REPORT

Southwold Harbour Investment Plan

Assessment of Breakwater Culvert Options

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Table of Contents

1 Introduction

A key recommendation of the Southwold Harbour Investment Plan is to replace the South Pier with a rock armour breakwater.

The existing South Pier incorporates ‘windows’ in the sheet piles, which enable a flow of water into the entrance channel from the south. The resulting interaction with waves moving along the entrance channel, and with the tidal flow in or out of the channel, is reported by harbour users to make it easier to navigate through the channel. This is understood to be particularly important during swell wave conditions.

A key objective for the Investment Plan is to sustain navigation conditions in the harbour entrance. To achieve this, the current recommendation is for large box culverts to be incorporated into the proposed rock breakwater, which would enable flow through the structure in a similar way to the existing windows (see Figure 1-1).

This innovative solution is considered to be technically feasible and is expected to have the desired effect. However, we have not identified any examples of the use of box culverts within a breakwater for this purpose. Therefore, additional tidal modelling is required to assess the performance of the proposed culverts, in terms of their influence on tidal currents within the harbour entrance channel, in comparison with the existing hydrodynamic conditions.

This Technical Note sets out the approach taken to assess this issue, the model results and conclusions, and the recommendations from this additional work.

Figure 1-1 – Proposed rock breakwater with box culverts

2 Approach

To review the performance of the proposed box culverts, we have undertaken the following activities:

a. Review of past projects and relevant technical literature to identify whether there are any examples of this type of solution being used elsewhere.

b. Review of the potential for wave penetration through the proposed culverts, and the potential impact on conditions in the entrance channel.

c. Review of the potential benefit of the proposed rock breakwater for wave energy dissipation, based on previous wave modelling.

d. Additional tidal modelling for the proposed rock breakwater with culverts (2 culvert arrangement options, 2 water level conditions).

e. Comparison of the additional modelling results with the previous modelling, considering the baseline conditions and solid South Pier options.

f. Presentation and discussion of the findings of the additional modelling at a stakeholder meeting.

g. Preparation of a Technical Note to summarise the findings of the additional modelling and any stakeholder comments. The main project report will also be updated to include the findings of this additional work.

3 Review of Existing Information

3.1 Examples of similar structures

The scenario at Southwold was shared with various colleagues with experience in the design and construction of rock armour breakwaters internationally. It has not been possible to identify any locations from our collective experience where a similar solution has been used. However, the discussion with colleagues did provide some useful comments on the benefits and constraints of the proposed solution, which are included in the subsequent discussion in this Technical Note.

3.2 Wave penetration through the proposed culverts

Incorporating open box culverts through the proposed rock breakwater would enable both waves and tidal flows to move through the breakwater into the entrance channel, with the aim of replicating the ‘windows’ in the existing structure. However, the culverts would be quite narrow, at approximately 3m, which means that a relatively limited amount of wave energy would be able to penetrate. Wave energy would be dissipated as waves move through the culverts, but wave-generated currents could be created.

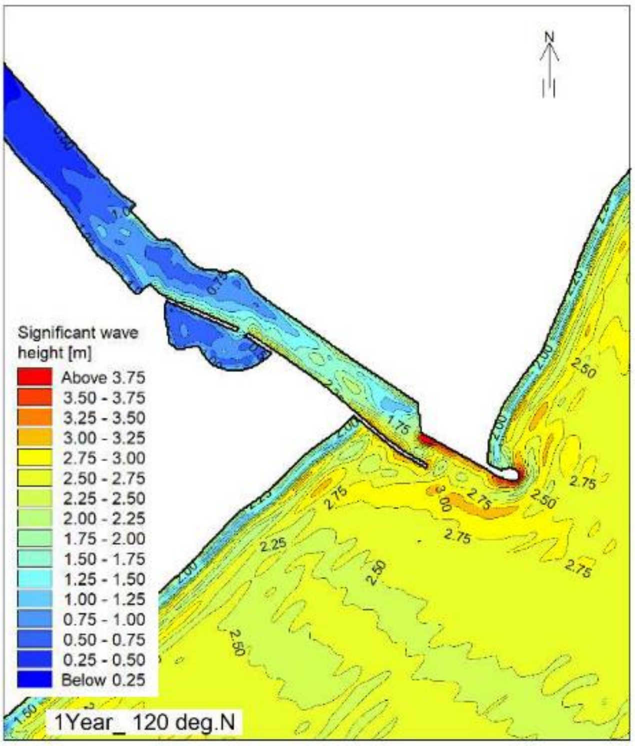
It is not possible to assess wave penetration through the proposed culverts using the existing wave model, as the culverts are too narrow compared to the model grid size. A 3-dimensional wave model would need to be used to represent the culverts as ‘cuts’ through the rock structure. This modelling could be undertaken as part of detailed design, if the proposal to incorporate culverts in the breakwater is taken forward. Such modelling could also be used to optimise the position and orientation of the culverts, considering the alignment of the breakwater and the prevailing wave direction. It would then be possible to either minimise or increase the amount of wave energy penetration and wave-generated currents, depending on the requirements for modifying conditions in the entrance channel.

3.3 Wave energy dissipation by proposed rock breakwater

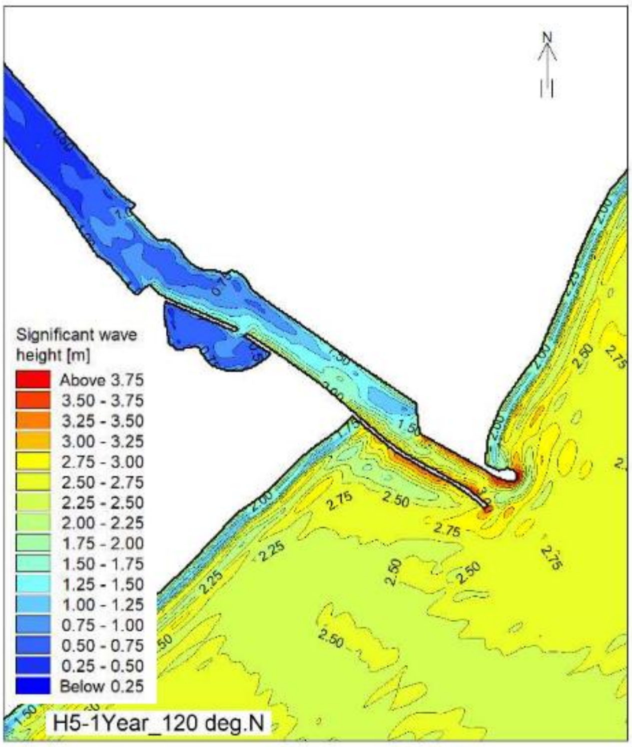
Figure 3-1 and **Figure 3-2** summarise the wave modelling results for 1-year return period waves from the 120 degree and 180 degree sectors, for various options for the future of the South Pier. It should be noted that a 1-year return period event represents a reasonably severe storm, so vessels are unlikely to be navigating the entrance channel during these conditions. These figures show that replacing the South Pier with a rock armour breakwater would significantly improve wave conditions in the entrance channel, as the rock armour will dissipate wave energy and reduce wave reflection.

The model results for the existing structure show that, for 1-year return period waves from the 120 degree sector, very disturbed wave conditions with waves of up to 2.75m are experienced along the middle of the channel over its full length. Potentially higher waves can occur close to the North Pier due to wave reflection. For waves from the 180 degree sector, the much higher waves mean that the variation in wave conditions within the channel is less obvious.

