NUMERICAL STUDY OF WAVE INTERACTION WITH A SUBMERGED POROUS BREAKWATER IN COMBINATION WITH A FLOATING BREAKWATER

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INTRODUCTION

Conventional emerged rubble mound breakwaters are commonly built to protect ports and marinas from direct wave action. With increased high-valued developments in the coastal region, engineers have to design innovative coastal protection structures that can provide adequate harbor tranquility with minimum visual impact. One such solution is the combination of a submerged breakwater with a floating breakwater. In this paper, the open-source CFD model REEF3D (Bihs et al. 2016) is used to simulate wave interaction with a submerged porous breakwater with a floating breakwater on the lee side. The wave interaction with the submerged porous breakwater is validated by comparison with experimental data from Hieu and Tanimoto (2006). The validated model is then used to simulate the wave interaction with a combination of the submerged breakwater and the floating breakwater. The transmission coefficient across the combination is calculated to be about 12.5%, demonstrating the possibility to provide harbor tranquility with minimum visual impact.

NUMERICAL MODEL

The Volume-averaged Reynolds-averaged Navier-Stokes (VRANS) equations are used to solve the flow problem. Here, the RANS equations are averaged over volumes assumed to be larger than the length scales of the pores. The numerical model uses a fifth-order WENO scheme for convection discretisation and a third-order TVD Runge-Kutta scheme for time treatment of the RANS equations. The projection method is used for pressure treatment and the resulting Poisson equation for pressure is solved using a geometric multigrid preconditioned BiCGStab solver provided by the high-performance solver library HYPRE. Turbulence modelling is carried out using the two-equation k-ω model. The level set method is used to determine the free surface. The code is parallelised using the MPI library to improve the computational efficiency. In the numerical simulations, the submerged breakwater is considered to be porous to account for the transmission coefficient across the breakwater in a more realistic manner. The floating breakwater on the lee side of the submerged breakwater is considered to be moored such that it is restricted from motion under the influence of the waves.

RESULTS AND DISCUSSION

First, the wave interaction with a submerged porous structure is validated. Regular waves of height H= 0.092 m and period T= 1.6 s (L=2.83 m) are incident on a submerged porous breakwater in a water d= 0.376 m. The submerged breakwater is 1.16 m long with a slope of 1:1.30, a crest height of 0.33 m with a free board of 0.046 m. The breakwater is made of stones with a mean diameter D_{n50}=0.025 m with a porosity n= 0.45.
The simulations are carried out in a 25 m long, 0.8 m high 2D numerical wave tank with a grid size dx=0.005 m. In order to model the porous media flow through the breakwater, the resistance coefficients in the VRANS equations have to be specified. The resistance coefficients are chosen to be α=650 and β=2.2 based on the coefficients presented by Sasikumar et al. (2017). The free surface elevations are calculated at 1.90 m upstream of the submerged breakwater (WG1), over the toe (WG2) and at the crest of the seaward slope (WG3). The wave transmission across the submerged breakwater is measured through wave gages placed at the lee ward toe (WG4), 0.3L (WG5) and 0.5L (WG6) behind the breakwater. The floating breakwater is placed at a distance of ≈1L from the submerged breakwater. The free surface elevation is calculated at in front (WG7) and behind the floating breakwater (WG8). The numerical setup is illustrated in Figure 1.

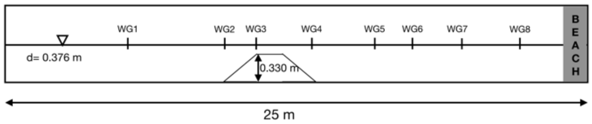

Figure 1 - Illustration of the numerical wave tank used in the study and the locations of the different wave gages

The numerical results for the free surface elevation at the different wave gage locations from the wave interaction with the submerged porous breakwater are presented in Figs 2-5, along with the comparison to the experimental data from Hieu and Tanimoto (2006). Figure 1 shows the waves incident on the submerged breakwater at WG1, while the free surface elevation at the crest of the seaward slope at WG3 is presented in Fig. 3. The free surface elevation over the leeward toe and at L/2 from the breakwater are presented in Figs. 4 and 5 respectively. It is seen that the numerical results show a very good agreement with the experimental data.

