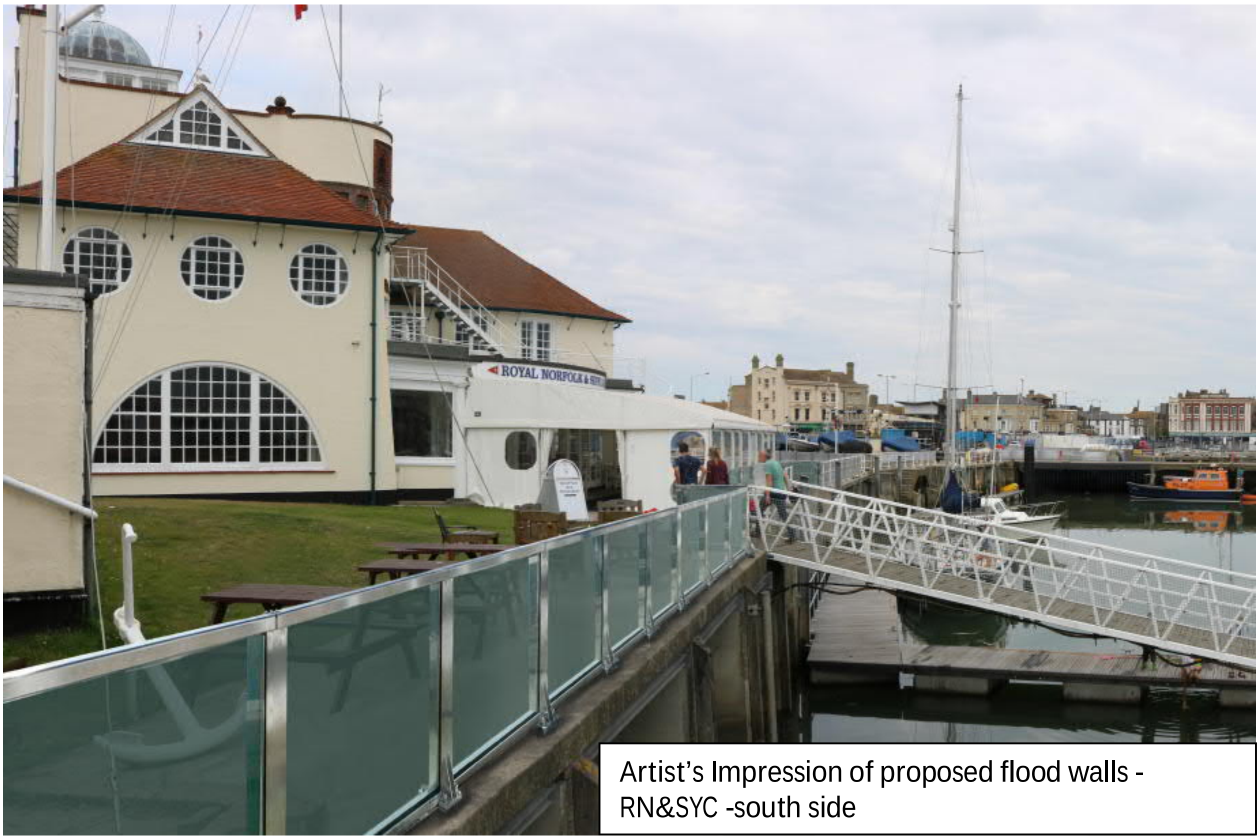
Review of the Residual Uncertainty Assessment – Flood Walls



Artist's Impression of proposed flood walls - RN&SYC -south side

Lowestoft Flood Risk Management Project

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Prepared for

Waveney District Council

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Revision History

Issue	Author	Date	Description
0	Laurent Cadieu / Tom Hunt	22/08/2018	Draft
1	Tom Hunt	18/12/2018	Update to overtopping flood volumes

Technical Check

Role	Name	Signature	Date
Checker	Tom Hunt	Tom Hunt	24/08/2018
Reviewer	Kevin Burgess	Kevin Burgess	24/08/2018

Approval

Role	Name	Signature	Date
Project Manager	Jehangir Nawaz	Jehangir Nawaz	28/08/2018

Contents

Abbreviations

RP	Return Period
AOD	Above ordnance datum
JPA	Joint Probability Assessment
RUA	Residual Uncertainty Allowance
EWL	Extreme Water Levels
AEP	Annual Exceedance Probability
JPA	Joint Probability Analysis

Summary

This assessment is to confirm the height of the proposed defences and therefore inform the Flood Risk Assessment and the detailed design of the flood walls. There are a number of approaches that could be taken to make this assessment and this note provides some detail on the approach taken

The results show that the walls heights do not need to be increased to the extents that the earlier more basic assessment previously indicated, and the proposed crest levels of 4.1mOD in 2070 and 4.65mOD in 2117 are suitable for the 0.5% AEP design event.

