SPECTRAL MODELING OF WAVE PROPAGATION IN COASTAL AREAS WITH A HARBOR NAVIGATION CHANNEL

by

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INTRODUCTION

This study presents a comparison of numerical model results and laboratory experiments of wave propagation in a coastal area with a harbor navigation channel. The results of wave models HARES, SWAN and SWASH are compared with physical model results in order to investigate the performance and accuracy of these models.

The finite element model HARES is a stationary phase-resolving 2D parallel wave model based on the Mild-Slope Equation, developed in-house by Svašek Hydraulics. Since the introduction of the modeling concept by Berkhoff (1972), mild-slope-type models have become widespread for the modeling of wave penetration into harbor areas (see also Dingemans, 1997). In recent years 3D non-hydrostatic wave models like SWASH (Zijlema et al., 2011) have been increasingly used. Conceptually, such full 3D models are more accurate because they take into account all non-linear wave propagation effects; a downside however is the large amount of computational time needed in practice due to resolution requirements. Another model type often applied in near-shore areas is given by phase-averaged spectral wave-energy models like SWAN (Booij et al., 1999).

In 2014 a comparison has been made between a SWASH and SWAN wave model and 3D laboratory experiments of a schematized harbor navigation channel area (Dusseljee et al., 2014). Recently, Svašek Hydraulics has remodeled these laboratory experiments using the mild-slope model HARES. The present study compares the HARES results with experimental results to investigate model accuracy, and compares with SWAN and SWASH results to assess the performance of a mild-slope model compared to wave models of quite different characters.

MODEL SETUP

The physical model setup of a harbor region with navigation channel is described in Dusseljee et al. (2014) and Riezebos (2014). At prototype scale, the laboratory experiment (performed at Deltares, Netherlands) represents a harbor with a 15 km long straight access channel of depth -21.3 m. A wave spectrum with normally-distributed directional spreading was generated on deep water (at average incident wave angle 0°, approaching the navigation channel under an angle of 23°). Two distinguished wave scenarios were presented and wave conditions were measured at several locations.

In the HARES model setup, the wave conditions are discretized by dividing the 2D wave spectra into a large number of frequencies with a 0.01 Hz interval; this results in typically 30 discrete frequency bins and 20 discrete directional energy bins. HARES applies a consistent and accurate spectral treatment of non-linear bottom friction and wave breaking based on the entire wave spectrum, inspired after the spectral wave model SWAN. The model domain and bathymetry used by HARES correspond to those used within SWASH and SWAN (Dusseljee D.W., et al., 2014). The flexible mesh of the HARES domain consists of 1.06 million triangular elements with size 1.5 meters on average.

RESULTS AND DISCUSSION

A harbor approach channel can change local wave conditions considerably. When travelling waves approach the channel under an angle larger than a certain critical angle, they are fully reflected at the downward channel slope and are hindered to cross the channel (see e.g. Zwamborn and Grieve, 1974). In the present physical model this is the case for most of the waves in the spectrum, resulting in a considerable concentration of wave energy at the left side of the approach channel. Fig. 1 shows spatial distributions of the significant wave height H_{m0} as computed by SWASH, SWAN and HARES.