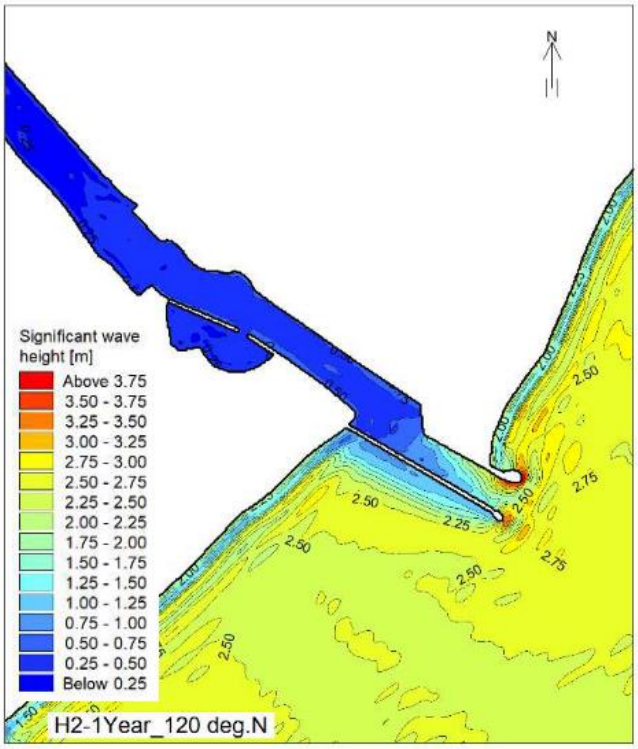
The model results for a vertical-walled South Pier (without the windows) show the increased wave reflection that would occur from the inner face of the South Pier. The model results for the 120 wave direction sector are compared in **Figure 3-1** below, as the differences are more apparent than for waves from the 180 degree sector. This figure further demonstrates the benefit of the windows in the existing structure for navigation into and out of the channel. An area of lower wave heights (approx. 2.25m) is shown at the mouth of the channel for the vertical-walled South Pier, with wave heights then increasing to about 2.75m as you move into the channel. For the existing structure, wave conditions within the channel are more disturbed over the length of the channel, so there would be less of a noticeable transition from lower waves at the mouth to higher (reflected) waves within the channel.



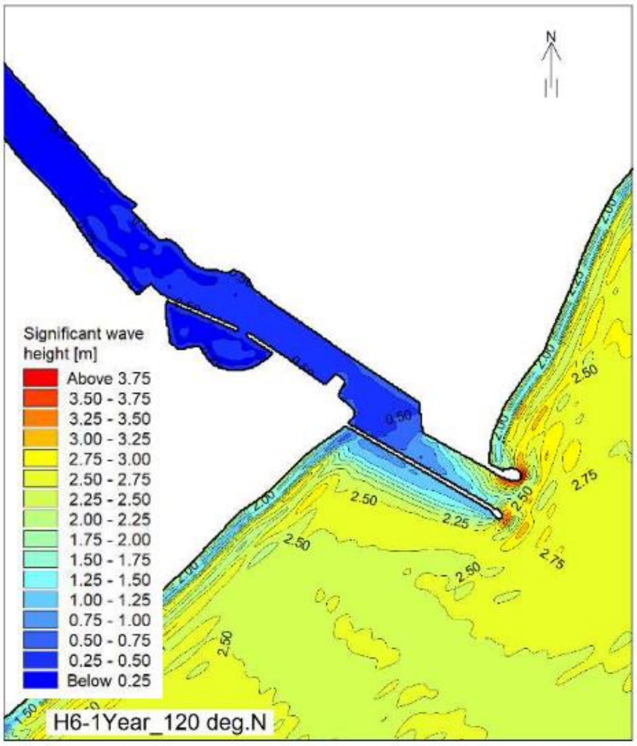
Existing South Pier, represented in wave model as an open structure above the cut-off level of the piles (bed level of model raised to the top of the piles).



South Pier replaced with vertical-walled structure.

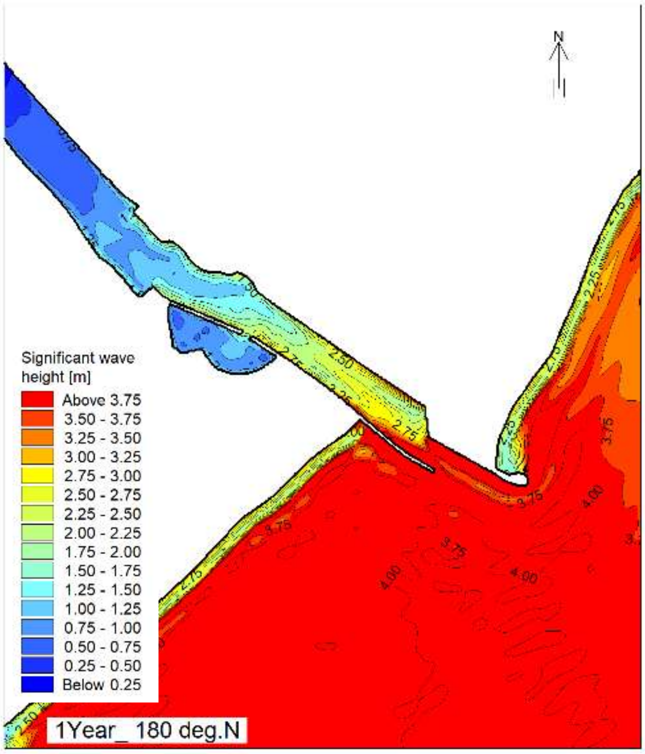


South Pier replaced with a rock armour breakwater.

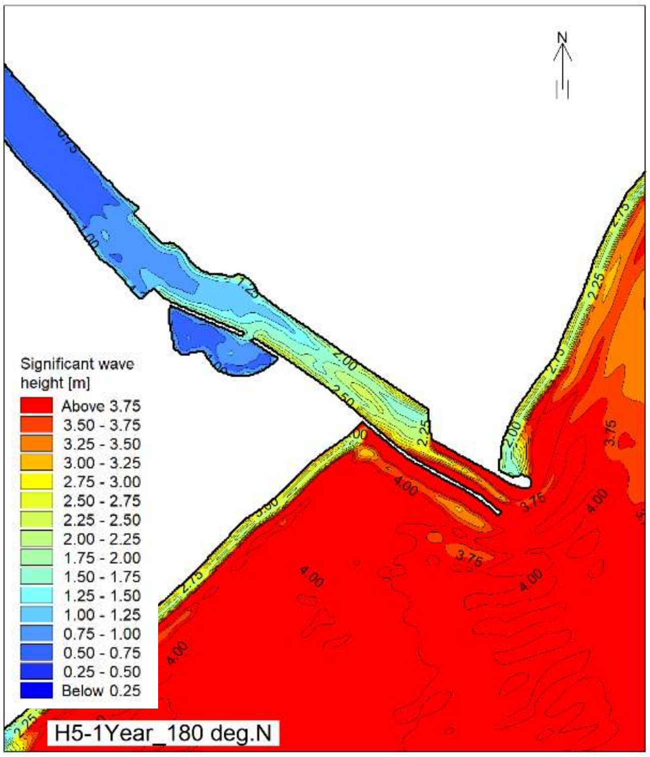


South Pier replaced with a rock armour breakwater, plus rock groyne opposite the North Wall.

