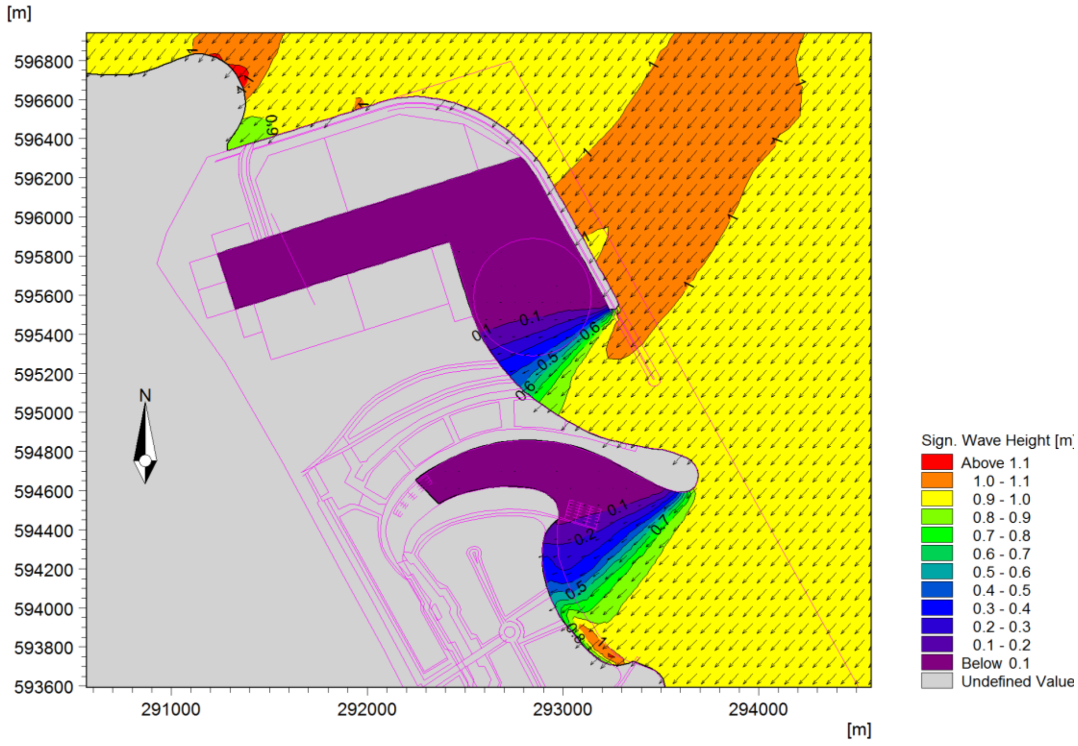


Figure 4.6 Significant wave height for incoming wave 50°N for Proposed Layout 5A

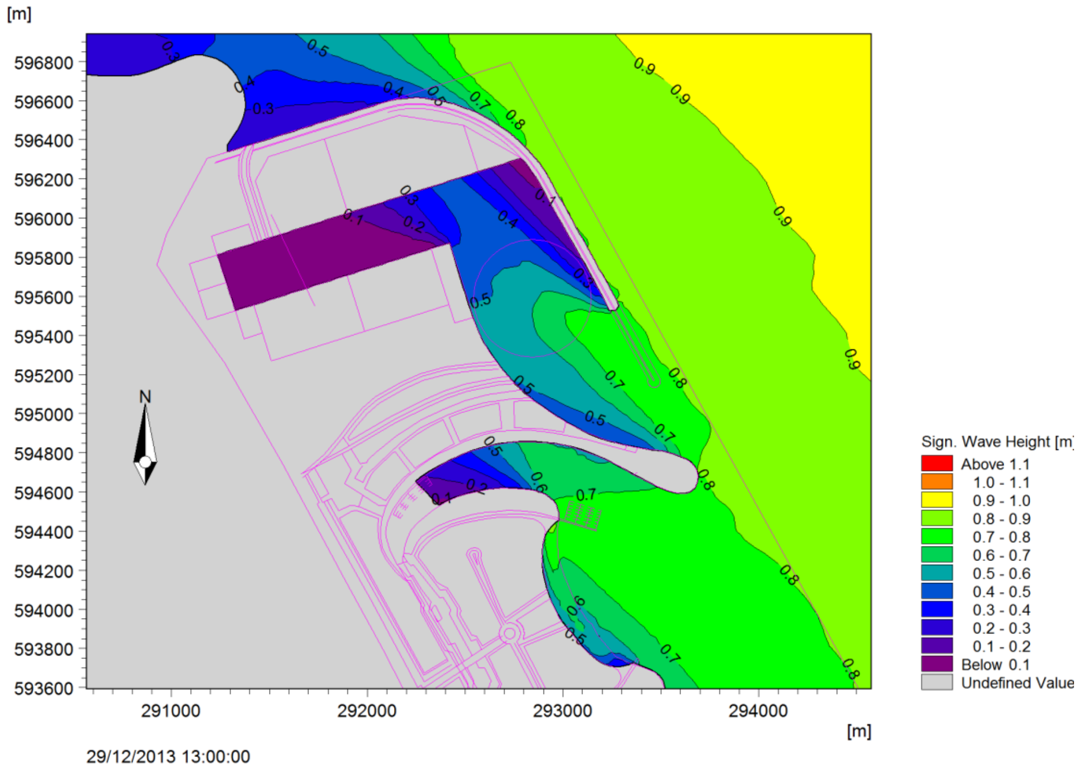


Figure 4.7 Significant wave height for incoming wave 130°N for Proposed Layout 5A

Table 4.2 Significant wave height at the berthing area inside the port and outside the port entrance

Significant wave height: Layout 5A									
MWD	P1	P2	P3	P4	P5	P6	P7	Entrance@-8mCD	Bnd02
MWD0	0.001	0.002	0.003	0.010	0.030	0.070	0.186	0.884	1
MWD10	0.002	0.003	0.004	0.013	0.039	0.093	0.248	0.913	1
MWD20	0.003	0.005	0.006	0.021	0.062	0.149	0.392	0.945	1
MWD30	0.004	0.007	0.009	0.029	0.093	0.215	0.525	0.960	1
MWD40	0.006	0.012	0.015	0.054	0.176	0.387	0.816	0.967	1
MWD50	0.007	0.014	0.018	0.064	0.208	0.440	0.845	0.966	1
MWD60	0.014	0.028	0.037	0.141	0.427	0.797	0.917	0.968	1
MWD70	0.017	0.034	0.044	0.178	0.467	0.843	0.929	0.969	1
MWD80	0.038	0.073	0.101	0.464	0.724	0.905	0.949	0.974	1
MWD90	0.060	0.116	0.164	0.579	0.850	0.925	0.954	0.979	1
MWD100	0.143	0.282	0.391	0.667	0.889	0.912	0.917	0.977	1
MWD110	0.251	0.494	0.682	0.808	0.875	0.840	0.782	0.951	1
MWD120	0.251	0.497	0.682	0.802	0.854	0.815	0.752	0.937	1
MWD130	0.192	0.412	0.460	0.522	0.542	0.515	0.478	0.807	1
MWD140	0.190	0.407	0.455	0.513	0.531	0.504	0.467	0.796	1

4.1.3 Layout 6

Spacing between the breakwater and Cruise Terminal quay wall increased to allow sufficient space for the 600m diameter turning circle required for the operation of the cruise vessels. This layout together with a series of points where wave height data is extracted along the Cruise Terminal area is shown in Figure 4.8.

Figure 4.9 and Figure 4.10 show plots of the wave penetration for offshore wave directions 50°N (a typical direction during the NE monsoon period) and 130°N (a typical direction during the SW monsoon period). Table 4.3 sets out the wave disturbance coefficients at the data extraction points.

The modelling of this layout indicated that wave heights are very low at the proposed Cruise Terminal location indicating that the breakwater length can be reduced.

