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Innovative techniques to reduce or remove the need for a breakwater

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INNOVATIVE TECHNIQUES TO REDUCE OR REMOVE THE NEED FOR A BREAKWATER

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Abstract

There has been a huge growth in port and terminal developments in recent years in developing countries to accommodate the expansion in container, oil and gas (including LPG and LNG developments), bulk and other general cargo trade which in turn enables economic growth. Designers often use traditional design techniques to develop these schemes. In this paper we describe an innovative approach to evaluating the design of a port facility that allows the designer to take account of key physical effects and use them in optimising the design.

1. Introduction

The growth in vessel sizes in recent years means that a significant number of port and terminal facilities are now approached through a deep dredged channel. Engineers and scientists have recognised the effects on waves of internal reflection from navigation channels for hundreds of years. As dredged channels get deeper, to accommodate larger vessels, the effects of internal reflections on the port and terminal areas become more important to the design and may provide a contribution to sheltering the berth areas. In some cases the effects of the channel may be sufficient to give adequate shelter at the berth without a requirement for additional protection to be provided by a breakwater. Clearly this is a site specific effect but it is important to have the appropriate technical tools to evaluate this effect as part of the design process.

In Section 2 of this paper we present information on the tools that can be used to evaluate the impact of waves at a berth in the presence of a dredged channel. None of these tools are new but they are linked in an innovative manner that permits full information on the wave conditions to be carried through from the offshore boundary of the numerical model through the area of dredged channel and onto the berth.

In Section 3 of the paper we provide a case study of a terminal development in India where the navigation channel has significantly altered the wave propagation to the berth areas.

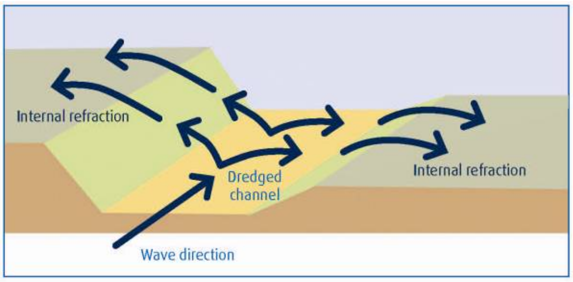
In Section 4 we comment on the methodology and also give a further example where a dredged area will not provide the required protection and a breakwater is needed to provide acceptable conditions at the berths. In this case the innovative approach to the evaluation of the design is also important as it gives better information on the optimum length and orientation of the breakwater than would be obtained from conventional approaches.

Section 5 draws conclusions from the work presented in the paper.

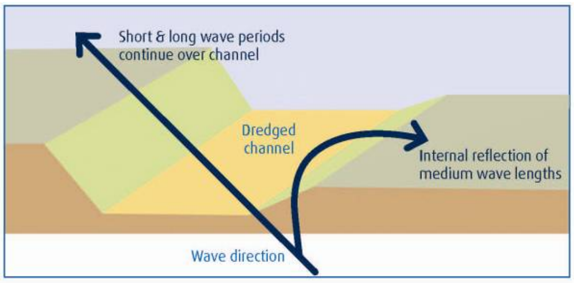
2. Evaluating the impact of waves in the presence of a dredged channel

2.1 The influence of a dredged channel on waves

It is well known that a dredged channel will effect the propagation of waves in shallow water. The effect of the channel on the waves will be a function of the wave period and direction, and the channel will act to refract or reflect energy as shown in Figure 1.



Internal refraction of waves



Internal reflection of waves

Figure 1 Schematic of refraction and reflection of waves by a dredged channel

Understanding the impact and correctly simulating wave conditions as they approach the berth is essential for modern terminal design. Large vessels can respond to wave periods of 7 seconds or greater. Short period waves (typically 7 seconds or less) tend not to affect these large vessels, unless they are exposed to waves beam-on. Figure 1 illustrates how different wave periods are affected by the presence a dredged channel and illustrates situations where a channel could either refract or reflect wave energy away from, or towards a berth area. In some instances these effects can be potentially beneficial in terms of achieving acceptable wave conditions at berths, especially if wave energy that could disturb moored ships is deflected away from the berth. Conversely, at other locations, wave energy that can affect moored ships may be focused towards the berth. This indicates that unless both wave heights and periods are correctly simulated as they approach the berth, the designer could draw erroneous conclusions regarding berth viability.

2.2 Coupling of spectral wave disturbance and transformation models

To properly evaluate the effect of a channel on wave activity it is important that the tools we use in investigating the design retain appropriate information on the wave parameters. For the level of detail required for this type of assessment information on spectral parameters must be retained throughout the use of linked computational models, which is the methodology often used in evaluation of such schemes.

A wide range of well established computational shallow water wave models now exist and are frequently used within coastal engineering studies. In many coastal engineering studies wave conditions may be required over a relatively large area or along a long stretch of open coast. In these cases the important physical processes include wave shoaling, refraction and energy dissipation which can be accurately represented by phase (or wave) averaged spectral wave transformation models.