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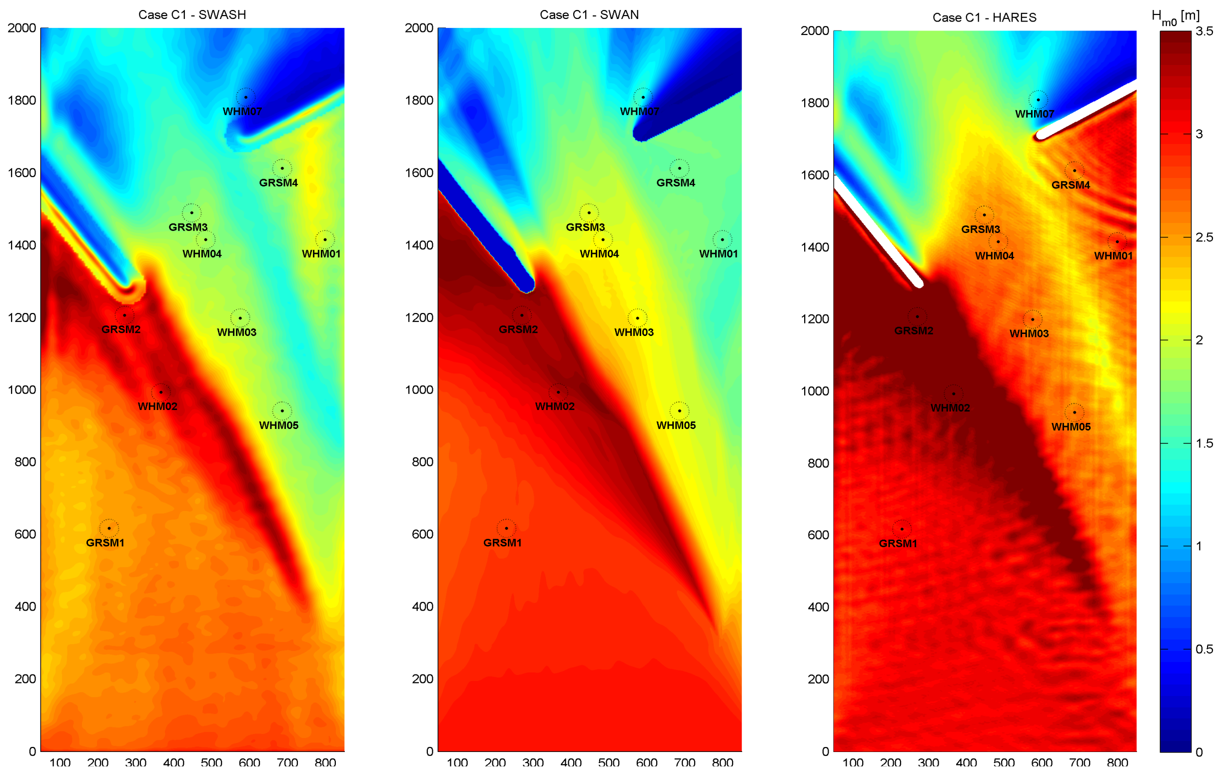

Figure 1: Spatially varying significant wave height Hm0 [m], as computed by SWASH (left), SWAN (middle) and HARES (right).

Compared to the 2014 experiments, it turns out that HARES (and to a lesser extent SWAN) results contain more wave energy and are generally more accurate than SWASH results; the latter show significant damping of high-frequency waves and hence a systematic underprediction of the wave energy. The amount of wave energy crossing the navigation channel as computed by the phase-resolving model HARES is in accordance with the physical experiments, whereas the phase-averaged spectral model SWAN underpredicts this wave energy flux across the channel. The average error over all wave measurement locations was found to lie between 15% and 24% for SWASH, between 18% and 20% for SWAN and between 3% and 10% for HARES results. The computational time on a 16-core cluster-computer was about 20 minutes for both SWAN and HARES, which was 0.7% of the SWASH computational time (about 50 hours).

As pointed out previously by Dusseljee et al. (2014) the accuracy of the present SWASH model might be improved by a further refinement of the model resolution, which would give rise to a significant and unfeasible increase of computational effort once more. It is concluded that the 3D time-dependent model SWASH is generally outperformed by time-independent and spectra-based models like SWAN and HARES, which prevents it from exploiting its full potential accuracy. Furthermore, although SWAN and HARES have comparable computational speed and both perform well near-shore, we observe that the phase-averaged model SWAN experiences difficulties regarding wave diffraction inside harbor basins and the passing of wave energy across approach channels; both problems do not apply to the phase-resolving models HARES and SWASH.

In view of the above observations, we may state that mild-slope models combine “the best of both worlds” conceptually. On the one hand, the 2D time-independent spectral approach yields an efficiency advantage above 3D time-dependent models; on the other hand, the phase-resolving mild-slope approach yields an accuracy advantage above phase-averaged spectral models for complex geometries like harbors with approach channels.

We conclude that wave models based on the Mild-Slope Equation, in combination with efficient and accurate spectral treatment of bottom friction and wave breaking based on the entire wave spectrum, are quite competitive to numerical models that are conceptually more sophisticated. In practice, mild-slope models like HARES remain a preferable tool for the design of harbor layouts.