ADVANCED MODELLING OF WAVE PENETRATION IN PORTS

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INTRODUCTION

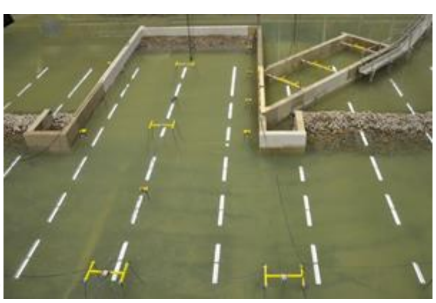
Wave penetration is a challenge for port engineers as it governs vessels' safe sailing and mooring and unequivocally regulates the handling of port operations. A complete way to describe this phenomenon is by a physical scale model. However, this approach can be time consuming and expensive, therefore the use of a numerical model is a valid alternative. In this study, wave penetration is simulated with the non-hydrostatic model SWASH (Zijlema, 2011). To validate the model, the output of an open benchmark dataset of physical scale model tests (Van der Ven, 2018) is used. Simulations of the most complex harbour layout from the given tests showed that SWASH can model primary waves resulting from a JONSWAP spectrum with an average wave height error of 15% (Van Mierlo, 2014). This study evaluates to what degree SWASH models correctly simulate wave penetration per wave process, separately in simplified models and in combination in the full harbour layout, to identify their role in the model accuracy. This research addresses regular waves conditions and a simple layout of a harbour basin (Figure. 1), in which reflection and diffraction are the main wave processes.

METHODOLOGY

Reflection outside and inside the harbour is studied by means of two simplified 1D SWASH models (Models A & B in Figure 2). Diffraction inside the harbour is demonstrated in the simplified 2D Model C (Figure 3), which includes only the concrete side walls of the harbour. The final SWASH model, Model D, (Figure 3) represents the full version of the harbour layout (Figure 1).

In total 7 tests conducted on the physical scale model are selected to be reproduced in SWASH. In one of the tests the waves exceed the breaking limit, while for another test the wave steepness approaches the breaking limit.

a.



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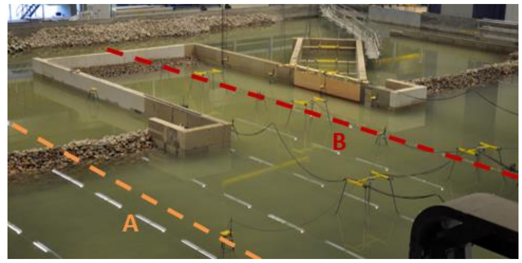
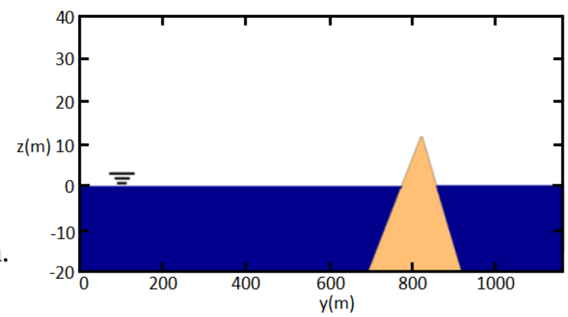


Figure 1 - Pictures a & b: The physical scale model of the simple port layout (Deltares, 2016). Dashed line A (orange) and B (red) show the cross sections of Model A & B respectively.

a.



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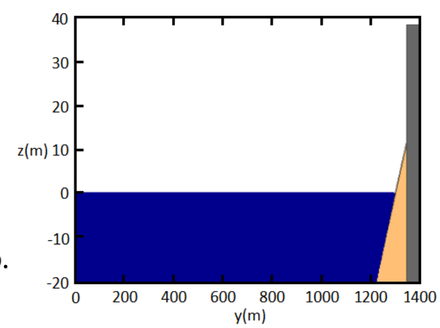

Figure 2 - Picture a : The 1D simplified SWASH Model A, where the orange triangle represents the gravel slope. Picture b: 1D simplified SWASH Model B. The orange triangle depicts the gravel slope, while the grey rectangle is the concrete quay wall.

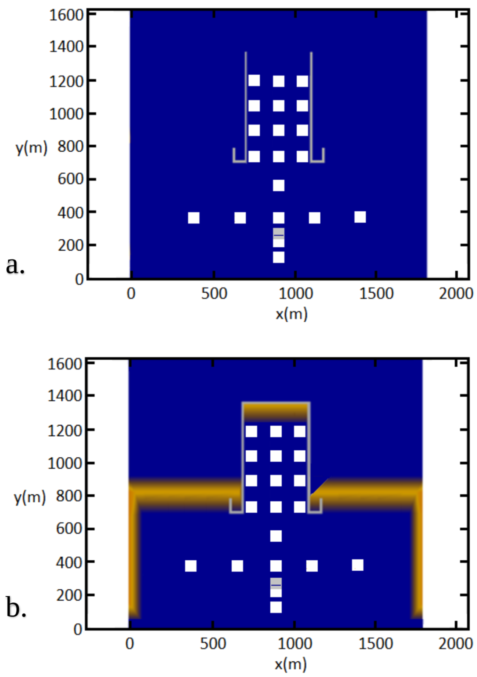

Figure 3 - Picture a: Simplified 2D diffraction SWASH Model C. The white boxes represent the output locations as defined in the physical scale model. Picture c : Final 2D SWASH Model D.

