Validation of Tide Simulation Scheme against Field Measurements at Sea Palling in UK

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Abstract

A tidal current simulation scheme has been tested against detailed field measurements along transactions in both alongshore and across-shore directions in adjacent to emerged breakwaters at Sea Palling in UK. Different boundary conditions for tidal simulation are applied at different boundaries. The agreements between model’s predictions and measurements are found overall satisfactory. Noticeable differences were found around the mean tidal level time which partly due to the common tidal level distribution along the driving boundary was used. However, the largest divergences were found in the offshore region, which is not significant from the objective of the present research project, i.e. the near shore morphological processes in associated with the emerging breakwaters.

1 Introduction

Tidal current is an important element of the near shore hydrodynamics which have significant influences on the coastal morphology processes. However, it is not straightforward to include such a process into the engineering near shore morphological model. One particular difficulty lies in the fact that the scale of a tide wave length is in the order of hundreds kilometres. The near shore engineering work, on the contrary, only interests in few kilometres close to the shoreline. In addition, to resolve details of the flow structure, the
spatial grid size in most of the present coastal engineering model also is small comparing with that in an offshore ocean model. Therefore, most existing coastal engineering morphological system considers near shore waves propagation and wave induced currents in great detail, while the direct simulations of combined tides and wave induced currents are still scatter. However, when the tide current is strong comparing with that due to short waves, the spatial variation of the tidal current has to be taken into account.

The Q3D numerical model developed by Liverpool Coastal Group has successfully integrated the tides effects into the complex near shore morphological prediction system through a number of research projects, INDIA and COAST3D, see O’Connor (2001) and Pan et al (2001). The present study describes further validation of a tide simulation scheme within this model system at Sea Palling where detailed field measurements have also been conducted under LEACOAST research program.

2 Field Measurements

The field experiments were carried out at Sea Palling site (Fig. 1) where four surface piercing shore parallel breakwaters have been constructed alongside with other four submerged shore parallel breakwaters. The primary objective of LEACOAST project was to further understand the morphological processes in associate with these structures within a storm time scale under a tidal condition. During the period of 9th - 11th September 2002 (Fig. 2), initial field campaign (pilot study) has been conducted by research group at the University of East Anglia. Details of tidal current velocities and water depth were measured along four transactions using ADCP (Fig.3), including three transactions in the across-shore-wise and one transaction in the alongshore-wise.

During the experiment, the offshore wave height was found small (less than 0.5m) and therefore was not taken into account in the numerical model. The tidal range during the measurements was between ±1.5m and ±1.8m (Fig. 2). The resultant tidal current were found in the alongshore direction with maximum value of 1.5m/s, coinciding with the highest and lowest tidal level.

Within the period of 2nd – 10th February 2004, more comprehensive field campaign has been conducted in which detailed measurements of bathymetry and wave conditions were collected. Unfortunately, continuous flow velocities and water level were measured only at one point in between Reef 6 and Reef 7, i.e. AquaDeep through ADCP. Between 4th and 5th February, a noticeable tidal surge was found with small offshore wave height (0.5m). The model was also applied to this period to test the proposed tides simulation scheme.
Fig. 1 Field campaign site in LEACOAST project at Sea Palling


Fig. 2 Period of field campaign at Sea Palling site during pilot study.
3 The Numerical Model

3-1 Model Equations

The Q3D numerical morphological model system developed at Liverpool Coastal Group solves the shallow water and mass conservation equations along with two difference type of wave propagation models. Sediment transport processes are also simulated through a time averaging or an instantaneous approach. The resulted bed level change can feed back into the hydrodynamic calculation and such interaction continues until the required prediction time has reached. Hydrodynamic model equations are given in this paper. More details of the mode system can be found elsewhere (Pan et al 2005).

The surface displacement is calculated using the two-dimensional continuity equation:

$$\frac{\partial \eta}{\partial t} + \frac{\partial (dU)}{\partial x} + \frac{\partial (dV)}{\partial y} = 0$$  (1)

The U and V velocities are calculated from the horizontal momentum equations:

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} + \frac{1}{\rho d} \left( \frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} \right) + g \frac{\partial \eta}{\partial x}$$

$$+ \sqrt{U^2 + V^2} \frac{\nu}{d} C_u U - \frac{\partial}{\partial x} \left( \nu \frac{\partial U}{\partial x} \right) - \frac{\partial}{\partial y} \left( \nu \frac{\partial U}{\partial y} \right) = 0$$

(2)

and,

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + \frac{1}{\rho d} \left( \frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y} \right) + g \frac{\partial \eta}{\partial y}$$

$$+ \sqrt{U^2 + V^2} \frac{\nu}{d} C_v V - \frac{\partial}{\partial x} \left( \nu \frac{\partial V}{\partial x} \right) - \frac{\partial}{\partial y} \left( \nu \frac{\partial V}{\partial y} \right) = 0$$

(3)

where d is the total depth, $d = h + \eta$, $C_u$ and $C_v$ are the frictional coefficients for the x and y current velocities, respectively, and $\nu$ is the turbulent eddy viscosity. $S_{xx}$, $S_{xy}$, $S_{yy}$ are the radiation stresses which can be got from the Intra-wave-period wave module.