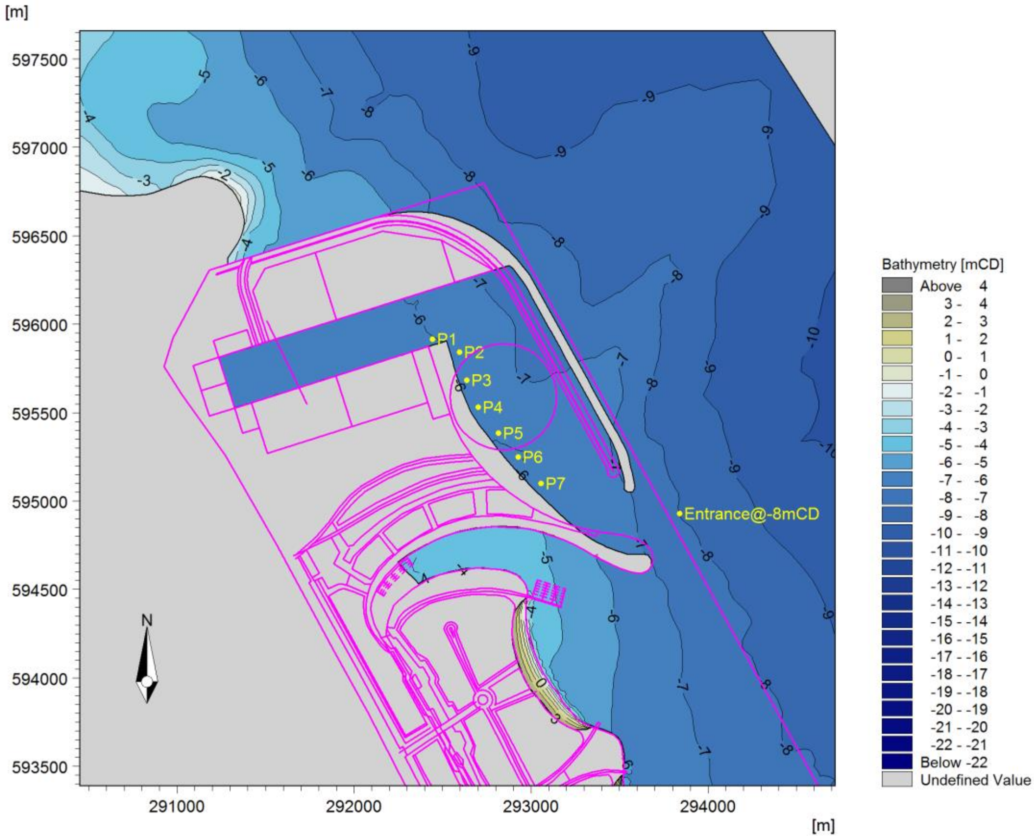


Figure 4.8 Proposed Layout 6

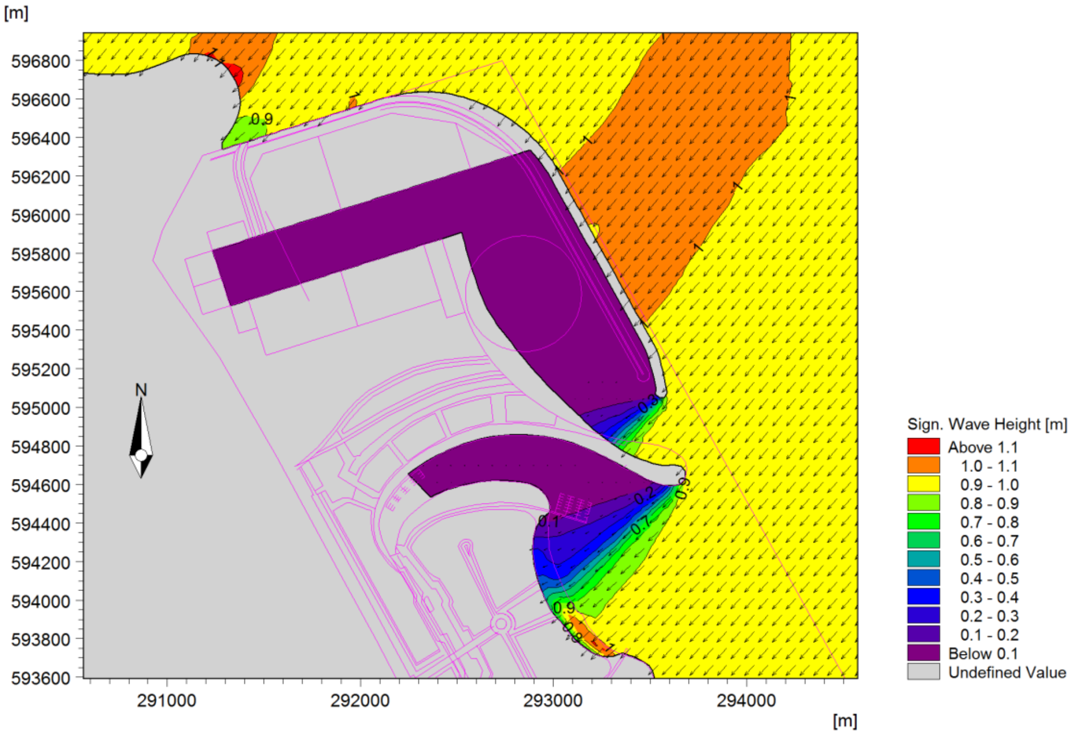


Figure 4.9 Significant wave height for incoming wave 50°N for Proposed Layout 6

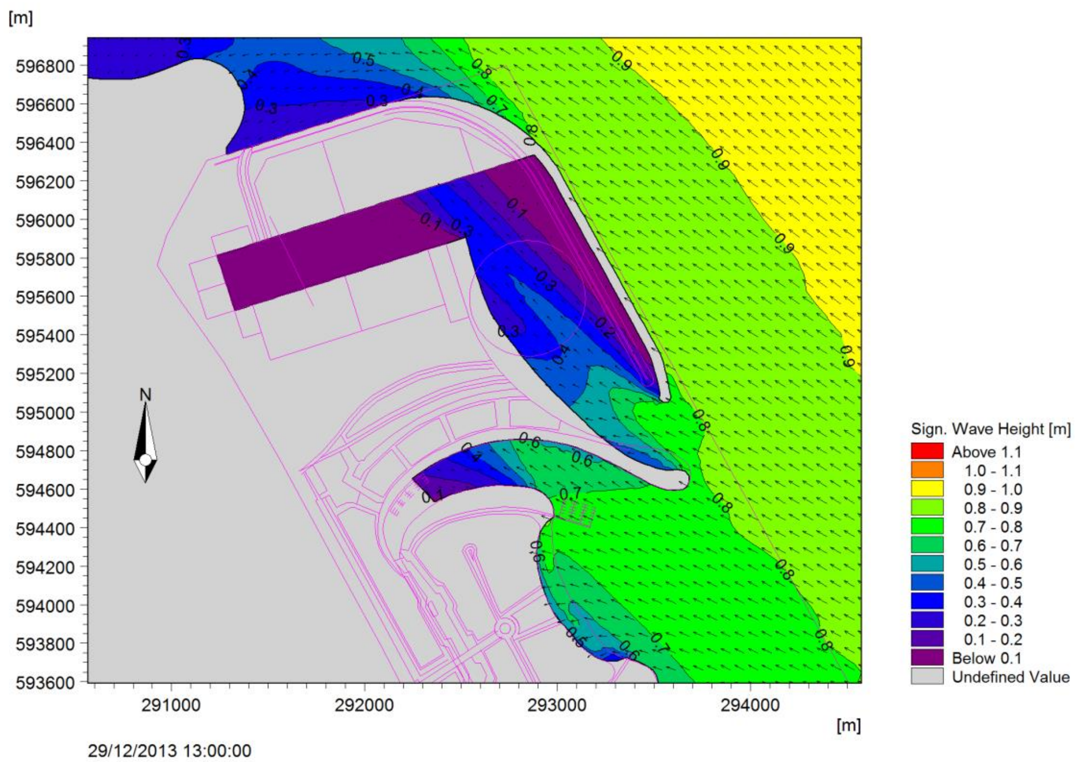


Figure 4.10 Significant wave height for incoming wave 130°N for Proposed Layout 6

Table 4.3 Significant wave height at the berthing area inside the port and outside the port entrance

