Modelling ship waves for the purpose of overtopping

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Keywords — ship waves, SWASH, pressure field method, secondary ship waves, numerical modelling

Introduction

In the Netherlands, inland waterways are an important part of the transport infrastructure. On the Waal alone, 120-140 million tonnes of freight gets transported annually. Every ship sailing on these waterways causes ship-induced waves, which have an impact on quays and dikes. Along low-lying quays and dikes, specifically overtopping by ship waves can pose hazards for pedestrians and vehicles and hamper operations. Overtopping is caused by both the long, primary ship waves as well as the shorter secondary ship waves.

Although a lot of effort has been spent on quantifying the effects of ship waves, there are no widely applicable, reliable methods for assessing ship-wave induced overtopping in engineering practice. Currently, the most used methods for estimating ship-wave effects are analytical methods (ENW, 2007). Analytical methods that are available for this purpose are too limited in accuracy and validity (Verheij and Van Prooijen, 2007) for general application. Modelling methods such as potential flow models (Pinkster et al. 2004, Pinkster et al. 2014) or shallow water flow models like Delft3D or XBeach (Zhou et. al., 2013) cannot sufficiently represent the short, secondary ship waves. Based on earlier research, there are strong indications that SWASH should be able to model both primary and secondary components of the ship wave, due to it having a higher dispersion accuracy than other models. SWASH is a three dimensional transient model for simulating non-hydrostatic, free- surface and rotational flow (Zijlema et al., 2011). It has frequently been applied for the assessment of wave overtopping (Vanneste et. al. 2014), (Suzuki et. al. 2017). This research aims to clarify whether SWASH is a suitable tool for modelling ship-induced wave conditions at the bank for the purpose of overtopping.

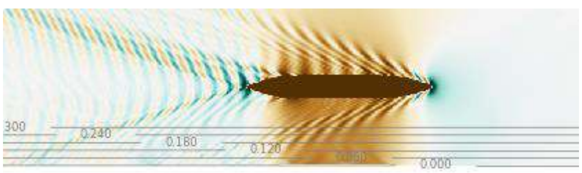

Figure 1: Top view of a simulation showing both primary and secondary ship waves as generated when simulating a towing tank experiment from Lataire et. al. (2009). The colors represent the water level with brown a water level below the reference level and green above it.

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Approach

To test our hypothesis, three main steps are undertaken to find out how SWASH performs when modelling ship-induced waves for overtopping. In the first step, the pressure field method is implemented in SWASH for the generation of ship-waves. This method has demonstrated good results for the primary waves in Delft3D and XBeach. In the pressure field method, a ship is represented as a space- and time-varying pressure field at the water surface. The sensitivity of the model to various settings is tested as well as several alternative spin-up procedures. The second step is the validation of the model with measurements. We have done this using measurements in the Port of Rotterdam, at the Nauw van Bath in the Scheldt river (Schroevers et. al., 2011) and with towing-tank measurements (Lataire et. al. (2009). The third step is a comparison of the performance of SWASH to available analytical methods: DIPRO+ which is prescribed in the Netherlands, and BAW guidelines used for the design of waterways in Germany.

Results

Implementing the pressure field method in SWASH proved to be feasible. First tests showed that the proposed methodology can be used to generate both primary and secondary ship waves, see Figures 1 and 2. An important aspect is the numerical stability which was shown to be wavering for typical situations (such as a the application of a surface piercing, sloped bank or bluntly shaped vessels). The notable persistent spin-up effects could be separated from the physical primary and secondary waves by a spin up procedure with included launching the ship first, and subsequently accelerating it. The resulting wave signal proved to be sensitive to the horizontal resolution of the computational grid. Model parameters which

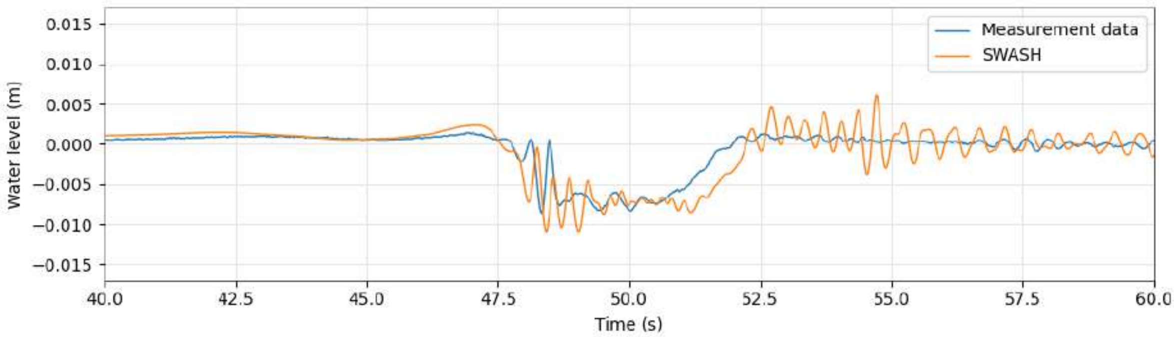

Figure 2: The water levels as measured by the top wave gauge in Figure 1. Both the long, primary wave as well as the shorter secondary waves are clearly visible.

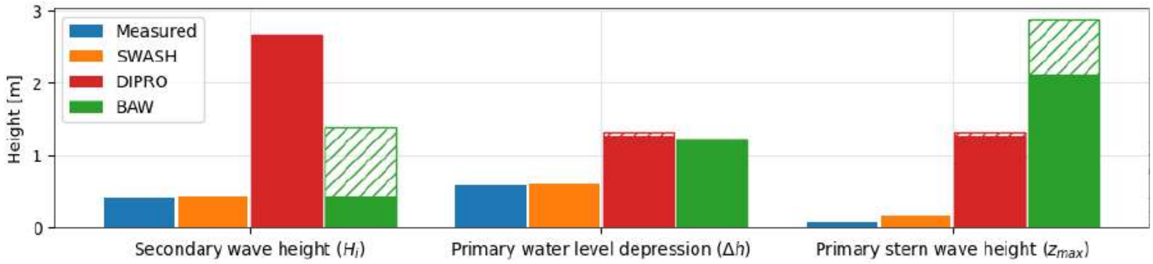

Figure 3: Wave characteristics as measured, simulated by SWASH and calculated using two analytical methods (DIPRO+ and BAW) for the simulation in Figure 1. The shading represents the uncertainty range in the analytical methods originating from the schematisation and assumptions.

are important for wave overtopping , such as bottom roughness and turbulence, have a small influence on the generated ship wave signal. The computational time for the each test was roughly one week on a conventional desktop system. Simulations of observed passages in the Port of Rotterdam and the Nauw van Bath demonstrate that our methodology can represent the wave signal accurately in complex geometries. Figure 3 shows wave characteristics in SWASH compared to measurements and guidelines used in the Netherlands (DIPRO) and Germany (BAW). SWASH clearly and consistently outperforms both Dutch and German guidelines.

Conclusions

Overall, it was demonstrated that SWASH is a valuable tool for estimating ship-induced wave conditions. The model has proven to be able to accurately represent both primary and secondary ship waves. Wave signals and components can be estimated more accurately than with any other existing method. For the purpose of overtopping, SWASH can be used to generate both primary and secondary waves to serve as input for an overtopping model. To use SWASH in a standardized engineering methodology for ship-wave generation, further study on the accuracy and sensitivity of the wave signals modelled by SWASH is necessary. For this kind of study, measurements on the ship-induced surface excursion and flow velocities at the banks would be a useful addition.

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