Note / Memo

HaskoningDHV UK Ltd.
Water & Maritime

To:	Alec Sleigh
From:	Peter Simpson
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Copy:	Keming Hu
Our reference:	PB8908-ZZ-ZZ-NT-C-0022
Classification:	Project related

Subject: **Conygar Harbour Wave Penetration Modelling**

1 Introduction

Royal HaskoningDHV was commissioned to undertake a series of numerical modelling exercises to inform the design of a proposed marina and shoreline revetments as part of the Holyhead Waterfront development project. The numerical modelling was required to inform the design on wave conditions near the proposed marina and reclamation areas as well as to study impacts on the hydrodynamics close to the study site. The wave conditions were assessed in two stages, first with transforming offshore waves to nearshore and then using the nearshore waves in wave penetration modelling to derive detailed wave conditions at the proposed development.

This technical note describes the methodology and results of the wave penetration modelling. A previous technical note (ref. PB8908-ZZ-ZZ-NT-C-0022) has been produced to detail the methodology and results of the wave transformation modelling. Figure 1 shows the wider view of the study area.

Figure 1: Overview of the study area (red star indicates the study site)

2 Methodology

One of the key design requirements of any marina is that the wave climate within the enclosed water body is sufficiently tranquil that the vessels which will be using the facility can safely enter, manoeuvre, berth and depart safely under normal day to day conditions.

In order to investigate if the proposed breakwaters provide sufficient protection to the water body, a detailed local wave model has been set up to model the wave penetration of operational wave events in order to assess the magnitude of the wave climate inside the proposed Conygar Marina. The layout was investigated using the 1 year return period wave climate from both sea and swell waves as well as locally wind generated waves across the harbour basin.

In addition, a number of extreme events were also modelled to confirm that the marina facilities (i.e. the pontoons etc.) could withstand the potentially increased wave climate inside the marina basin without suffering significant damage.

2.1 Model Choice

Previously a spectral wave transformation model such as MIKE21SW was used to transform the offshore sea and swells and also any locally generated wind waves to the Conygar Marina frontage. This type of numerical model is capable of modelling wave refraction and diffraction in regional terms around large headlands, but it is not capable of accurately simulating the diffraction and refraction of waves in and around the smaller harbour breakwater structures. Therefore, a different numerical wave model is required which can simulate these important wave processes to accurately assess wave conditions within the Conygar Marina.

A boussinesq wave model (MIKE21BW) has been selected as it has been specifically developed to model the interaction of waves as they propagate in and around smaller coastal structures and it has been shown to be a reliable model tool on a significant number of similar harbour and port related projects around the world and has the following advantages:

- The model incorporates the latest development of the enhanced boussinesq equations which include nonlinearity (natural sea conditions) as well as frequency dispersion making it more suitable for simulation of the propagation of directional wave trains travelling from deep water to shallow water.
- The model is capable of analysing both short (sea and swell) and long (infra-gravity) period waves (which can lead to harbour resonance or oscillations) in ports, harbours and coastal areas.
- The model simulates natural (random, non-linear) sea conditions.
- The model is capable of accurately simulating wave propagation over a steeper sloping bathymetry such as the steep side slopes of the nearshore dredged channels and approach navigation channel to the proposed harbour basin.

2.2 Model Setup

The same bathymetry data that was used for the wave transformation modelling was used for this modelling task, except the boussinesq model mesh was refined. In addition, the model bathymetry was modified to include the proposed breakwater and any land reclamations, which would change the existing shoreline.

The computational grids and computational time step in a boussinesq wave model need to be relatively small in size to accurately model the wave processes in and around smaller coastal structures. Initially RHDHV setup a rectangular grid with a size of 5m by 5m but unfortunately this was found to be too coarse and it was subsequently refined to 2.5m by 2.5m to accurately model the influence of the smaller breakwater structures. The computational time step also needed to be reduced significantly to achieve a reliable and stable numerical model which had implications on the overall run time for each scenario. The local wave penetration model domain covers an area of 6km by 4km as shown in Figure 2 below.

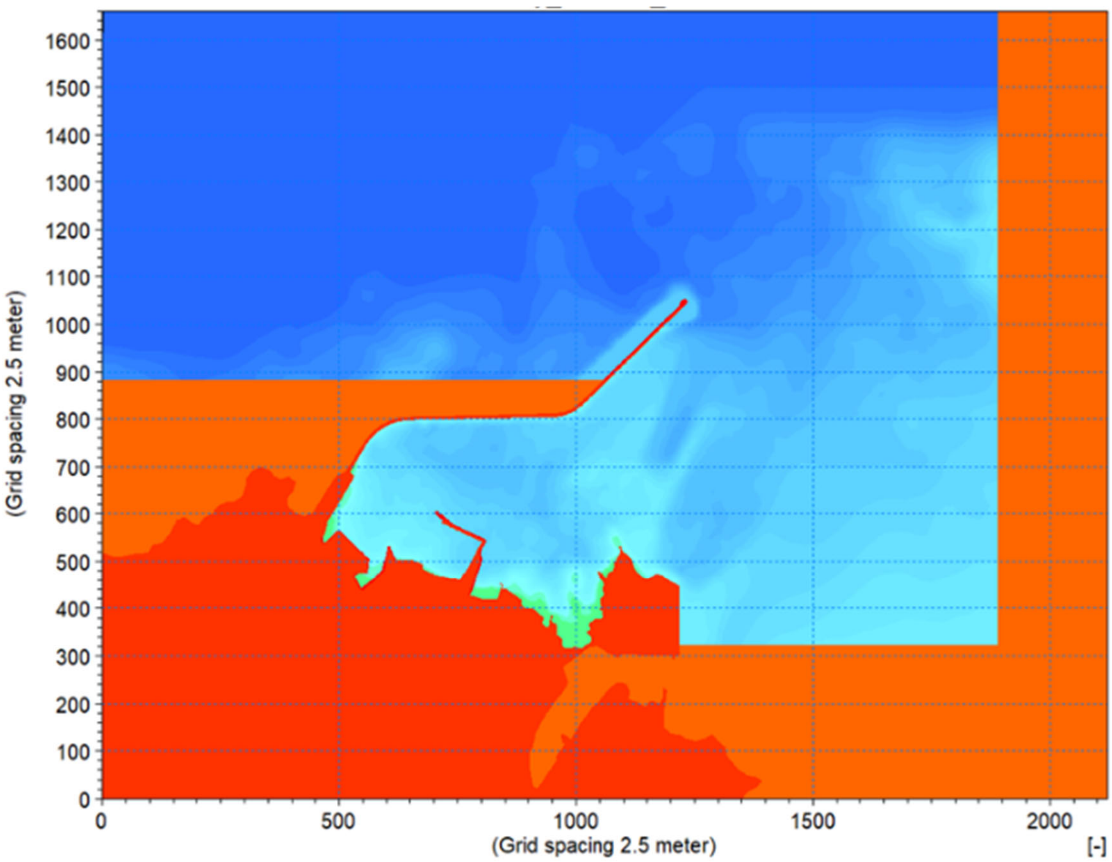

Figure 2: Modelling domain for wave penetration study

2.2.1 Wave Generation Line and Sponge Layers

In boussinesq wave model simulations, wave generation lines (wave input boundaries) are set along the open boundaries of the numerical model and the model is driven by random waves generated along these generation lines. In this study, one internal wave generation line was placed along the seaward boundary of the model domain.

The wave conditions derived along these wave generation lines have been generated by assuming a JONSWAP spectrum with the default spectral shape parameters (γ = 3.3, σa = 0.07, σb = 0.09).

Sponge (or absorbing) layers are used as numerical wave absorbers within boussinesq wave model simulations. These layers are set along all open water boundaries as well as along boundaries where wave reflections are not allowed. Sponge layers have been applied behind the wave generation line and along the open boundaries to absorb wave energy and prevent waves from returning to the model domain.

Figure 3 illustrates the general arrangement of the wave generation lines and sponge layers for Layout 1. A similar arrangement was also applied for any other layouts modelled during the optimisation process.

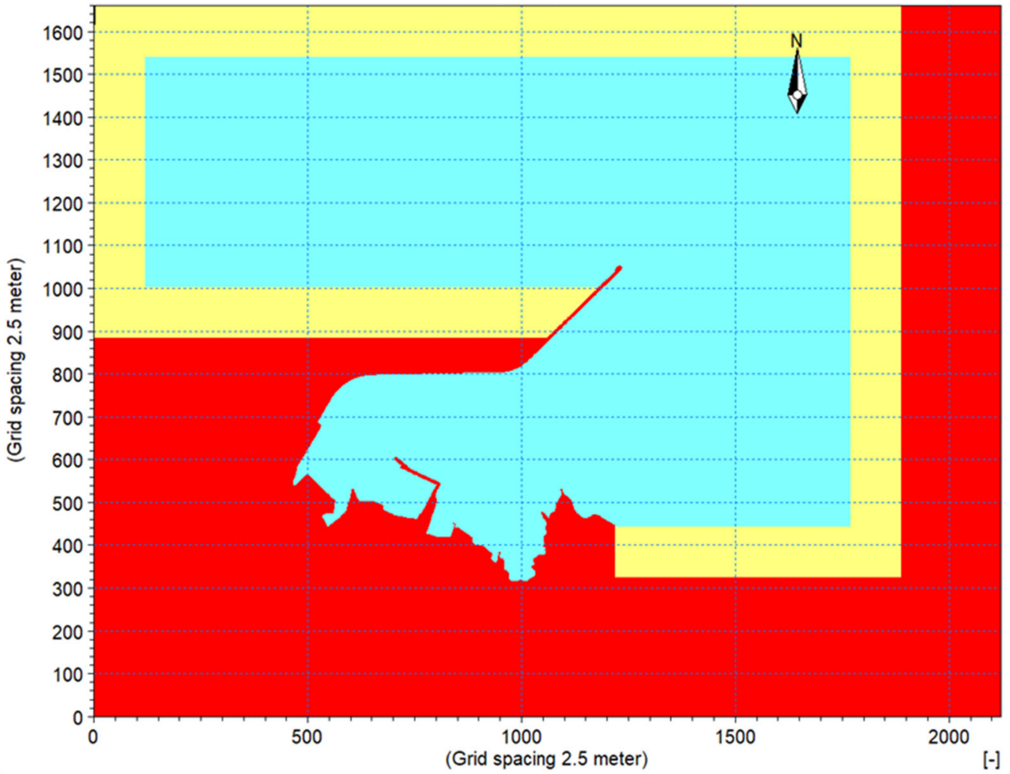

Figure 3: Arrangements of Sponge layer and wave generation lines

2.2.2 Wave Reflections

In addition to diffraction, wave reflection is a key process to be considered within a wave penetration model. The type of construction used to form the internal edges of the proposed Conygar Marina have a significant influence on wave reflections and hence the wave conditions within the marina basin. In the wave penetration model, the edges are assigned values to account for the amount of wave reflection and/or transmission through structures that occurs.