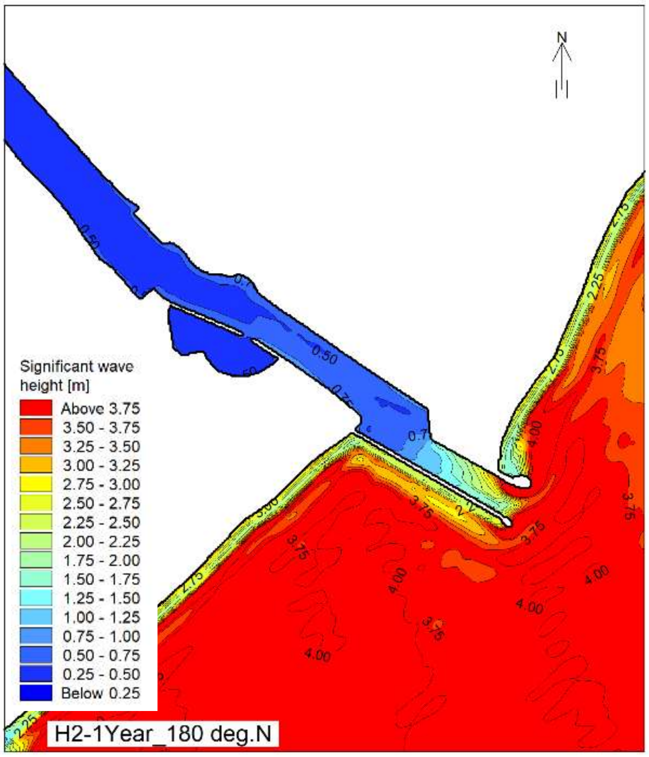
Figure 3-1: Comparison of wave conditions - options for replacement of South Pier, 1-year return period wave conditions from 120 degree sector



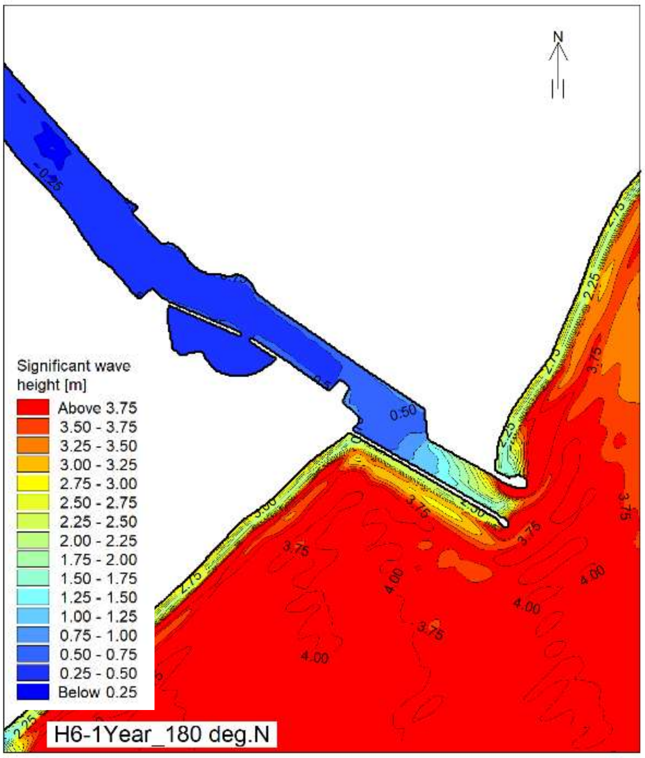
Existing South Pier, represented in wave model as an open structure above the cut-off level of the piles (bed level of model raised to the top of the piles).



South Pier replaced with vertical-walled structure.



South Pier replaced with a rock armour breakwater.



South Pier replaced with a rock armour breakwater, plus rock groyne opposite the North Wall.

Figure 3-2: Comparison of wave conditions - options for replacement of South Pier, 1-year return period wave conditions from 180 degree sector

With a rock armour breakwater, for waves from the 120 degree sector, wave heights in the entrance channel would reduce from about 2.5m at the mouth of the channel to less than 1.0m about halfway along the South Pier. For waves from the 180 degree sector the rock breakwater is even more effective in wave energy dissipation, reducing wave heights from about 3.75m at the mouth of the channel to less than 1.5m about halfway along the South Pier. This rapid change in wave conditions could be a constraint to navigation, as it could be difficult to move from the very disturbed wave conditions at the mouth of the channel into the calmer conditions within the channel, or vice versa when moving from the channel into the open sea. The change in wave conditions from the mouth to within the channel is expected to be less sudden for more typical day-to-day conditions.

The wave modelling results demonstrate that with a rock breakwater in place, the wave energy dissipation achieved due to the rock armour will significantly improve the conditions for vessels within the entrance channel. Therefore, it may not be necessary to further modify the conditions in the channel by introducing a cross-flow, such as is currently experienced from the windows in the South Pier, and which the proposed culverts aim to replicate.

There is a potential risk to navigation in relation to the relatively rapid transition from disturbed wave conditions outside the harbour entrance to much calmer conditions within the channel. The available wave modelling results are for a 1-year return period storm event, which is more severe than the typical conditions for navigation. Additional modelling would be required to better understand this issue for less severe wave conditions, as well as further discussion with harbour users.

If necessary, there are modifications that could be made to the design of the breakwater to reduce the rate of change in the wave height or to mitigate the impact on vessels. This might include reducing the crest level of the head of the breakwater so that some (limited) wave overtopping can occur, changing the shape of the harbour entrance, or altering the angle of approach by vessels. The further development of the design for the proposed rock breakwater should therefore consider this issue in some detail, including consultation with harbour users.

4 Additional Tidal Modelling

4.1 Approach to additional modelling

Additional tidal modelling has been undertaken to assess the impact of the proposed box culverts on tidal flows within the harbour entrance channel, by comparison with the model results for the existing situation (windows through the South Pier), and for a breakwater without windows or culverts.

The tidal model was revised to include a rock breakwater in place of the South Pier. Box culverts were incorporated within the breakwater, assumed to be 3m wide and 2m high and positioned at mid-tide, i.e. with the invert level set at 0.5m ODN. The culverts were aligned to 210 degrees, to limit wave penetration. Two options were modelled, with either 3 or 5 box culverts. The figures showing the model results show the location of the culverts.

Table 4-1 sets out the scenarios that have been considered for this assessment, including the conditions that were assessed in earlier phases of this project, as well as the new model runs. The previous model runs for a solid vertical-walled pier show what the tidal flows would be for a rock breakwater without culverts, as the different reflection characteristics of these two options are not relevant for the tidal model.

Table 4-1: Scenarios assessed using the tidal model

Option		Tide level (m ODN)	
Harbour entrance	**Estuary defences**	**1.49 (2020)**	**2.04 (RCP2.5, 2020)**
Present-day South Pier	Present-day defences (E0)	✓	✓
Solid South Pier (F1) / Rock Breakwater	Present-day defences (E0)	✓	✓
Rock breakwater with 3 box culverts	Present-day defences (E0)	✓	✓
Rock breakwater with 5 box culverts	Present-day defences (E0)	✓	✓

4.2 Model results

The tidal model results for the present-day harbour structures (**Figure 4-1**) show that the flow through the 'windows' in the South Pier does influence the tidal flows in the harbour entrance channel to some extent, with high flows shown adjacent to the inner face of the South Pier, for both the flood and ebb tide.