However, although it can be guaranteed that the proposed defences will remain stable for all the possible combinations in water levels and waves for a 0.5% AEP, there is a low residual risk that certain combination of conditions would produce wave overtopping that could create localised flooding. Due to this risk a flood model has been created and overtopping volumes input to the model to determine localized flooding.

Whilst this technical note does not include details or results from the flood model the overtopping results that are included in the flood model are presented.

Introduction

This assessment is to confirm the height of the proposed defences and therefore inform the Flood Risk Assessment and the detailed design of the flood walls. There are a number of approaches that could be taken to make this assessment and this note provides some detail on the approach taken.

The initial assessment undertaken and communicated to the client used conservative inputs. This technical note demonstrates that the initial assessment did overestimate the probability of conditions and thus the levels of overtopping that might be likely to occur.

The primary updates have included:

- Undertaking of joint probability analysis (JPA) of the wave and water levels to provide an appropriate combined wave and water level for a 0.5% AEP.
- An update of the wave transformation into the harbour using the JPA outputs.
- A detailed overtopping assessment using EurOtop 2016 empirical formula and discharge thresholds.

In addition to the crest level assessment overtopping volumes to be input to a flood model are also calculated. Whilst it may seem that the values will be the same there are subtle differences that are explored.

This technical note presents further detail on this analysis.

Crest level assessment

Flood defence crest levels obviously need to be set to provide acceptable limits to flooding and/or probabilities of occurrence. This can be simply achieved by providing a crest elevation that is above an acceptable extreme storm event. This height above an extreme water level is referred as the “freeboard”. An alternative approach is to set limits of acceptable wave overtopping and determine the structure geometry that can achieve this.

The Environment Agency have published a new freeboard guidance, “Accounting for residual uncertainty: updating the freeboard guide: Report SC120014; Environment Agency

(2017)”. However, the advice received is that projects that are not in pilot schemes should not use this guidance document until a review of the application of the guidance has been completed. In the meantime, the original Fluvial Freeboard Guidance Note (W187) with adaptation for tidal schemes or the coastal overtopping assessment approach (EurOtop: 2016) is to be used. Note that that W187 does not provide guidance for tidal and coastal schemes in its current form as noted on section 1.2.

It is worth remembering that the existing approaches do not result in any lesser design standard rather the new guidance seeks to provide a more robust analysis with greater levels of communication with the client so informed decisions can be made, along with bringing the coastal element (significant waves) into a consistent approach with fluvial assessments. To do this, particularly on coastal schemes requires a change in the application of the overtopping methods and a lot of additional work to present results which were often instinctively understood by experienced engineering practitioners.

Given the nature of this site a mixed approach has been applied which strongly leans on the Fluvial Freeboard Guidance Note (W187) with adaptation for tidal schemes. The reason for this is that the location of the new seawalls is sheltered from significant open coast wave conditions which lends itself to the more fluvial, freeboard approach.

The scheme requires flood protection until 2117 for an extreme event with a 0.5% annual exceedance probability (AEP) (also referred to as 1 in 200 year Return Period (RP)). It is recommended that this is achieved by taking an adaptive approach by providing a defence that achieves the levels of flood protection until 2070 but is sufficiently designed that adaption can be made to raise the defences to 2117 extreme storm events at a later date. The advantage of this is that excessive defences are not provided at the outset of the scheme which have high present day costs and can impact visually on the area as well allow the actual impacts of climate change to be address as we learn more.

The recommendation crest levels are as follows:

- 1 in 200 Year return period in 2070 - Wall crest level to be 4.1mOD (100mm higher than recommended earlier);
- 1 in 200 Year return period in 2117 - Wall crest level should be kept at 4.65mOD previously recommended.

These values are based upon an assessment that considered the marginal extreme water levels (0.5% AEP) plus a freeboard allowance of 0.3m. The marginal extreme water levels are as follows:

- 3.775mOD at year 2070
- 4.185mOD at year 2117

As recommended in W187 the freeboard allowance should account for physical processes that affect the defence level and adverse uncertainty in the prediction of physical process. The physical process that were discussed as relevant for this scheme were:

- Uncertainty due to Extreme water level = 0.3m. Value taken from confidence intervals from the Coastal Flood Boundary Data for 0.5% AEP. This value was confirmed by Matthew Hird, FCRM Principal Analysist, on 15/08.
- No additional uncertainly allowance has been added for wave overtopping as the assessment of the recommended crest levels showed that overtopping discharges were within the ranges of acceptable limits.