Many studies, however, are more challenging due to natural and man made structures that lead to wave diffraction for which the phase averaged models do not at present an accurate representation. In such cases, for example where wave conditions are required in the shelter of a breakwater or within a harbour, a phase model resolving computational model may be required. Due to the computational constraints of phase resolving wave models, which means that run times can be excessive, these models are not suitable for large-scale coastal area wave modelling.

Figure 2 illustrates these problems by showing the results of a phase averaged and phase resolving model in the vicinity of a breakwater that provides shelter within a harbour. The faint vectors represent the wave height and direction predicted by a phase averaged spectral wave model and the bold vectors represent the wave height and direction predicted by a phase resolving wave disturbance model. The figure shows that the phase averaged model predicts significantly lower wave heights in the shelter of the breakwater compared with the phase resolving model, but the extent of the phase averaged model is greater. Since, at present, there are no specific computational wave models that are practical for this situation, one solution is to combine or couple phase averaged and phase resolving models. The coupling of computational models is widely acknowledged as a solution to this problem, within the field of wave and in the modelling of other physical phenomena.

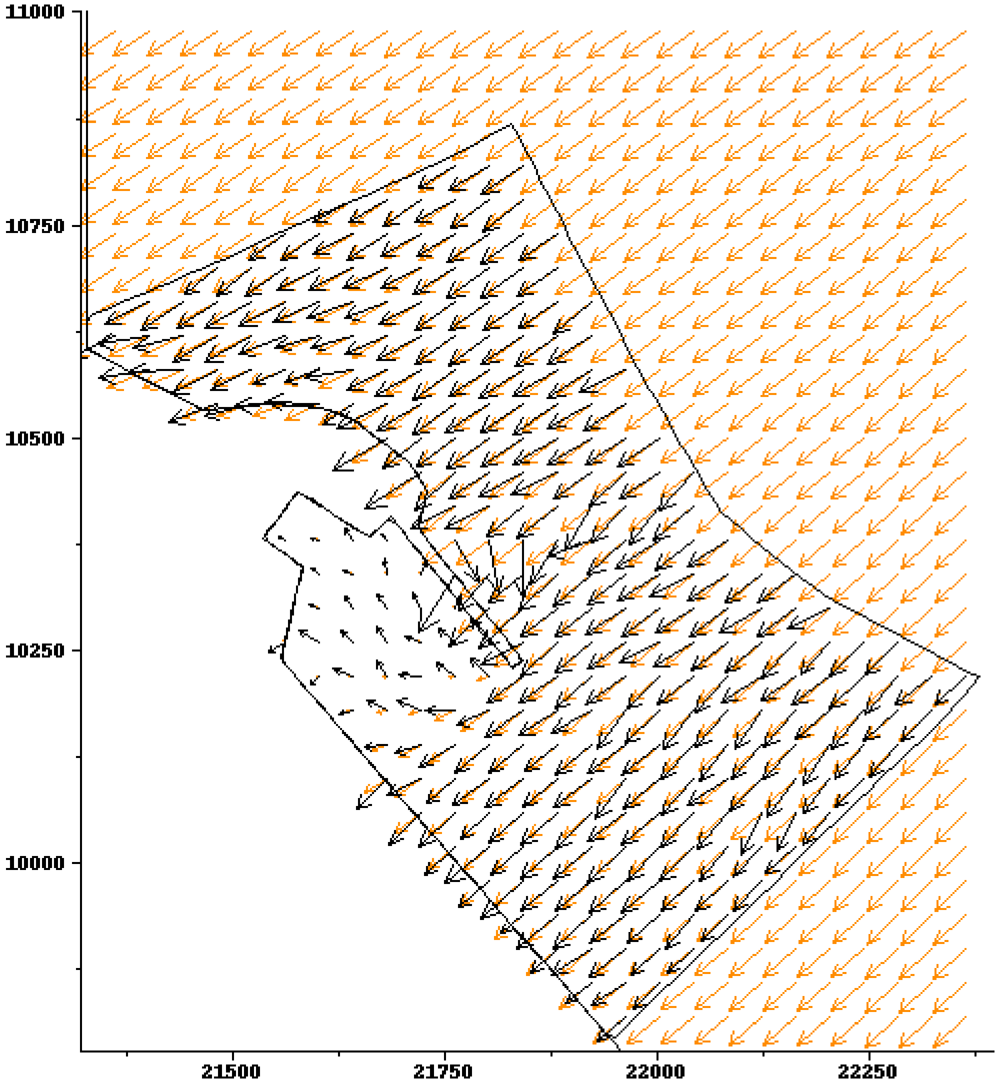


Figure 2 Comparison of phase averaged and phase resolving models in the presence of a breakwater

2.3 Technical methodology

HR Wallingford has developed methods that allow efficient and accurate one-way coupling between existing spectral wave transformation models and wave disturbance models. The couplings result in more efficient and accurate wave disturbance modelling. This is achieved by reducing the area modelled by the wave disturbance model and using the spatially varying spectral wave conditions predicted by the spectral wave transformation model as boundary conditions for the wave disturbance model. Maximising the transfer of information between models is expected to result in more accurate representation of nearshore wave conditions. Figure 3 shows the methodology of the nested models in flow chart form.

