JACOBS — CALCULATION TITLE SHEET

Project title:	Musselburgh FPS	**Project code:**	701909
Calculation title:	Freeboard Analysis	**Serial no:**	
Project manager:	Kirsteen Nixon	**No. of sheets:**	6
Status:		**Created by:**	Rose Parry
Schematic		Preliminary: X	**Date:** 19-Aug-19
Tender		Other (state)	**Verified by:** Elaine Hood
Final for Construction			**Date:** 28-Aug-19
Levels of verification:			**Approved by:** -
			Date: -

1	Self-check and approval	☐	3B	Comparison with similar proven designs and approval	☐
2	Review and approval	☑	4	External check and internal approval	☐
3	Detailed check and approval	☐	5	Other verification as stated in the Management Plan	☐
3A	Alternative calculations and approval	☐			

Computer analysis:

Yes: ☐ No: ☑

Program(s):

Hardware:

Contents (continue on calculation sheet if necessary)

Freeboard Determination Proforma Sheet - extract from the Environment Agency Fluvial Freeboard Guidance Note

Supporting information and calculations for the determination of freeboard in accordance with EA Guidance

NB: Calculations should state or refer to design input data and methodology

CONTENTS AMENDMENT RECORD

Sheet(s)	Rev.	Date	Description	Created	Verified	Approved
All	A	22-Oct-19	Final updates following review	ELH	ELH	

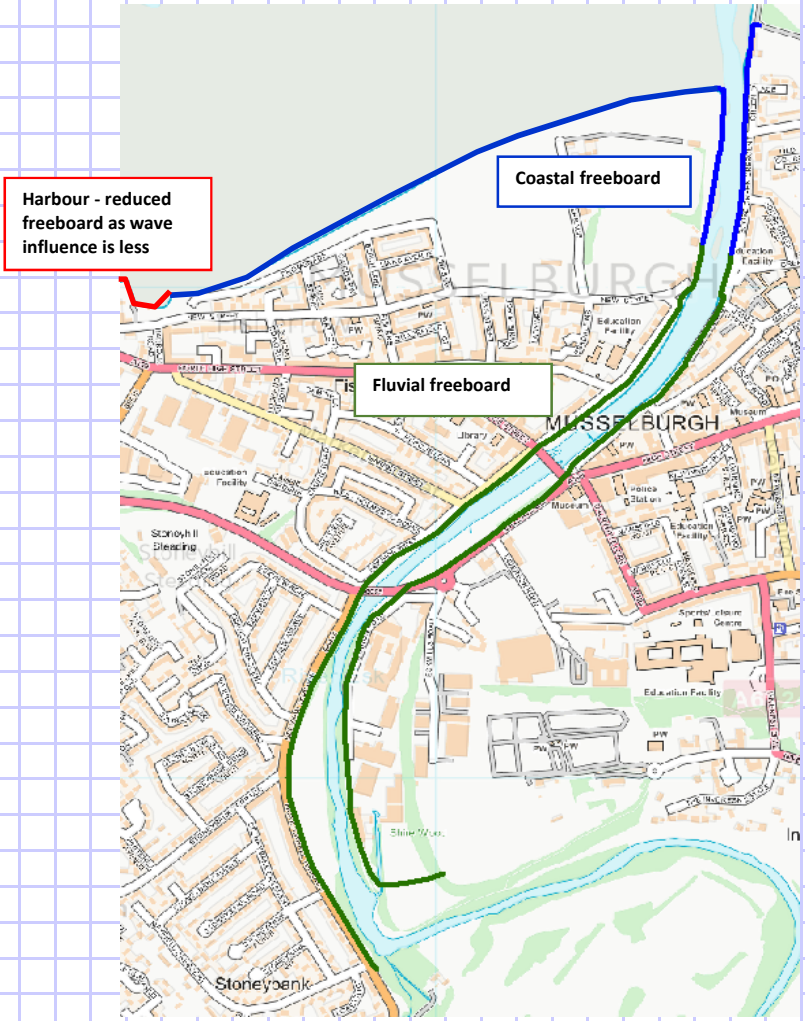
File Name:

Path:

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Scheme Defences Elements



In terms of factors that influence freeboard, the assumptions are relevant:

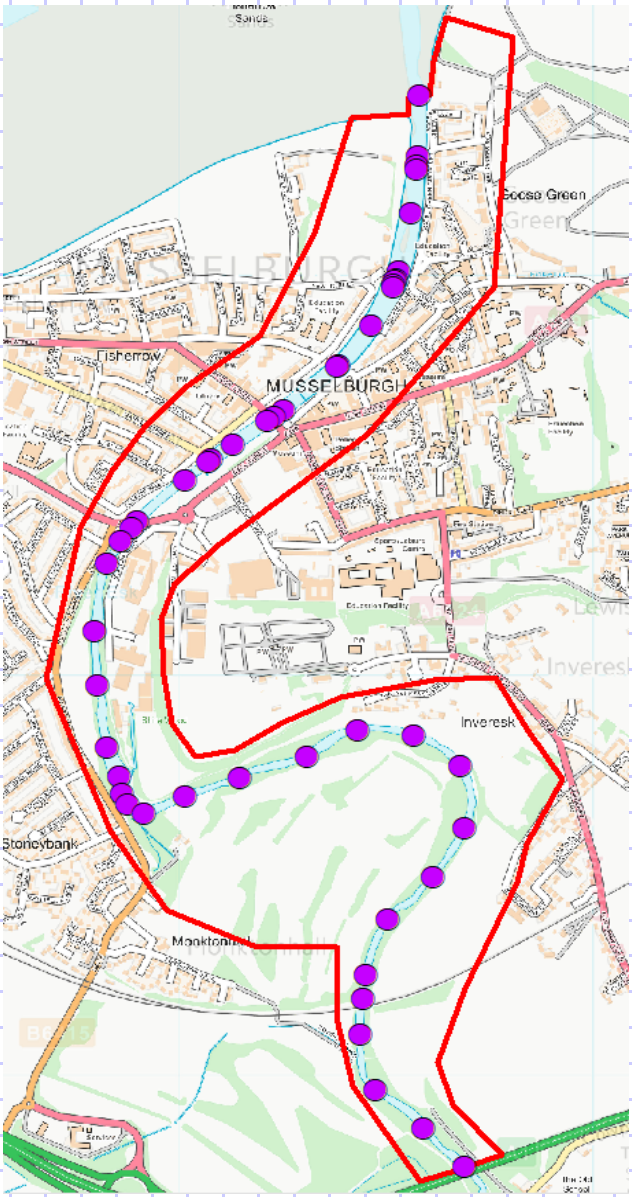
1	Set back flood defences where possible
2	The curves in the river where the direct defences will likely be located have a large radius, therefore superelevation at bends is not significant
3	Settlement allowance post-construction not significant
4	Wave overtopping is included both in fluvial and tidal conditions

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Water levels

The plans below show the modelled river cross-sections. The water levels corresponding to the relevant cross-sections will be used in the freeboard analysis.



Cross-section	MAMFL (1 in 2 yr level)	1 in 50 yr flood level	Difference
	m	m	m
SECTION_44	2.51	4.92	2.41
SECTION_28A	1.80	2.55	0.75
SECTION_23B	1.96	4.33	2.37
SECTION_13	2.09	3.11	1.02
SECTION_6	2.50	2.91	0.41
Average	2.17	3.56	**1.39**