Figure 4-1 can be compared against the peak flow velocity with a solid, vertical-walled pier structure without the windows (**Figure 4-3**), which does not show the same high flows along the pier. A figure showing the difference between these two model runs is also provided (**Figure 4-4**), which shows that with a solid, vertical walled South Pier without windows the tidal flows along the centre of the channel would be slightly less (up to 0.4m/s) than they are at present. **Figure 4-2** to **Figure 4-4** show maximum flow velocity over the full tidal cycle, which typically occurs on the ebb tide.

The model results for the existing harbour entrance structures (**Figure 4-1**) show that the influence of the tidal flow through the windows in the South Pier does not extend very far into the entrance channel, as the high flow rates are concentrated close to the pier. In the centre of the entrance channel, it appears that tidal flows are dominated by the strong flood and ebb flows into and out of the Blyth estuary.

The tidal model results for the proposed rock breakwater with 3 culverts show high current speeds adjacent to the breakwater on the ebb tide (**Figure 4-5**). For this rock breakwater option, maximum current speeds in the centre of the channel are approximately 1.4m/s for the February 2020 tidal conditions, which is also the maximum current speed with the present-day harbour entrance structures, although the highest current speeds occur over a greater length of the channel in that scenario. Comparing the results for this option against the present-day conditions (**Figure 4-6**) shows the flow through the culverts on the flood tide, although not on the ebb tide, and that current speeds immediately adjacent to the South Pier could be up to 1.0m/s higher on the ebb tide compared to the present-day conditions. However, the flow through the culverts does not have a strong influence on flow velocities in the centre of the entrance channel.

The tidal model was also run with a higher water level condition (2.04mODN tide level) for this rock breakwater option (**Figure 4-9** and **Figure 4-10**), to assess the impact of the proposed culverts with higher flow velocities. Areas of high flow velocity are again visible adjacent to the breakwater, but do not extend into the centre of the channel. As for the lower water level, peak flow velocities immediately adjacent to the South Pier could be up to 1.2m/s higher with the rock breakwater and culverts, but in the centre of the channel the peak flow velocities would be comparable to present-day conditions (+/- 0.2m/s) for the same tide level.

The peak flow velocities for a rock breakwater with 5 culverts are shown in **Figure 4-7**. When more culverts are incorporated into the breakwater structure, the flow through the culverts means that the flows in the entrance channel would be slightly is closer to the present-day situation. This is more noticeable for lower water levels. The difference plots for both the 1.49mODN and 2.40mODN tide levels (**Figure 4-8** and **Figure 4-12**) show that current speeds in the entrance channel would be up to 0.2m/s higher for this breakwater option than with the present-day South Pier.

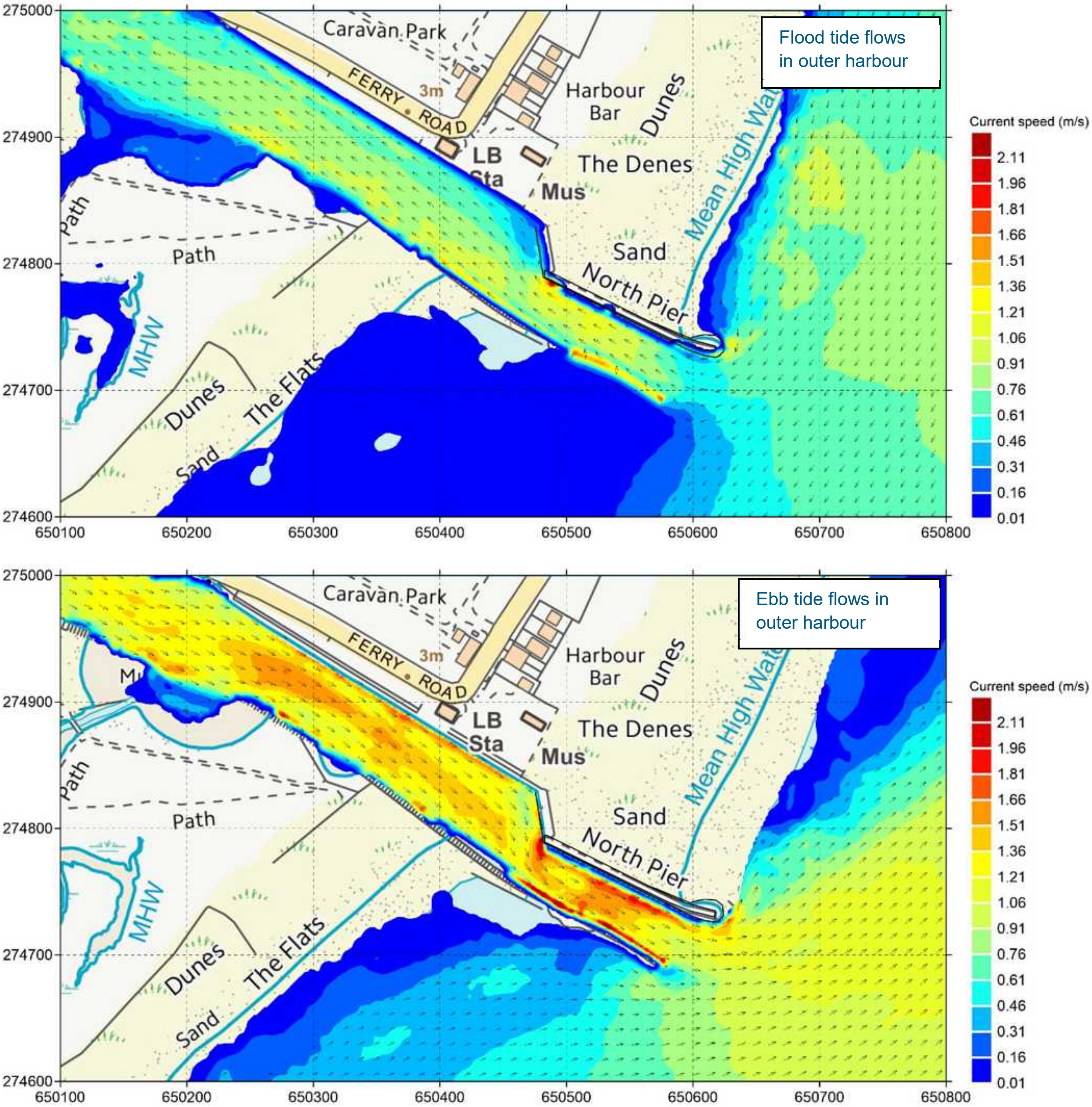


Figure 4-1: Spatial variation of peak flow velocity for present-day South Pier (with windows), Feb 2020 conditions