The methodology and results of the computational results using this methodology in a number of test cases are described in more detail in Tozer and Durand (2002). It observed that the methodology is generic rather than model specific and can in theory be used to link any phase average model to any phase resolving model. The data flow for this methodology is illustrated in Figure 4.

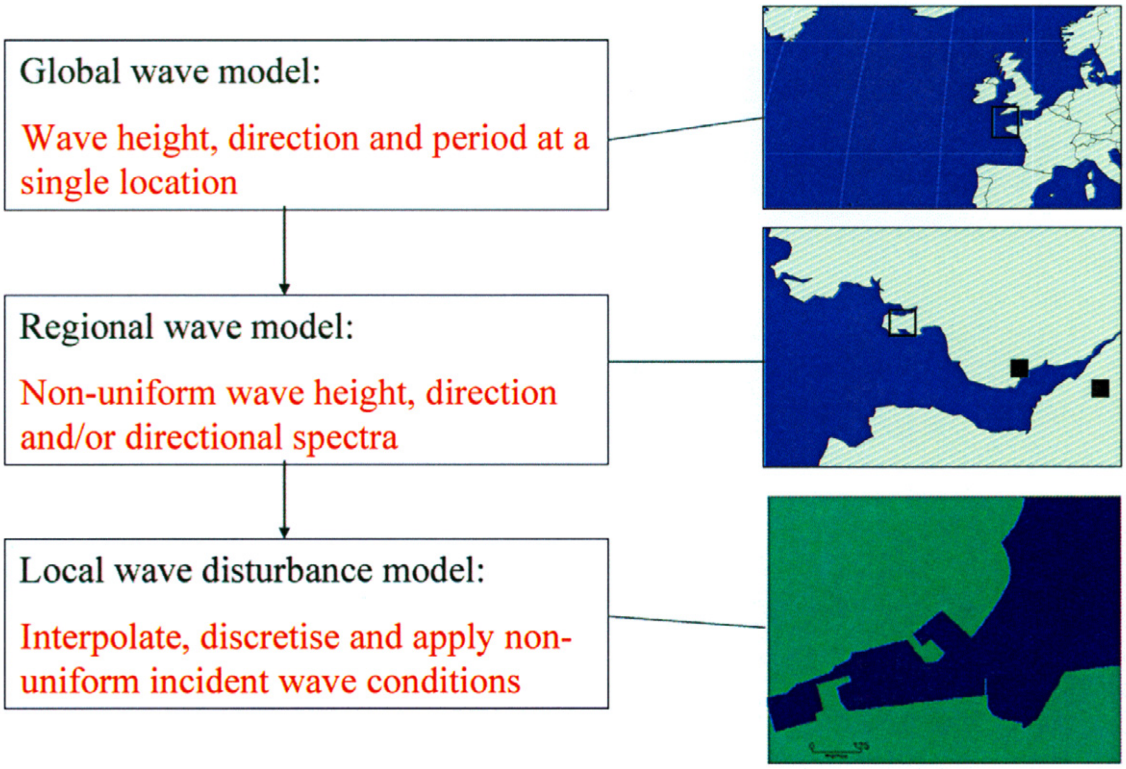


Figure 3 Methodology for coupling of nested wave models

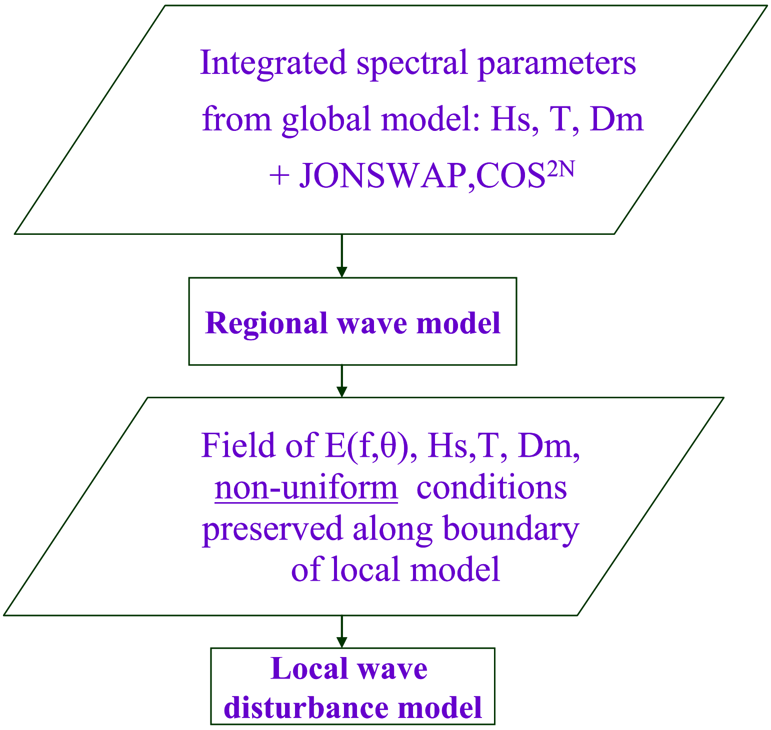


Figure 4 Data flow for coupling of wave models

As stated above the key benefit is that the methodology minimises the data loss between the models where possible, leading to a more accurate approach than previously employed. The coupling also allows the area represented in the wave disturbance model to be smaller than previously considered resulting in improved computational efficiency.

2.4 Benefits of this methodology