  Uncertainty has been considered through the undertaking of sensitivity analysis. This uncertainty analysis showed that despite increases in the overtopping discharges compared to the best estimate approached that recommended limits for the ultimate limit state (ULS) were not exceeded and that the service limit state (SLS) whilst exceeded would be acceptable given the robustness of normal overtopping assessments using joint probability analysis (JPA) of wave and water levels. These increased overtopping discharges in the sensitivity analysis could potentially lead to localised flooding under specific conditions of the extreme environmental conditions.

- Settlement allowances are often considered but advice has been that settlement is not an issue at this location so no allowance has been applied.

Only the overtopping assessment which is used in the above freeboard allowance is presented in this technical note.

Wave overtopping assessment

4.1 Wave conditions within the harbour

4.1.1 Joint Probability Analysis

JPA was undertaken using the Environment Agency's JPA spreadsheet (FD2308_TR2 Desk study calculator) of wave and water levels at two offshore locations near to Lowestoft harbour. The benefit of JPA is that a range of conditions are derived for each of the extreme return periods. The result of this is that the higher water levels have a smaller corresponding wave height and lower water levels have a higher corresponding wave height for a specific AEP. Previously the marginal extreme 0.5% AEP was used for both wave and water level. The reality is this would correspond to a much higher AEP.

The extreme water level for a range of AEP's (return period events) was taken from the coastal flood boundary data as supplied by the Environment Agency. Theses water levels were adjusted for a range of years to account for climate change using United Kingdom climate predictions (UKCP09) website.

	Epoch								
Event	**2014**	**2018**	**2020**	**2021**	**2040**	**2070**	**2071**	**2090**	**2117**
T2*	2.222	2.244	2.255	2.261	2.377	2.593	2.601	2.759	3.003
T5*	2.417	2.439	2.450	2.456	2.572	2.788	2.796	2.954	3.198
T10	2.566	2.588	2.599	2.605	2.721	2.937	2.945	3.103	3.347
T20	2.742	2.764	2.775	2.781	2.897	3.113	3.121	3.279	3.523
T30	2.850	2.872	2.883	2.889	3.005	3.221	3.229	3.387	3.631
T75	3.109	3.131	3.142	3.148	3.264	3.480	3.488	3.646	3.890
T100	3.192	3.214	3.225	3.231	3.347	3.563	3.571	3.729	3.973
T200	3.404	3.426	3.437	3.443	3.559	3.775	3.783	3.941	4.185
T500	3.690	3.712	3.723	3.729	3.845	4.061	4.069	4.227	4.471
T1000	3.912	3.934	3.945	3.951	4.067	4.283	4.291	4.449	4.693
Levels to mAOD									

Figure 1 – Coastal flood boundary data with climate change adjustment.

The extreme wave heights were derived using the 'countback method' of the State of the Nation (SON), a synthetic data set provided by the environment agency.

Figure 2 shows the JPA curves for the present day offshore conditions. Table 1 presents the 0.5% AEP results for present day, 2070 and 2117.