3-2 Model Domain

The simulations concentrated on the hydrodynamics and morphological responds from the four emerged breakwaters. The computational domain therefore was chosen to cover an area with 3km in across-shore direction and 3.5km in alongshore direction as shown in Fig. 3. A large alongshore distance was found necessary to minimise any disturbances from the top and bottom boundaries.
3-3 Boundary Conditions

To include the tidal current into the model system, the measured water level (z) at one particular point offshore was distributed along the bottom boundary (Y = 0m) which acts as a driving mechanism. Although the water level variation along the cross-shore direction was not simulated, such an approach is convenient for the simulation of tidal waves propagating along the shoreline. At the same time, the differences between the water level at the offshore and onshore are not significant in most time of the tide as shown in latter model-measurements comparisons. Therefore, this approach was adopted in the present study. A non-gradient condition was applied to both alongshore velocity (v) and cross-shore velocity (u) to ensure flow can enter and leave the domain without disturbances.

According to the assumption, i.e. the tidal waves are propagating along the shoreline, water level, alongshore velocity and across-shore velocity along the left hand side boundary (X = 0 m) are all set according to a non-gradient condition.

At the top boundary (Y = 3500m), the water level was computed according to the non-gradient boundary condition to allow the tidal waves pass though. Same condition also was applied to the cross-shore velocity. A radiation boundary was employed for the velocity computation in the alongshore direction with celerity equal to \( C = \alpha \sqrt{gh} \), where \( h \) is the local water depth and \( \alpha \) is a calibration parameter with a default value equal to 1. With a \( \alpha \) value less than unit, the lag between the tidal phase and the resultant velocity will become larger comparing to that with \( \alpha \) equal to unit. In addition, a velocity limit was also applied to the computed value using the above radiation condition, i.e. the velocity magnitude

![Fig. 3 Field survey position on the numerical model grids](image-url)
Table 1 List of boundary conditions for tidal simulation, the number is the numerical index in the model code.

<table>
<thead>
<tr>
<th>Boundary Position</th>
<th>Z</th>
<th>U</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom</td>
<td>Given</td>
<td>None-gradient (-2)</td>
<td>None-gradient (-2)</td>
</tr>
<tr>
<td>Left hand</td>
<td>None-gradient (-2)</td>
<td>None-gradient (-2)</td>
<td>None-gradient (-2)</td>
</tr>
<tr>
<td>Top</td>
<td>None-gradient (-2)</td>
<td>Non-gradient (-2)</td>
<td>Radiation (-1)</td>
</tr>
<tr>
<td>Right hand</td>
<td>Zero (0)</td>
<td>Zero (0)</td>
<td>Zero (0)</td>
</tr>
</tbody>
</table>

Along the boundary, the flow cannot exceed a certain value when the flow enters the computational domain. Such a condition is set to eliminate any unrealistic velocities from outside coming into the computational domain.

At the right hand side boundary (X = 3000m), the zero flow velocity was applied at the shoreline which varies with the tidal level.

All of above boundary conditions are also summarised in Table 1.

4 The Model Results

The Q3D model was applied to three test cases, i.e. the field campaign on the 10th along transaction 1 and on the 11th along transaction 2 in September 2002, and the ADCP measurements at one point (AquaDeep) between Reef 6 and Reef 7 as shown in Fig 3 on the 4th, February 2004.

The spatial grid size in the across-shore and alongshore direction was 12.5m and 25.0m respectively. To satisfy the stable criteria, the temporal time step was set as 0.5s.

After a number of tests against the measurements along Transect 1, it was found that the \( \alpha \) value equals to 0.75 and the velocity limit at the top boundary should be around 1.2 m/s. These values were then kept the same for all the following validation tests.

4-1 Transect 1 (10/09/2002)

Field survey along transect-1 during 10/09/2002 was selected for the model testing as the first case. Due to the nature of the field campaign, no computational results along a single grid line can be used for the comparison. Therefore, the computed alongshore velocity \( (v) \) between \( Y = 600m \) and \( Y = 800m \) were chosen to compare with the measurements in Fig 4 at a number of tidal phases, i.e. from the highest tidal level to the lowest tidal level.
During the flooding period, the computed data follow with the measurements reasonably well although certain differences are found in the near shore region. After the ebb starts, the differences between the computed and measured values become noticeable in the offshore region. Around the mean water level, the divergences are much larger. This is due to the fact that the tidal waves propagation in the measurements apparently shows a higher celerity in the offshore than that in the model results, which leads to a water level gradient in the cross-shore direction and more equal alongshore velocity distribution. Such a feature is not included in the present simulation scheme. However, the model results agree with field data in the near shore area very well during these periods, which can be explained by the fact that the shallow water depth accelerates the tidal wave propagation speed. As the water level further drops towards the lowest value, the agreements between the model results and the measurements are satisfactory.