The key point in relation to the work included in this paper is that this technical methodology allows a more accurate representation of wave conditions in the vicinity of a dredged channel and berth areas. As a consequence the impact of the channel on waves can be better evaluated as part of the design process.

3. Case Study

3.1 Development of the Cohin (Kochi) LNG Terminal

The case study we describe here was carried out for Petronet LNG Ltd (Petronet) who are planning to set up an LNG Receiving and Regasification Terminal at Cochin (in Kerala, southern India), see Figure 5, for 2.5mtpa nominal capacity with provision for expansion up to 5mtpa. The estimated cost of the project is £250 million (US$500 million).

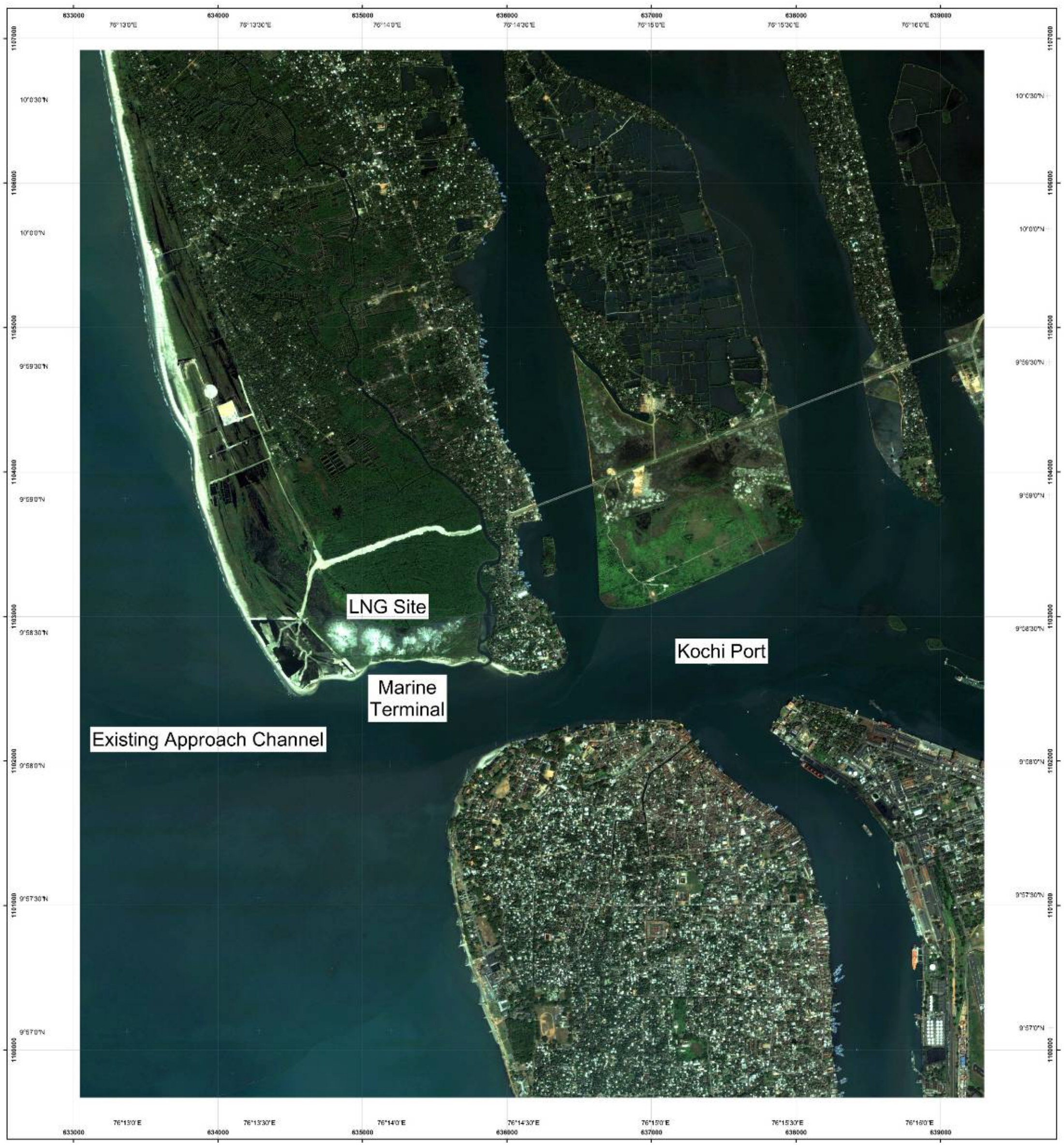


Figure 5 Site of the Cochin LNG Terminal

Petronet believes in looking for innovative solutions to technical challenges, and they awarded HR Wallingford the contract to update the layout design, using earlier studies as the basis for design. Our study included:

- Site visits to gather additional data
- An analysis of site data and a review of existing studies
- Establishment of a Design Basis
- A study of marine traffic and impact of the proposed terminal
- A layout analysis (drawing on information about wave, flow and sediment transport modelling)
- Navigational access and ship manoeuvring simulation
- Mooring analysis (to establish operational limits) and
- Development of the Front End Engineering Design (FEED).

3.2 Review of the proposed layout

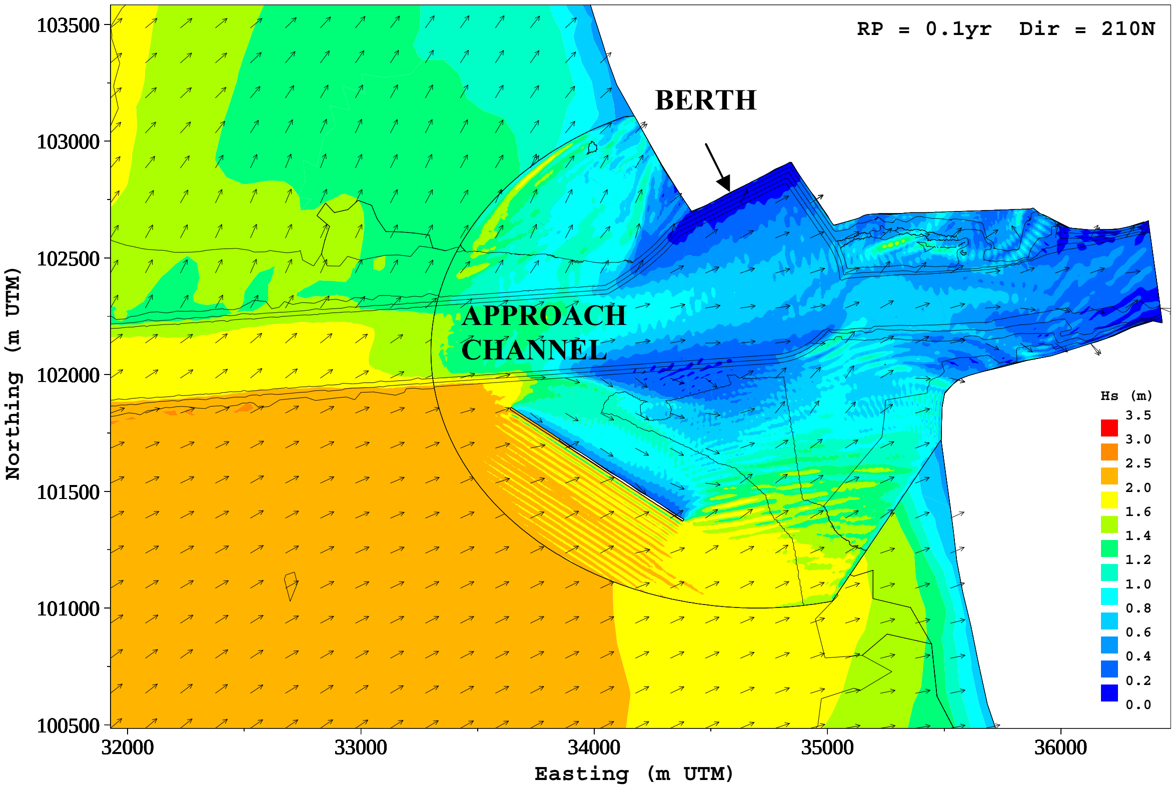
The initial design for the terminal had a breakwater located to the south-west of the terminal site on the south side of the channel. The modelling that had been done for the design (by a third party) had used a simplified approach to modelling waves in the immediate vicinity of the berth. This initial modelling indicated that a breakwater was required to provide adequate shelter at the berth.

On review of this initial design, it was not clear that the modelling had been done in sufficiently detailed way to definitely determine whether a breakwater was needed. HR Wallingford therefore asked the question "Is a breakwater actually required?"

