Testing TELEMAC-2D suitability for tsunami propagation from source to near shore

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***Abstract*—When a tsunami has a large source area it may be the case that important wavelengths of the resulting tsunami wave are in the shallow water domain (i.e. wavelength is greater than 20 times the water depth). In this case TELEMAC-2D should be suitable. If shorter wavelengths are important then the best approach could be to use TELEMAC-3D non-hydrostatic.**

TELEMAC-2D should be tested for ability to model wave propagation correctly as well as diffraction and refraction phenomena. In this case, it is not expected that the inundation behaviour will be represented in the same model as the propagation to near shore is modelled using the wave equation formulation in TELEMAC-2D and the inundation phase (if required) will use the finite volume (kinetic scheme) in TELEMAC-2D.

So it is important to find analytical or laboratory test cases that are within the shallow water equations' limit of validity. Some such test cases have been identified and the performance of TELEMAC-2D in comparison is presented in this paper.

I. INTRODUCTION

To be used for tsunami propagation modelling it is important that a flow model be able to propagate waves a long way across oceans with small energy dissipation, especially where the wave is of small amplitude in great water depth. It should also be able to refract waves under conditions of varying water depth and diffract around structures and islands. It should evolve the wave shape correctly in going into shallower water.

TELEMAC has many possible options for the modelling of tsunami propagation. For example, TELEMAC-2D wave equation formulation or primitive equations or Roe scheme or Kinetic scheme first or second order or Boussinesq equations or TELEMAC-3D hydrostatic or non-hydrostatic.

When a tsunami has a large source area it may be the case that important wavelengths of the resulting tsunami wave are in the shallow water domain (i.e. wavelength is greater than 20 times the water depth). In this case TELEMAC-2D should be suitable. If shorter wavelengths are important then the best approach could be to use TELEMAC-3D non-hydrostatic.

TELEMAC-2D should be tested for ability to model wave propagation correctly as well as diffraction and refraction phenomena. In this case, it is not expected in general that the inundation of dry land will be represented in the same model. This is because the propagation to near shore is modelled using the wave equation formulation in TELEMAC-2D and the inundation phase (if required) will use the finite volume (kinetic scheme) in TELEMAC-2D.

So it is important to find analytical or laboratory test cases that are within the shallow water equations' limit of validity. Some such test cases have been identified and the performance of TELEMAC-2D in comparison is presented.

II. TESTING TELEMAC-2D SUITABILITY FOR TSUNAMI PROPAGATION

The test cases considered here are cases where the waves are long and so can be simulated using the shallow water equations. The first two cases are of wave diffraction occurring at the point of a semi-infinite breakwater [1] and refraction around a circular island [2]. Both of these processes are extremely important as tsunami waves travel a long way and are subject to diffraction around islands, headlands etc., and are subject to refraction wherever there are significant variations of water depth. A third test case is the Monai tsunami physical model test case [3].

A. Diffraction by semi-infinite breakwater [1]

This case is the analytical solution for a sinusoidal train of waves travelling north and diffracting around the tip of a semi-infinite breakwater along the positive x-axis as depicted in Fig. 1.

The TELEMAC-2D flow model was run using the wave equation formulation and no friction or viscosity. The implicitation coefficients were taken as 0.501 (the model is second order accurate if implicitation = 0.5, but on the edge of instability as the scheme is unstable if implicitation < 0.5) and the free surface gradient compatibility was taken as 0.9 (recommended value). The water depth was taken uniform so that the wave celerity is constant everywhere. The water depth was also taken sufficiently low that the wave length was greater than 20 times the water depth and so the shallow water wave equations were valid. The wave amplitude was also taken very small so as to minimise nonlinear effects.

The incident wave boundary condition (from the south) was taken as an absorbing wave paddle and the open exit boundaries (east, west and north) were all taken as absorbing boundaries using the Thompson boundary condition. The model extends south of the breakwater so that the tip of the breakwater is an internal point of the model grid and the boundary condition on the front and back face of the breakwater is a solid wall (100% reflection condition).