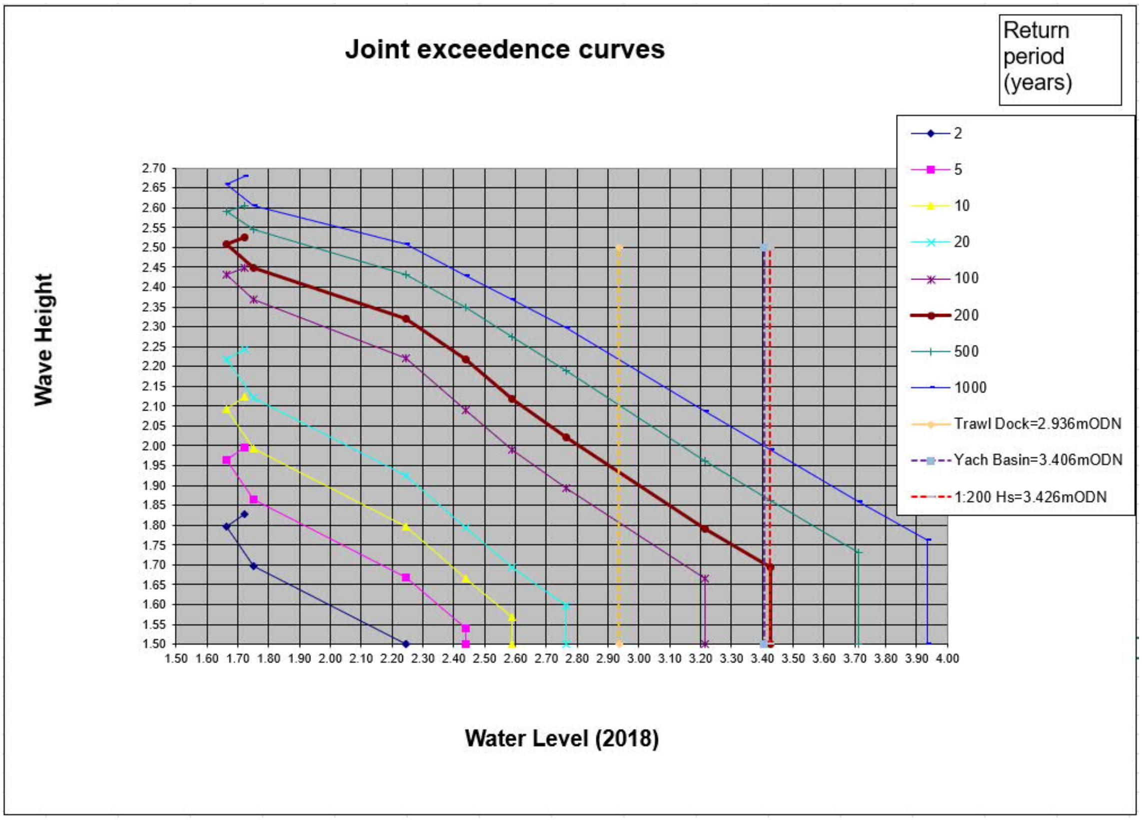

Figure 2 – Present day JPA results offshore of Lowestoft harbour

Run ID	Extreme Water Level mODN			Wave height, H_s (m)	Peak wave period, T_p (s)
	2018	2070	2117		
1	1.72	2.07	2.48	2.52	10.82
2	1.66	2.01	2.42	2.51	10.78
3	1.75	2.10	2.51	2.45	10.62
4	2.24	2.59	3.00	2.32	10.29
5	2.44	2.79	3.20	2.22	10.01
6	2.59	2.94	3.35	2.12	9.74
7	2.76	3.11	3.52	2.02	9.46
8	3.21	3.56	3.97	1.79	8.81
9	3.43	3.775	4.185	1.69	8.51

Table 1 – 0.5% AEP wave and water level conditions for present day, 2070 and 2117

4.1.2 Wave diffraction and transformation

Analysis was undertaken to transform the JPA waves from the offshore location to positions inside the harbour for use in overtopping analysis.

The layout and height of the harbour with inner and outer breakwaters and extreme water levels that can rise above the crest level of the inner breakwaters makes transforming the waves from the open coast to points next to the new defences complicated. In the absence of undertaking expensive and lengthy numerical modelling a couple of approaches were taken to transform the waves.

The tools and methods included Goda (2000) wave transmission formula and diffraction diagrams. In addition, the simplified method for determining wave transmission through breakwaters was considered. Each of these methods is presented in the CIRIA Rock manual: C683; 2007.

The wave heights were determined at a range of locations within the harbour for use and comparison. Figure 3 presents each of these locations. How the transformation was carried out is as follows:

- The waves at locations OH, YB and TD have all used the Goda diffraction charts to determine the wave height change from the harbour entrance. These are likely to be the most accurate waves we are transforming but do not represent the locations we require for overtopping analysis.
- The waves at locations YB1 and TD1 have taken the waves determined at YB and TD and used the simplified wave transmission calculation to transfor to within the inner basins. The simplified transmission approach has really been developed for permeable rubble mound breakwaters rather than impermeable vertical blockwork walls. However given the extreme water levels are over the height of the inner breakwaters it can give a sense of what waves within the inner basins might be.
- The waves at location A and B have used the Goda diffraction charts to determine the wave height change from the inner harbour entrance ignoring the presence of the inner breakwaters. This will result in conservative results but are useful when comparing to YB1 and TD1.

Table 2 and 3 presents the results from the transformation and diffraction analysis for the 0.5% AEP for years, 2070 and 2117.

Figure 3 – Locations of transformed waves into the harbour

Run ID	Extreme water level (mOD)	Wave heights Hs (m)						
		OH	TD	TD1	A	YB	YB1	B

1	2.07	0.73	0.45	0.05	0.38	0.66	0.07	0.38
2	2.01	0.73	0.45	0.05	0.38	0.65	0.07	0.38
3	2.10	0.71	0.44	0.04	0.37	0.64	0.06	0.37
4	2.59	0.67	0.42	0.10	0.35	0.60	0.06	0.35
5	2.79	0.64	0.40	0.15	0.33	0.58	0.08	0.33
6	2.94	0.61	0.38	0.19	0.32	0.55	0.11	0.32
7	3.11	0.59	0.36	0.23	0.30	0.53	0.15	0.30
8	3.56	0.52	0.32	0.26	0.27	0.47	0.26	0.27
9	3.775	0.49	0.30	0.24	0.25	0.44	0.31	0.25