Significant wave height: Layout 6									
MWD	P1	P2	P3	P4	P5	P6	P7	Entrance@-8mCD	Bnd02
MWD0	0.0001	0.001	0.001	0.001	0.002	0.003	0.006	0.881	1
MWD10	0.0002	0.001	0.001	0.001	0.003	0.004	0.008	0.911	1
MWD20	0.0003	0.001	0.001	0.002	0.004	0.005	0.011	0.939	1
MWD30	0.0004	0.002	0.002	0.002	0.005	0.008	0.015	0.957	1
MWD40	0.0006	0.003	0.003	0.004	0.009	0.013	0.027	0.967	1
MWD50	0.0007	0.004	0.003	0.005	0.010	0.015	0.033	0.967	1
MWD60	0.0014	0.007	0.006	0.011	0.022	0.032	0.076	0.970	1
MWD70	0.0017	0.008	0.008	0.013	0.027	0.040	0.099	0.971	1
MWD80	0.0033	0.017	0.016	0.030	0.060	0.085	0.282	0.975	1
MWD90	0.0054	0.026	0.026	0.049	0.100	0.144	0.371	0.979	1
MWD100	0.0089	0.046	0.048	0.105	0.241	0.358	0.516	0.977	1
MWD110	0.0185	0.090	0.093	0.181	0.413	0.627	0.747	0.950	1
MWD120	0.0252	0.132	0.122	0.190	0.413	0.625	0.746	0.936	1
MWD130	0.0780	0.378	0.316	0.263	0.321	0.412	0.480	0.808	1
MWD140	0.0780	0.371	0.311	0.261	0.318	0.408	0.473	0.797	1

4.1.4 Layout 7

Layout 7 is identical to Layout 5 except that the breakwater length has been reduced. This layout together with a series of points where wave height data is extracted along the Cruise Terminal area is shown in Figure 4.11.

Figure 4.12 and Figure 4.13 show plots of the wave penetration for offshore wave directions 50°N (a typical direction during the NE monsoon period) and 130°N (a typical direction during the SW monsoon period). Table 4.4 sets out the wave disturbance coefficients at the data extraction points.

The modelling of this layout indicated that wave heights likely to be acceptable at the proposed Cruise Terminal location indicating that the breakwater length is close to optimal.