In Fig. 1 the y axis shows distance from the breakwater line non-dimensionalised by the wave length. Fig. 2 shows a comparison between the wave amplitude from the model and the analytical solution along two lines parallel to and behind the breakwater at two and eight wavelengths.

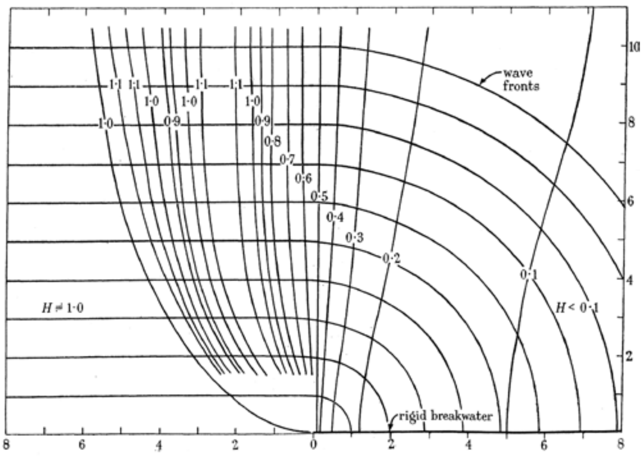

Figure 1. Wave fronts and contour lines of maximum wave heights in the lee of a breakwater. Waves are coming from the south.

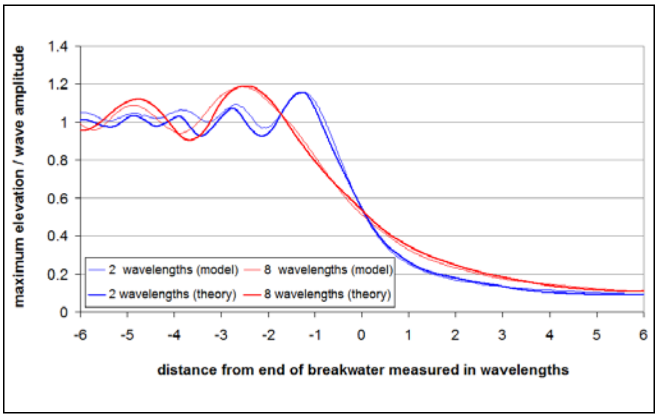

Figure 2. Wave amplitude along two lines parallel to and behind the breakwater at 2 and 8 wavelengths.
Model (thin lines) and analytical (thick lines) solutions.

The model gives a good representation of the reduction of the wave amplitude in the lee of the breakwater at two and eight wavelengths from the structure showing the diffraction process. The variation of the wave amplitude not in the lee is reasonable but rather less accurate.

B. Wave refraction and diffraction around a circular island [2]

This case is the analytical solution for a wave train travelling over a circular island, which vertical cross-section is shown in Fig. 3.

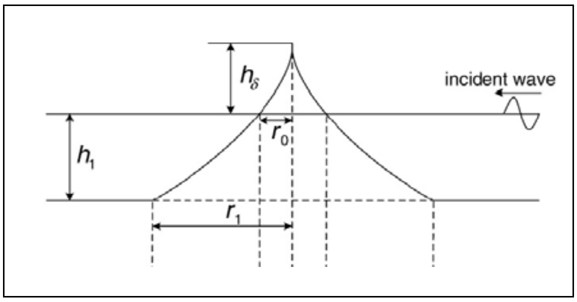

Figure 3. Vertical cross-section through circular island.

This is a case where refraction and diffraction of a wave both occur. TELEMAC-2D was again run using the wave equation formulation. The bed friction and viscosity were again set to zero and Thompson boundary condition was used so waves could pass out from the modelled domain. Free surface gradient compatibility was 0.9 and implicitation coefficients were 0.501 again.