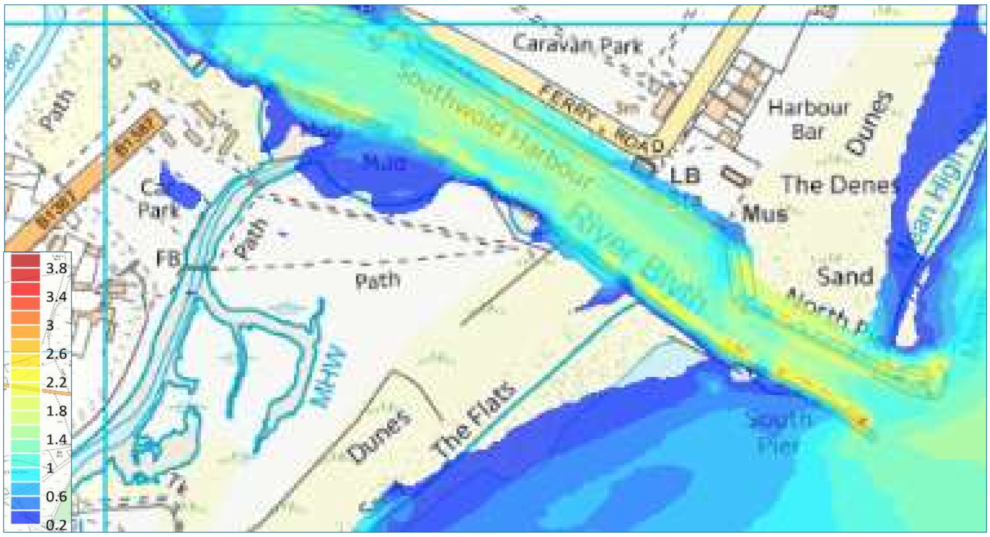


Figure 4-2: Maximum flow velocity in harbour entrance for vertical-walled South Pier (no windows), Feb 2020 conditions

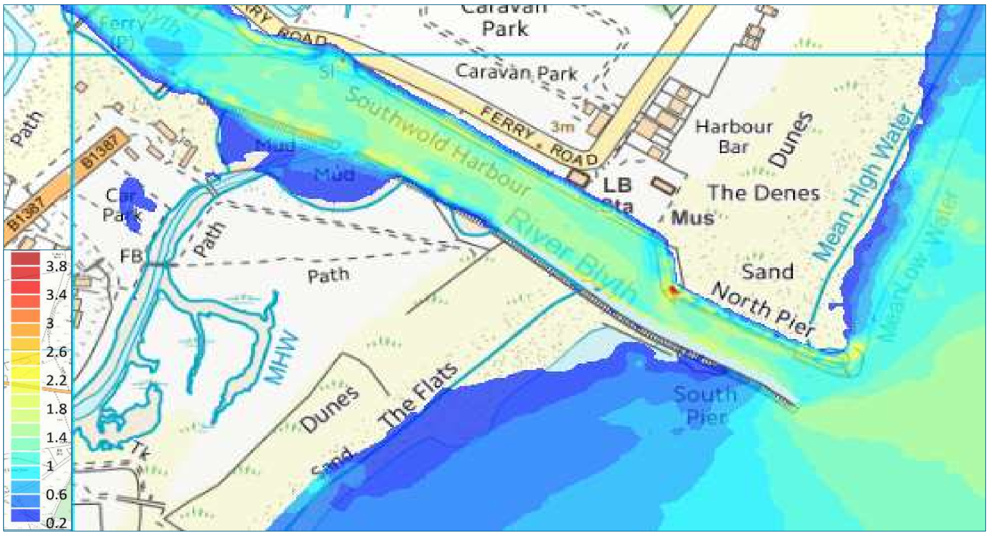


Figure 4-3: Maximum flow velocity in harbour entrance for vertical-walled South Pier (no windows), Feb 2020 conditions

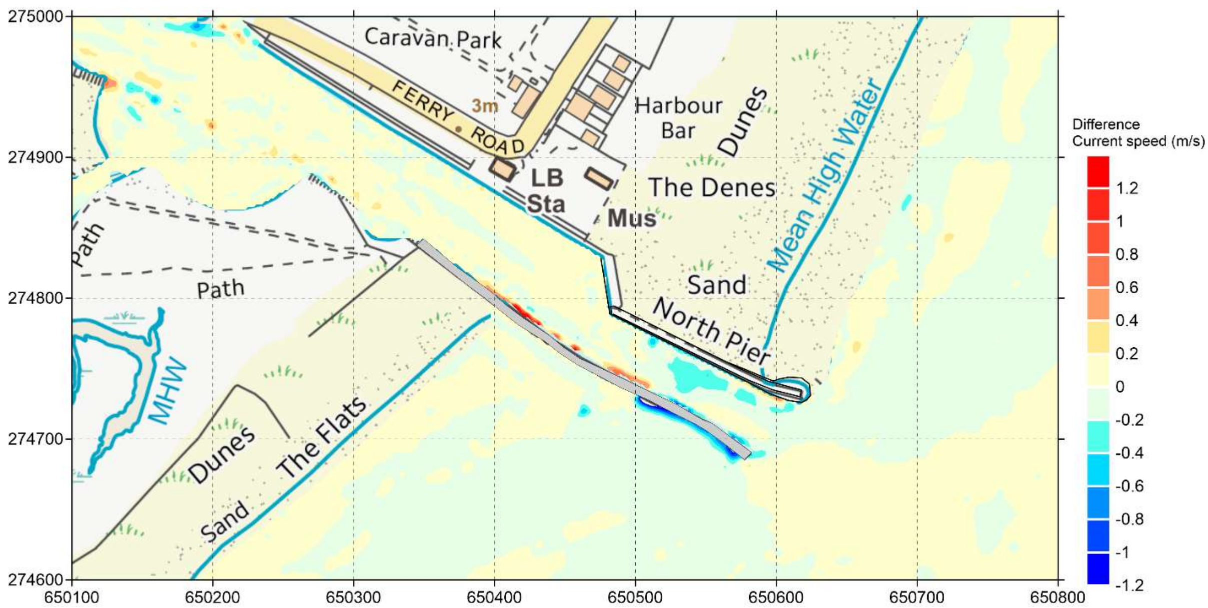


Figure 4-4: Difference in maximum flow velocity for solid South Pier (no windows) compared to present-day structure (with windows), Feb 2020 conditions

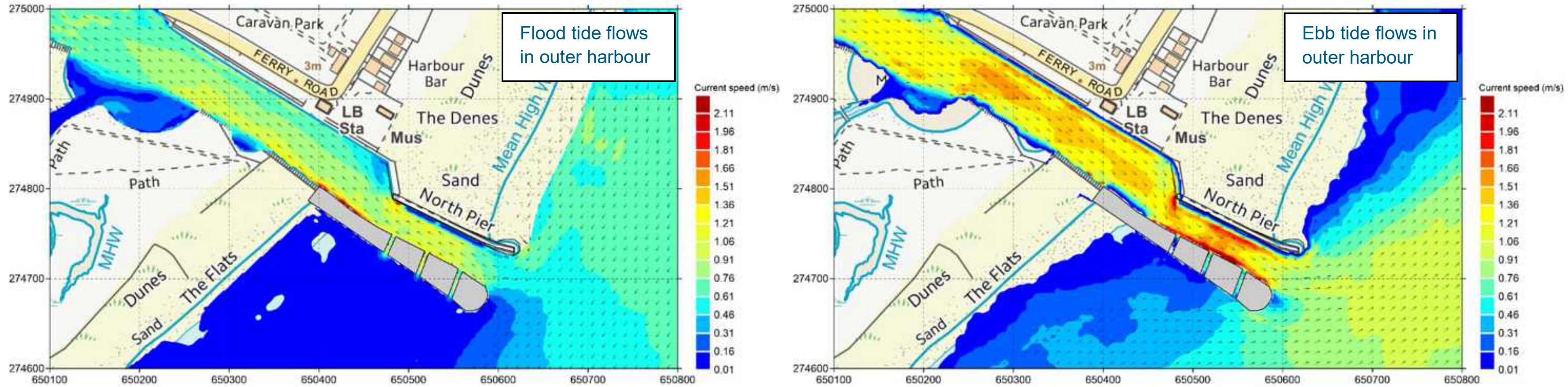


Figure 4-5: Spatial variation of peak flow velocity for rock breakwater (3 culverts), Feb 2020 conditions

