DESIGN – TECHNICAL NOTE

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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 PSM1, an option to place a raised sea wall in Port St Mary to reduce both the still water level and wave overtopping flood risk.

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 Port St Mary are frequently overtopped by waves during a storm event and has also been shown to be at risk of still water level flooding during a high return period event. In order to design an option that efficiently reduces the wave overtopping and still water level flood risk 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. Still water level flooding occurs where the extreme water level exceeds the impermeable defence crest level and water spills over the defences, flooding 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 from both still water level and wave overtopping flood mechanisms.

2.2.1 Existing defence geometry

The existing defences are composed of a concrete armour unit revetment with a small raised concrete kerb behind the revetment crest. The low lying topography behind these defences mean that water travels over the defences and becomes trapped in a basin behind.

Attribute	Dimension
Concrete cap crest level	4.6mD02
Revetment crest level	4.2mD02
Cap height	0.2m
Revetment toe level	2.0mD02
Revetment slope	1:2.5

Table 2-1: Existing defence geometry summary

2.2.2 Current wave overtopping risk

Based on baseline modelling of the existing defences, Port St Mary is currently offered a 1 in 20-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 Port St Mary 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 project[1], a maximum SWL of 4.59mD02 for the 1 in 200-year event including an allowance for climate change is predicted. Based on this prediction, it is considered that there is a risk of flooding to the hinterland caused solely by static water / tide levels over the defences, as the impermeable defence has a crest elevation of 4.50mD02. The defence solution at this location, must therefore consider both the still water and wave overtopping flood risk.

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 Port St Mary.

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

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

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[2], 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[3] 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 less than a 1 in 200-year level of protection in 2115 against still water level flooding. Hence this design option will seek to raise the impermeable defence level to address still water level flood risk. This will be achieved, through ensuring that the impermeable defence crest is situated at the 1 in 200-year extreme water level plus a 150mm freeboard allowance.

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[4])

Hazard type and reason	Mean discharge q (l/s/m)	Max volume V_{max} (l/m)
Driving at low speed, overtopping by pulsating flows at low flow depths, no falling jets, vehicle not immersed.	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.

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 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 Integrity of the concrete armour unit revetment

For the purposes of progressing this concept design, it is assumed that the existing concrete armour unit revetment will not be allowed to deteriorate further from its existing condition. It is currently in a fair to poor condition, so will need to consider remedial work / replacement within the next 20 years or so which should be factored in when comparing the defence options in the options appraisal.

2.9 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.

2.10 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.

2.11 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.

[6] Note: These limits relate to overtopping defined at the defence, assumes the highway is immediately behind

2.12 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 enhancements could be considered.

2.13 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.

2.14 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 kerb line of the defence. This has a dual purpose. Firstly by raising the height of the wall, the transport pathway for wave overtopping water has been increased, reducing the quantity that travels over the defence crest. Secondly, by raising the impermeable defence crest level, the risk of still water level flooding is reduced.

The wall has been designed as a reinforced concrete cantilever retaining wall. A small recurve has been included in the defence to deflect any spray generated during the wave breaking process.

4.1.1 Defence crest level

A defence crest level of 5.63mD02 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 1in 200 year event. However, as part of this design, there has to be a consideration of what is achievable with both cost and the environment in mind. Based on the overtopping modelling, a raised sea wall in the order of 1500mm above the promenade level would be require to reduce the overtopping rates to those outlined above. A wall of this magnitude would be have a considerable visual impact on the landscape of Port St Mary. Instead, the wall has been limited to a total height of 1200mm above deck level, to maintain the heritage and landscape in the area.

