

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 Laxey Open Coast – Option LOC2 – Raised Sea Wall



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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 LOC2, an option to raise the existing sea wall to reduce wave overtopping in Laxey to prevent flooding of the hinterland.

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 open coast defences at Laxey 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.

Wave overtopping occurs where the waves run up the face of the coastal defence. Where this run up exceeds the defence crest level, water passes over the structure and inundates the land behind. This design option will therefore seek to reduce the volume of flood water travelling over the existing defences during a storm event.

2.2.1 Existing defence geometry

The existing defences are composed of a small concrete sea wall fronted by a concrete stepped revetment. To the west of the site, a coarse shingle beach has buried the revetment, providing an added level of protection to the defence. Anecdotal evidence suggests that the wave overtopping issues are exacerbated in the east of the unit, where the beach has been drawn down exposing the revetment.

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Attribute	Dimension
Sea wall crest level	7.1mD02
Sea wall toe level	3.9mD02
Sea wall height	3.2m

Table2-1: Existing defence geometry summary

2.2.2 Current wave overtopping risk

Based on baseline modelling of the existing defences, Laxey promenade is currently offered a 1 in 50-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 Laxey promenade and the adjacent property.

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 project¹, a maximum SWL of 5.35mD02 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 to the town caused solely by static water / tide levels over the open coast defences, as the primary defence has a crest elevation of 7.13mD02.

However, worth noting is the still water level flood risk in the harbour area (covered by the technical note for LH1), showing the need for defence improvements for the two areas at Laxey, in both the harbour and open coast environments.

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 5th, 50th and 95th 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 95th percentile confidence rating is used. This gives a projected sea level rise of 650mm by the year 2115 for Laxey.

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.

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

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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 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 project², 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* project³ 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: EurOtop⁴)

Hazard type and reason	Mean discharge	Max volume
	q (l/s/m)	V _{max} (l/m)
Driving at low speed, overtopping by pulsating flows at low flow depths, no falling	10 - 50 ⁵	100 – 1,000

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

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

⁴ 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

⁵ Note: These limits relate to overtopping defined at highways.

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jets, vehicle not immersed.		
Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets.	0.01 – 0.05 ⁶	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 or 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 – $<0.1\text{l/s/m}$
- 1 in 200-year event – $<10\text{l/s/m}$.

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. 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

⁶ 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 (2nd Edition)
- DEFRA (2009) UK Climate Projections 09
- 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, raises the defence crest level on the existing line of defence. By raising the defence level, the volume of wave overtopping is reduced, by increasing the transport pathway for the overtopped water. The wall has been designed as a reinforced concrete cap.

4.1.1 Defence crest level

A defence crest level of 7.63mD02 has been proposed for the raised sea wall. This has been defined by an iterative process using the EurOtop overtopping tool and engineering judgement. The proposed wall geometry has been 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.

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. However, as part of this design, there has to be a

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consideration of what will be structurally stable, the influence on the surrounding landscape and cost.

Based on the overtopping modelling, an additional wall raising of 1700mm above the existing wall crest would be required to reduce the overtopping rates to those outlined above, producing a maximum wall height of 2150mm. Aside from the significant obstacles of achieving structural stability on a wall of this magnitude, a wall of this height would have a significant visual impact on the landscape of Laxey Harbour.

Optimisation of raised sea wall height (1 in 200-year event)