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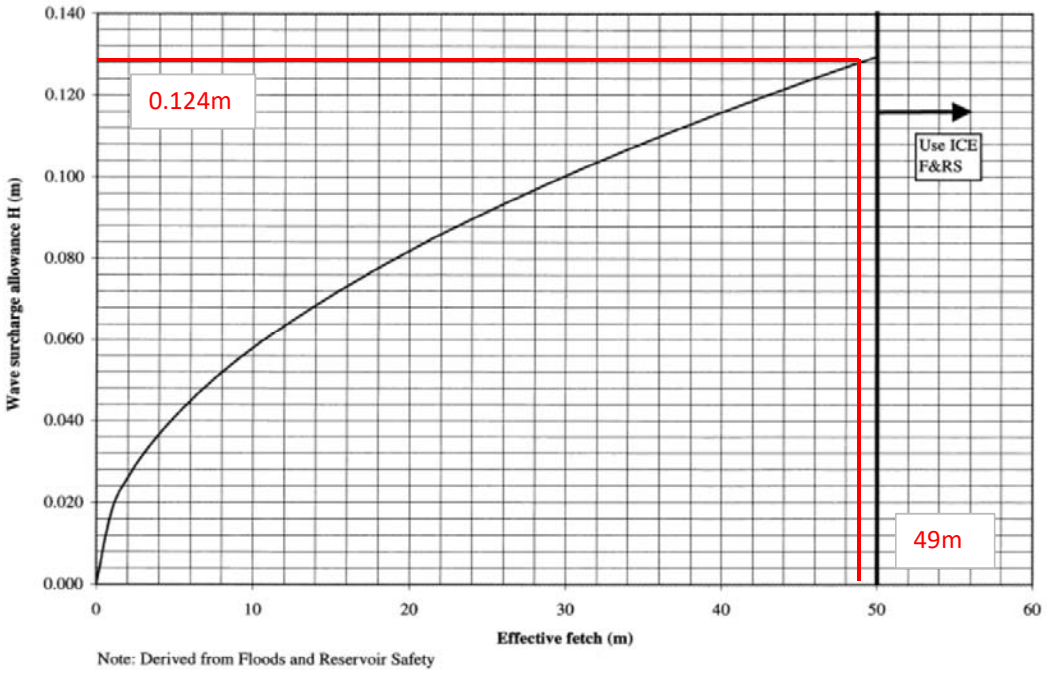
Blockages and the operation of structures

Two factors which can affect the flood water level are blockages and the operation of structures, such as bridges, culverts, etc. The EA Guidance considers that the effect of such structures should be dealt with during the estimation of flood levels rather than as a specific freeboard allowance i.e. the hydraulic modelling should take into account blockage and no additional allowance should be added to freeboard.

Wave Overtopping Allowance

Fetch length - width between defence and top of opposite bank (approx 49m)
Channel width - approximate taken from OS plans
Wave surcharge allowance - taken from Figure 4.2 below.

Figure 4.2: Wave Surcharge Allowance



Note: Derived from Floods and Reservoir Safety

Table 4.4
Wave surcharge allowance

Calculated wave surcharge allowance H (m)[1]	Actual wave surcharge allowance to be provided (m)
0.000 < H < 0.025	0
0.025 < H < 0.075	0.05
0.075 < H < 0.125	0.10
0.125 < H	Re-calculate using ICE's Floods and Reservoir Safety

Notes: [1] From Figure 4.2 and multiplied by factors in Table 4.3 where appropriate.

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Settlement Allowance

EA Guide gives the following advice:

4.4.4 Settlement allowance for cohesionless soils

Settlements of cohesionless soils, such as sands and gravels, take place almost as soon as the foundation load is imposed. For the purposes of determining a settlement allowance immediate settlement is of little consequence since most of it will have been taken up prior to the completion of the flood defence, whether embankment or concrete retaining wall.

Advice:
For the purposes of freeboard, long-term settlement for a flood defence on a cohesionless soil foundation can be considered to be zero.

From a review of the ground investigation available for the area, it is not anticipated that significant settlement of the foundation material will occur post-construction, therefore no settlement allowance is included.

The following guidance is also provided in relation to settlement:

Settlement during construction - the Contractor is generally responsible for ensuring that the flood defence is constructed to the correct level and remains so until the end of an agreed defects period. Settlement during construction is normally negligible.

Advice:
It is not normally necessary to take account of the settlement that will occur during construction

Settlement of the flood defence embankment - it is assumed that all new flood defence defence embankments are properly compacted during construction and so no additional allowance for settlement is recommended.

Advice:
It is not normally necessary to take account of the settlement of a flood embankment itself

Superelevation at bends

The change in water surface elevation at a bend in the channel can be determined by:

$$\Delta h = \frac{\bar{u}^2 b}{gR}$$

where $\bar{u}$ = average velocity (m/s)
Δh = change in water surface elevation across channel width, between banks (m)
b = channel width (m)
R = distance from centre of curve to centreline of channel (m)

Superelevation is not relevant in this case since channel is relatively straight over proposed defence location

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Uncertainty Allowance

$$\text{Uncertainty Allowance(m)} = k \times \frac{\text{Overall score (in range 6 - 30)}}{30} \times (\text{FL} - \text{MAMWL})$$

where FL = derived flood level (m)