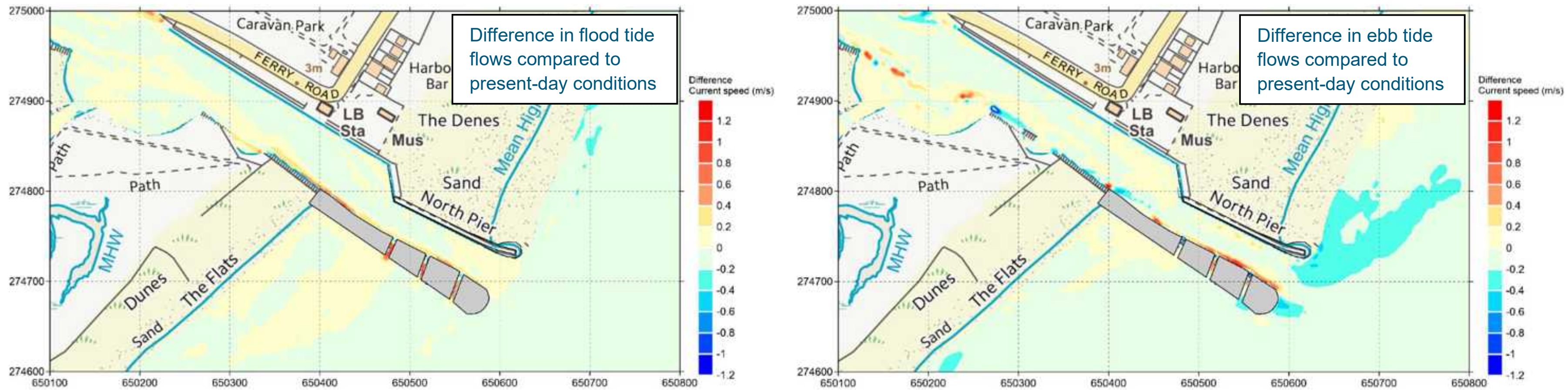


Figure 4-6: Difference in peak flow velocity for rock breakwater (3 culverts) compared to present-day structure, Feb 2020 conditions

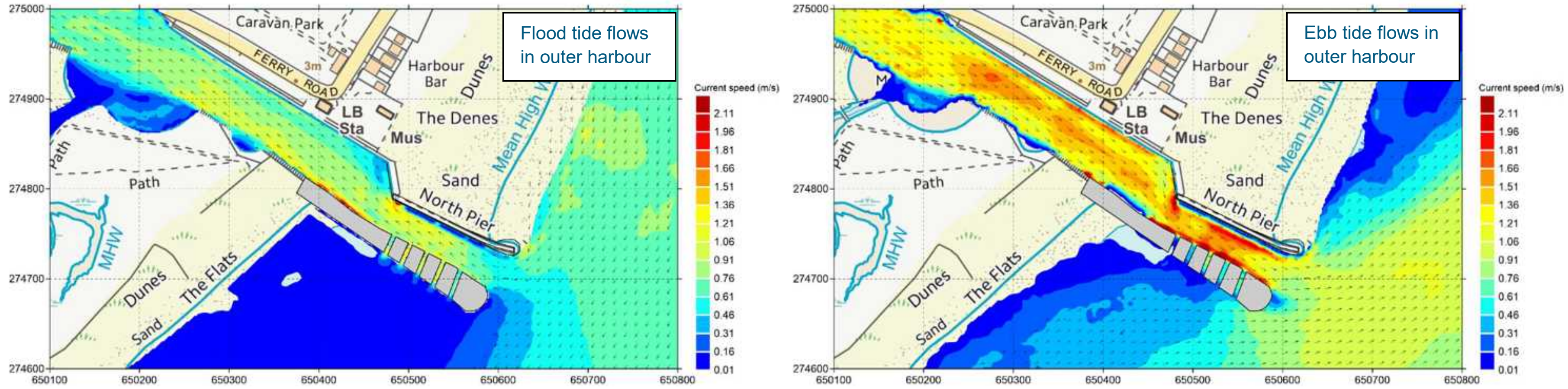


Figure 4-7: Spatial variation of peak flow velocity for rock breakwater (5 culverts), Feb 2020 conditions

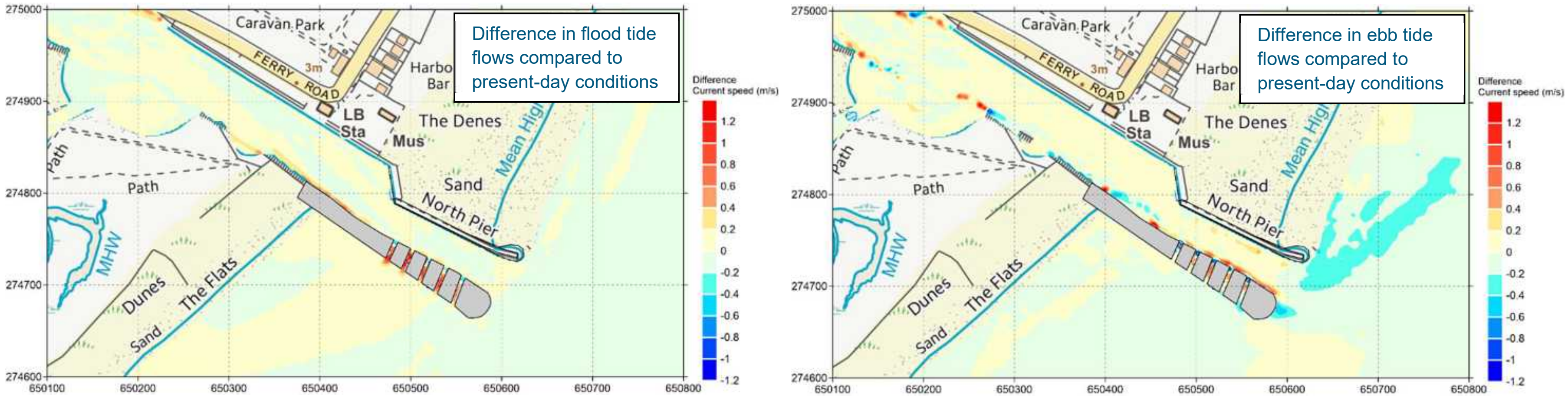


Figure 4-8: Difference in peak flow velocity for rock breakwater (5 culverts) compared to present-day structure, Feb 2020 conditions