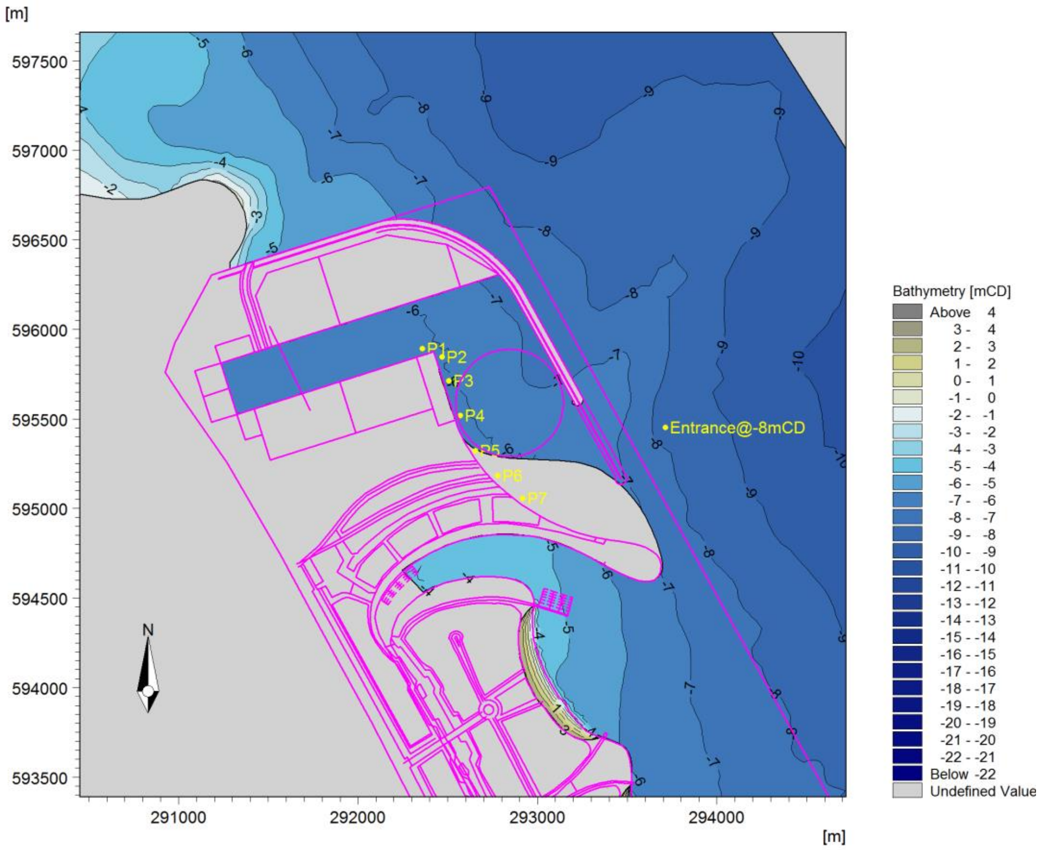


Figure 4.11 Proposed Layout 7

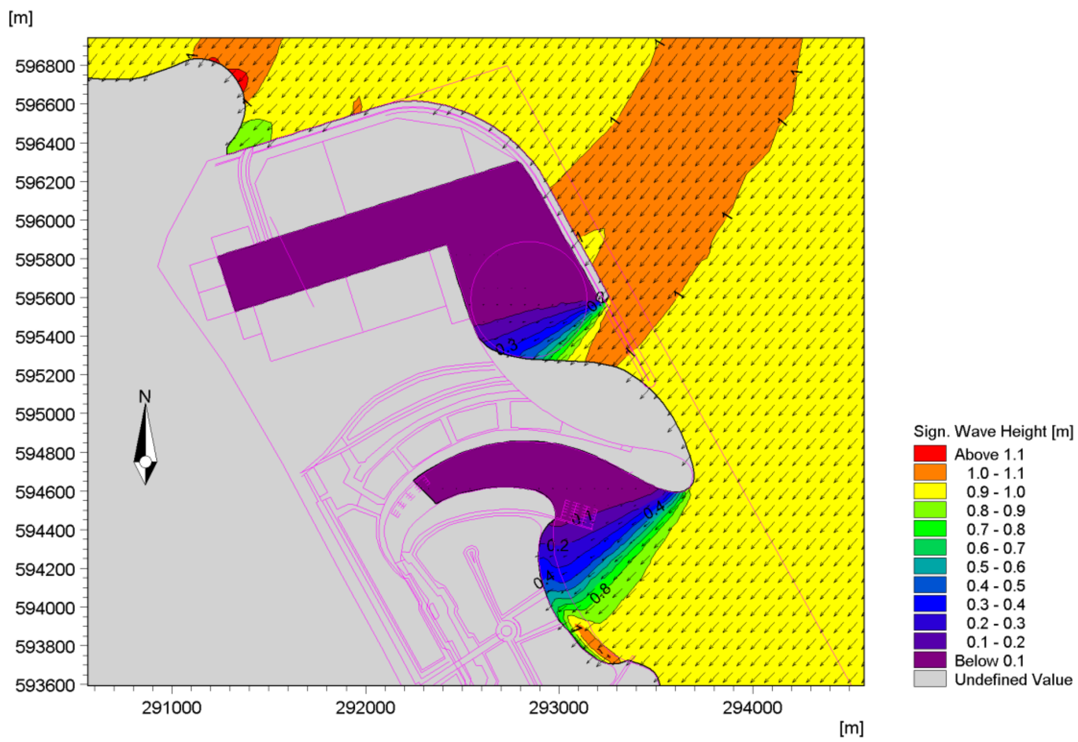


Figure 4.12 Significant wave height for incoming wave 50°N for Proposed Layout 7

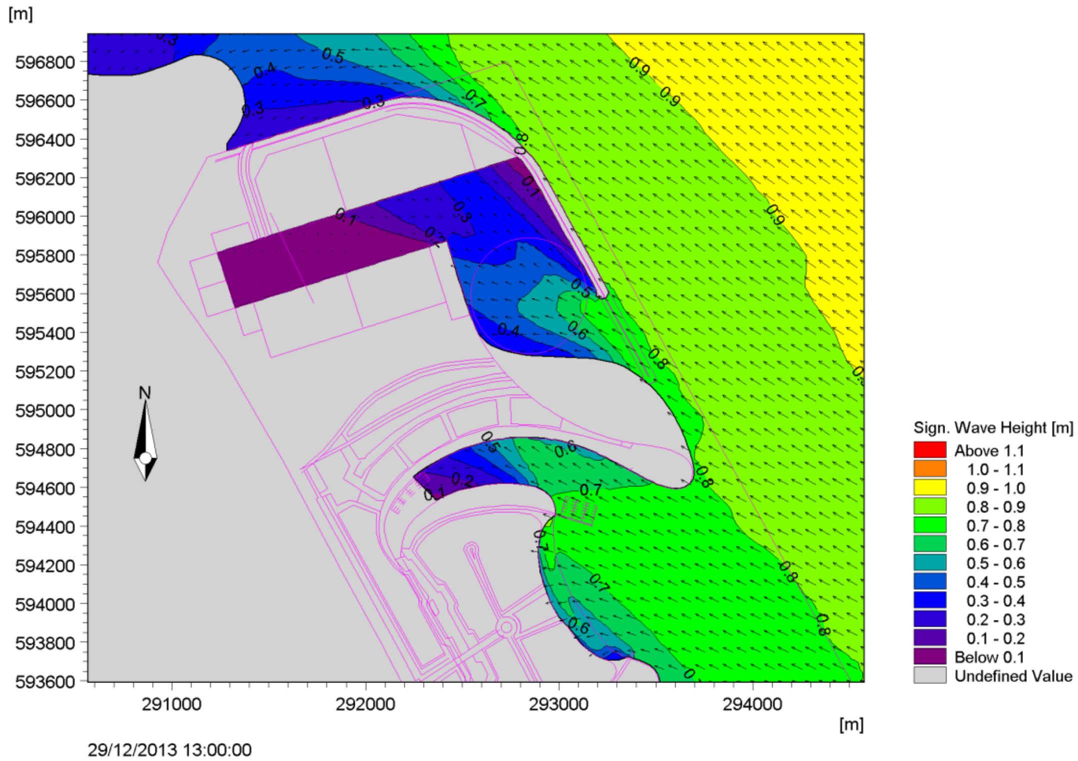


Figure 4.13 Significant wave height for incoming wave 130°N for Proposed Layout 7

Table 4.4 Significant wave height at the berthing area inside the port and outside the port entrance with water level corresponding to HAT

Significant wave height: Layout 7									
MWD	P1	P2	P3	P4	P5	P6	P7	Entrance@-8mCD	Bnd02
MWD0	0.001	0.002	0.003	0.010	n.a.	n.a.	n.a.	0.882	1
MWD10	0.002	0.003	0.004	0.014	n.a.	n.a.	n.a.	0.913	1
MWD20	0.003	0.005	0.006	0.022	n.a.	n.a.	n.a.	0.946	1
MWD30	0.004	0.007	0.009	0.031	n.a.	n.a.	n.a.	0.959	1
MWD40	0.008	0.013	0.017	0.060	n.a.	n.a.	n.a.	0.967	1
MWD50	0.009	0.016	0.020	0.073	n.a.	n.a.	n.a.	0.967	1
MWD60	0.017	0.031	0.042	0.167	n.a.	n.a.	n.a.	0.968	1
MWD70	0.021	0.036	0.051	0.212	n.a.	n.a.	n.a.	0.969	1
MWD80	0.043	0.075	0.114	0.559	n.a.	n.a.	n.a.	0.973	1
MWD90	0.073	0.129	0.178	0.695	n.a.	n.a.	n.a.	0.977	1
MWD100	0.182	0.324	0.396	0.702	n.a.	n.a.	n.a.	0.976	1
MWD110	0.320	0.572	0.685	0.632	n.a.	n.a.	n.a.	0.950	1
MWD120	0.319	0.571	0.684	0.616	n.a.	n.a.	n.a.	0.937	1
MWD130	0.196	0.358	0.419	0.403	n.a.	n.a.	n.a.	0.807	1
MWD140	0.194	0.353	0.412	0.394	n.a.	n.a.	n.a.	0.796	1

4.2 Detailed Modelling of Wave Penetration to the Cruise Terminal Area – Layout 8

Layout 8 includes the final layout for the breakwater and Cruise Terminal received from BCT following review of the modelling of Layouts 1 to 7. A detailed assessment of wave penetration in the vicinity of the Cruise Terminal and Ship Repair facility has been carried out using MIKE 21 BW. This model includes the diffraction of waves at the breakwater head and wave reflections.

Directional irregular waves with corresponding wave height (1m H_{m0}), wave period (T_p), and mean wave direction were applied for defining the incident wave conditions. By using a boundary condition with 1m significant wave height, H_{m0}, the wave conditions determined inside the port can be viewed as wave disturbance coefficients, i.e. defining the wave height relative to the incident wave height. Hence, if a different incident wave height (but with same wave direction and wave period) is used at the boundary, the corresponding wave heights inside the port are found by multiplying the incident wave height and the wave agitation coefficients for operational conditions. A prerequisite for this approach is that the non-linear wave effects are small, which is the case in the present project where the water depths are relatively large compared to the wave heights so that wave breaking will not be important.

To cover the relevant wave conditions, the following wave periods and wave directions were included in the scope of wave disturbance simulations:

- Peak wave periods, T_p = 4s, 7s, 9s and 14s
- Mean wave directions, MWD = 50°N, 70°N, 90°N, 110°N, 130°N,

The layout modelled is shown in Figure 4.14. This figure also indicates the structural types assumed around the Cruise Terminal and Ship Repair areas and the points at which wave data is extracted. Figure 4.15 and Figure 4.16 show plots of the wave penetration from a range of directions for wave periods of 7 and 14 seconds. It will be noted from these that there is significant reflection of the waves allowing them to penetrate into the inner basin.

In order to assess the impact of this wave penetration the disturbance coefficients from the wave modelling have been used to transform the time series wave conditions offshore between 2006 and 2014 to seven locations within the sheltered area. This process is illustrated in Figure 4.17, and the percentage of time that significant wave heights exceed 0.5m, 0.75m and 1.0m at these points are set out in

Table 4.5.

This modelling indicates that at the Cruise Liner berth significant wave heights exceed 0.5m between 15% and 30% of the time, with significant wave heights exceeding 1.0m for between 1% and 4% of the time. The largest waves occur during the NE monsoon period.

In the inner basin where the Ship Repair facility is located significant wave heights exceed 0.5m for between 10% and 15% of the time.