For the Conygar Marina layouts modelled the following assumptions have been made for reflection of incident wave energy:

- 100% reflection from the vertical quay walls (porosity coefficient = 1);
- 40% reflection from rubble mound breakwater, revetments and rocky headland (porosity coefficient = 0.4);
- 20% reflection from any sandy beaches (porosity coefficient = 0.2); and
- 0% reflection and/or transmission for the floating breakwater structure (porosity coefficient = 0).

Figure 4 below shows the general arrangement for the porosity layer applied to the final Conygar Marina layout.

Figure 4: Arrangement of porosity layers

2.2.3 Wave Breaking

Depth induced wave breaking has not been included in the numerical model. The majority of the model domain is in relatively deep water when compared to the height of the incoming waves, so neglecting wave breaking will not affect the accuracy of the model results but will help to minimise run times, which can be very lengthy for this type of numerical wave modelling.

2.2.4 Bottom Friction

Bottom friction is also excluded for the model runs. This is because the area covered is relatively small and except for high waves and/or very shallow water there is insufficient distance for the bed resistance to have a significant effect on wave propagation.

2.2.5 Model Validation

The calibration of a wave penetration model is generally not a straightforward process. In most cases the breakwater structures that are being studied have not yet been constructed. It is sometimes possible to undertake calibration based on physical model test results, however, at this stage such a study has not been undertaken.

As a consequence, some sensitivity tests have been undertaken to confirm that the setup of the model is robust and that it is performing according to (engineering) expectations. These tests have confirmed that the model is robust and suitable for use in this study.

2.3 Input Wave Conditions

The input wave conditions were extracted from the wave transformation modelling (MIKE21SW) result for the 1 year return period joint probability events (lowest water level and highest offshore waves (JP1)). A total of six operational conditions (1 year return period) from 0, 30, 60, 270, 300 and 330 degree N sectors have been simulated. These input wave conditions were applied along the wave generation lines outlined above in Section 1.1.1.

The input wave parameters of these six modelling scenarios are presented in Table 1 below.

Table 1: Operational and extreme wave conditions for wave penetration modelling

Return Period (years)	**Offshore Wave DIR. (deg.N)**	**Offshore Climate (SW input)**		**1 year EWL (2020) = 5.98mCD**		
		H_{mo}(m)	T_p (s)	H_{m0} (m)	T_p (s)	MWD (deg.N)
1	0	4.62	6.71	3.2	8.0	0
	30	4.32	5.90	1.6	6.0	10
	60	4.05	5.71	1.2	6.0	44
	270	4.72	7.13	3.7	8.0	270
	300	4.95	6.94	3.7	8.0	300
	330	4.78	7.17	3.9	8.0	330

Once the wave penetration modelling confirmed the layout of the Conygar Marina would satisfy the operational requirements inside the basin, two extreme wave events were also considered for return periods of 100 and 200 years. The extreme events consider are shown in Table 2 below.

Table 2: Extreme wave conditions for wave penetration modelling

Return Period (years)	**Offshore Wave DIR. (deg.N)**	**Offshore Climate**		**100 year EWL (2020) = 6.17mCD**		
		H_{mo}(m)	T_p (s)	H_{m0} (m)	T_p (s)	MWD (deg.N)
100	0	8.48	9.09	5.92	10	357
200	0	9.09	9.41	6.23	10.3	356

3 Model Results

Before the wave model results are presented and discussed it is important to define the target wave climate required for the safe day to day operation and for the survival conditions within the Conygar Marina.

3.1 Target Wave Climate

The key design criteria for any breakwater whether this is a rubble mound, a caisson or a floating breakwater solution relates to the wave climate on the inside (or leeside) of the structure.

The target criteria for wave conditions on the leeside of any breakwater can be established from the following guidance documents:

- Yacht Harbour Association, A Code of Practice for the Design, Construction and Operation of Coastal and Inland Marinas and Yacht Harbours,5th Edition, June 2007.
- Australian Standard (AS3962), Guidelines for design of marinas, 2nd Edition incorporating Amendment No. 1, March 2010
- PIANC RecCom Working Group Report (WG149) Guidelines for Marinas, Part IV, August 2017.

The Yacht Harbour Association guide suggests that the desired wave heights on the leeside of the structure should be 0.3m for the annual wave height and 0.4m for the extreme wave height. Wave height is taken as significant wave height, Hs and extreme condition is normally taken as 50 years.

The Australian Standard (AS3962) guidelines for design of marinas is not as stringent and gives a range of values dependant on:

- the orientation of berthed vessels and;
- a measure of "how good" the wave climate actually will be in the lee of the breakwater.

AS3962 provides three criteria for "how good" the conditions in the lee of the breakwater should be and these are:

- excellent,
- good, and;
- moderate.

For example, if all waves with wave periods greater than 2 seconds are considered and the wave climate in the lee of the structure must provide "good" wave conditions, then the guide suggests the following annual (1 year) and extreme (50 year) target wave climates.

Table 3: Target wave climate for a "good" wave conditions on the leeside of a structure (AS3962)

Orientation of berths	Annual Climate (m)	Extreme climate (m)
Head seas	Less than 0.3	Less than 0.6
Oblique seas	Less than 0.3	Less than 0.4
Beam seas	Less than 0.25	Less than 0.15

If the aim is to achieve "excellent" wave conditions, then the target wave climates should be multiplied by 0.75 and if they are to be relaxed to achieve "moderate" wave conditions then the target wave climate can be multiplied by 1.25.

AS3962 also says "if the vessel size is less than 20m then the most severe climate should satisfy the 'moderate' conditions". Given RHDHV expects the majority of the vessels using the proposed marina will be less than 20m then RHDHV would recommend that following target wave criteria:

- Moderate operational conditions (1 year): 0.375m
- Moderate extreme conditions (50 year) 0.75m

Finally, a more recent guide has been published by PIANC in 2017, which also provides guidance for the target wave climates for marinas. In this guide it suggests the target wave climate for small craft and pleasure boats with a length less than 10m should be as shown in Table 4.

Table 4: Target wave climates in the lee of a structure (PIANC)

Orientation of berths	Wave height, Hs (m)	Wave period, T (s)
Beam / Quarter seas	Less than 0.15	Greater than 4
Head seas	Less than 0.2	Greater than 4

The guide also states the upper limit for wave heights with respect to safety should be a shown in Table 5.

Table 5: Upper limit for wave climate (PIANC)

Type of mooring	Wave height, Hs (m)
Flexible mooring systems	Less than 0.6
Mooring on rigid berths with permanent contact between vessel and berth	Less than 0.4

Therefore, based on this guide, RHDHV would recommend a target wave climate of:

- Comfortable operational conditions (1 year): 0.15m
- Survival conditions (50 year): 0.4m

To summarise, there are numerous guides which specify a range of target wave climates for marinas. Based on all of these guides, RHDHV has chosen the following target wave climate to assess the performance of the proposed rubble mound breakwater forming the Conygar Marina.

- Operational wave conditions (1 year): 0.3m
- Extreme wave conditions (100 year) 0.6m

3.2 Wave Penetration Results

The wave penetration plots are included in Appendix A.

The boussinesq wave modelling clearly demonstrated that the proposed breakwater will provide sufficient protection to create a recreational marina behind. Along the vertical edges close to the shoreline, the modelling clearly shows that slightly higher wave conditions might occur.

As expected, when an operational (1 year) offshore wave propagating from due North (0 degrees N) are considered these waves generate the worst case for the proposed Conygar Marina. Figure 5 below shows the numerical model result for this direction and it is clear that the offshore waves generally reflect from the main breakwater back into the harbour thus creating a reasonably tranquil marina. Some wave energy does refract and diffract around the breakwater roundhead and this refracted wave does reflect from the proposed vertical edges that will form the shoreline defences and marina edges. Overall, the wave heights within the marina basin are generally below the target wave height of 0.3m apart from along the vertical edges along the shoreline where they may be up to 0.1m higher. Some softening of these shoreline defence would help to improve the wave climate within the proposed Conygar Marina.

