergency on-the-ground manpower during this storm event, to cordon off and close parts of the frontage to reduce the risk of public interaction with wave overtopping. This should be factored when considering the suitability of each defence option.

## 5.5 Services

Limited services information has been provided as part of this study. If the project progresses to outline and detailed design it will be essential that a full service plan is developed.

## 5.6 Construction accessibility

Prior to the development of outline designs it would be advisable to appoint a construction contractor to provide constructability advice. Although the site is considered reasonably accessible it would be beneficial to confirm the proposed methods of construction and temporary works required.

## 5.7 Stakeholder requirements

A Multi Criteria Analysis was completed as part of this study to try and determine the key considerations of the project stakeholders. It is anticipated that during the course of a formal options appraisal project stage that more in depth stakeholder consultation will be completed. The results of which may lead to changes in the concept designs that have already been developed.

## 5.8 Environmental impacts

No formal Environmental Impact Assessment was completed during this project stage. It is anticipated that during the course of an options appraisal stage that an in depth assessment of the environmental impacts associated with all proposed options would be considered. This process may result in changes being made to the proposed designs.