The model is compared with the analytical solution by contouring the wave amplitude (Fig. 5) to compare with the analytical solution (Fig. 4). These figures are for a profile in which the depth varies as the 2/3 power of the radius as shown in Fig. 3.

It can be seen that the wave height pattern is well reproduced for this situation.

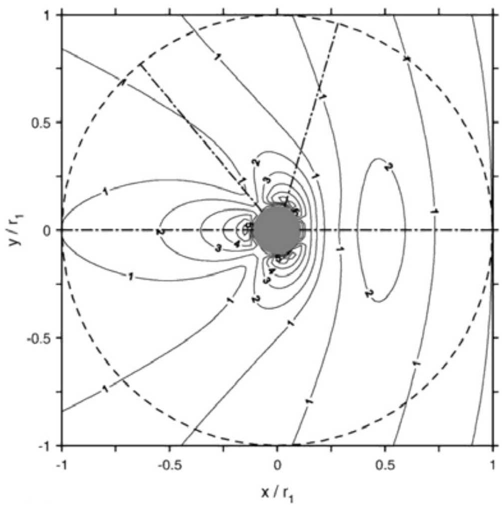

Figure 4. Wave amplitude contours for a circular island with $r_1=9r_0$, $r_0=10$ km, $h_1=4$ km. Analytical solution.

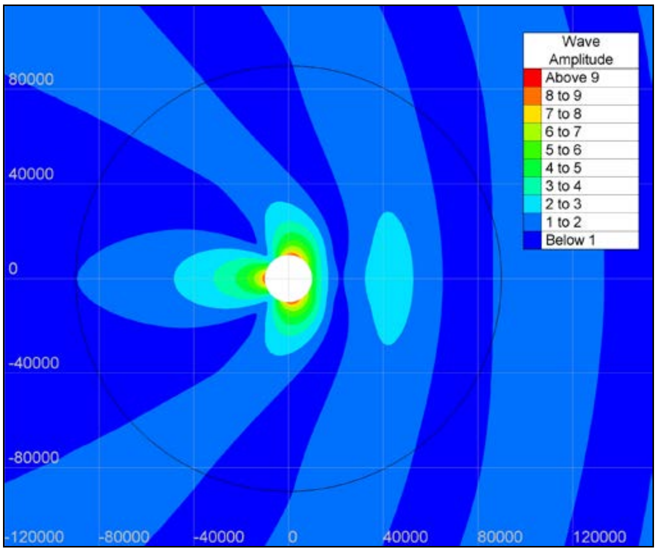

Figure 5. Wave amplitude contours for a circular island with r_1=9r_0, r_0=10 km, h_1=4 km.. Model solution.

C. *Monai tsunami physical model test case [3]*

In the Monai tsunami physical model test case [3], a tsunami wave propagates in to an inlet and transforms as the water becomes shallow. The physical model is depicted in Fig. 6.

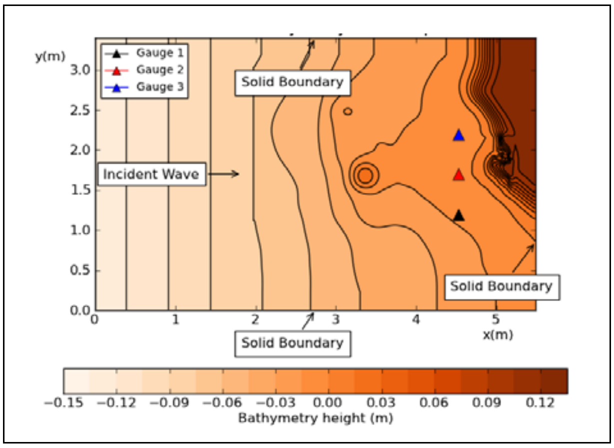

Figure 6. Monai tsunami physical model test. Bathymetry and setup.