3.3 Results from the computational models

Computational modelling using coupled wave models from the TELEMAC suite in this case TOMAWAC (Benoit et al., 1996) and ARTEMIS (Aelbrecht et al., 1997a,b) (phase averaged and phase resolving respectively) were used with the methodology described in Section 2. Various options for the repositioning of breakwaters, changes in their length or their removal were investigated. TOMAWAC and ARTEMIS showed us that (depending on wave direction and wave period) the dredged channel acted either to internally refract or reflect wave energy away from the berth.

Examples of the results from the coupled models are given in Figures 6 and 7. Figure 6 shows the layout with the breakwater and Figure 7 without the breakwater for the same wave conditions. In both figures the circular line marks the transition between the phase averaged and phase resolving models. The shading on the figures is wave height and the vectors represent wave direction. Comparison of waves in the berth area clearly show there is no significant additional benefit in terms of reduction of wave height to be gained from introduction of the breakwater. More detailed analysis clearly demonstrated that the layout without the breakwater provided acceptable downtime.



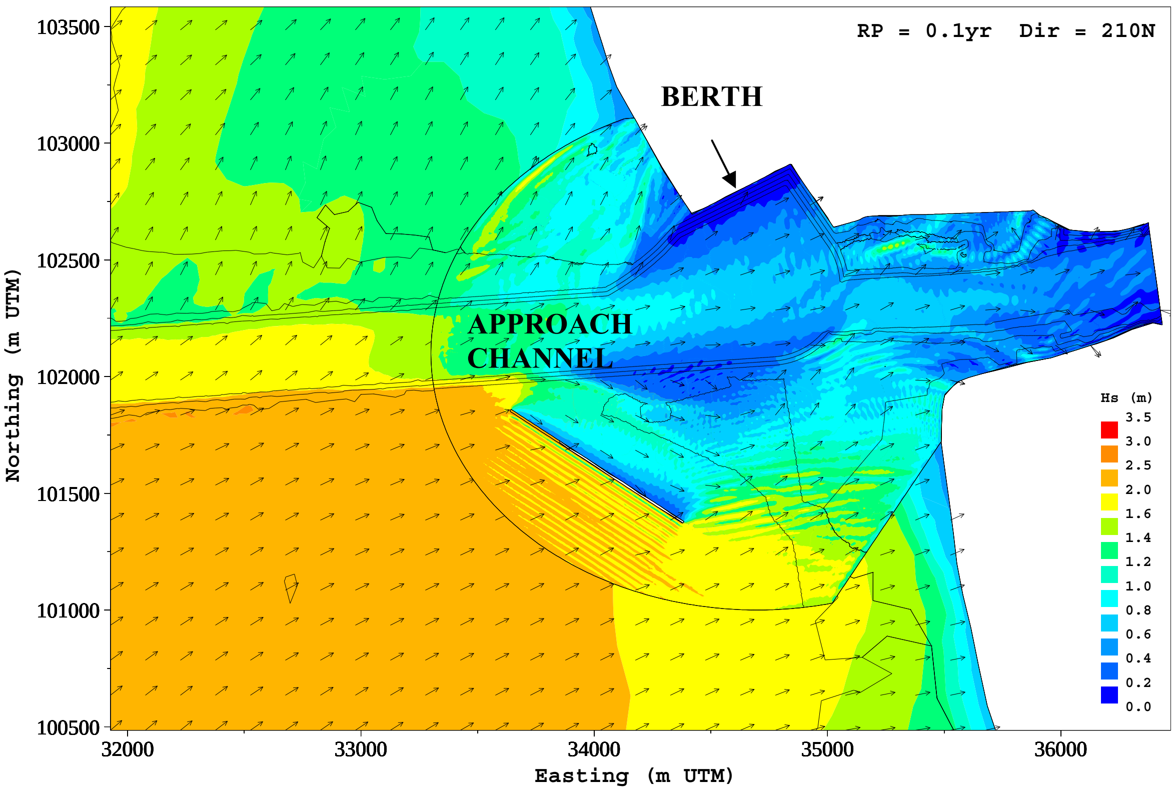


Figure 6 Cochin LNG – Layout including a breakwater

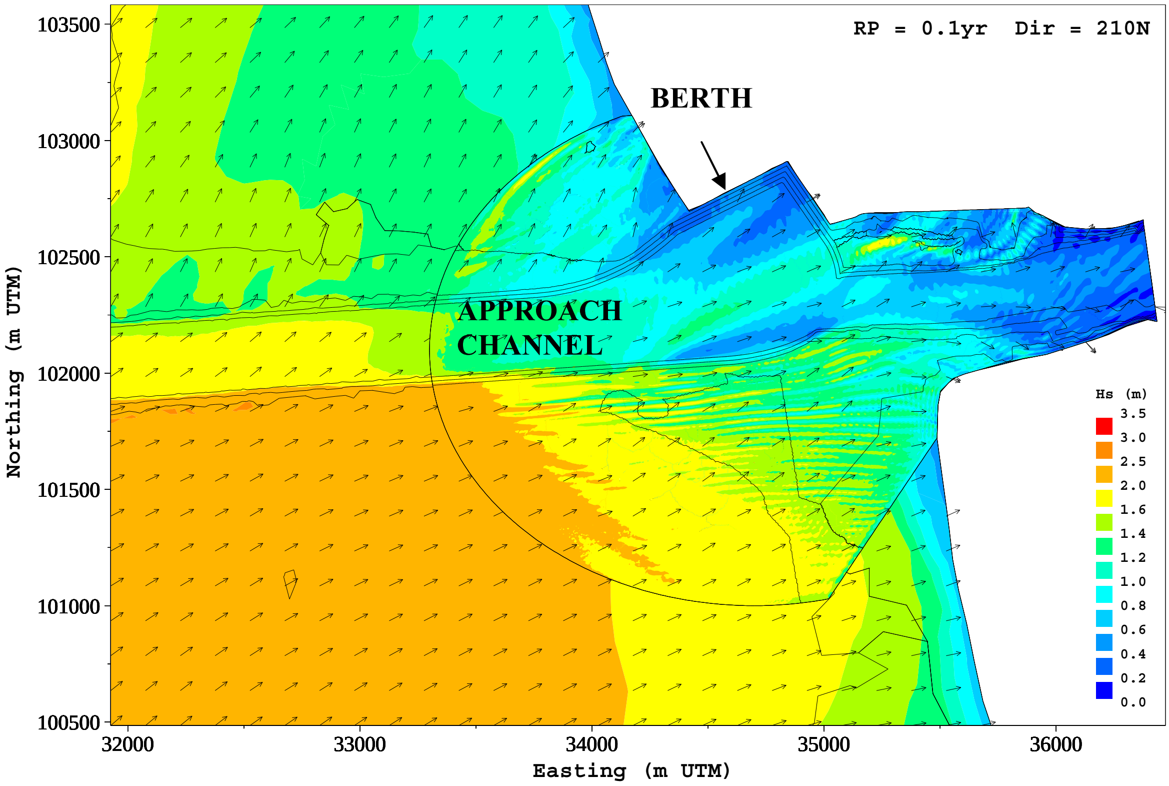


Figure 7 Cochin LNG – Layout without the breakwater

On completion of the computational modelling, the preferred design was tested in a physical model, which also included moored ships (Figure 8). The results from the physical model validated the wave conditions from the computational model showing the refraction and reflections that occurred around the dredged channel. In particular, it confirmed that there was no requirement for a breakwater at this site as predicted in the computational model. The physical model also provided more information on moored ship motion during operational (ship on berth) and extreme design cases (needing the ship to depart). In addition, the mooring line layout was optimised enabling the vessel to remain on the berth under more extreme conditions.

Figure 8 Physical model experiments

3.4 Conclusions from the case study

In this case, despite the location of the terminal on an open coast, we were able to demonstrate by using the described method that the configuration of the proposed dredged channel and turning area served to sufficiently redirect wave energy from the berth area.