Table 2 – 0.5% AEP Transformed waves for 2070

Run ID	**Extreme water level (mOD)**	**Wave heights Hs (m)**						
		OH	TD	TD1	A	YB	YB1	B
1	2.48	0.73	0.45	0.08	0.38	0.66	0.07	0.38
2	2.42	0.73	0.45	0.06	0.38	0.65	0.07	0.38
3	2.51	0.71	0.44	0.09	0.37	0.64	0.06	0.37
4	3.00	0.67	0.42	0.22	0.35	0.60	0.15	0.35
5	3.20	0.64	0.40	0.27	0.33	0.58	0.20	0.33
6	3.35	0.61	0.38	0.30	0.32	0.55	0.23	0.32
7	3.52	0.59	0.36	0.29	0.30	0.53	0.27	0.30
8	3.97	0.52	0.32	0.26	0.27	0.47	0.38	0.27
9	4.185	0.49	0.30	0.24	0.25	0.44	0.35	0.25

Table 3 – 0.5% AEP Transformed waves for 2117

When the results are compared between TD1 and A and compared for YB1 and B it can be seen that the larger wave heights come from A and YB1. Whilst these results maybe conservative it is considered reasonable that we use these results in the overtopping assessment to ensure a safe assessment.

4.2 Overtopping Assessment

Two overtopping assessments are required to inform the design of the flood protection.

The first assessment looks to determine the required crest level of the defences. This assessment looks to assess the 'safe' values in design and so includes factors to account for this safety requirement.

The second assessment is to provide overtopping quantities for inclusion in a flood inundation model to determine localised flooding due to overtopped waves. The need for this assessment is born from the fact the overtopping thresholds for ensuring the structural stability of the defences are not always insignificant. The difference in requirement is that because the flood inundation assessment is looking for the best estimate of flooding levels the mean value of overtopping is required rather than a safety in design assessment which would overstate the flooding extents.

4.2.1 Wall height overtopping assessment

a) Method

Overtopping analysis has been undertaken using the EurOtop Manual 2016. Specifically using the vertical wall, design or assessment approach found in Chapter 7. Whilst the method accurately represents the scenario at the back of the Yacht Basin it will over estimate the value at the Trawler Dock. The reason for this is that the new wall at the Yacht Basin sits along the existing quay wall alignment whereas the new wall behind the Trawler Dock is set back from the existing quay. This set back would cause some disruption of the wave and reduce overtopping.

Crest levels at coastal locations are determined to meet an acceptable overtopping discharge threshold with the amount of 'freeboard' or acceptable wave run-up included as part of that assessment. The use of JPA wave and water level inputs, the 'design or assessment approach' which includes a partial safety factor as well as other application decisions result in a robust assessment that account for the uncertainties as described in W187 guidance.

Notwithstanding the conclusion that the overtopping assessment is robust to account for uncertainty it isn't uncommon for sensitivity analysis to be undertaken to understand the potential impacts. For this scheme sensitivity analysis has been undertaken on the wave conditions and on the EWL. For the wave conditions the increase was completed by using the waves located outside of the inner basin, specifically YB and TD. This amounts to an increase in wave height of 25%. For the extreme water level (EWL) the uncertainty confidence interval determined by the Coastal Flood Boundary Data. As can be seen in Figure 2 an increase to the water level by 0.3m to the 0.5% AEP increases the storm event to a 0.2% AEP (1 in 500 year RP).

b) Discharge thresholds

Discharge thresholds are usually a range of scenarios both ultimate limit state (ULS) and service limit states (SLS). For SLS thresholds analysis is usually undertaken on lower and more frequent AEP conditions. For our assessment lower AEP conditions were not prepared given time constraints and so results for the SLS are considered conservative. The overtopping discharge thresholds for this scheme are as follows:

1) ULS – This threshold is set to maintain the integrity of the proposed structure. As located within an urban environment, the rear of the defences are heavily paved hence mitigating the risk of erosion during the overtopping event and in turn preventing the structure to be destabilised. The updated EurOtop guidance (2016) does not provide thresholds for this. Therefore, in theory overtopping would not be governing under the ULS condition beyond volumes of water impacting localised flooding. However to give a sense of what reasonable discharge rates might be the old EurOtop guidance provided a limit of **200l/s/m** for damage to paved or armoured promenade behind a seawall.

2) SLS – This discharge threshold governs practical consideration and the impacts on people and infrastructure which simply consider safety rather than flood risk.. For the SLS, a lower Return Period is usually considered, however to limit the amount of numerical work, we have only considered the 1 in 200 Year which overstate SLS assessment and therefore provide some conservatism. The EurOtop guidance provides the following discharge threshold:

   - SLS (Pedestrians) – For people at the seawall and a wave height of <0.5m There is **no limit** for overtopping. i.e. not a risk to people.