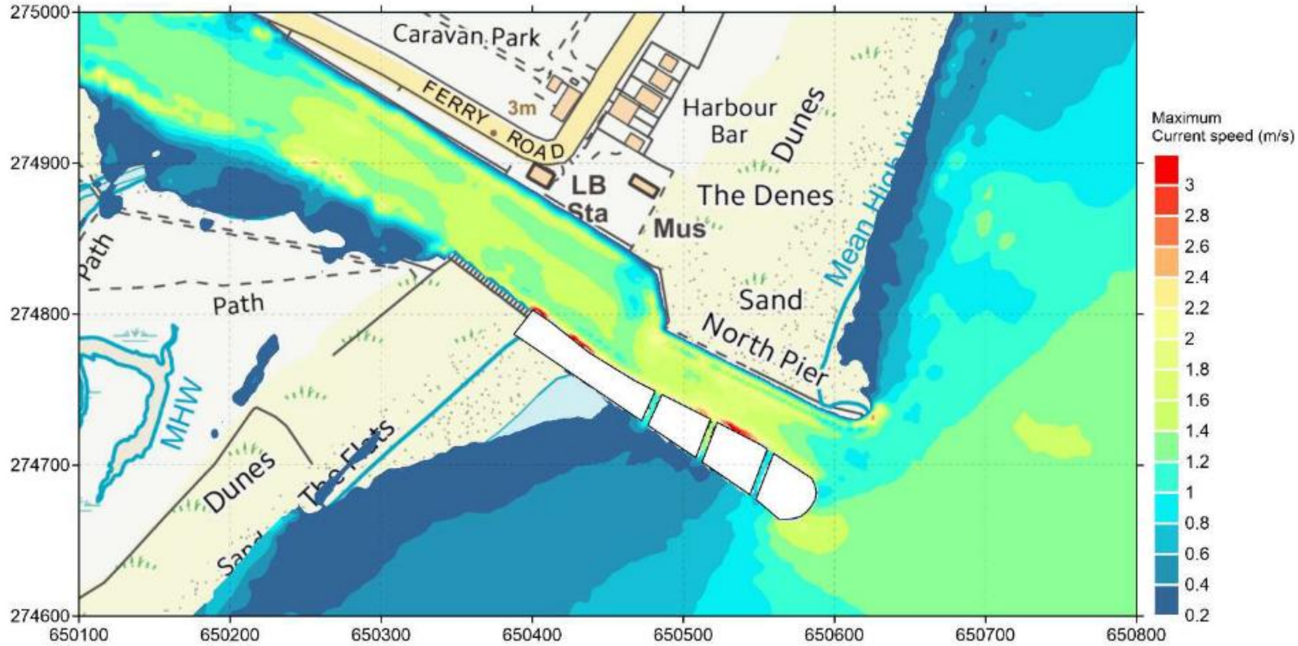


Figure 4-9: Maximum flow velocity in harbour entrance for rock breakwater (3 culverts), 2.04m tide level

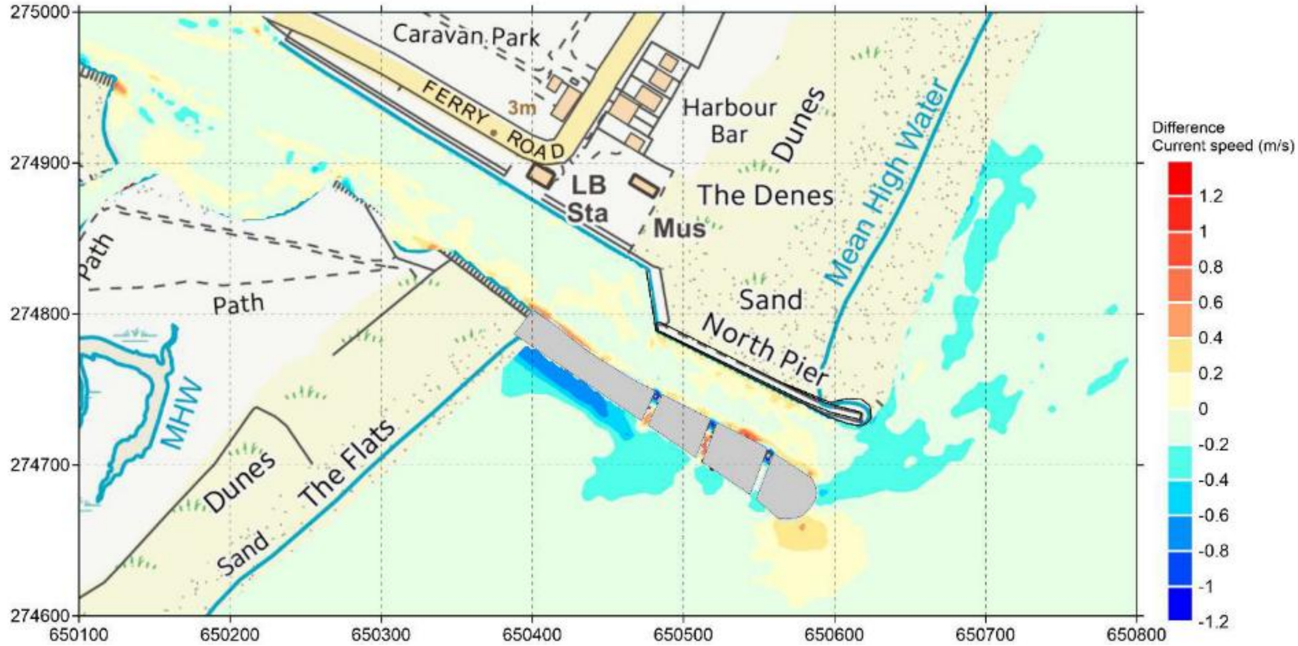


Figure 4-10: Difference in maximum flow velocity for rock breakwater (3 culverts) compared to present-day structure, 2.04m tide level

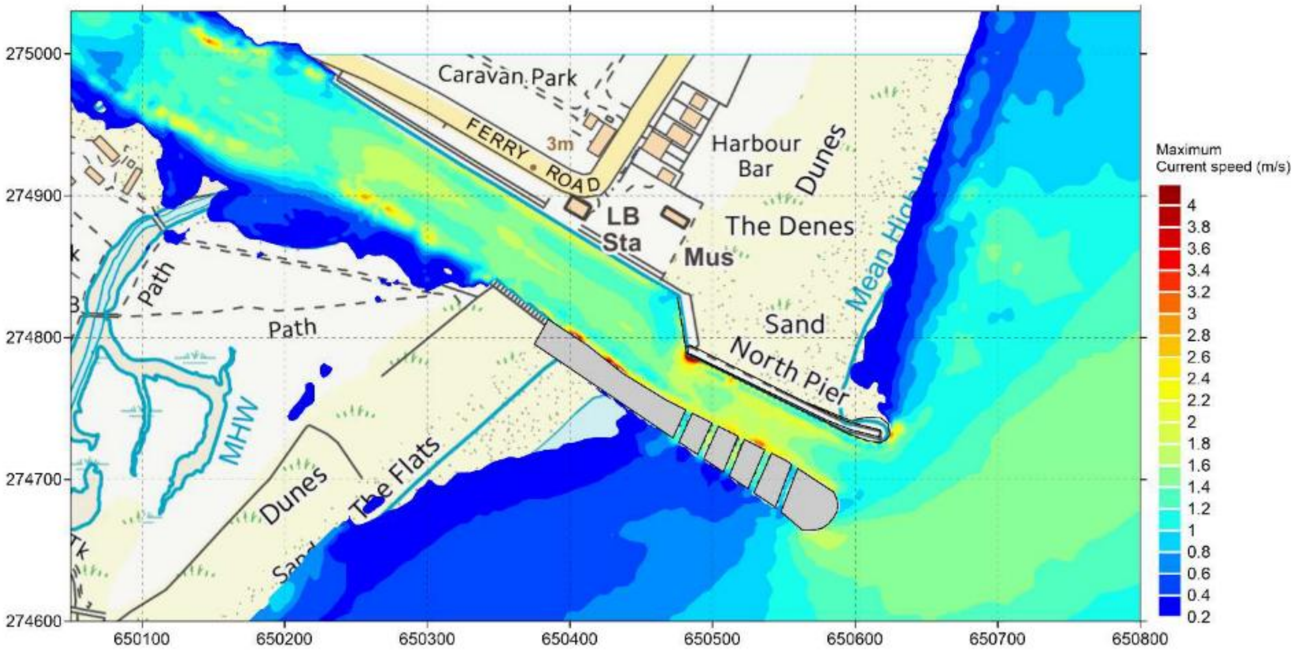


Figure 4-11: Maximum flow velocity in harbour entrance for rock breakwater (5 culverts), 2.04m tide level