Our studies indicated that construction of a breakwater would provide no significant benefit at the berth and that it would be a costly investment for the client. As a result, no breakwaters are proposed for berth protection in the Front End Engineering Design (FEED) package that has been adopted. The operations are more likely to be limited by Pilot access to the vessel at sea than the downtime at the berth. Expected operational downtime for vessels at the berth with the final layout is negligible and periods when pilot boarding/navigation in the channel may be constrained is also low (around 3%).

Navigation simulator runs showed that the channel width of 280m was adequate to provide safe navigation. The minimum required channel depth is -14.5m, but to ensure that this channel is maintained additional capital overdredge will be required.

Assessment of sedimentation in the proposed channel and manoeuvring area indicates that there will be a requirement for significant maintenance dredging works (in the order of 3 to 4 Mm^3 per annum) to maintain safe depths.

The FEED design was then prepared based on this layout including drawings and FEED level specifications of the loading platform, mooring dolphins, berthing dolphins, access trestle, shoreline protection, dredging and navigation aids. Sometimes, as can be seen here, the most appropriate solution to an engineering challenge is one that is 'lighter' in terms of the engineering infrastructure involved.

4. Commentary

Clearly the situation described in the Case Study in Section 3 is one where the configuration of the dredged channel and its effect on waves propagating inshore has a beneficial effect on wave conditions at the berth area. As noted in Section 2, this behaviour is a function of the wave period and direction in relation to the depth and alignment of the channel. As such it is a hydraulic effect that may not be present at every site. It is also possible that non-hydraulic constraints may mean that even if such wave conditions are present at a site it may not be possible to use then in a beneficial manner. In these situations however the methodology described in Section 2 is still valid and will provide better information on the optimum length and orientation of the breakwater than would be obtained from conventional approaches.
In the illustration below, HR Wallingford was investigating a terminal in an area affected by long-period southerly waves. The configuration of the dredged approach channel and turning area were constrained by non-hydraulic considerations that left little flexibility for optimisation. Figure 9 shows results from a wave modelling using the methodology described in Section 2. In this case a breakwater is included in the model as initial runs without a breakwater demonstrated that wave conditions at the berth were unacceptably high for the planned operations. It is however interesting to note the significant effect on wave propagation of the approach channel and the sheltering effect of the breakwater.