- SLS (Vehicles) – For vehicles at the seawall and a wave height of = 1.0m Limit overtopping to **75l/s/m** and/or **2000l/m** for overtopping.
- SLS (Buildings) – Building structure elements for a wave height of 1.0m limit overtopping to **1l/s/m** and/or **1000l/m**. As mentioned above, meeting this for a 1 in 200 year RP is deemed to be over-conservative. It should also be noted that the waves are lower than the EurOtop guidance as the waves are lower than 0.4m in height.

c) Results

Table 4, 5, 6 and 7 below present the results for the best assessment of the overtopping discharges for the 0.5% AEP JPA in 2070 with a wall crest height of 4.1mOD and in 2117 for wall crest heights of 4.65mOD.

Run ID	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Crest level (mOD)	Overtopping discharge (l/s/m)	V_{max} (l/m)
1	2.07	0.07	4.1	0	0
2	2.01	0.07	4.1	0	0
3	2.10	0.06	4.1	0	0
4	2.59	0.06	4.1	0	0
5	2.79	0.08	4.1	0	0
6	2.94	0.11	4.1	0	0
7	3.11	0.15	4.1	0	0
8	3.56	0.26	4.1	0.02	108
9	3.775	0.31	4.1	1.7	630

Table 4 – 0.5% AEP, 2070 overtopping results at the Yacht Basin

Run ID	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Crest level (mOD)	Overtopping discharge (l/s/m)	V_{max} (l/m)
1	2.07	0.38	4.1	0	0
2	2.01	0.38	4.1	0	0
3	2.10	0.37	4.1	0	0
4	2.59	0.35	4.1	0	0
5	2.79	0.33	4.1	0	0
6	2.94	0.32	4.1	0	0
7	3.11	0.30	4.1	0	0
8	3.56	0.27	4.1	0.14	138
9	3.775	0.25	4.1	0.50	319

Table 5 – 0.5% AEP, 2070 overtopping results at the Trawler Dock

Run ID	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Crest level (mOD)	Overtopping discharge (l/s/m)	V_{max} (l/m)
1	2.48	0.07	4.65	0	0
2	2.42	0.07	4.65	0	0
3	2.51	0.06	4.65	0	0
4	3.00	0.15	4.65	0	0
5	3.20	0.20	4.65	0	0
6	3.35	0.23	4.65	0	0

7	3.52	0.27	4.65	0	0
8	3.97	0.38	4.65	0.30	305
9	4.185	0.35	4.65	0.78	518

Table 6 – 0.5% AEP, 2117 overtopping results at the Yacht Basin

Run ID	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Crest level (mOD)	Overtopping discharge (l/s/m)	V_{max} (l/m)
1	2.48	0.38	4.65	0	0
2	2.42	0.38	4.65	0	0
3	2.51	0.37	4.65	0	0
4	3.00	0.35	4.65	0	0
5	3.20	0.33	4.65	0	0
6	3.35	0.32	4.65	0	0
7	3.52	0.30	4.65	0	0
8	3.97	0.27	4.65	0	6
9	4.185	0.25	4.65	0.06	150

Table 7 – 0.5% AEP, 2117 overtopping results at the Trawler Dock

What the tables above show is:
Most combination of wave and water level result in zero overtopping.
The maximum overtopping rates are also extremely small but are:

- At the wall behind the Yacht basin.
  - o 2070 wall height 4.1mAOD – Max overtopping 1.7l/s/m or 630l/m (*).
  - o 2117 wall height 4.65mAOD – Max overtopping 0.78l/s/m or 518l/m (*).

- At the wall behind the Trawl Dock.
  - o 2070 wall height 4.1mAOD – Max overtopping 0.50l/s/m or 319l/m (*).
  - o 2117 wall height 4.65mAOD – Max overtopping 0.06l/s/m or 150l/m (*).

(*) l/m values are the maximum volume of water predicted for a single maximum wave.

The maximum wave overtopping discharge is 1.7l/s/m and 630l/m which easily meets the ULS thresholds so we can have confidence our defence will remain stable. Under the SLS thresholds the only instance where it is exceeded is the building threshold. It is considered reasonable to accept this risk for the following reasons:

- The use of 0.5% AEP condition significantly overestimates the overtopping. Using a more appropriate and reduced extreme event such as a 10% AEP would significantly reduce the overtopping below the threshold set.
- The buildings are set back from the seawall which would further reduce the overtopping which hasn't been accounted for here.
- The maximum overtopping value is one scenario of nine. This scenario represents the highest water level but under the same extreme event lower water levels with higher wave heights are possible. These other scenarios considered show in most cases the overtopping is zero, or very low. You have a higher chance under a 0.5% AEP storm event to have zero overtopping than you are the maximum threshold.
- The methodology used has some conservatism added in as discussed through the technical note. Namely:
  - o Choice of selected input wave condition.
  - o Choice of empirical equations.