MAMWL = Mean Annual Maximum Water Level (m) as derived from the mean annual maximum flow

k = a factor, initially proposed as 0.5

1 - Accuracy of Hydrological Data

Table 5.1 Accuracy of Hydrological (Rainfall/Streamflow) Data

Score	Description
1	Hydrological conditions throughout catchment well-defined or reliable continuous flow gauging records on river at area of interest.
2	Hydrological conditions throughout catchment fairly well defined or flow gauging records available on river at some distance from area of interest or water level records available at area of interest.
3	Some variability in hydrological conditions in catchment or water level records available at more than one site at some distance from area of interest or flow gauging records available for similar nearby catchment flow.
4	Hydrological conditions in catchment fairly variable or water level records available at one site some distance from area of interest.
5	Complex catchment with wide variation in hydrological conditions or limited water level records.

Notes: Hydrological conditions within the catchment relate to the mix of land use, change in river gradient, number of tributaries.

2 - Accuracy of Hydrological Method

Table 5.2 Accuracy of Hydrological (Rainfall Runoff/Statistical) Method

Score	Description
1	Rainfall runoff analysis give consistent results using different methods, or greater than 75 years of flow records for statistical analysis.
2	Rainfall runoff analysis give consistent results using different methods, long duration storm gives greatest discharge or 50 to 75 years of flow records available for statistical analysis.
3	Rainfall runoff analysis give fairly consistent results using different methods, moderate duration storm gives greatest discharge or 25 to 50 years of flow records available for statistical analysis.
4	Rainfall runoff analysis gives poor correlation between results using different methods, short duration storm gives greatest discharge or 10 to 25 years of flow records available for statistical analysis.
5	Rainfall runoff analysis gives very poor correlation between results using different methods, very short duration storm gives greatest discharge or less than 10 years of flow records available for statistical analysis.

3 - Accuracy of Hydraulic Data

Table 5.3 Accuracy of Hydraulic Data

Score	Description
1	Very well defined channel, no floodplain flow, channel roughness low and consistent seasonally along river and across river section.
2	Well defined channel, no floodplain flow, channel roughness fairly low, only small changes in roughness likely.
3	Minor floodplain flow, moderate changes in roughness likely.
4	Poorly defined channel, some floodplain flow, changes in roughness likely.
5	Very poorly defined channel with mobile bed, considerable complex floodplain flow, channel roughness very variable seasonally, along river and across river section.

4 - Accuracy of Hydraulic Model

Table 5.4 Accuracy of Hydraulic Model

Score	Description
1	Well defined boundary data, well-defined flood routing, transient model.
2	Fairly well defined boundary data and flood routing, transient model.
3	Moderately well defined boundary data and flood routing, steady state model.
4	Fairly poorly defined boundary data and flood routing, steady state model.
5	Poorly defined or complex boundary data and flood routing, simple backwater analysis.

5 - Significance of Physical Parameters

Table 5.5 Significance of Physical Parameters

These are evaluated in Sections 4.3 to 4.10. The allowances for these are summed to give an allowance for physical processes and compared with the difference between the derived Flood Level (FL) and the Mean Annual Maximum Water Level (MAMWL) as derived from the mean annual maximum flow.

Score	Description
1	Uncertainties in physical processes are negligible, allowance is < 5% of (FL – MAMWL).
2	Uncertainties in physical processes are of marginal significance, allowance is = 5 to 10% of (FL – MAMWL).
3	Uncertainties in physical processes are of some significance, allowance is = 10 to 20% of (FL – MAMWL).
4	Uncertainties in physical processes are significant, allowance = 20 to 30% of (FL – MAMWL).
5	Uncertainties in physical processes are very significant, allowance is > 30% of (FL – MAMWL).

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6 - Consequences of Failure

Table 5.6 Consequences of Failure

The scores are based on the categories adopted by MAFF in the latest version of Project Appraisal Guidance Reports (PAGN), PAG3 Economic Appraisal.

Score	Description
1	Typically low grade agricultural land, often grass, at risk from flooding or impeded land drainage, with isolated agricultural properties at risk from flooding, or environmental assets at little risk from frequent inundation.
2	Typically mixed agricultural land with occasional, often agriculturally related, properties at risk from flooding. Agricultural land may be prone to flooding or water-logging. May also apply to environmental assets of local significance.
3	Typically large areas of high grade agricultural land and/or environmental assets of national significance at risk from flooding or impeded drainage with some properties also at risk from flooding.
4	Typically less extensive urban areas with some high grade agricultural land and/or environmental assets of international importance requiring protection.
5	Typically large urban areas at risk from flooding.