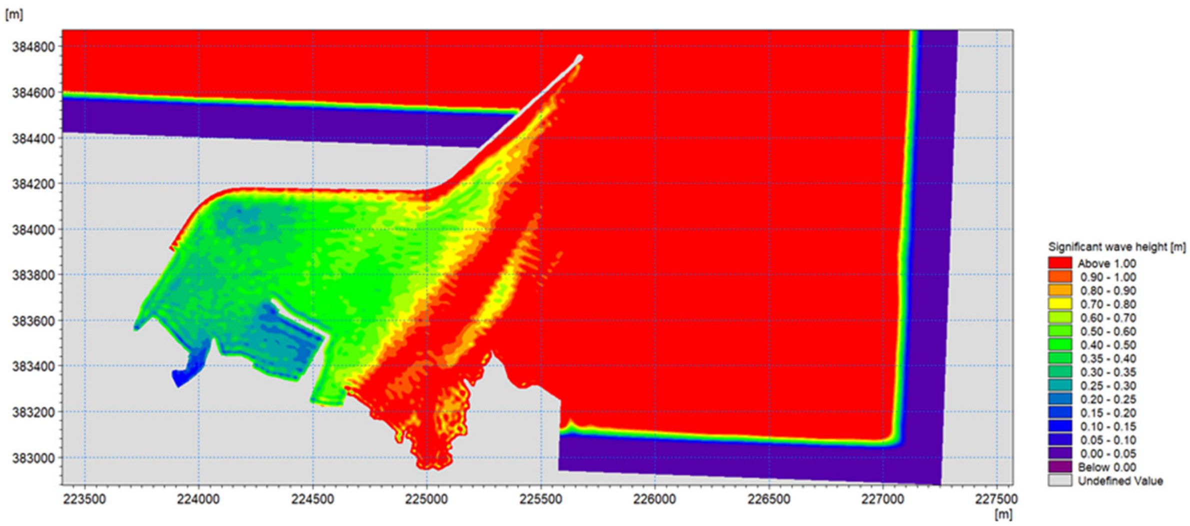

Figure 5: BW wave model result for an operational (1 year) wave climate propagating from 0 degrees N

When a more locally generated operational (1 year) wave climate is considered the numerical wave modelling shows that the waves are reflected from the existing Great Breakwater and travel into the proposed Conygar Marina, see Figure 6 below. Again, the wave heights within the proposed Conygar Marina are generally below the target wave hight of 0.3m although there are a number of locations where the wave height might be slightly higher due to the combination of refracted and reflected wave energies. This clearly demonstrates that the marina will only be satisfactory if a floating breakwater is installed to reduce the amount of reflected wave energy that is propagating from the existing Great Breakwater.

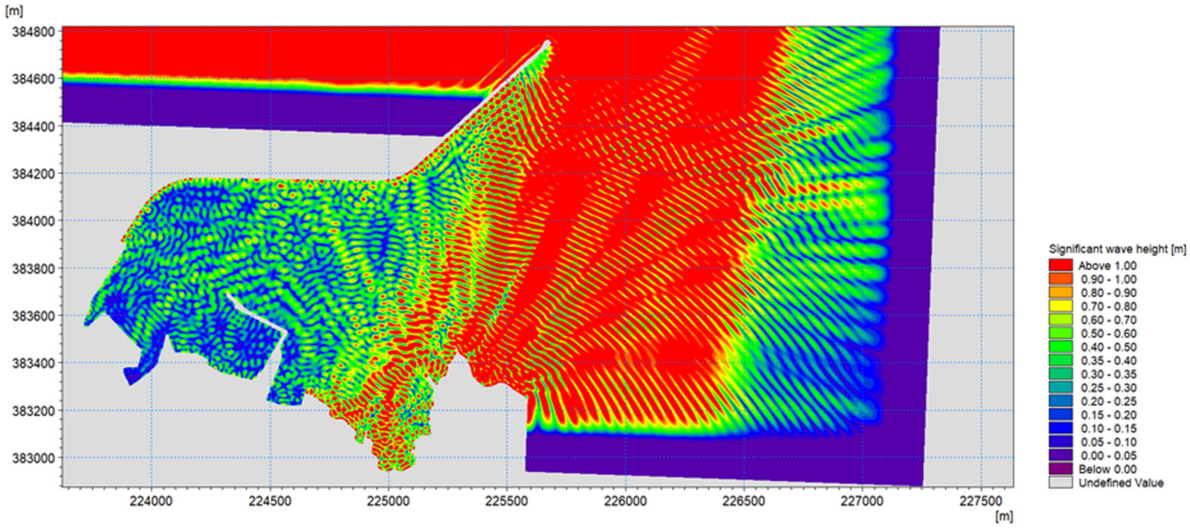

Figure 6: BW wave model result for a locally generated operational (1 year) wave climate propagating from 60 degrees N

When the extreme wave events (100 and 200 year) are considered the numerical wave modelling clearly demonstrates that the wave climates within the proposed marina will be just below the maximum target wave height of 0.6m, see Figure 7 below. This means any floating infrastructure that is installed within the marina will need to be carefully designed to be able to cope with an increased wave climate during storm events. It may also have implications for the safe operation of the marina during storm events and mean that effectively the marina is only suitable for the berthing of vessels during the late spring, summer and autumn and not during the winter months when more storm events are more likely to occur.

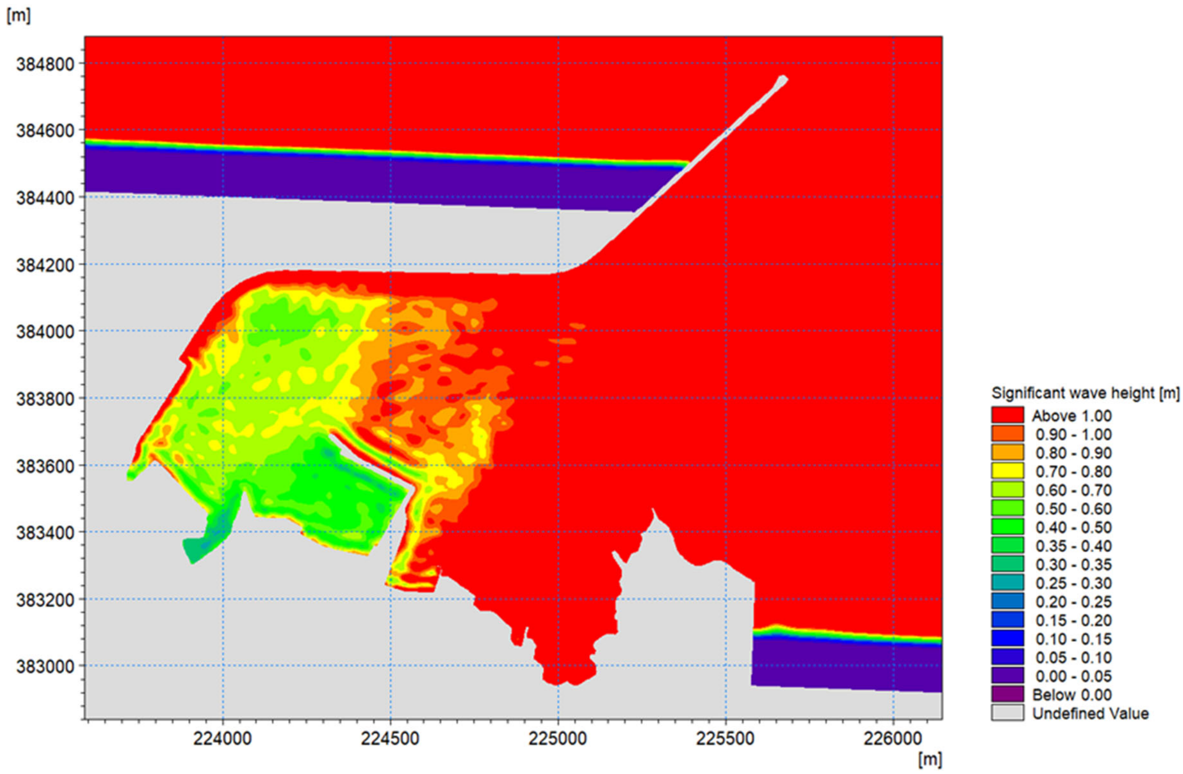

Figure 7: BW wave model result for an extreme event (200 year) wave climate propagating from 0 degrees N

It is RHDHV's opinion that the installation of a floating breakwater to reduce the amount of reflected wave energy coming into the Conygar Marina from the Great Breakwater will also help to reduce the amount of wave energy that is able to directly travel into the marina from the northerly sectors.

RHDHV also can confirm that during the winter months (October to March) it is more likely that an extreme event will occur and the wave climate within the Conygar Marina has been shown to be close to the target wave climate. Consideration may therefore need to be given to mitigating the effect of winter storms by ensuring that vessels that are left on-berth during the winter are moored in more sheltered parts of the facility.

3.3 Wave Reflections from the Great Breakwater

As already shown by the boussinesq wave modelling above, one of the main concerns with constructing a new marina along the Newry Beach frontage is that any waves which may travel across Holyhead Bay potentially could reflect from the vertical edges that form the leeward side of the Great Breakwater.

In order to investigate this matter further, RHDHV went back to their wave transformation model (MIKE21SW) and undertook a number of wave model assessments to determine if this was likely to cause any issues for the Conygar Marina itself but also for the new shoreline defences required to protect the newly reclaimed land that will for the Porth y Felin residential development.

The results of this modelling have also allowed RHDHV to assess and design a floating breakwater (boussinesq wave modelling shows it is required), to reduce reflective wave energy from reaching the Conygar Marina berths.

Initially a total of six modelling scenarios were considered for two return periods of 100 and 200 years and for three directions 50, 60 and 70 degree N. The vertical edges of the Great Breakwater were assigned a porosity value of 1 representing the worst case that all the wave energy is reflected.

The model results were initially compared against the previous wave transformation modelling results without reflectivity to quantify the increase in wave height at points 8 and 9 previously used for the design of the Conygar Marina.

Table 6 below presents the input wave conditions used in the simulations and the initial model results obtained at the nearshore points 8 and 9. An example graphical plot is presented in Figure 8 showing the wave climate with and without wave reflections for a 200 year wave event propagating from 70 degree N. Appendix B present all the graphical plots.