In all the models the water level time series at the output locations are compared qualitatively (increasing trends, constant/stable parts, decreasing trends) to the respective series measured at the wave gauges. Moreover, the measured steady state wave height is compared quantitatively to the SWASH outputs. The "Difference", Eq. (1), is computed to evaluate the model accuracy and to quantify the relative importance of each wave process.

$$\text{Difference/diff.} = \frac{\overline{H_{SWASH}} - \overline{H_{measured}}}{\overline{H_{measured}}} \qquad (1)$$

Where $\overline{H_{SWASH}}$ is the mean steady state wave height obtained from the wave level time series by SWASH [m], and $\overline{H_{measured}}$ the mean measured steady state wave height [m].

RESULTS

Although the reflection trends are reproduced qualitatively in 1D SWASH models, the exact steady state wave height values calculated by the model may deviate significantly from the measured values (diff.>30%). Moreover, the initial trends due to diffraction are identified in SWASH despite their short duration in the measurements. The comparison of the measured steady state wave height to the respective value computed by the 2D SWASH model C, which simulated diffraction, shows that the total measured wave penetration inside the harbour is influenced considerably by diffraction.

In the final SWASH model D, the overall changes in the wave height are reproduced by SWASH. The comparison of the SWASH results to the measurements (Figure 4) is depicted for the representative test T002 (wave length L=120.74m, kd=1.03, H/L=0.012). T002 is a representative test of the examined tests for which the ratio wave height to wave length H/L does not exceed or approach the breaking limit (5 tests). The agreement between the measured and the computed wave height is smaller than 10% at many output locations (diff.<10%), especially where the waves enter in the harbor. However, at some locations the differences are much higher (diff.>40%), especially at the harbor end as well as at the area near the harbor entrance, in front of the concrete quay walls. These high deviations are attributed to the dominant influence of reflection and the standing wave patterns which change fast within a short horizontal distance. Thus, the wave height can vary significantly at the area close to a specific wave gauge. Finally, for relatively high waves and/or breaking waves, numerical instabilities are detected. Higher spatial resolution is required to avoid instabilities and capture such phenomena.

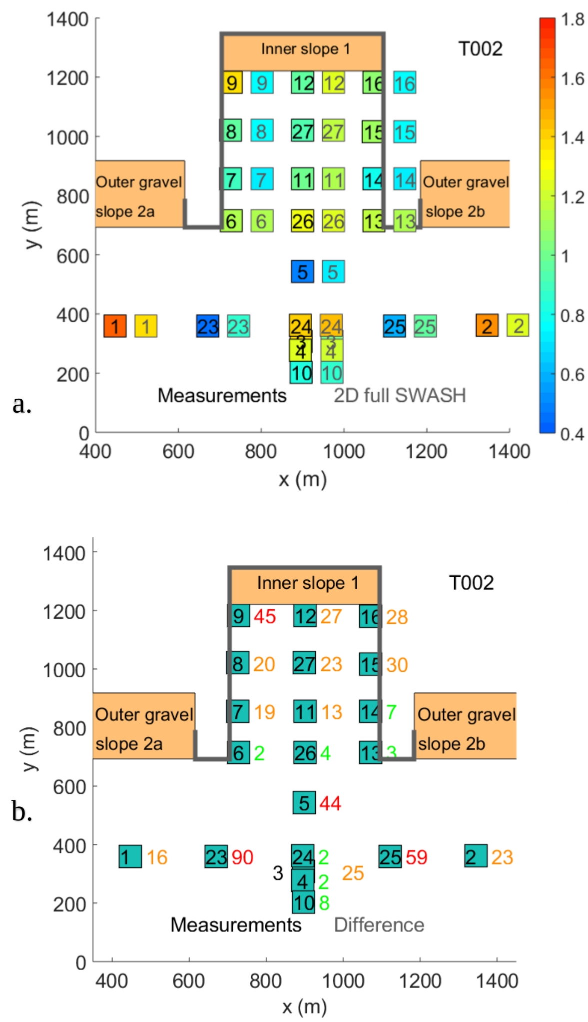

Figure 4 - Comparison of the 2D final model results to the measurements for test T002, The boxes indicate the location of the wave gauges. The number inside each box is the number of each gauge as defined in the physical scale model. Picture a: The values of the

ratio Hsteady state/ Hincoming are indicated by colours at the output locations. Each left box refers to the measured ratio, while the right box is the SWASH output value. Picture b: The difference (%) calculated based on Eq1 is depicted at all of the output locations (at the right side of the boxes).

CONCLUSIONS & RECOMMENDATIONS

The study shows SWASH's capability to reproduce qualitatively the most important reflection and diffraction trends. To a large extend, diffraction is the main process determining the wave height inside the harbour; reflection at the harbour end comes second. Outside the harbour, reflection off a quay wall is the dominant process, while reflection off a gravel slope is noteworthy. All in all, it is concluded that for non-breaking, relatively low waves, SWASH accuracy in modelling wave penetration is sufficient for engineering purposes in a harbour environment. With further validation to guarantee the model stability, the implemented methodology can be a useful tool to understand the performance of SWASH in modeling wave penetration per wave process and in combination.

REFERENCES

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