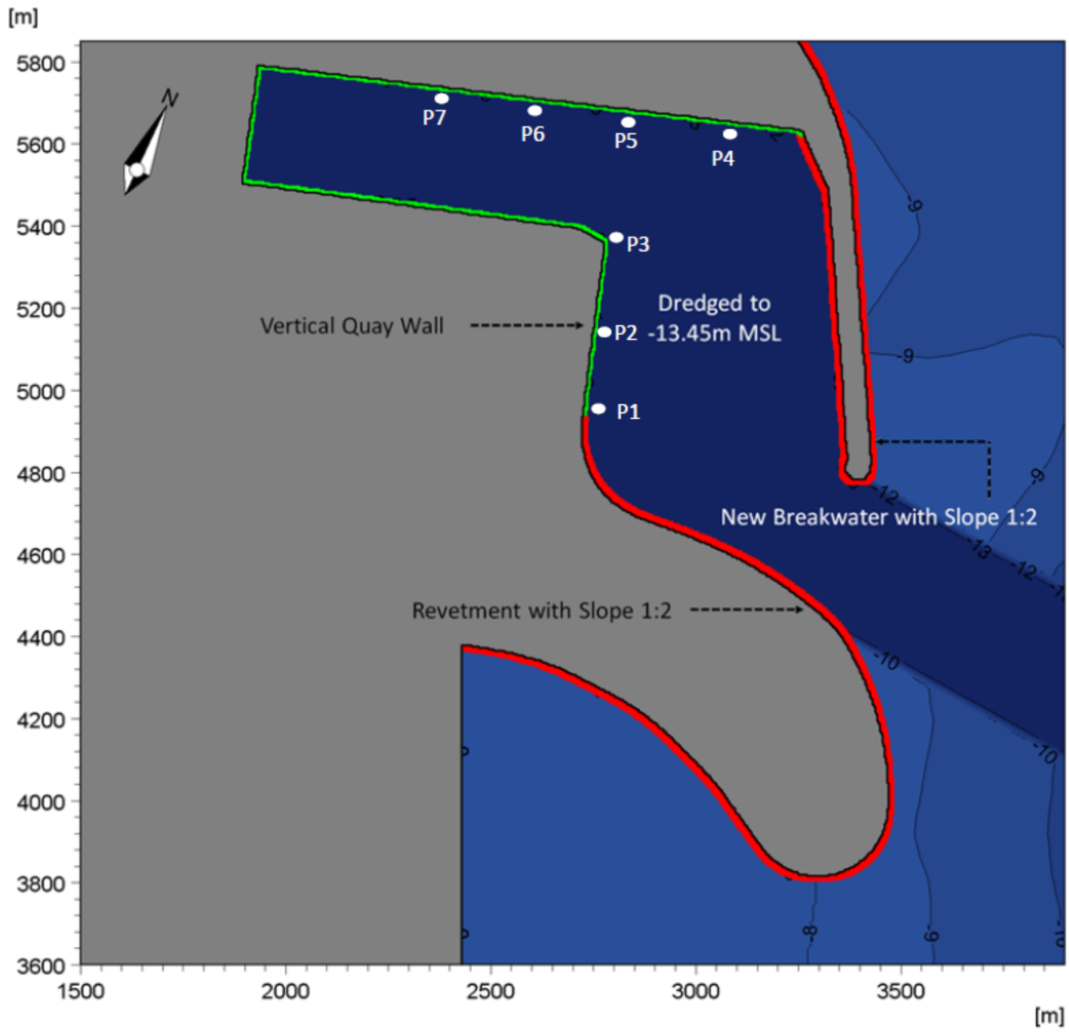


Figure 4.14 Structure type used to estimate reflection characteristic in the model domain. Bathymetry used for the wave disturbance modelling is being referred to MSL datum.

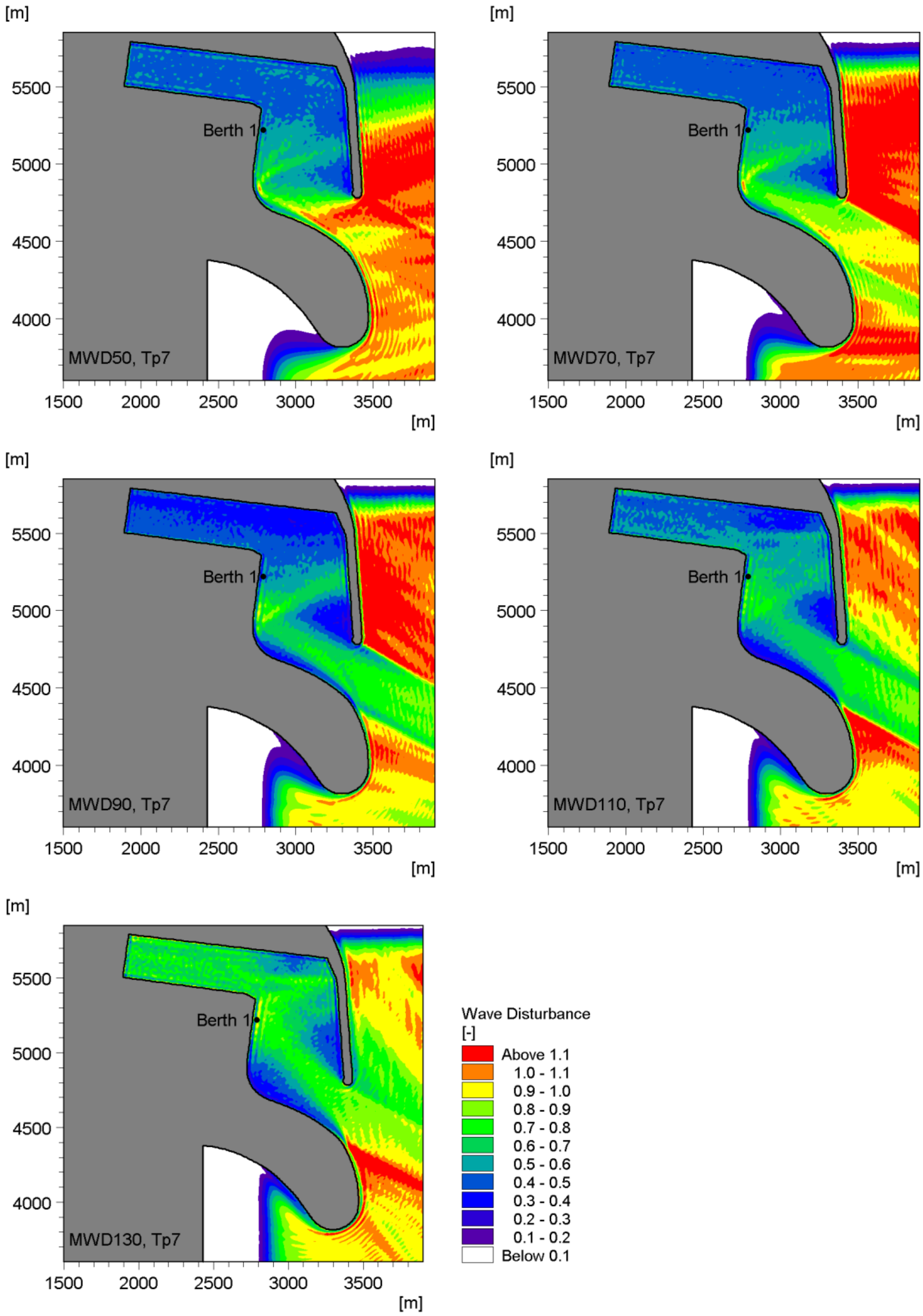


Figure 4.15 Contour plot of wave disturbance coefficient for peak wave period of 7s and mean wave directions of 50°N, 70°N, 90°N, 110°N and 130°N