Table 6: Input wave conditions and initial results from the wave reflectivity assessment

Wind Waves: Joint Probability Return Periods - JP1				**No Reflection**		**With 100% Reflection**	
				Point 8	Point 9	Point 8	Point 9
Return Period	Extreme Water Level (2120)	Wind Speed (m/s) (2120)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Height (m)	
T100	7.49	30.0	50	0.88	1.15	0.92	1.22
T100			60	0.96	1.19	1.03	1.26
T100			70	1.02	1.20	1.13	1.28
T200	7.49	31.6	50	0.94	1.21	0.97	1.29
T200			60	1.01	1.25	1.09	1.34
T200			70	1.08	1.27	1.20	1.36

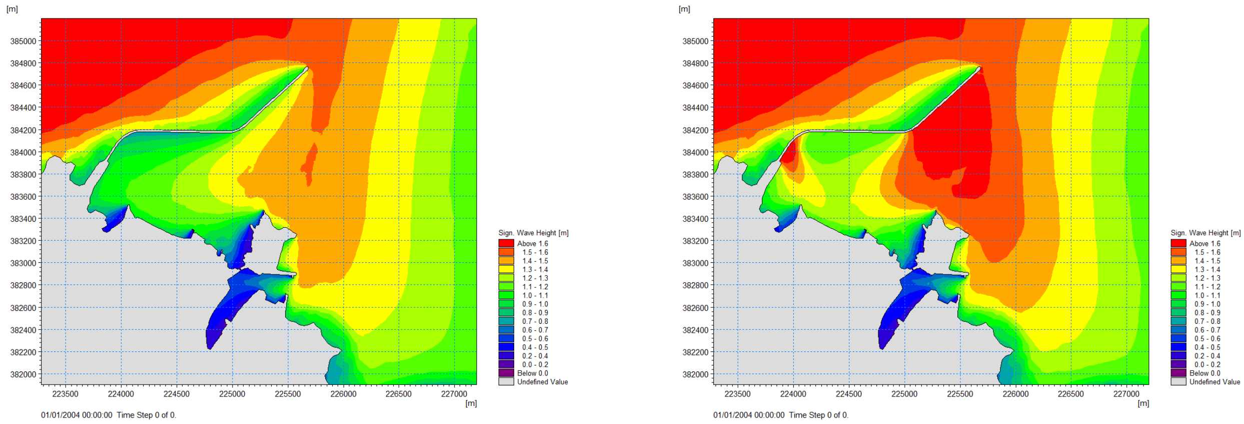

Figure 8: Wave reflection assessment for 200 year wave event from 70 degree N, Left - no reflections, Right - with reflections

The results clearly demonstrate that 70 degree N is the worst direction and that the magnitude in wave height is approximately 0.1m higher.

Having determined that wave reflections from the Great Breakwater could be significant (up to 10%) it was decided that an additional scenario should be investigated for a return period of 50 years propagating from 70 degree N.

Given the results of the reflection assessment were required for the design of the shoreline structures along Porth y Felin and for the potential floating breakwater it was decided to extract results at 3 points along each of these features. The locations of the points are shown in Figure 9 and the results are presented in Table 7. All graphical plots are presented in Appendix B.

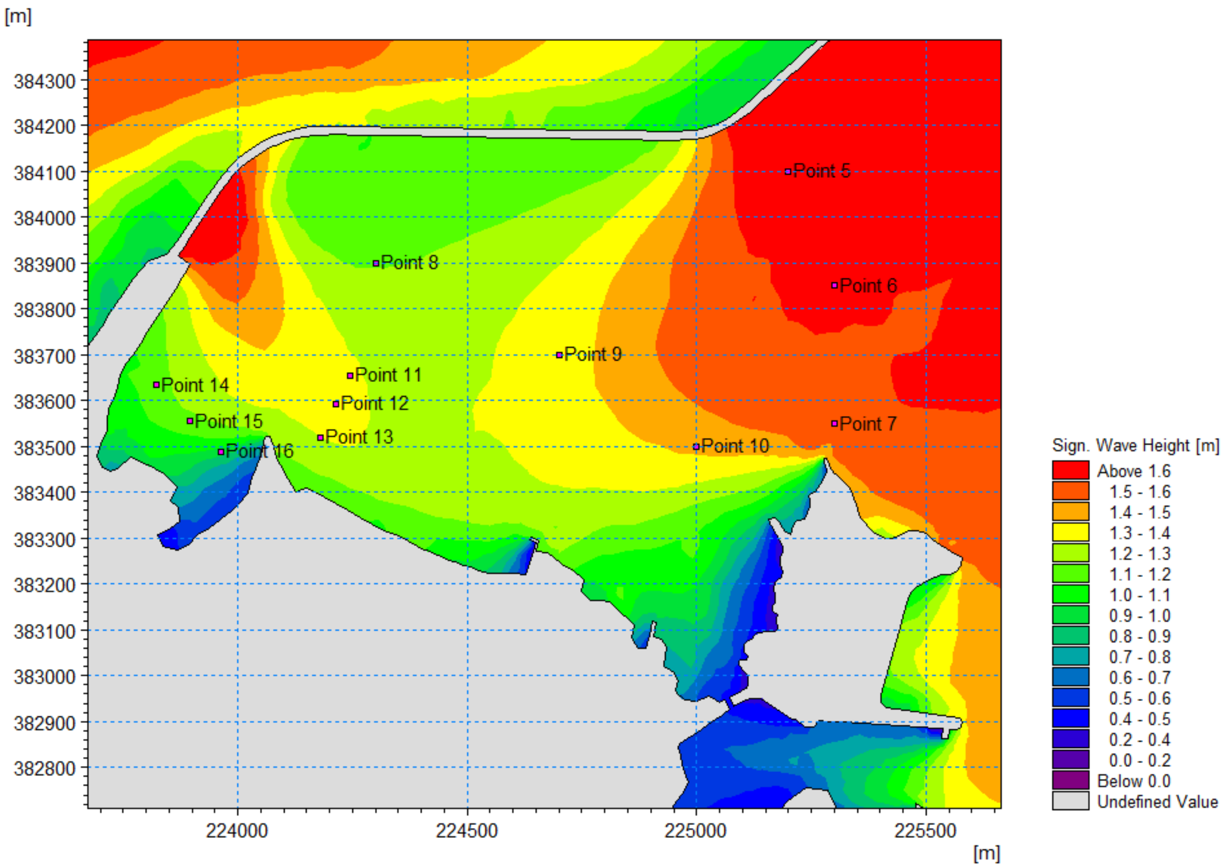

Figure 9: Location of points 11, 12, 13 along line of floating breakwater and points 14,15 and 16 along the Porth y Felin frontage

Table 7: Wave reflection assessment model results for wave events propagating from 70 degree N

Point	50year - 2120		100year - 2120		200year – 2120	
	Nearshore Wave Height (m)	Nearshore Wave Period (s)	Nearshore Wave Height (m)	Nearshore Wave Period (s)	Nearshore Wave Height (m)	Nearshore Wave Period (s)
Point 11	1.17	4.29	1.25	4.41	1.32	4.53
Point 12	1.18	4.30	1.25	4.42	1.32	4.54
Point 13	1.16	4.30	1.23	4.42	1.30	4.55
Point 14	1.04	4.37	1.10	4.49	1.16	4.61
Point 15	1.05	4.41	1.11	4.53	1.17	4.66
Point 16	0.85	4.37	0.90	4.49	0.95	4.61

Appendix A: Wave Penetration Plots

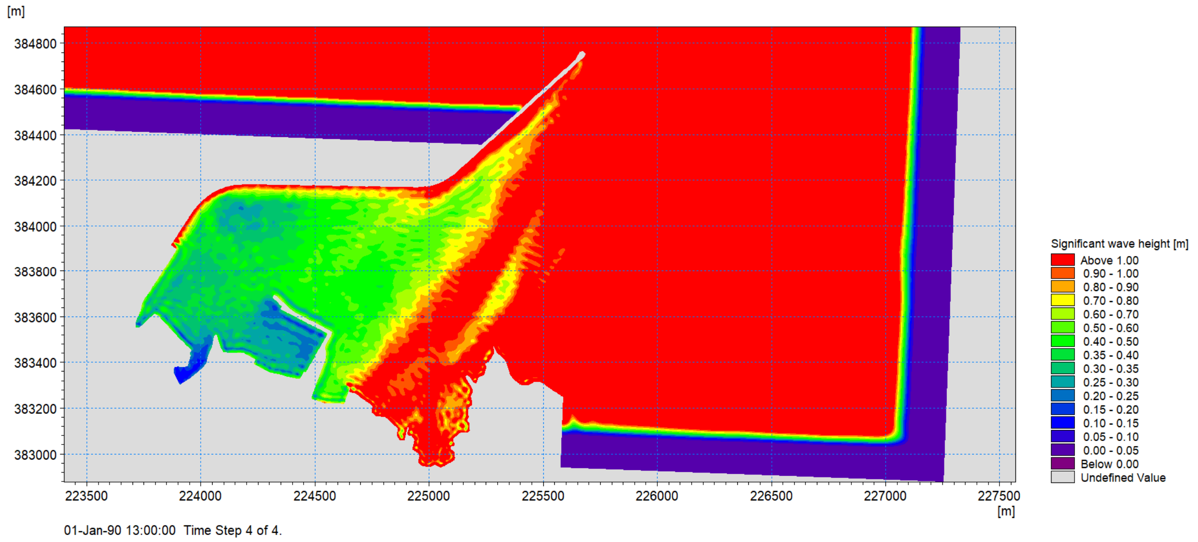

Figure A1: Significant wave heights (Run 1 – 1 year waves from 0°N)

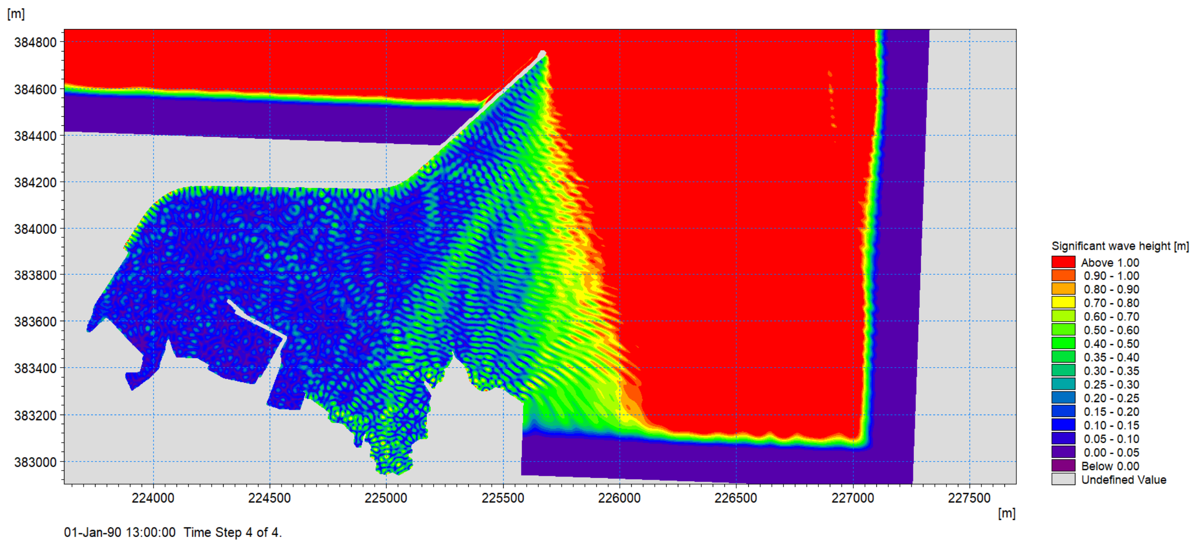

Figure A2: Significant wave heights (Run 2 – 1 year waves from 30°N)