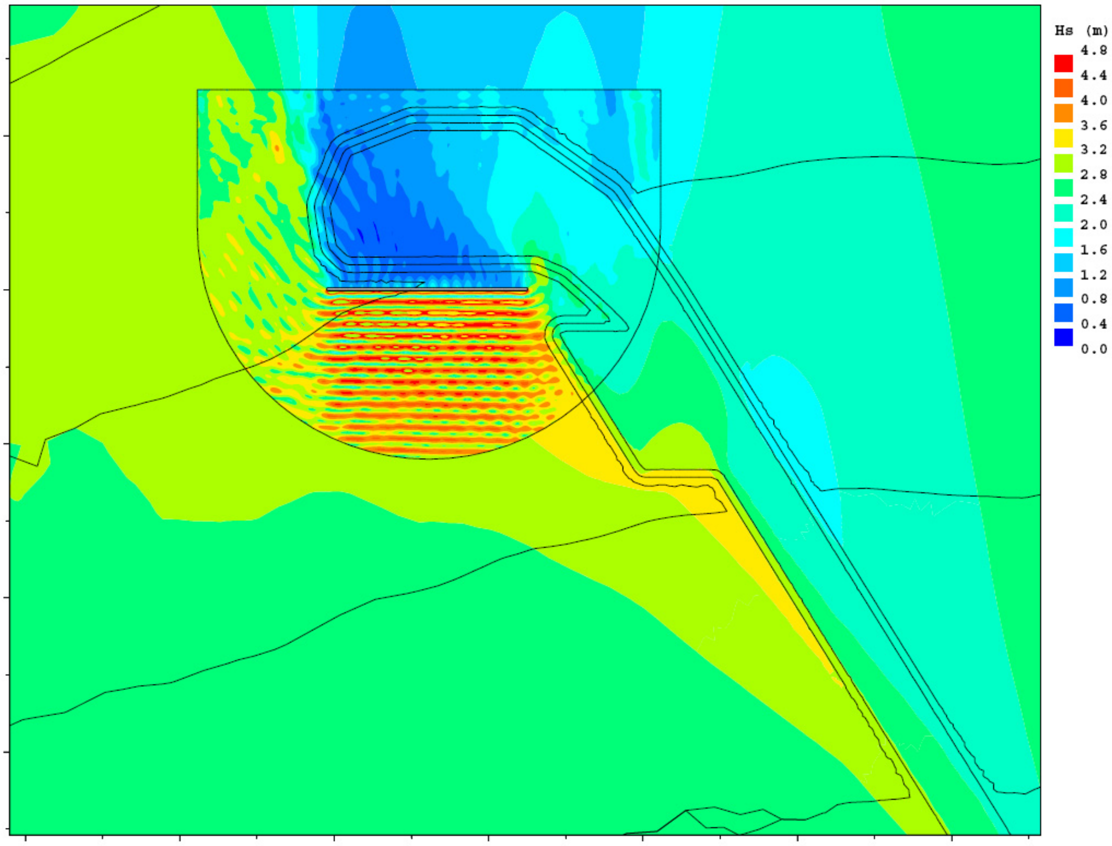


Figure 9 Illustration where the approach identified that a breakwater is required

Since the incident waves are of relatively long period, the dredged approach channel causes waves to refract strongly north westwards away from the western side of the channel. This leads to a higher concentration of wave energy impacting on and around the breakwater and a lower concentration of wave energy in the approach channel. This process results in higher wave energy at the east end of the berth area and penetrating into the manoeuvring area than at the west end of the berth area. The dredged pocket on the west side of the channel is one design option put forward to deflect wave energy away from the east end of the breakwater and reduce the wave energy reaching the eastern end and was found to be more effective than a straightforward extension to the breakwater.

Whilst unlike the earlier case study the configuration of the dredged area will not provide the necessary protection and a breakwater is needed to provide acceptable conditions at the berths the combined sheltering effects of the channel and the breakwater leads to a wider zone of shelter than would be generated by the breakwater alone.

5. Conclusions

Designers should be aware that as dredged channels increase in depth their influence on wave conditions increases also. Designers should also be aware that traditional design techniques to assess their affects are sometimes not fully appropriate for large scale port and terminal developments and their use may mask some key physical effects. It is essential that the designer recognises these effects and in doing so can use them to optimise the design.

The paper has presented some innovative ways of reducing wave conditions at terminal locations through the optimisation of channel alignment and dredging design. These techniques can be used to optimise both existing and proposed port and terminal developments but also do not necessarily apply to all situations. There are a wide range of situations where a breakwater will most definitely be required to provide the necessary level of protection for port and terminal operations.

6. Acknowledgements

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7. References

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