Total Uncertainty Allowance

$$\text{Uncertainty Allowance(m)} = k \times \frac{\text{Overall score (in range 6 – 30)}}{30} \times (\text{FL} - \text{MAMWL})$$

where FL = derived flood level (m)

MAMWL = Mean Annual Maximum Water Level (m) as derived from the mean annual maximum flow

k = a factor, initially proposed as 0.5

Average (FL - MAMWL)	1.39	m
Total uncertainty score	17	(out of maximum 30)
k factor	0.50	
Uncertainty Allowance	0.394	m

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Freeboard Determination Proforma

Defence Type
Location
Reference

Flood defences along River Esk
Musselburgh FPS

Physical Processes

Wave Overtopping Allowance — Section 4.3

Fetch length (m)	49		Step 1
Allowance from Figure 4.2 (m)	0.124		Step 2 Figure 4.2
Modification factor	N/A i.e. 1.0		Step 3 Table 4.3
Actual allowance provided (m)		0.10 A	Step 4 Table 4.4

or:

Table 4.4 advises use of Flood and Reservoir Safety

Allowance from Floods and reservoir Safety (m)		N/A A	

Settlement Allowance (Cohesive Soils) — Section 4.4

Embankment

Height (m)			
Slopes (1:X)			
Crest width (m)			
Foundation soil type			
Coefficent μ_g			Step 1 Table 4.5
Influence factor I_p			Step 2 Figure 4.4
Coefficent of volume compressibility m_v			Step 3 Test results or Table 4.6
Applied load p (kN)			Step 4
Foundation width B (m)			Step 4
Settlement allowance (m)		0 B	Step 5

Wall

Settlement allowance for foundation material is zero for non-cohesive soils.

Foundation base width (m)			
Foundation length (m)			
Foundation soil type			
Coefficent μ_g			Step 1 Table 4.5
Influence factor I_p			Step 2
Coefficent of volume compressibility m_v			Step 3 Test results or Table 4.6
Applied load p (kN)			Step 4
Foundation width B (m)			Step 4
Settlement allowance (m)		n/a B	Step 5

Superelevation — Section 4.7

River width B (m)			
Radius of bend r (m)			
Flow velocity (m/s)			
Superelevation significant ? (Y/N)	N		Figure 4.5
Superelevation allowance		0 C	

Other physical processes

		D	

TOTAL ALLOWANCE FOR PHYSICAL PROCESSES		0.10m E	A+ B + C + D

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Uncertainty Allowance - Quick Method

Section 5.3

Hydrological Data — Step 1

Description of information available:

Refer to Sheet 4 - Uncertainty

Score from Table 5.1: 3

Hydrological Analysis — Step 1

Description of information available:

Score from Table 5.2: 3

Hydraulic Data — Step 1

Description of information available:

Score from Table 5.3: 3

Hydraulic Analysis — Step 1

Description of information available:

Score from Table 5.4: 1

Significance of physical processs — Step 1

Description of information available:

Score from Table 5.5: 2

Consequences of failure — Step 1

Description of information available:

Score from Table 5.6: 5

Total score: 17 — Step 2

Mean annual maximum water level (m)

Derived flood level (m)

(Refer to Sheet 2 - Levels)

TOTAL UNCERTAINTY ALLOWANCE: 0.099 m **F** — Step 3

REALITY CHECK (OK ?): OK

TOTAL FREEBOARD ALLOWANCE: 0.494m **E + F**

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Comparison of W187 method (2000) and new method (2017)

Consideration	Applicability	Score	Reason
How appropriate is the flood risk analysis?	Yes	1	Topo and LiDAR from 2018, culverts and bridges included.
How good is the floodplain topography?	Yes	1	LiDAR used with 0.5m resolution, cross-sections every 150m
How well has the potential for defence failure been modelled?	No		No defences of note
What is the confidence in the hydrology?	Yes	3	SEPA to update gauges
How good is the tidal boundary?	Yes	2	Initial levels modified to match normal depth conditions.
How have fluvial threats been represented?	Yes	1	Over 5 annual likelihoods covered, 1D and 1D-2D models used
How have coastal threats been represented?	Yes	1	Wave overtopping considered, model run using different tidal scenarios
How has surface run-off been represented?	Yes	1	LiDAR resolution of 0.5m - should represent surface run-off accurately
How have groundwater hazards been represented?	No		Not a major source of flooding
What is the strength of evidence?	Yes	3	Model to be calibrated against one flood event more frequent than the design event