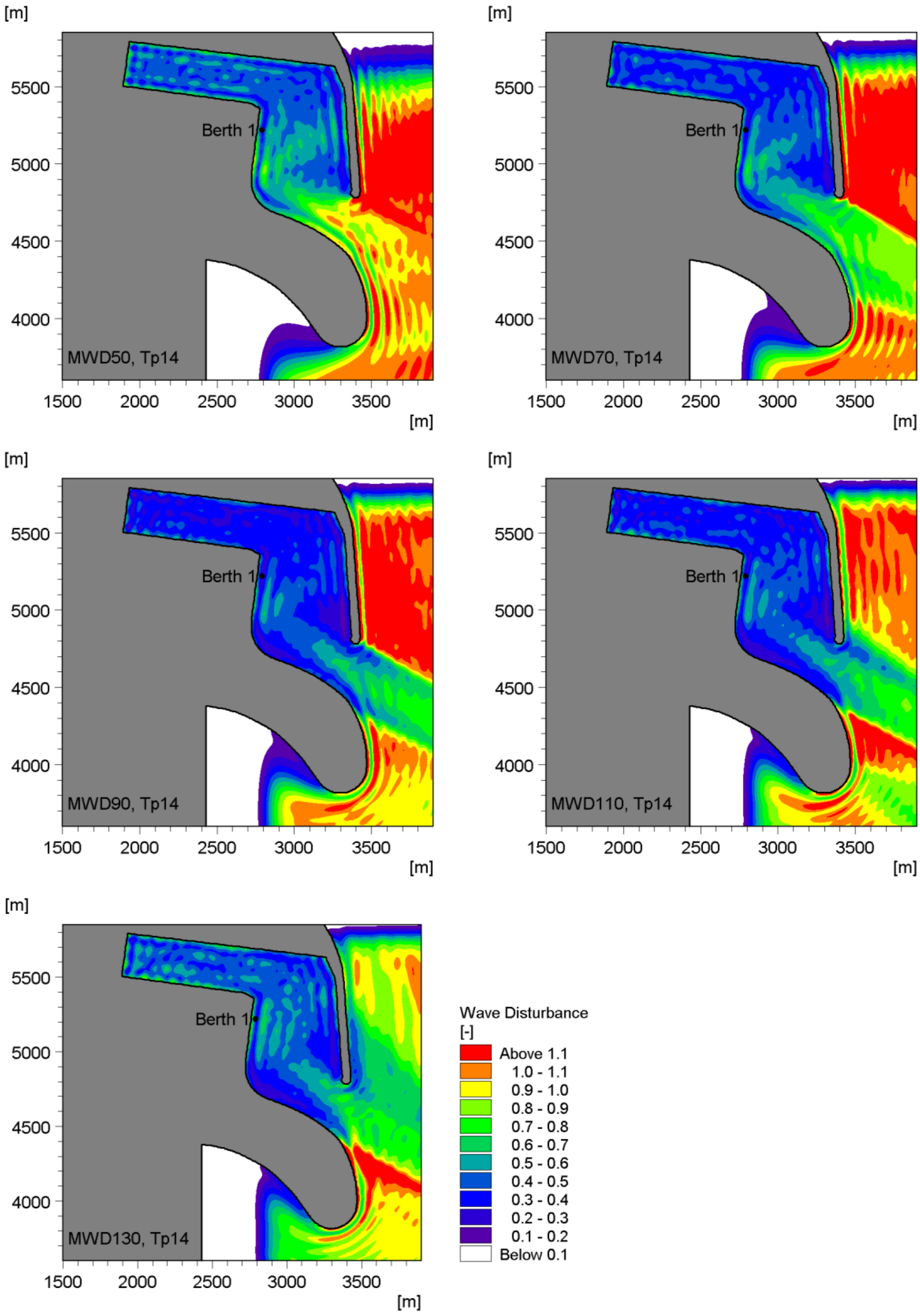


Figure 4.16 Contour plot of wave disturbance coefficient for peak wave period of 14s and mean wave directions of 50°N, 70°N, 90°N, 110°N and 130°N

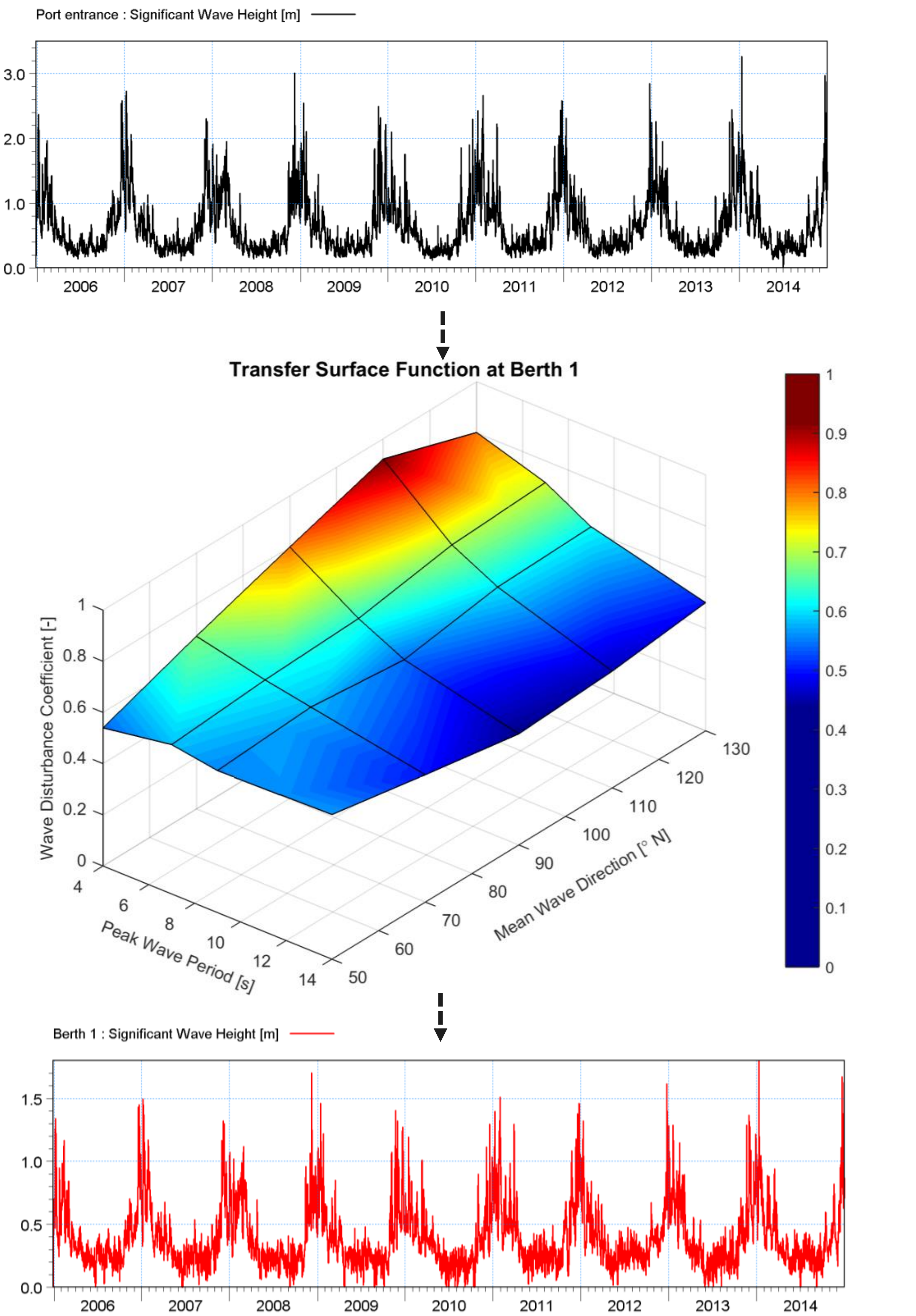


Figure 4.17 Transfer surface function for transformation of wave conditions from port entrance to P1

Table 4.5 Percentage exceedance of significant wave height of 0.50m, 0.75m and 1.00m at P1 to P7

Location	Hm0 = 0.50 m	Hm0 = 0.75 m	Hm0 = 1.00 m
P1	30.4	13.0	4.1
P2	20.2	6.0	1.2
P3	14.2	3.3	0.6
P4	11.2	1.5	0.1
P5	13.1	2.7	0.4
P6	12.1	2.1	0.2
P7	13.6	2.9	0.5

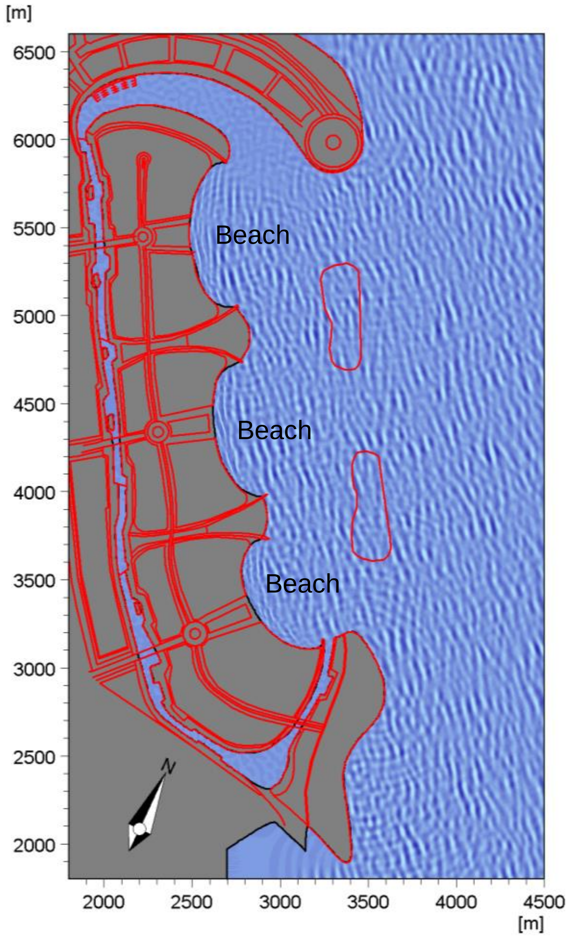
4.3 Wave Conditions at the Beaches – Layout 8

The MIKE 21 BW model has also been used to assess wave conditions at the proposed beaches for Layout 8. This model has been run for a partially complete scenario where the nearshore reclamation and beaches are complete but the offshore islands have not been reclaimed, and a final layout where these islands have also been reclaimed.

Plots of the wave patterns in the vicinity of the beaches during typical NE monsoon conditions are shown in Figure 4.18 and Figure 4.19typical SW monsoon conditions in Figure 4.20 and Figure 4.21.