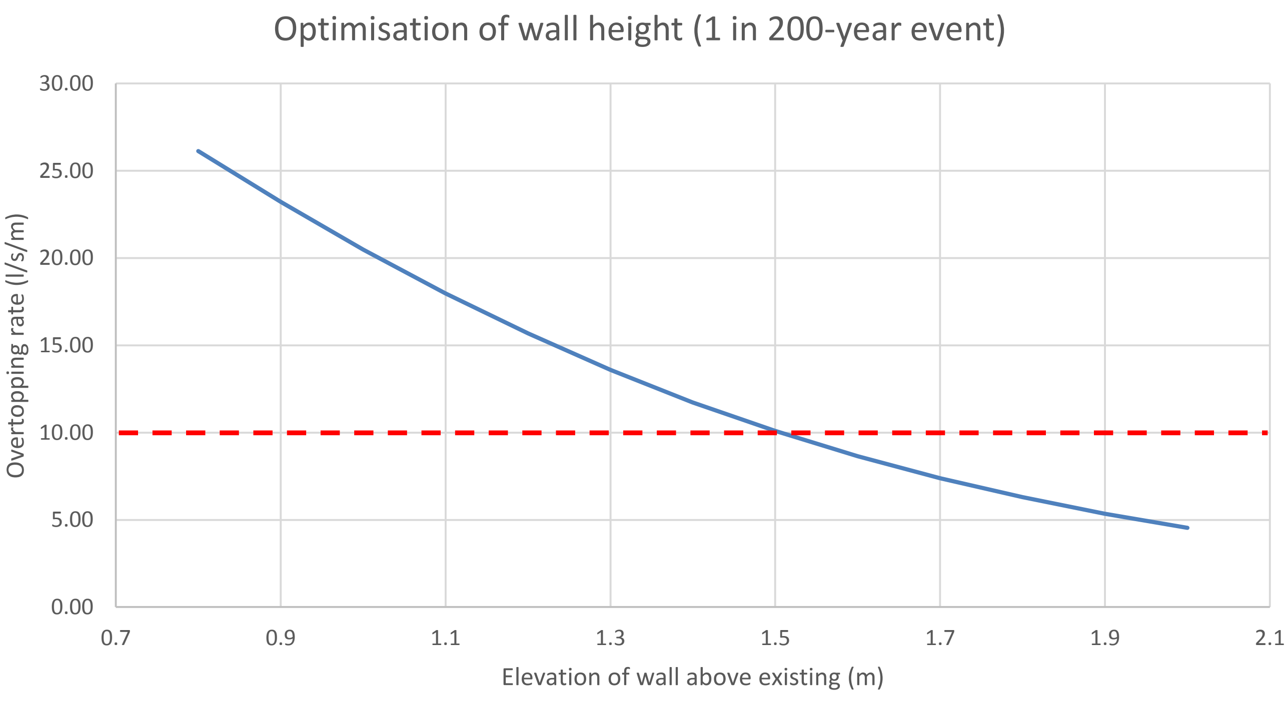

Figure 4-1: Optimisation of raised sea wall crest height

Obviously, this wall 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 100-year event in 2115.

Alternatively the DoI could take a view to accept a higher tolerable threshold of overtopping at Port St Mary, e.g. 20 l/s/m during the 200-year event. EurOtop suggests that an overtopping rate of this magnitude would be acceptable for vehicles travelling at low speeds, but that it would be unsafe for pedestrians to be in the area. As a result of accepting this higher overtopping rate, the DoI would have to implement a storm action plan, to prevent public access to the overtopped area. Providing the DoI can efficiently manage this situation, this higher overtopping rate would be acceptable for the newly proposed defence. Given Port St Mary's relatively industrial landscape, this sort of management could be instigated effectively.

Table 4**Error! Use the Home tab to apply 0 to the text that you want to appear here.**-1: Overtopping rates for LOC1

Storm event	Overtopping rate (l/s/m) present day	Overtopping rate (l/s/m) 2115
1 in 1-year	0.02	0.84
1 in 50-year	1.54	9.41
1 in 100-year	2.25	11
1 in 200-year	3.34	16

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.

This crest height will also provide the required still water level protection, with the 5.63mD02 being in excess of the required 4.742mD02 needed to conform to the still water level design standard.

4.1.2 Wall height and foundation cover

To aid in the constructability of the defence, a shallow foundation is proposed. This specifies a minimum cover of 300mm from the top of the foundation to ground level. This gives the wall a total height of 1800mm. The wall height above ground level is equal to 1200mm which is in compliance with BS 6180 for the minimum height of concrete barriers and handrails for horizontal guarding (1100mm).

The foundation cover is to be made of suitably compacted fill topped with a paved surface to be in keeping with the existing landscaping design.

4.1.3 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. Options to reduce this cover could be explored during detailed design. A wall of this type would be suitable for prefabrication which allows for a greater control of tolerances, which could reduce the necessary cover to concrete.

4.1.4 Base slab dimensions

The cantilever base slab has been designed at a conceptual level to provide stability to the wall. This has been achieved through using rules of thumb (Cobb, 2009), considered acceptable for the structural design of concept walls:

- Base slab width 1H = 1800mm
- Toe protrusion = 300mm
- Base slab thickness = stem thickness = 400mm
- Shear key depth = 500mm

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/m^3
- **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 Drainage

The design does not provide additional open drainage through the new structure, as it is assumed that the existing highway drainage should be sufficient to convey the overtopped water. During detailed design, it would be beneficial to explore the rate of drainage to identify whether additional drainage will be required.

4.5 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.

4.6 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.

4.7 Access for the public

A slipway in the centre of the section is required to remain open during normal conditions to launch vessels. In order to achieve this, it is proposed that a demountable flood gate is installed to ensure the access remains functional whilst also complying with the design performance standards. This will require careful consideration during detailed design.

4.8 Architectural enhancements

The new walls provide the opportunity to re-develop the harbour 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.

4.9 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 wall is situated at 1200mm above the harbour deck level which complies with the recommended guidance for minimum barrier height for horizontal guarding, reducing the risks of slips, trips and falls. However, the use of signage should be considered to warn members of the public of the risks associated with climbing on the rear 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. 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 existing coastal defence

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 concrete revetment will not be allowed to deteriorate further as this may undermine the newly proposed superstructure. Significant asset maintenance is likely to be required in the next 20 years to ensure the condition does not become critical. This should be considered when undertaking the options appraisal.

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. This should also consider the flowpath of overtopped water to prevent water pooling behind the structures.

5.4 Vehicle collisions with new raised wall wall

The walls have not been designed to take the impact of a vehicle collision. Should a vehicle collide with the wall, the defence will be weakened or breached and the integrity of the coastal defence undermined.

5.5 Road closure during a storm event

The higher tolerable thresholds or lower standard of protection offered by the wall mean that thecar park area behind the defences 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 harbour 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.