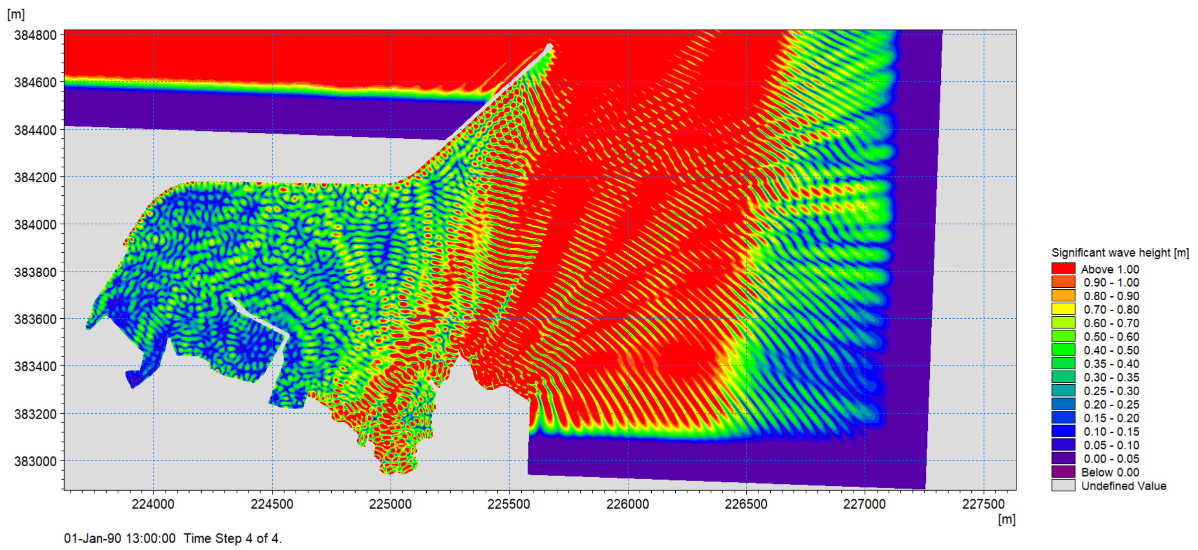

Figure A3: Significant wave heights (Run 3 – 1 year waves from 60°N)

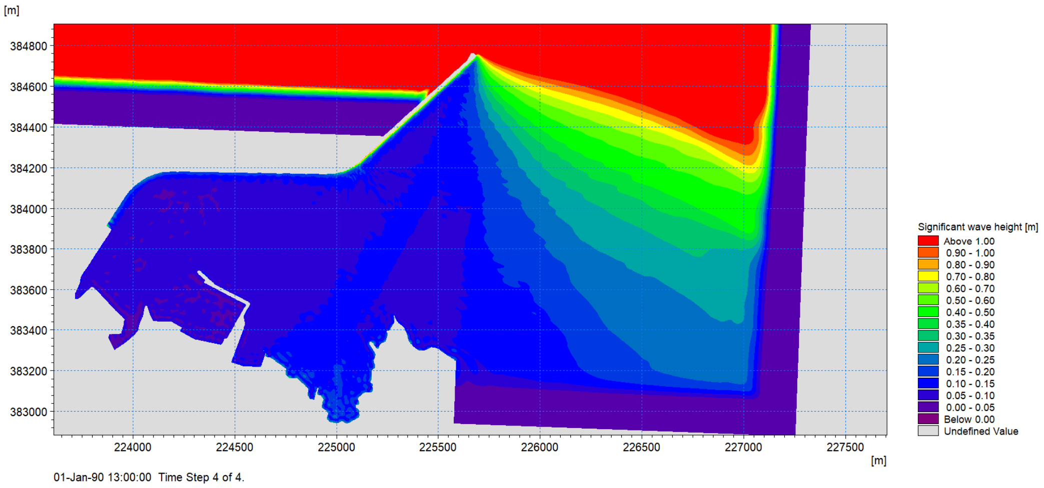

Figure A4: Significant wave heights (Run 4 – 1 year waves from 270°N)

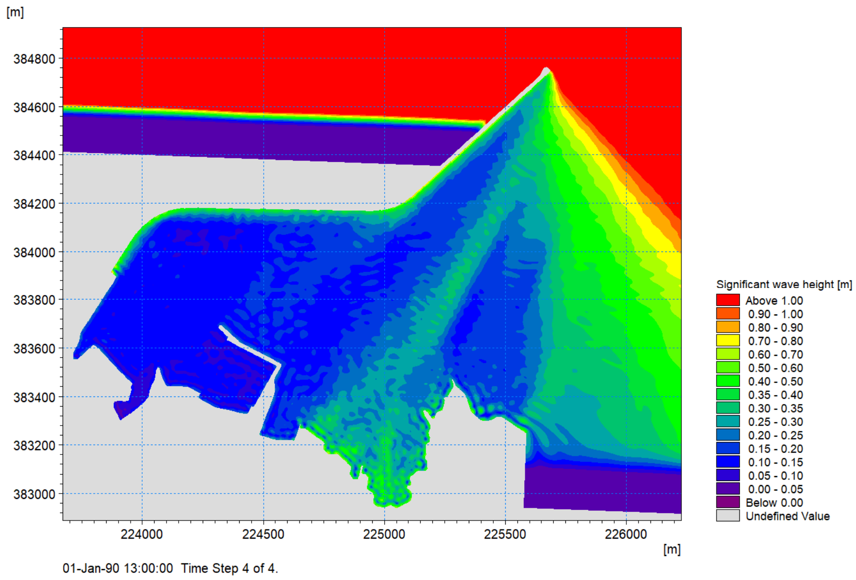

Figure A5: Significant wave heights (Run 5 – 1 year waves from 300°N)

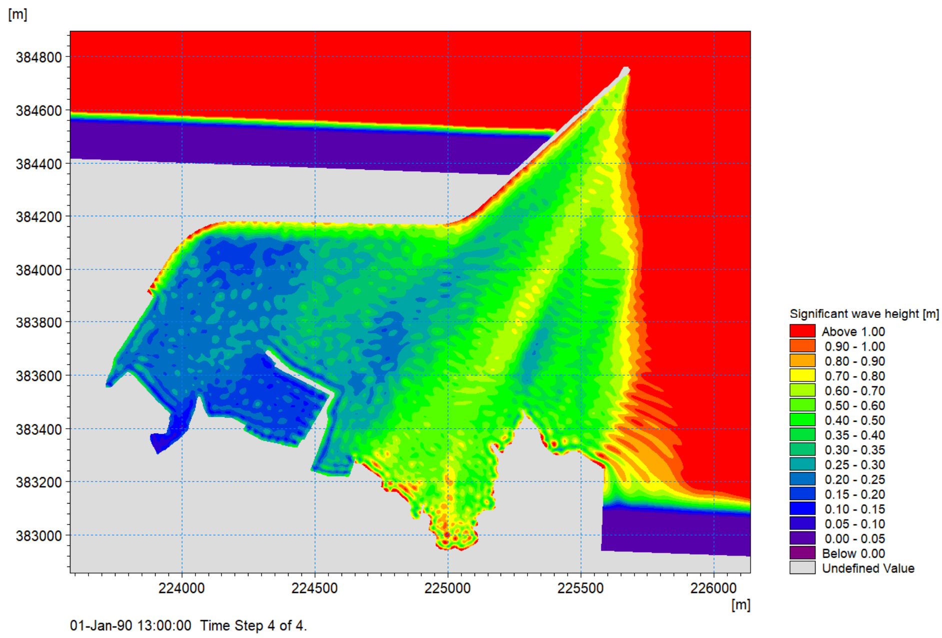

Figure A6: Significant wave heights (Run 6 – 1 year waves from 330°N)

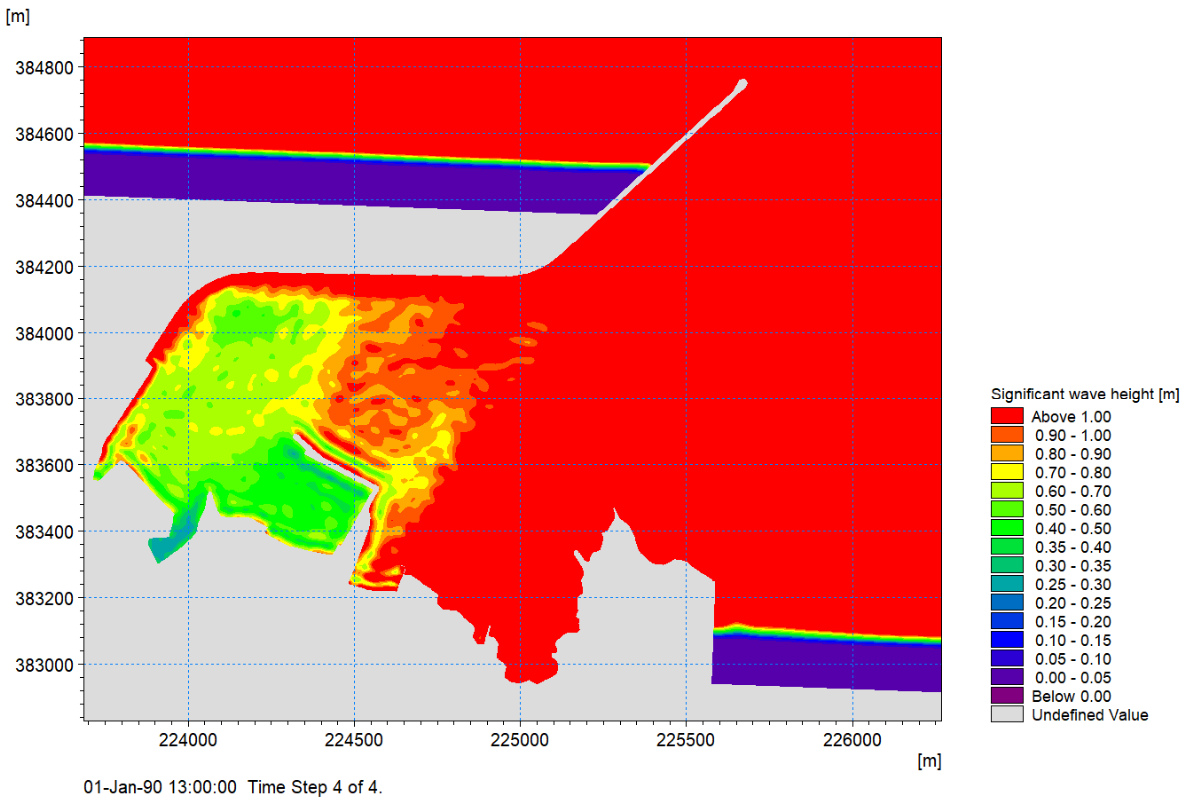

Figure A7: Significant wave heights (Run 7 – 100 year waves from 0°N)