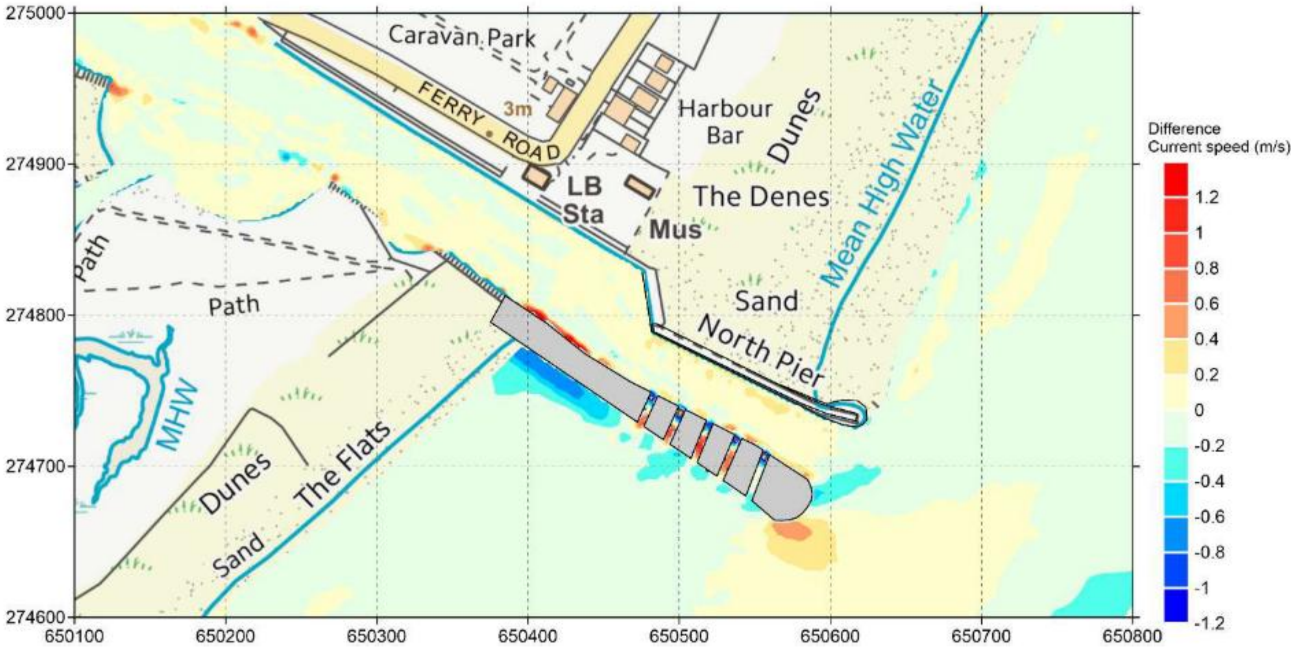


Figure 4-12: Difference in maximum flow velocity for rock breakwater (5 culverts) compared to present-day structure, 2.04m tide level

5 Conclusions

A series of box culverts are proposed to form part of the rock armour breakwater which is currently recommended to replace the South Pier at Southwold. The aim for these culverts is to replicate the 'windows' in the existing South Pier, which enable waves and tidal flows to penetrate into the harbour entrance channel. This additional assessment as part of the development of the Southwold Harbour investment Plan has assessed the likely hydraulic performance of the proposed box culverts, considering:

- Wave penetration through the box culverts;
- Wave energy dissipation in the harbour entrance channel due to the proposed rock armour breakwater; and
- Tidal flow through the box culverts.

Whilst the proposed box culverts would dissipate wave energy, wav-generated currents could occur, with waves and tidal flows moving through the culverts resulting in intermittent jets of water into the channel. It is not possible to quantify this wave penetration using the existing wave model, although this could be done as part of detailed design using a 3-dimensional wave model, which could also be used to optimise the position and orientation of the culverts.

The tidal model results show that both the existing 'windows' in the South Pier and the proposed culverts create cross-flows into the entrance channel. Higher current speeds are shown in the model results close to the South Pier structure, but these flows appear to have only a limited influence on the overall flow conditions compared to the diurnal tidal flows in and out of the estuary. The cross-flows are slightly more apparent over the full channel width for lower tidal levels.

The wave modelling results show that replacing the South Pier with a rock armour breakwater would significantly improve the wave conditions within the entrance channel, as the rock armour will dissipate wave energy and reduce wave reflection. With a rock armour breakwater, wave heights in the entrance channel are shown to reduce quite rapidly from disturbed conditions at the mouth to relatively calm conditions (>60% reduction in wave height) from about halfway along the South Pier, for 1-year return period wave conditions. The reduction in wave reflection achieved with a rock armour breakwater means that a cross-flow would no longer be necessary in terms of reducing wave reflection.

Comparing the wave conditions experienced with the existing South Pier structure to those that would occur with a vertical-walled structure without any windows demonstrates the benefits of the windows for limiting wave reflection and the potential build-up of swell waves running directly along the vertical wall. The relatively disturbed conditions that currently occur in harbour entrance channel are understood to benefit navigation into and out of the channel, because there is a more gradual change in wave conditions from disturbed through the channel to calmer at the North Wall.

Based on the wave modelling results that are available for review as part of this assessment, there may be a risk to navigation due to the rapid reduction in wave heights from the mouth of the harbour entrance channel into the channel itself. It could be difficult to move from the disturbed wave conditions at the entrance into the calmer conditions within the channel, or vice versa when moving from the channel into the open sea. This risk may not be so great for less severe wave conditions when vessels are more likely to be navigating the harbour entrance. This issue would need to be addressed in the design of the breakwater, irrespective of whether culverts are to be incorporated in the breakwater.

Considering the wave and tidal modelling results together in the context of the proposed rock armour breakwater and associated culverts, the overall conclusion is that the culverts would be of limited benefit to improving navigation conditions in the channel. Flow through the culverts has limited influence on the overall tidal flows in the channel, and the wave energy dissipation achieved by the rock breakwater reduces the impact of reflected waves. There is also the risk that tidal flow or wave penetration through the culverts could be experienced by vessels as a strong jet of water.

6 Recommendations

Based on the conclusions of this assessment, a rock armour breakwater continues to be the preferred option to replace the South Pier. However, we now recommend that the breakwater is designed without the inclusion of box culverts. This recommendation is subject to discussion of the conclusions and recommendations of this report with harbour users in February 2023.

The design of the mouth of the harbour entrance channel should optimise conditions for navigation into and out of the channel. Additional wave modelling should be undertaken for less extreme wave conditions, to fully understand any risks to navigation from the transition from disturbed conditions at the harbour entrance to calmer conditions within the channel. Any residual risk should be addressed in the design, informed by consultation with harbour users.

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