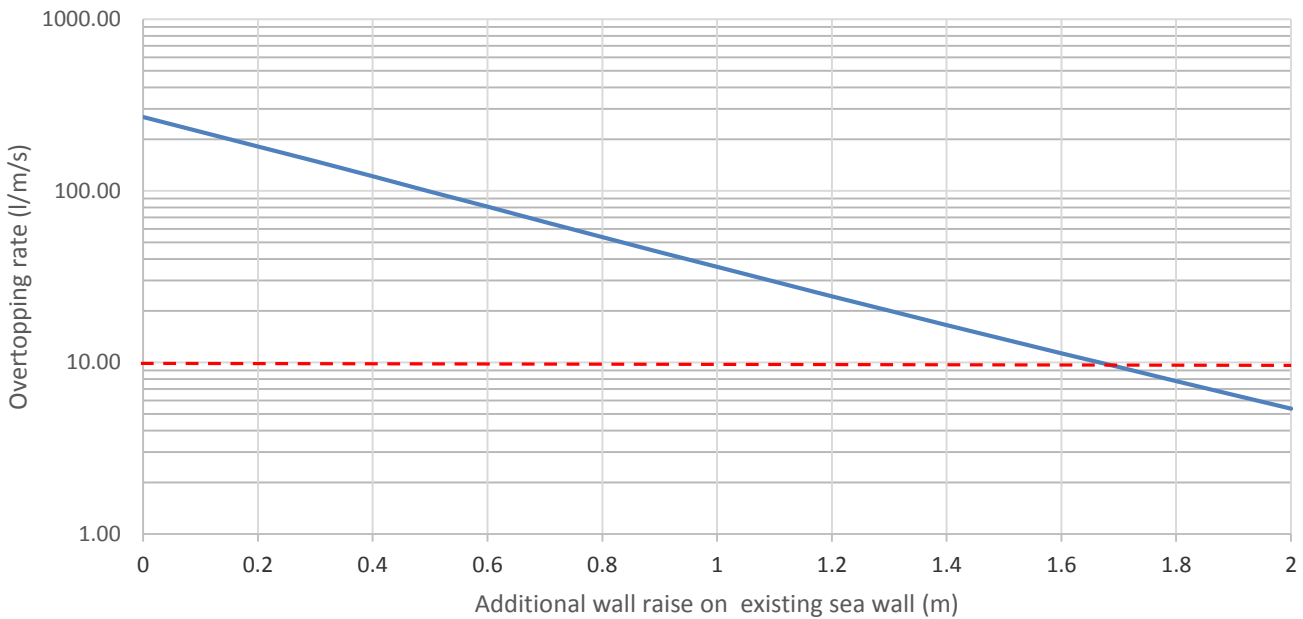


Figure 4-1: Optimisation of raised sea wall crest height

Due to the unknown structural capacity of the existing sea wall, it is assumed that the walls will be able to bear a maximum raise of 500mm, as stated in the Design Input Statement.

Obviously, this does not conform to the intended design standards. The overtopping rates during the design storm events are outlined in Table 4.1. This design option offers a standard of protection against a storm in the order of 1 in 5 to 1 in 10-year event in 2115. This option is therefore not really considered a viable solution. Options to completely remove and re-design the sea wall could easily be developed to meet the required overtopping thresholds. However, this was not taken forward due to the costs being in orders of magnitude higher than other options proposed for Laxey.

Table 4-1: Overtopping rates for LOC2

Storm event	Overtopping rate (l/s/m) present day	Overtopping rate (l/s/m) 2115
1 in 1-year	0.02	1.3
1 in 10-year	0.3	14.1
1 in 50-year	1.5	41
1 in 200-year	5	100

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.

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4.1.2 Wall height

The 500mm raise gives the wall height above ground level equal to a total wall height of 960mm above ground level, which is in not compliance with BS 6180 for the minimum height of concrete barriers and handrails for horizontal guarding (1100mm). Consequently a 150mm stainless steel handrail has been provided to meet the required elevation.

4.1.3 Tie in to existing wall

The raised concrete cap will tie in to the existing wall through use of two 12mm diameter 500mm long stainless steel dowel bar located through the centre of the cap at 500mm centres. This has been estimated using engineering judgement, but should be considered in more depth should this option be taken forward to detailed design. The dowel bars should be sufficiently protected from the main reinforcement to avoid the interaction between the mild steel and stainless steel.