Table 3.3 Scoring matrix to derive confidence rating

Worst topic 2 score \ Worst topic 1 score	10	5	3	2	1
10	1 star			2 star	3 star
5	1 star		2 star	3 star	4 star
3	1 star	2 star	3 star	4 star	
2	2 star	3 star	4 star		5 star
1	3 star	4 star		5 star	

Table 3.4 Residual uncertainty allowance in development planning

Confidence rating	Confidence description	Proportion of design flood depth [1]	Minimum depth (mm)
1 star	Very unlikely to be locally reliable	40%	900
2 star	Unlikely to be locally reliable	30%	750
3 star	Likely to be locally reliable	20%	600
4 star	Very likely to be locally reliable	10%	450
5 star	Highly likely to be locally reliable	5%	300

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Comparison of Results

The proportion of design flood depth from Table 3.4 gives an allowance of **600mm.**

The traditional method gives a freeboard allowance of **500mm.**

Therefore adopt minimum 550mm freeboard on all fluvial defences.

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Record of assessment for coastal situation using new simplified method

Consideration	Applicability	Score	Reason
How appropriate is the flood risk analysis?	Yes	1	Topo and LiDAR from 2018 - model represents changes in floodplain
How good is the floodplain topography?	Yes	1	High resolution LiDAR
How well has the potential for defence failure been modelled?	No	-	No defences of note
What is the confidence in the hydrology?	No	-	Tidally dominated
How good is the tidal boundary?	Yes	2	Initial levels modified to match normal depth conditions.
How have fluvial threats been represented?	Yes	1	Over 5 annual likelihoods covered, 1D and 1D-2D models used
How have coastal threats been represented?	Yes	1	Wave overtopping considered, model run using different tidal scenarios
How has surface run-off been represented?	Yes	1	LiDAR resolution of 0.5m - should represent surface run-off accurately
How have groundwater hazards been represented?	No		Not a major source of flooding
What is the strength of evidence?	Yes	3	Model will be calibrated and validated

Musselburgh is very close to the tidal gauge at Leith. Data from this gauge fed into the Coastal flood boundary dataset so is considered very robust.

EurOtop (2018) methods applied LiDAR for toe/foreshore slopes flown in June 2018. Overtopping calculations carried out for 8 annual likelihoods.

Table 3.3 Scoring matrix to derive confidence rating

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10	1 star			2 star	3 star
5	1 star		2 star	3 star	4 star
3	1 star	2 star	3 star	4 star	
2	2 star	3 star	4 star		5 star
1	3 star	4 star		5 star	

Table 3.4 Residual uncertainty allowance in development planning

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4 star	Very likely to be locally reliable	10%	450
5 star	Highly likely to be locally reliable	5%	300

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Discussion

Based on the above assessment using current guidance and the simplified method, the minimum freeboard that should be adopted for coastal defences in Musselburgh is 450mm.

However, SEPA's latest guidance on Flood Risk Assessment issued in May 2019 (SS-NFR-P-002) contains the following guidance:

> SEPA would expect a minimum 600mm freeboard allowance, however more may be necessary depending on local characteristics, such as evidence of wave action in the past and/or the recommendation of the local authority flood prevention teams. The freeboard allowance is to account for uncertainties associated with the design flood estimation and coastal processes including, wave action and spray, local bathymetric processes, and reduction of design level due to erosion.

In order to adopt a conservative approach and in line with current guidance, a freeboard of 600mm will be added to the design flood level for all coastal defences.

It should be noted that typically in the design of coastal defences, the design crest level is determined using joint probability waves and water levels and focuses on limiting wave overtopping to an acceptable threshold. This generally means the design crest level is significantly higher than the still water level due to wave run up and so no further freeboard is included.

Therefore coastal freeboard allowance to be reviewed at outline design stage, once the coastal defence design has been carried out and a full joint probability wave analysis has been done.