From these it is concluded that:

- Before construction of the offshore islands waves during the NE monsoon are well aligned with the beach, however during the SW monsoon period the waves approach at an angle and there will be some reshaping of the beaches in this period.
- With the offshore islands in place there is still good wave action on the beaches, particularly during the NE monsoon period. This exposure to wave action is important to maintain the beach quality. However wave patterns are not constant along the beaches and it is therefore likely that some small control structures will be required to maintain beach alignment, especially for the southern beach.



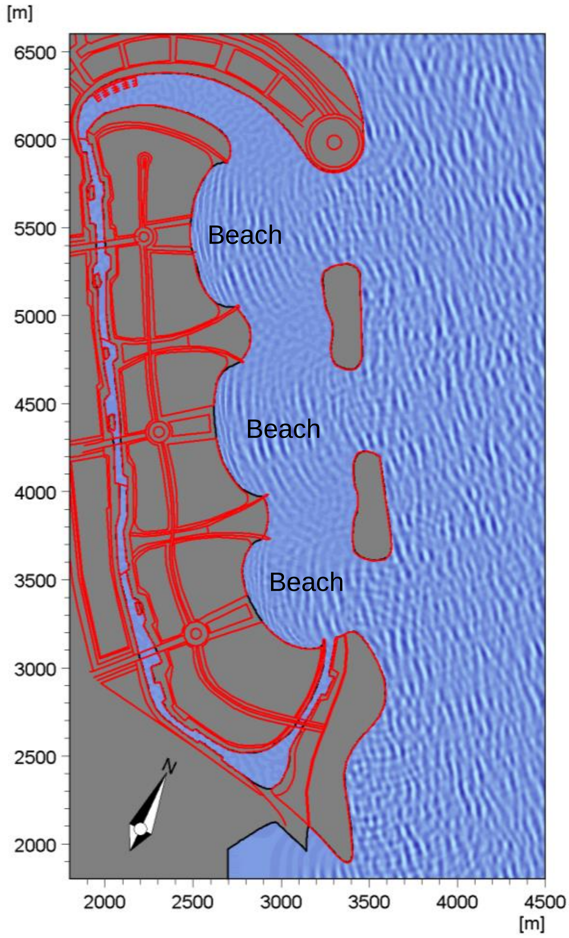


Figure 4.18 Snapshots of surface elevation for incident waves with peak wave period of 7s and mean wave direction of 50°N. Left: Proposed layout 9 without island, Right: Proposed layout 9 with island

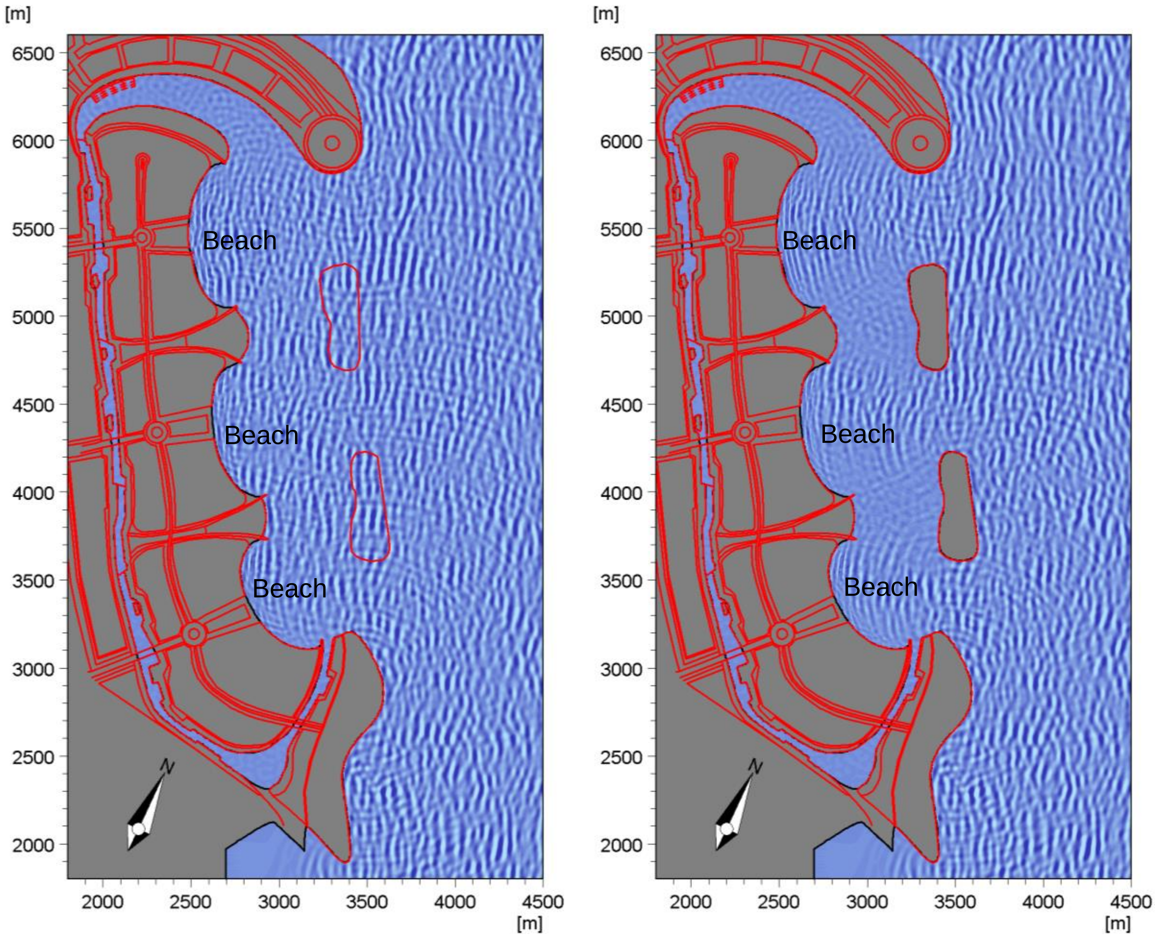


Figure 4.19 Snapshots of surface elevation for incident waves with peak wave period of 7s and mean wave direction of 70°N. Left: Proposed layout 9 without island, Right: Proposed layout 9 with island