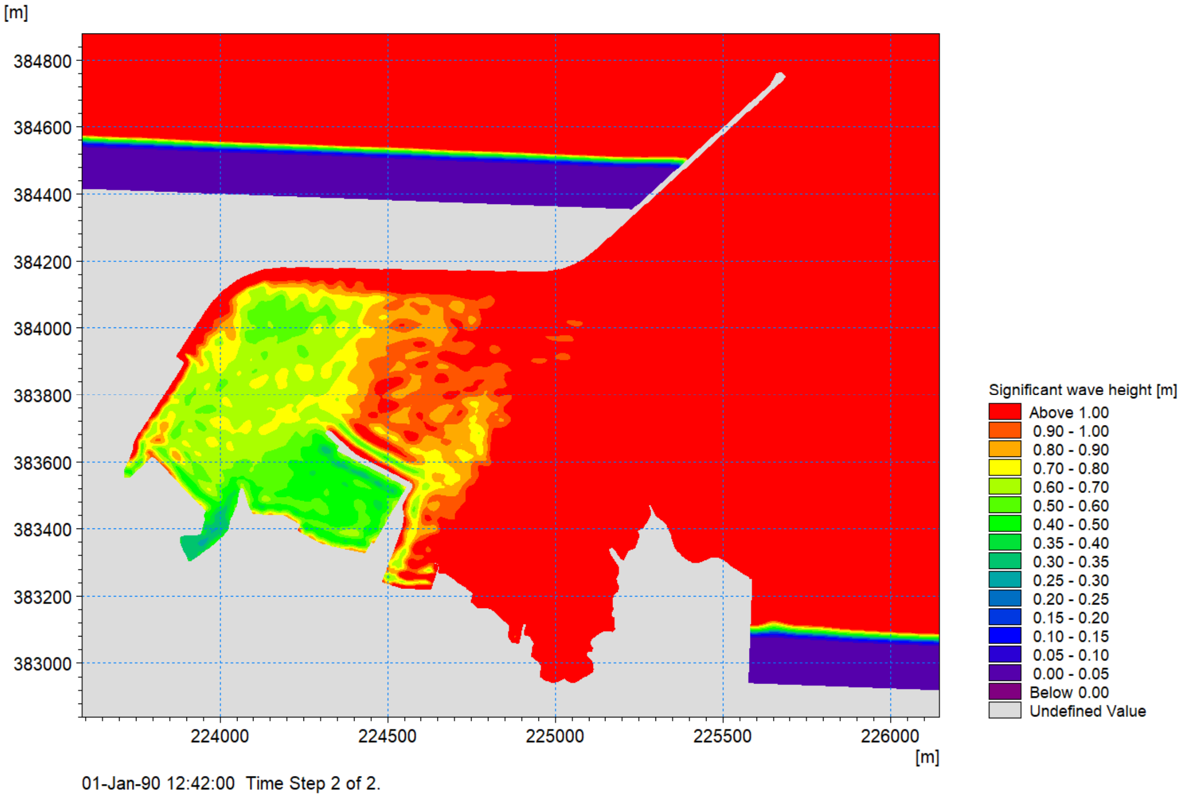

Figure A8: Significant wave heights (Run 8 – 200 year waves from 0°N)

Appendix B : Summary of Wave Reflection Assessment

The graphical plots for all the wave reflectivity assessment modelling are shown below in Figures B1 – B7. The location of the outputs points is shown in Figure B8 and the results of the initial sensitivity tests are presented in Table B1 before the final modelling results for a range of return periods are presented in Table B2.

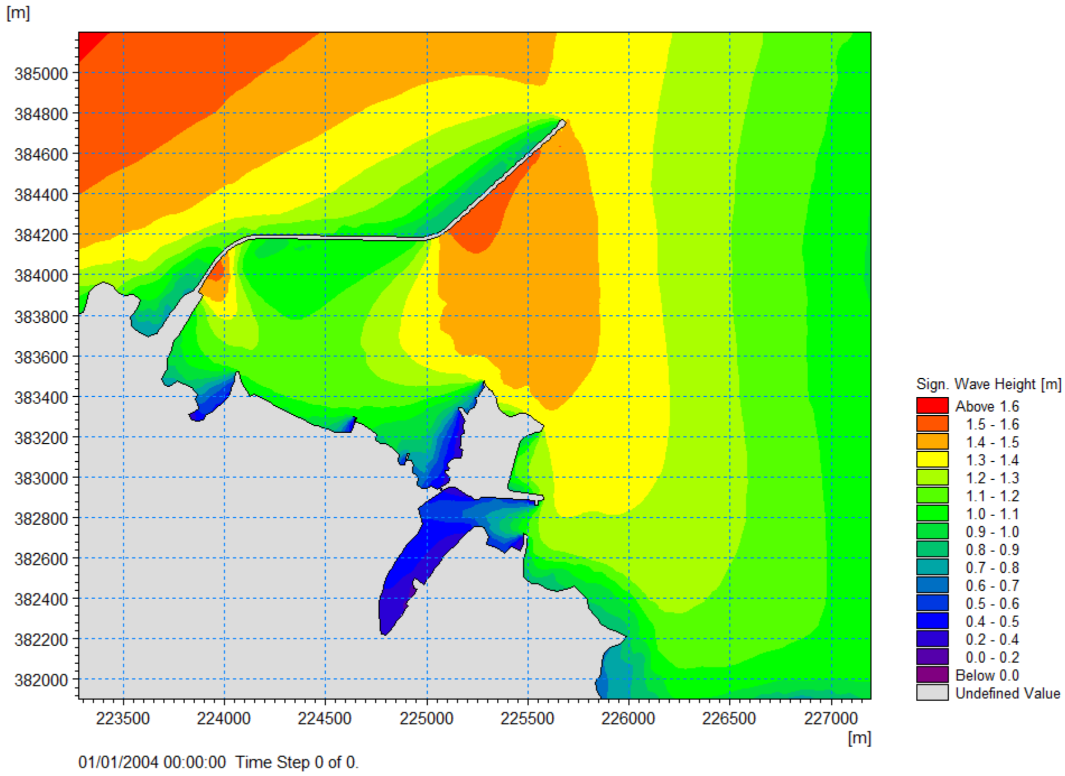

Figure B1: Wave reflectivity assessment for a 50 year return period wave event from 70 degree N (2120)

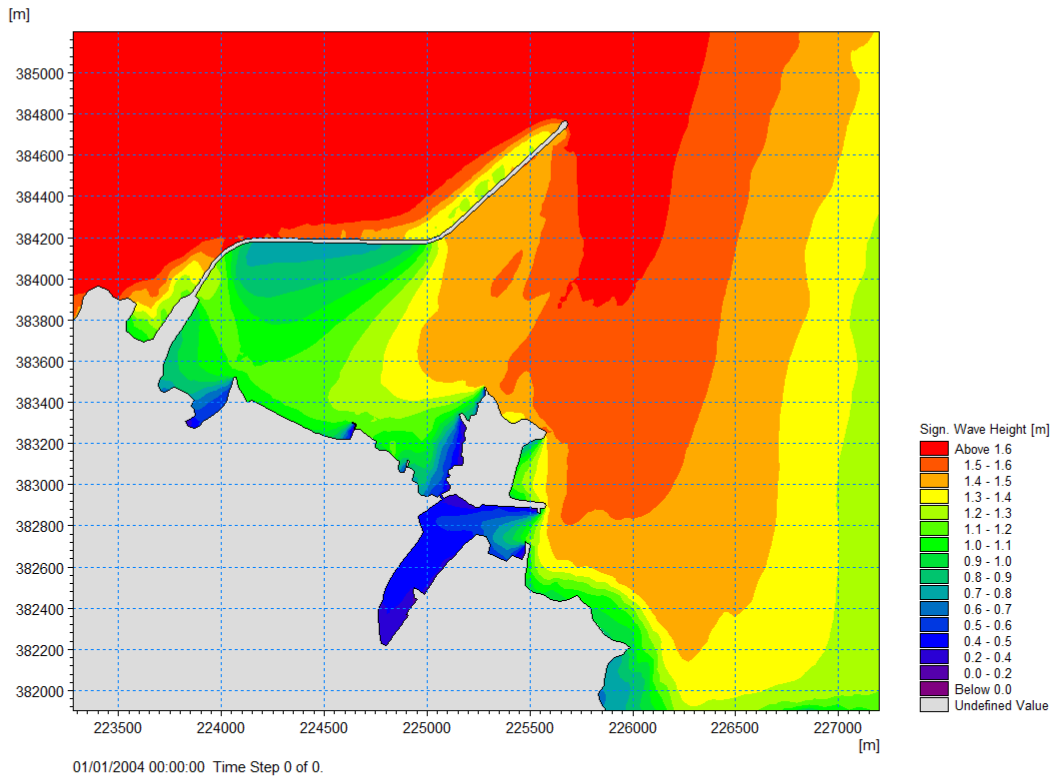

Figure B2: Wave reflectivity assessment for a 100 year return period wave event from 50 degree N (2120)