Because this is a case where there is some inundation (see incident wave in Fig. 7) it was modelled first using the second order Kinetic finite volume scheme. Good results for all three gauges were found (Fig. 8, 9 and 10).

In view of this success the simulation was repeated using the finite element method (with free surface gradient compatibility taken as 0.9, and implicitation coefficients as 0.55). The results using the FE method are depicted in Figs 11-13. Comparing them with the finite volume method solution it seems that the results are a bit less good. In

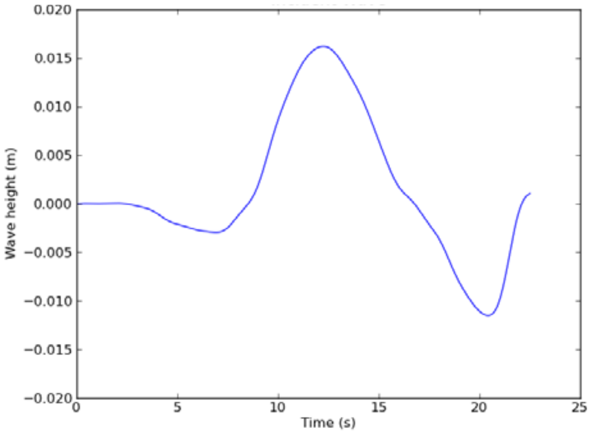

Figure 7. Monai tsunami physical model test. Incident wave.

particular the solution readily creates oscillations as the wave steepens. However it could also be considered that the finite volume model produces fewer oscillations than the observed data. It seems that the FE method is giving good results in the initially wet parts of the domain but the finite volume method becomes better in the areas which are initially dry.

III. CONCLUSIONS

Tests carried out have shown good reproduction in TELEMAC-2D, using the finite element wave equation formulation with free surface gradient compatibility of 0.9, of diffraction and refraction processes provided cases are in the domain of validity of the shallow water equations (wave length at least 20 times the water depth). For the case of wave transformation in an inlet with inundation of initially dry zones it is found that the results using the wave equation approach reproduce the height of the wave, but a closer match to the water level gauges is found by using the finite volume method.

ACKNOWLEDGEMENTS

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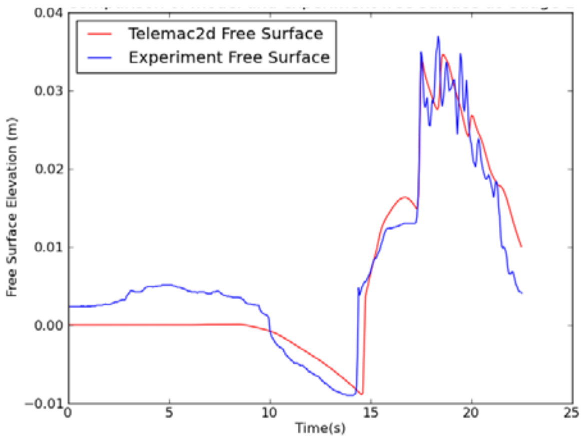

Figure 8. Comparison of model (second order Kinetic finite volume scheme) and experiment free surface at Gauge 1.

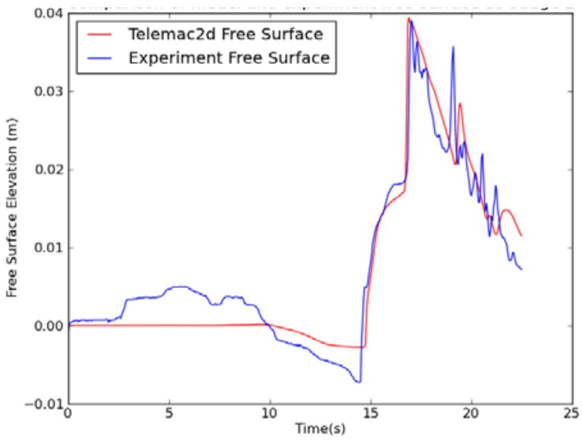

Figure 9. Comparison of model (second order Kinetic finite volume scheme) and experiment free surface at Gauge 2.