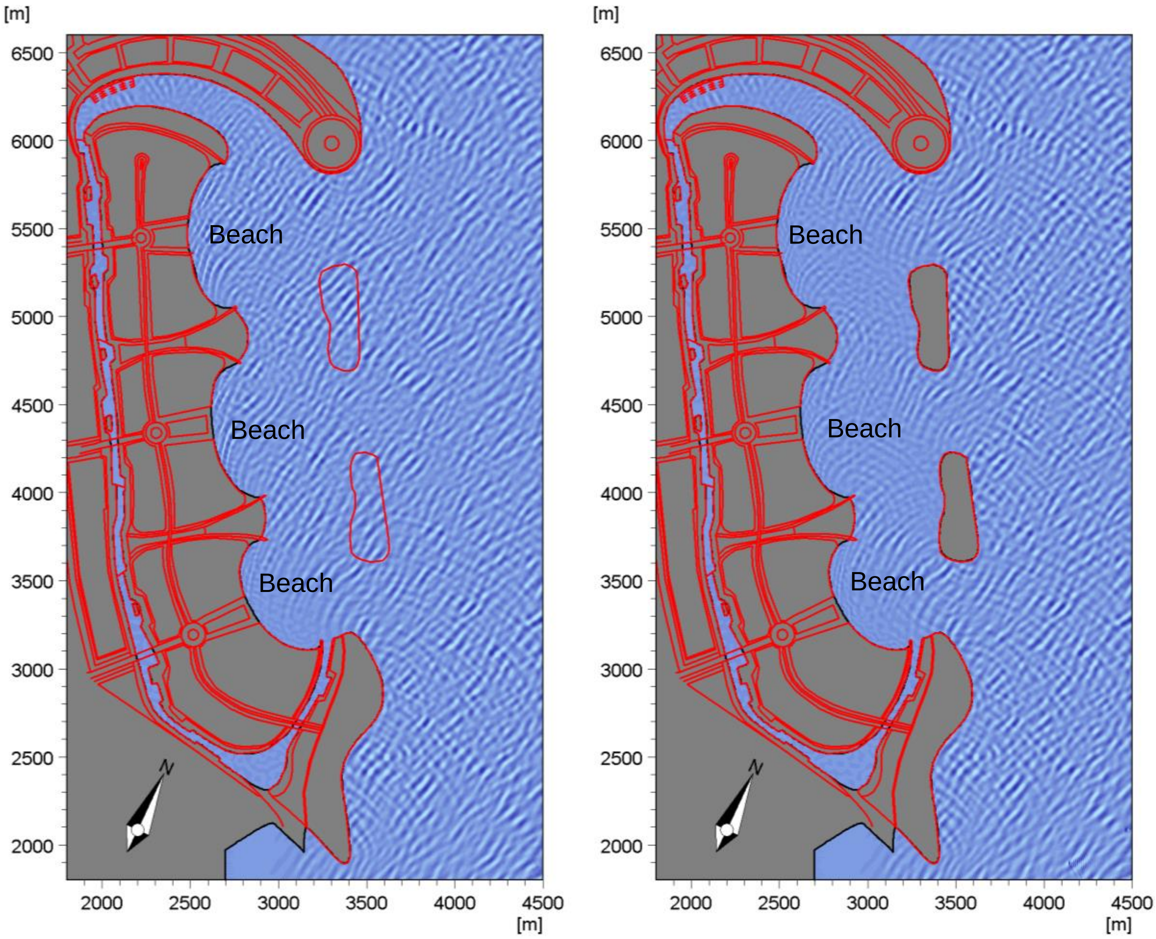


Figure 4.20 Snapshots of surface elevation for incident waves with peak wave period of 7s and mean wave direction of 110°N. Left: Proposed layout 9 without island, Right: Proposed layout 9 with island

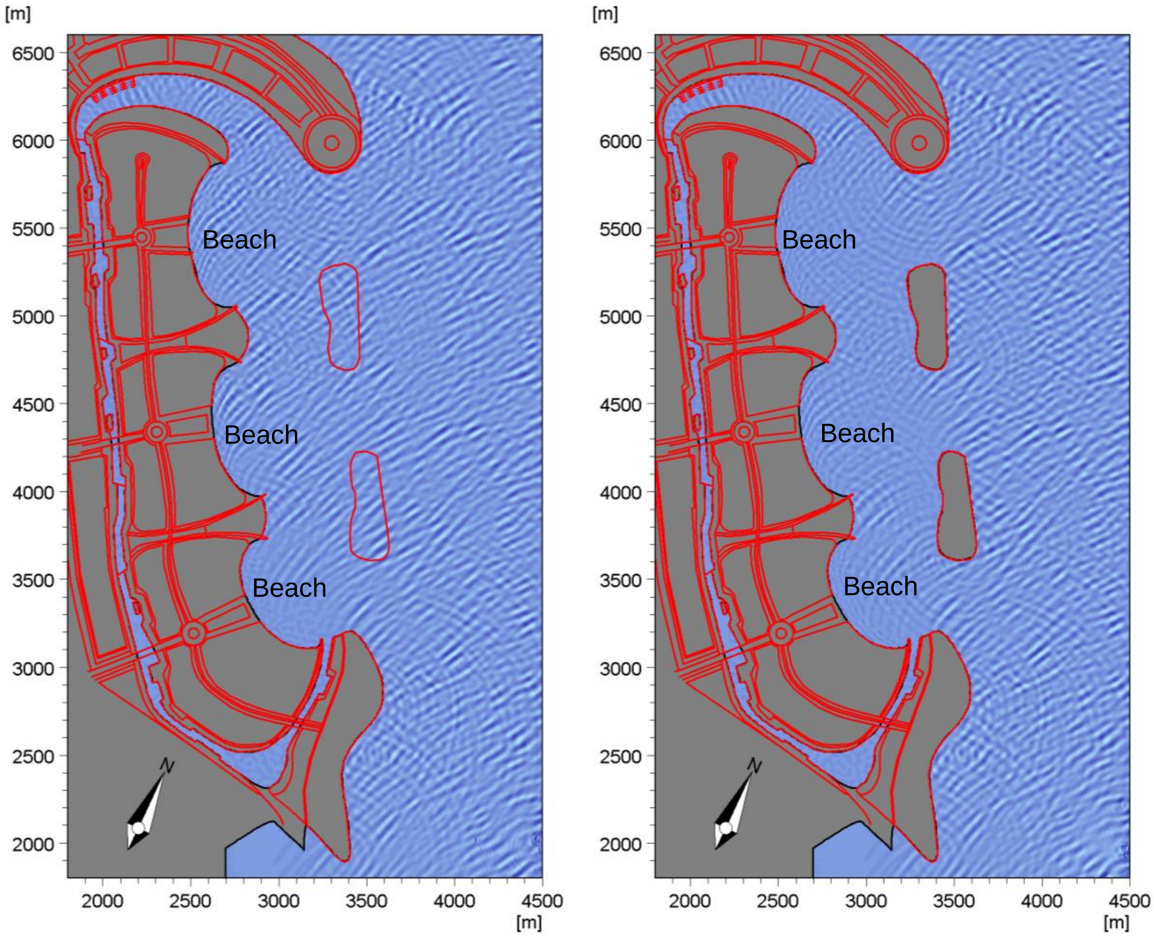


Figure 4.21 Snapshots of surface elevation for incident waves with peak wave period of 7s and mean wave direction of 130°N. Left: Proposed layout 9 without island, Right: Proposed layout 9 with island

5 Summary and Conclusions

Hydraulic modelling has been carried out to provide input to the development of the master plan for the Sunrise City reclamation. This masterplan layout is being prepared by BCT, and throughout the modelling study there was a close interface between DHI and BCT to ensure that the proposed layouts met the functional requirements and the required hydraulic design parameters.

The modelling works carried out included:

- Hydrodynamic modelling to assess current conditions in the vicinity of the development.
- Advection dispersion modelling of a conservative tracer to assess the risk of poor water quality developing within the project area.
- Wave modelling to optimise the breakwater length to provide a suitable degree of protection to the Cruise Terminal and to investigate conditions on the proposed beaches.

Modelling has been carried out on nine layouts during the development of the masterplan. The modelling of Layouts 1 to 7 was used to assess the issues and test options with the results from the modelling of these being passed to BCT to support the development of the masterplan.

Layout 8 is the masterplan layout developed by BCT in January 2017 which incorporated the recommendations from the modelling of Layouts 1 to 7 and was tested to check it met the hydraulic criteria. Layout 9 included a minor change to the layout of the inner channel form that used in Layout 8 in order to improve flushing capacity.

The modelling of Layouts 8 and 9 indicated that:

- Current conditions within and in the immediate vicinity of the development are suitable for navigation, and the project does not lead to any significant changes in current conditions away from the immediate vicinity of the project.
- The modelling of the flushing capacity shows that the project layout is generally suitable and that water quality is not expected to be an issue. However two areas will require detailed investigation in the final design:
  - The flushing of the inner channel between the main reclamation island and the shore is marginal. This is in part due to the irregular shape of the sides of this channel. The flushing of this channel can be improved by streamlining the sides and possibly making a small increase to the channel width or by defining other alternatives to optimise the flushing capacity of the channels.
  - The basin in the vicinity of the ship repair facility has relatively poor flushing. This is however an industrial area and water quality may well be within acceptable limits despite this. However if an improvement to the water quality is required this can be easily achieved by including a small channel from the inner part of this basin to the open sea to the north of the breakwater as was modelled in Layout 5.
- Based on the modelling of current conditions and flushing it was concluded that the STP outfall should not be located within the development. It is recommended that this is located north of the breakwater to the east of the airport reclamation where the currents will lead to a rapid dispersion of the treated effluent that is discharged. This location is identified on the masterplan and the treatment plant has been located to enable discharge from this location.
- The wave modelling for the Cruise Terminal inner basin for ship repair has indicated that:
  - At the Cruise Terminal a significant wave height of 1.0m is exceeded up to 5% of the time with most of this exceedance occurring during the NE monsoon.
  - In the inner basin where the ship repair facility is located significant wave heights of .5m are exceeded between 10% and 15% of the time.

These conditions are expected to be suitable for the proposed shipping operations in these areas, however confirmation is required from the designer of these facilities to confirm that these conditions will be acceptable.

- The wave modelling of the beached has indicated that it is likely that some small control structures will be required to maintain beach alignment, especially for the southern beach.

Appendix I

Socio-economic Report