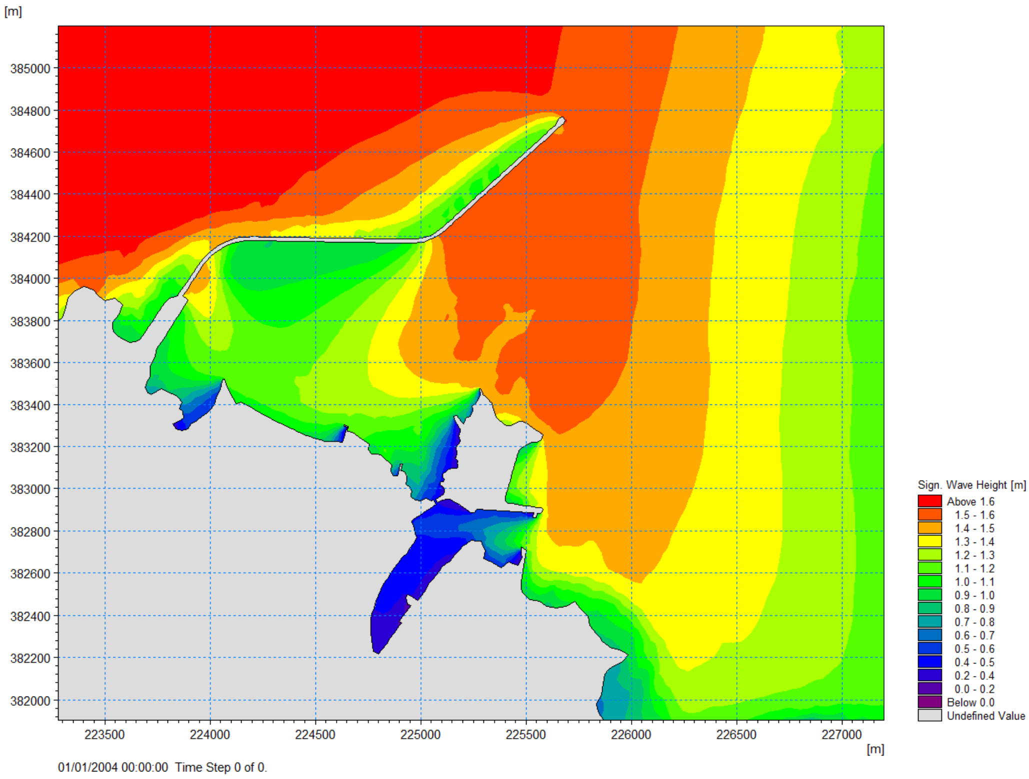

Figure B3: Wave reflectivity assessment for a 100 year return period wave event from 60 degree N (2120)

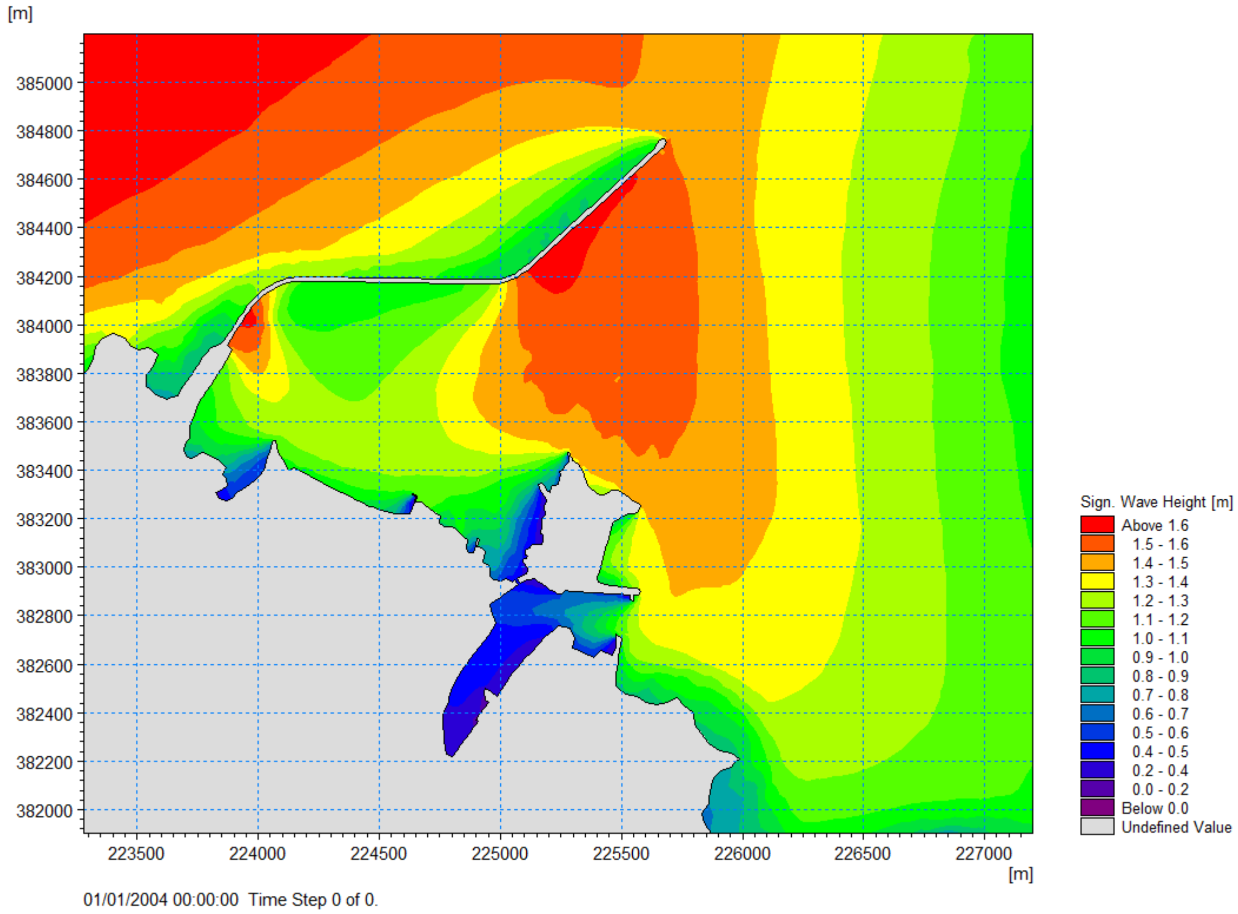

Figure B4: Wave reflectivity assessment for a 100 year return period wave event from 70 degree N (2120)

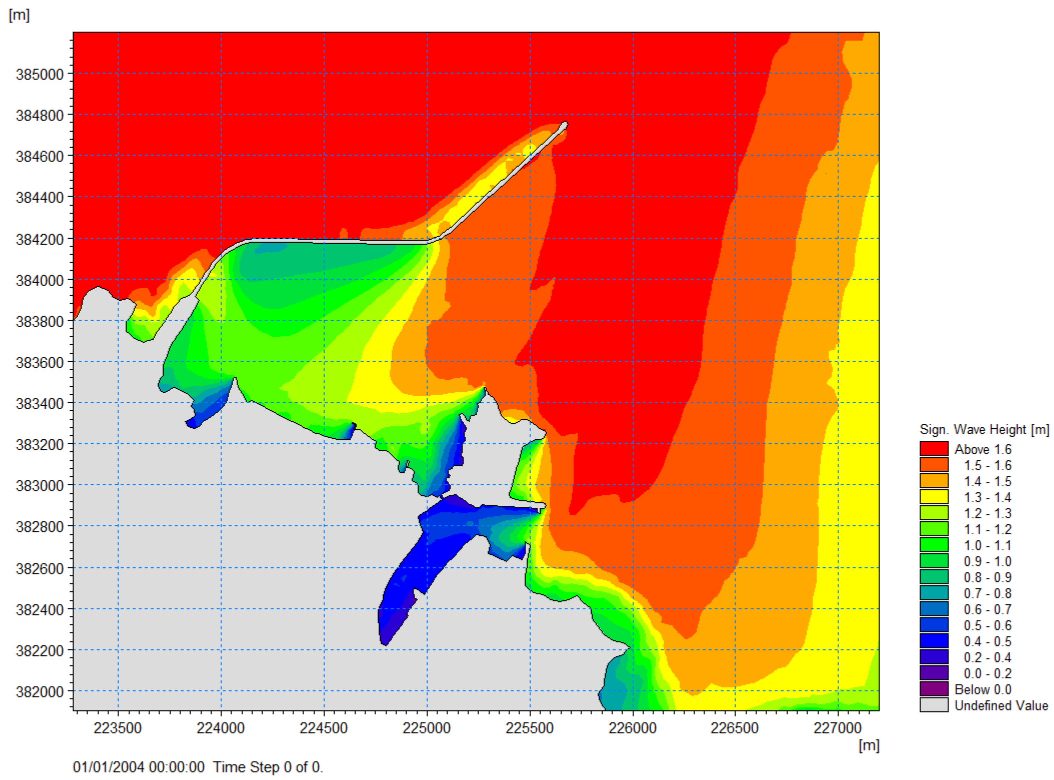

Figure B5: Wave reflectivity assessment for a 200 year return period wave event from 50 degree N (2120)