4.1.4 Wall thickness and reinforcement cover

The wall thickness has been defined, allowing for 200mm wide reinforcement cage with a minimum 100mm concrete cover. This allows for a wall thickness of minimum 400mm. A large minimum cover to concrete has been applied due to the exposed nature of the environment.

4.2 Structure reinforcement

The proposed new concrete walls will have a nominal 200mm wide steel reinforcement cage, this should be considered in more detail during the detailed design phase. The structural design of the proposed raised walls are beyond the scope of this study.

4.3 Concrete mix design

The concrete mix design should consider a number of factors, firstly issues associated with the heat of hydration and thermal cracking as detailed above should be investigated. Secondly, the type of exposure that the concrete is subjected to and it's resistance to the ingress of chlorides which will cause corrosion to any reinforced elements must be assessed. The properties of the concrete for the raised harbour walls are suggested below based on guidance from EN 206-1:2000:

- **Density:** A typical concrete density of 2.4t/m³
- **Grade:** C40/C50
- **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)

However, this specification will be subject to modification during refinement in detailed design.

4.4 Wall cladding

Additional cladding may be incorporated into the visible wall faces to keep the defences in-keeping with the surrounding environment. The use of different forms of cladding and capping kerbs will be explored in more detail during detailed design.

4.5 Tie in details

It is anticipated that the defences will tie in with the infrastructure so as to avoid creating a point of weakness. Where access is considered critical, demountable defences will be required to ensure the defence level is maintained while allowing normal usage during normal conditions. 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 promenade and the beach, it is necessary to provide designated access routes for the public to access the beach. These should be through use of demountable flood barriers placed through the existing access points in the defence.

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4.7 Architectural enhancements

The new walls provide the opportunity to re-develop the promenade area, with more architectural enhancements, creating a more visually pleasing environment. This has not been considered during concept design, but the new walls could incorporate additional seating, material textures and forms, plant boxes and trees that could improve the current landscape.

4.8 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. In providing a physical barrier between the promenade and the beach, the risk of injury from falls from the wall are increased. The wall and handrail are situated at 1100mm above the promenade deck level which complies with the recommended guidance for minimum barrier height for horizontal guarding. However, the use of signage should be considered to warn members of the public of the risks associated with climbing on the wall.

In addition, by offering a lower standard of protection or allowing a higher tolerable threshold, 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

The option has been designed to tie directly on to the existing concrete wall through use of a dowel bar connection. It is not known whether or not the existing wall will be structurally stable with the proposed design water level. Should ground investigations show that the foundation is insufficient, the wall will need replacing.

In addition, the 100 year design life of the coastal defence is dependent on the structural integrity of the existing defences. This design assumes that the existing sea wall will not be allowed to deteriorate further as this may undermine the newly proposed 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 Beach morphological change

This study has not included any assessment of the likely evolution of the beaches that front the existing defences. A beach typically forms one component of a composite coastal defence, providing a reduction in the wave overtopping performance when compared to defences without a healthy beach. The calculations on the necessary defence configurations to achieve overtopping performance has considered the form of the beach in front of the defence. If that beach was to reduce in size, it is possible that the proposed option may not offer the required standard of protection. Therefore, during detailed design, an assessment of the likely beach evolution should be made, coupled with the development of a beach management plan to ensure that the beach levels do not drop below the critical dimensions needed to provide the necessary overtopping performance. The parameters that will require confirmation are the critical beach crest width and elevation needed to provide adequate protection to the sea wall.

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5.4 Tie-ins with existing defence

The tie-ins have been considered at a conceptual level but will require careful consideration during detailed design. This should also consider the flowpath of overtopped water to prevent water pooling behind the structures.

5.5 Road closure during a storm event

The higher tolerable thresholds or lower standard of protection offered by the wall mean that the promenade and car park area behind the defence will be unsuitable for pedestrian access during the design storm event. Consequently, DoI should provide emergency on-the-ground manpower during a 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.

5.6 Services

No 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.

5.7 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.

5.8 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.

5.9 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.