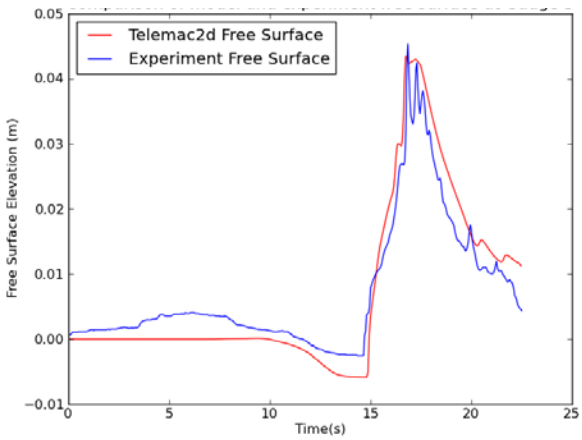

Figure 10. Comparison of model (second order Kinetic finite volume scheme) and experiment free surface at Gauge 3.

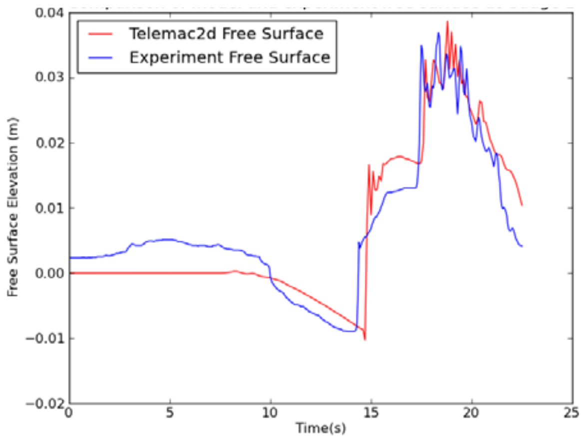

Figure 11. Comparison of model (finite element) and experiment free surface at Gauge 1.

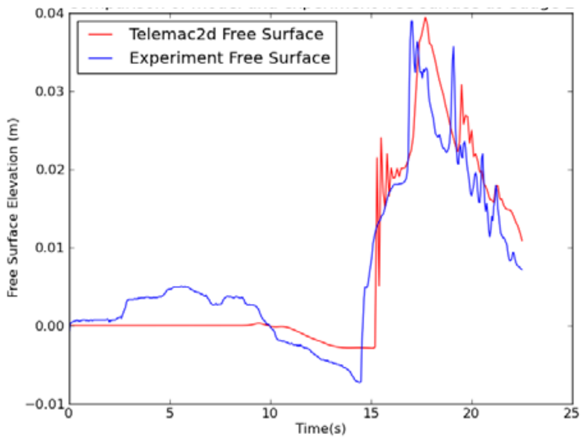

Figure 12. Comparison of model (finite element) and experiment free surface at Gauge 2.

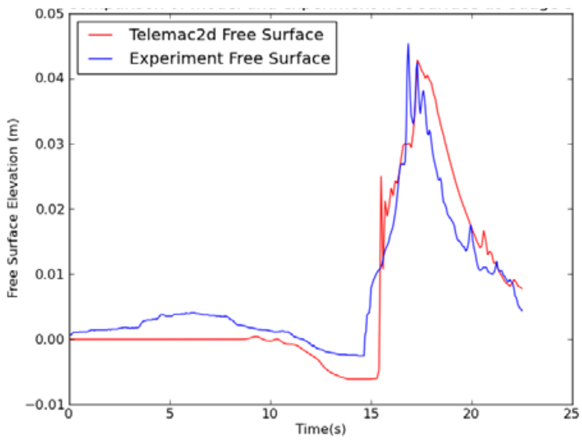

Figure 13. Comparison of model (finite element) and experiment free surface at Gauge 3.