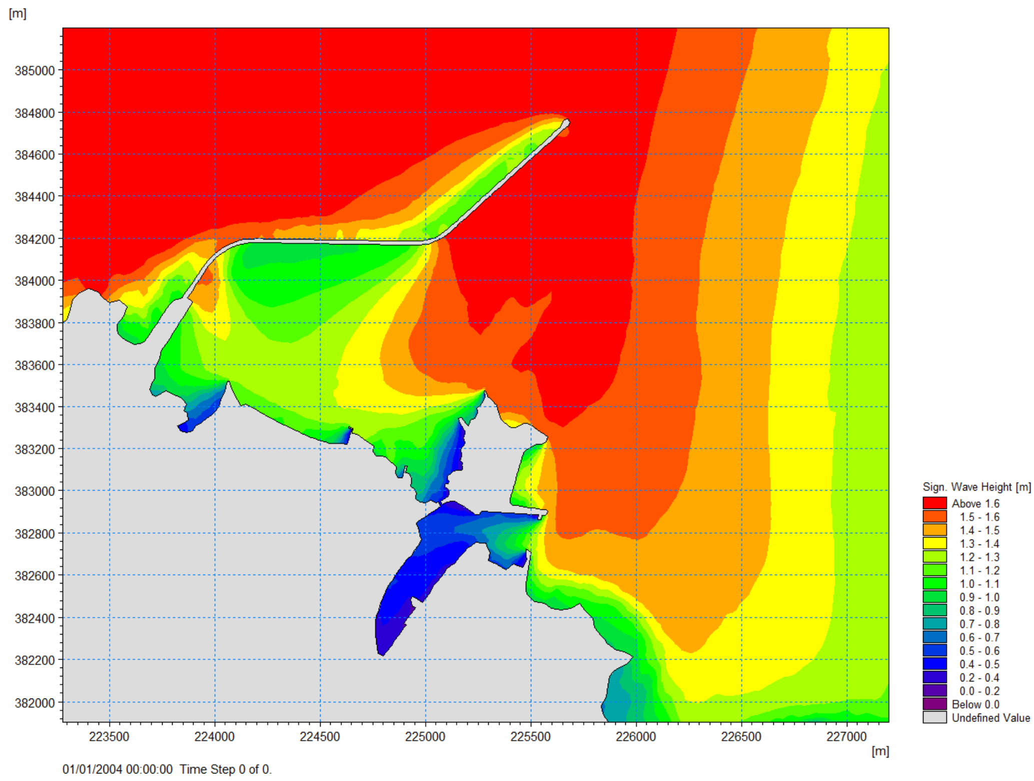

Figure B6: Wave reflectivity assessment for a 200 year return period wave event from 60 degree N (2120)

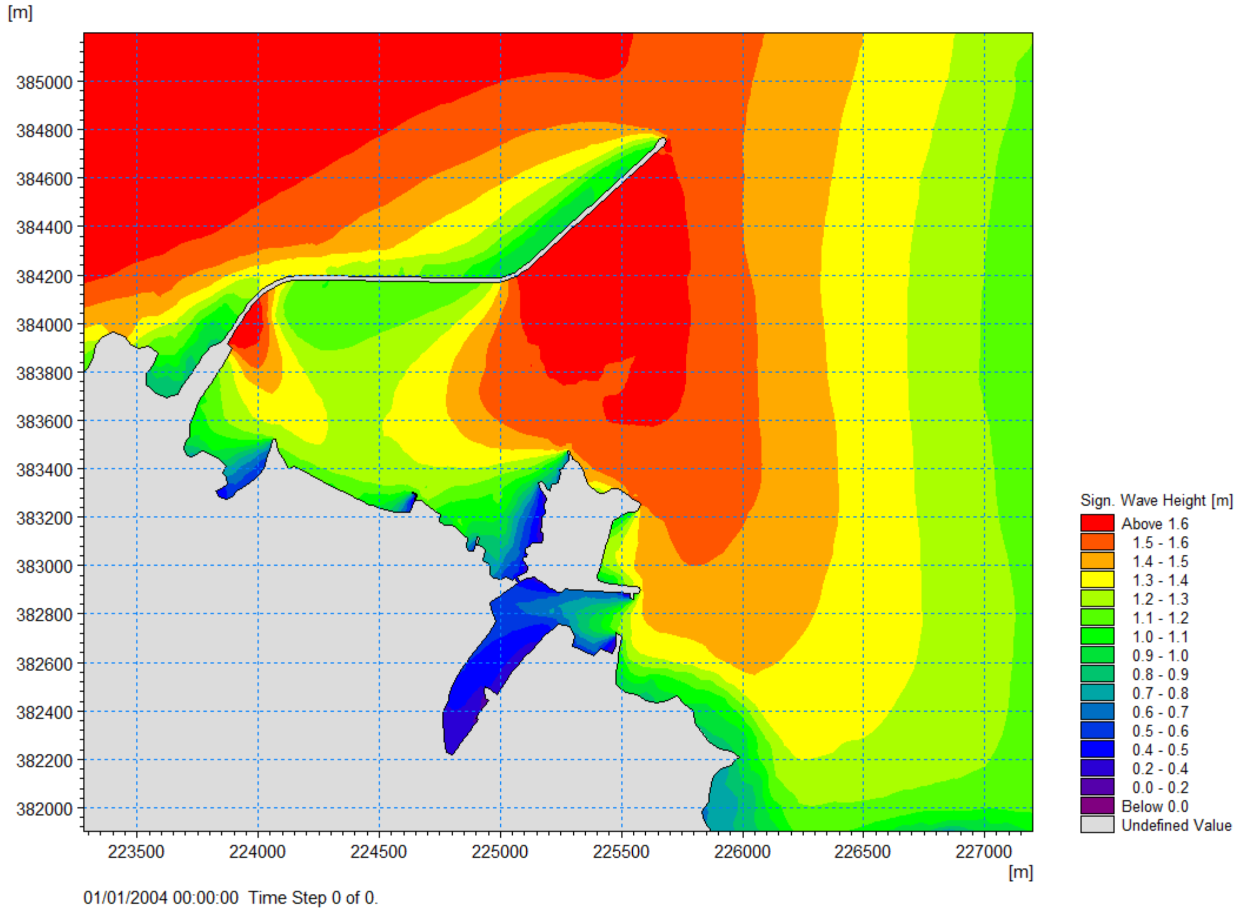

Figure B7: Wave reflectivity assessment for a 200 year return period wave event from 70 degree N (2120)

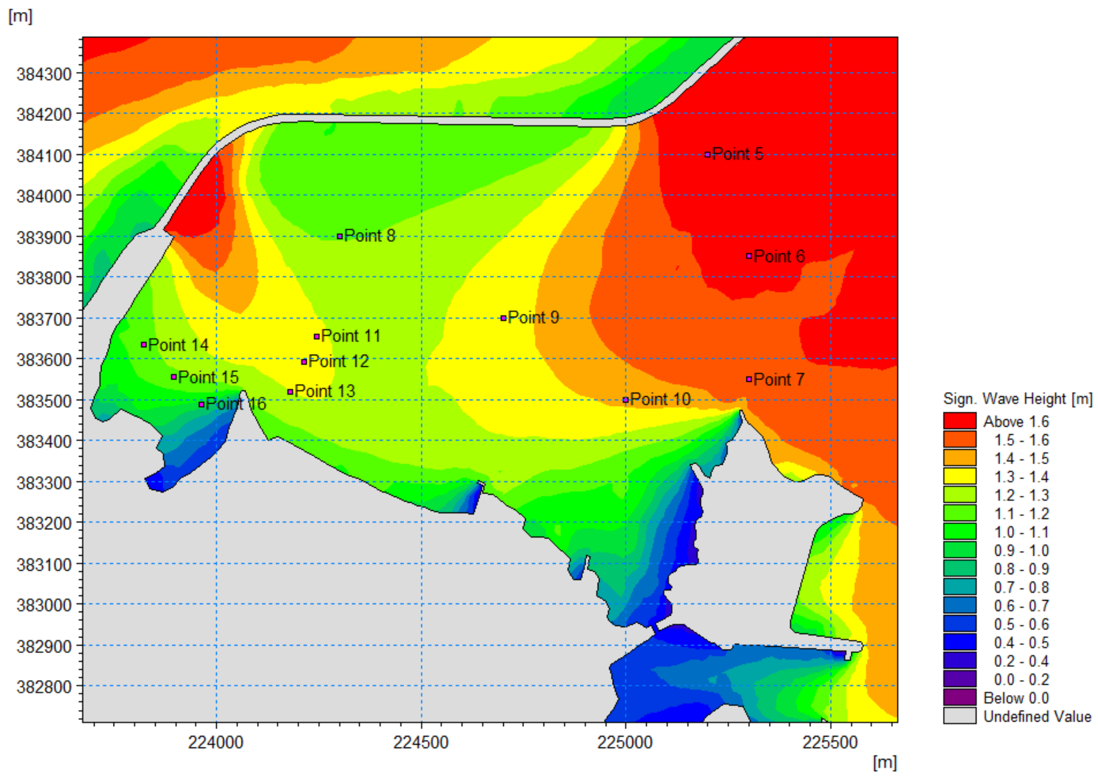

Figure B8: Location of nearshore points 11, 12, 13 along floating breakwater and 14, 15 and 16 along Porth y Felin frontage

Table B1: Initial sensitivity test results for wave reflectivity assessment

Wind Waves: Joint Probability Return Periods - JP1				No Reflection		With 100% Reflection	
				Point 8	Point 9	Point 8	Point 9
Return Period	Extreme Water Level (2120)	Wind Speed (m/s) (2120)	Wind Direction (deg)	Nearshore Wave Height (m)		Nearshore Wave Height (m)	
T100	7.49	30.0	50	0.88	1.15	0.92	1.22
T100			60	0.96	1.19	1.03	1.26
T100			70	1.02	1.20	1.13	1.28
T200	7.49	31.6	50	0.94	1.21	0.97	1.29
T200			60	1.01	1.25	1.09	1.34
T200			70	1.08	1.27	1.20	1.36

Table B2: Wave reflectivity assessment model results for a range of return periods from 70 degree N

Point	50yr - 2120		100yr - 2120		200yr - 2120	
	Nearshore Wave Height (m)	Nearshore Wave Period (s)	Nearshore Wave Height (m)	Nearshore Wave Period (s)	Nearshore Wave Height (m)	Nearshore Wave Period (s)
Point 11	1.17	4.29	1.25	4.41	1.32	4.53
Point 12	1.18	4.30	1.25	4.42	1.32	4.54
Point 13	1.16	4.30	1.23	4.42	1.30	4.55
Point 14	1.04	4.37	1.10	4.49	1.16	4.61
Point 15	1.05	4.41	1.11	4.53	1.17	4.66
Point 16	0.85	4.37	0.90	4.49	0.95	4.61