Time history of the resultant velocity magnitude along Transect 1 is compared with the field data at number of across-shore positions in Fig. 5. The phase difference is clearly seen in the offshore around 18hr when the tidal level approaching to its maximum. In the near shore area, i.e. X > 2000m, however, the computed and measured values are much closer as indicated in the previous alongshore velocity comparisons in Fig 4.

![Diagram showing comparison of computed and measured velocity](image_url)

**Fig. 4** Comparison of computed and measured alongshore velocity spatial distribution along Transect 1 at number of tidal phases during 10/09/2002.
The computed velocities along Transect 1 in the eastern and northern directions are compared with the field data in Fig 6 and 7. Fig 8 shows the comparison of the computed and measurements water level along Transect 1. The broken lines in these figures also indicate ±20% error. It can be seen that the predicted water levels are all within the 20% error band. Most the computed velocities fall into the error bands apart from a number of points around the zero which reflects these over and under estimations at mean water level in Fig 4 and 5. Nevertheless, the overall agreements are found reasonable given the uncertainties involved in the measurements and the simple representation of the tides in the present scheme.
Fig. 6 Comparison of computed and measured eastern velocity along Transect 1 during 10/09/2002.

Fig. 7 Comparison of computed and measured northern velocity along Transect 1 during 10/09/2002.

Fig. 8 Comparison of computed and measured water level along Transect 1 during 10/09/2002.
4-2 Transect 2 (11/09/2002)

The second model test includes the simulation of the field survey between 10/09/2002 – 11/09/2002 in which the model results along Transect 2 are compared with the field data in Fig 9 – Fig 13. Similar to the Transect 1 comparisons, the computed results in the region of 2625<Y<2725 were selected instead of results along a single alongshore grid line.

Fig 9 shows the model simulates the alongshore velocity reasonably well throughout the period from the highest to the lowest tidal level. In few instance, however, it can be seen that the alongshore water level gradient in the measurements are not predicted by the model, particularly around the mean water level. Such differences are largely due to the cross-shore water level gradient as shown in previous Fig 4.

Unlike the comparisons along Transect 1, no significant phase differences between the predictions and the measurements are found in the alongshore direction along Transect 2 in Fig 10. This is partly due to the fact that the Transect 2 is within X > 2000m where the prediction follows the measurements very well as shown in Fig 5.

The comparisons in Fig 11 and Fig 12 indicate certain divergences in the predicted northern and eastern velocities along Transect 2. It also should be pointed out that in the comparison, no direct computed values are available at some of the measuring point and the predictions at the nearby grid points are used instead, which may also explain some of the large scatters. In addition, the differences found during the mean water level also contribute to such scatters. However, the water level predicted in Fig 13 agrees with the measurements quite well apart from few points outside the 20% error band around zero level.

Fig. 9 Comparison of computed and measured alongshore velocity spatial distribution along Transect 2 during 11/09/2002
Fig. 10 Comparison of computed and measured resultant velocity magnitude time history along Transect 2 at number of alongshore positions.

Fig. 11 Comparison of computed and measured velocity in the eastern direction along Transect 2 during 11/09/2002.
Fig. 12 Comparison of computed and measured velocity in the northern direction along Transect 2 during 11/09/2002.

Fig. 13 Comparison of computed and measured water level along Transect 2 during 11/09/2002.

4-3 AquaDeep (04/02/2004)

To test the simulation scheme for tidal surge, the model was also applied to a survey carried out during 4th February, 2004. The measured water level at AquaDeep was used as tidal level input. The computed water level and this particular point and associated alongshore and across-shore velocities were then compared with field measurements in Fig 14, 15 and 16 respectively.

As indicated in Fig 15, the model predicted alongshore velocity reasonably well at this point. The downstream directional velocity due to the eddy generation two breakwaters just after the tide current change direction has been correctly simulated. The across-shore velocity is somewhat underestimated around the mean water level time in Fig 16. However, the overall agreements are considered to be satisfactory.
Fig. 14 Comparison of computed and measured water level at AquaDeep during 04/02/2004.

Fig. 15 Comparison of computed and measured alongshore velocity at AquaDeep during 04/02/2024.

Fig. 16 Comparison of computed and measured across-shore velocity at AquaDeep during 04/02/2024.
5 Conclusions

A tidal current simulation scheme has been tested against detailed field measurements along transactions in both alongshore and across-shore directions in adjacent to emerged breakwaters. The agreements between model’s predictions and measurements are found overall satisfactory. Noticeable differences were found around the mean tidal level time which partly due to the common tidal level distribution along the driving boundary was used. However, the largest divergences were found in the offshore region, which is not significant from the objective of the present research project, i.e. the near shore morphological processes in associated with the emerging breakwaters.

6 References