Results from the sensitivity analysis was undertaken, and the overtopping reported for the following scenarios:

- Increase to the wave heights. Use the wave heights in the outer Harbour and included no effects due to the inner breakwaters. This ignored any effect that would be realised by the extra distance to the defence line or the impact of the inner breakwaters. The minimum increase in wave height is approximately 26%.
- Increase to the Water level by adding the EWL uncertainty allowance (0.3m) to the JPA conditions.

Overtopping Sensitivities results.

- Wave sensitivity analysis. Minimum 26% increase in Wave height
  - At the wall behind the Yacht basin.
    - 2070 wall height 4.1mAOD. Max overtopping 8.23l/s/m or 1791l/m. 3 out of the 9 JPA combinations result in zero overtopping.
    - 2117 wall height 4.65mAOD. Max overtopping 2.84l/s/m or 1063l/m. 4 out of the 9 JPA combinations result in zero overtopping.
  - At the wall behind the Trawl Dock.
    - 2070 wall height 4.1mAOD. Max overtopping 1.46l/s/m or 575l/m. 7 out of the 9 JPA combinations result in zero overtopping.
    - 2117 wall height 4.65mAOD. Max overtopping 0.25l/s/m or 300l/m. 7 out of the 9 JPA combinations result in zero overtopping.
- Water level sensitivity analysis. Add 0.3m EWL uncertainty to the water levels.
  - At the wall behind the Yacht basin.
    - 2070 wall height 4.1mAOD. At the Yacht basin wall – Max overtopping 32.43l/s/m or 4177l/m. 7 out of the 9 JPA combinations result in zero overtopping.
    - 2117 wall height 4.65mAOD. At the Yacht basin wall – Max overtopping 13.1l/s/m or 2080l/m. 6 out of the 9 JPA combinations result in zero overtopping.
  - At the wall behind the Trawl Dock.
    - 2070 wall height 4.1mAOD. Max overtopping 17.28l/s/m or 2238l/m. 6 out of the 9 JPA combinations result in zero overtopping.
    - 2117 wall height 4.65mAOD. Max overtopping 3.89l/s/m or 789l/m. 7 out of the 9 JPA combinations result in zero overtopping.

It can be seen from these results that under SLS thresholds, the values are increases and do not meet the threshold required for buildings notwithstanding the same conservatisms identified above. For the ULS threshold the overtopping is still from exceeding the threshold so we can have confidence the structure shall remain stable under design loading.

The worst overtopping results come from the increased water level analysis for the 2070 epoch. However, any additional allowance for wave overtopping is believed to be unwarranted, given the results are for a condition:

- that occurs only against a water level that is reached 50 years in the future;

- with a wave that on average will only occur once in every 200 years and considering the conservative approach taken during this analysis;
- that condition has to be water level extreme dominant rather than wave extreme dominant (in most JPA scenarios, overtopping is not an issue);
- that is easily acceptable under the ULS condition;

4.2.2 Flood volumes

a) Method

Overtopping analysis has been undertaken using the EurOtop Manual 2016. Specifically using the vertical wall, mean value approach found in Chapter 7. This method is the same as that stipulated in 4.2.1a above but with different coefficients effectively removing the partial factors to give the representative overtopping volume for a given wave and water level. Similarly, to the previous assessment that whilst the method accurately represents the scenario at the back of the Yacht Basin it will over estimate the value at the Trawler Dock. The reason for this is that the new wall at the Yacht Basin sits along the existing quay wall alignment whereas the new wall behind the Trawler Dock is set back from the existing quay. This set back would cause some disruption of the wave and reduce overtopping.

Overtopping analysis results in a value measured in litres / second per meter length of defence. For the flood model a volume of water over a period of time where overtopping is anticipated. Overtopping is usually anticipated over the duration of the storm but is linked to the changing water levels due to the natural tidal cycle so there may be instances where during a storm overtopping does not occur. When ordinarily considering overtopping for stability design the peak overtopping value is required which occurs at the top of the tide. This is what has been determined in section 4.2.1. Because we need to understand how the overtopping quantity changes over the cycle of the tide it is necessary for us to consider a range of water levels at different time steps (usually linked to the model time steps) to more accurately represent the overtopping volumes over this tidal cycle.

The changing overtopping volumes over the tidal cycle has been determined by:

1. Determine the tidal cycle including surge.
2. Determine the water level around the peak storm at an appropriate time interval. For this exercise along with the peak water level, the overtopping has been determined hourly covering a 9 hour window around the peak along with the half hour before and after the peak water level. This duration has been selected as experience shows this will include sufficiently low water levels where no overtopping will occur and sufficiently detailed at the higher overtopping volumes.
3. The assessment has only been considered on the largest peak overtopping JPA condition. In this analysis this was Run ID 9 as can be seen in 4.2.1c.
4. The peak overtopping wave height was used with the varying water level. Whilst it is possible that the wave condition could change over the tidal cycle for a safe assessment this unlikely reduction was not considered.

b) Results

Table 8, 9, 10 and 11 below present the results for the overtopping volumes to be included in the flood models. For the 0.5% AEP JPA in 2070 with a wall crest height of 4.1mOD and in 2117 for wall crest heights of 4.65mOD.

Time stamp	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Defence Length	Overtopping discharge (l/s/m)	Time step (mins)	Overtopping Volume per time step (m^3)

(hour around peak)						
-2	3.35	0.31	165	0.00	60	0.00
-1	3.59	0.31	165	0.08	45	35.64
-0.5	3.72	0.31	165	0.46	30	136.62
Peak	3.775	0.31	165	0.99	30	294.03
+0.5	3.72	0.31	165	0.47	30	139.59
+1	3.55	0.31	165	0.04	45	17.82
+2	3.04	0.31	165	0.00	60	0.00
				Total		**623.7**

Table 8 – 0.5% AEP, 2070 overtopping results at the Yacht Basin

Time stamp (hour number)	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Defence Length	Overtopping discharge (l/s/m)	Time step (mins)	Overtopping Volume per time step (m^3)
-2	3.35	0.25	320	0.00	60	0.00
-1	3.59	0.25	320	0.01	45	8.64
-0.5	3.72	0.25	320	0.08	30	46.08
Peak	3.775	0.25	320	0.26	30	149.76
+0.5	3.72	0.25	320	0.10	30	57.6
+1	3.55	0.25	320	0.00	45	0.00
+2	3.04	0.25	320	0.00	60	0.00
				Total		**262.08**

Table 9 – 0.5% AEP, 2070 overtopping results at the Trawler Dock

Time stamp (hour number)	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Defence Length	Overtopping discharge (l/s/m)	Time step (mins)	Overtopping Volume per time step (m^3)
-2	3.76	0.35	165	0.00	60	0.00
-1	4.00	0.35	165	0.04	45	17.82
-0.5	4.13	0.35	165	0.19	30	56.43
Peak	4.185	0.35	165	0.39	30	115.83
+0.5	4.13	0.35	165	0.20	30	59.4
+1	3.96	0.35	165	0.02	45	8.91
+2	3.45	0.35	165	0.00	60	0.00
				Total		**258.39**

Table 10 – 0.5% AEP, 2117 overtopping results at the Yacht Basin

Time stamp (hour number)	Extreme Water Level (mOD)	Extreme Wave Height, H_s (m)	Defence Length	Overtopping discharge (l/s/m)	Time step (mins)	Overtopping Volume per time step (m^3)
-2	3.76	0.25	320	0.00	60	0.00
-1	4.00	0.25	320	0.00	45	0.00
-0.5	4.13	0.25	320	0.01	30	5.76
Peak	4.185	0.25	320	0.02	30	11.52
+0.5	4.13	0.25	320	0.01	30	5.76
+1	3.96	0.25	320	0.00	45	0.00
+2	3.45	0.25	320	0.00	60	0.00

	Total	**23.04**

Table 11 – 0.5% AEP, 2117 overtopping results at the Trawler Dock

The results in the table above give the overtopped volume of water during a storm for the given timestep. Note that the overtopping discharge at the peak water level is the same event as the correspond overtopping discharge for run ID 9 in section 4.2.1c. i.e. the peak mean overtopping discharge in table 8, 0.99 l/s per m is the same as the 'design and assessment', value with partial safety factors as shown for run ID 9 in table 4, 1.7 l/s per m.

The tables also provided the total volume of water anticipated over a storm event.

These results are to be input to the flood model.

It is worth remembering when viewing the flood model results that the overtopping volumes are for a storm event with a 0.5% EAP in 52 and 99 years' time. Furthermore they are the worst case combination wave and water level for a given JPA return period.

4.3 Conclusions

The walls heights do not need to be increased to the extents that earlier more basic assessment previously indicated, and the proposed crest levels of 4.1mOD in 2070 and 4.65mOD in 2117 are suitable for the 0.5% AEP design event.

However, although it can be guaranteed that the proposed defences will remain stable for all the possible combinations in water levels and waves for a 0.5% AEP, there is a low residual risk that certain combination of conditions would produce wave overtopping that could create localised flooding.

Overtopping volumes have been determined for the inclusion of a flood model using an appropriate mean overtopping assessment. The results for the flood model are presented elsewhere.