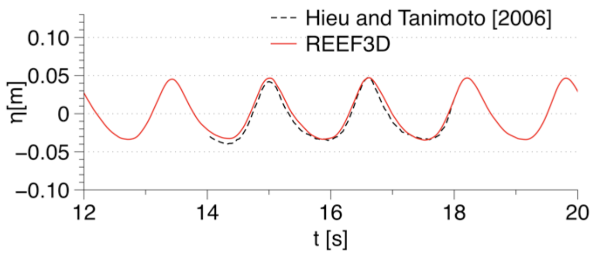

Figure 2 - Free surface elevation at WG1, upstream of the porous submerged breakwater showing the incident waves

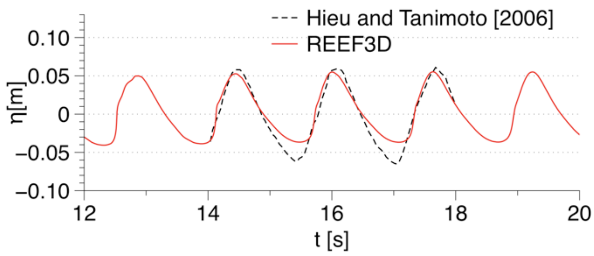

Figure 3 - Free surface elevation at WG3 on the crest of the seaward slope of the submerged breakwater

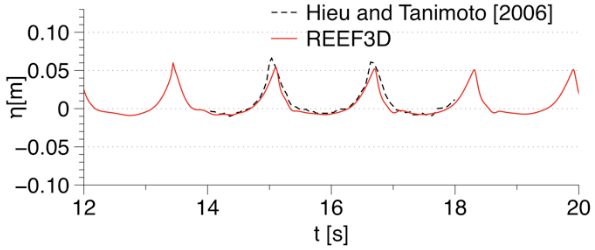

Figure 4 - Free surface elevation at WG4 over the toe of the leeward slope of the submerged breakwater

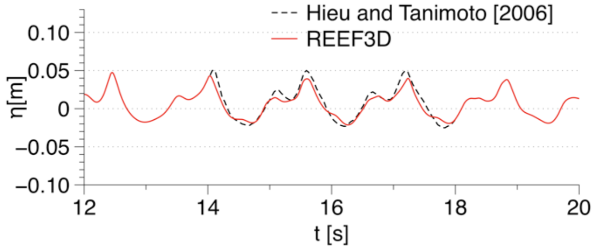

Figure 5 - Free surface elevation at WG6 at about L/2 from the toe of the leeward slope of the submerged breakwater

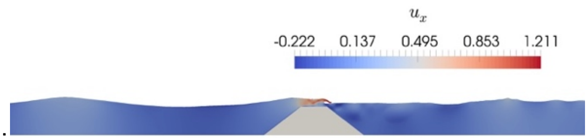

Figure 6 - Breaking wave on the crest of the submerged porous breakwater

The simulation is repeated with the floating breakwater on the leeside of the submerged breakwater. The free surface elevations at locations L/2 behind the submerged breakwater (WG6), in front of the floating breakwater (WG7) and behind the floating breakwater (WG8) are compared in Figs. 7-9 respectively. It is seen in Figs. 7 and 8 that the presence of the floating breakwater affects the free surface elevations at WG6 and 7 only slightly due to some reflection. Behind the floating breakwater at WG8 in Fig. 9, the free surface is seen to be largely damped out in the presence of the floating breakwater. The transmitted wave height across the combined submerged and floating breakwaters is about 12.5% of the incident wave height. The submerged breakwater alone allows for a transmission of about 40% of the incident wave height. The wave interaction with the combined submerged and floating breakwater in the numerical wave tank is shown in Fig. 10.

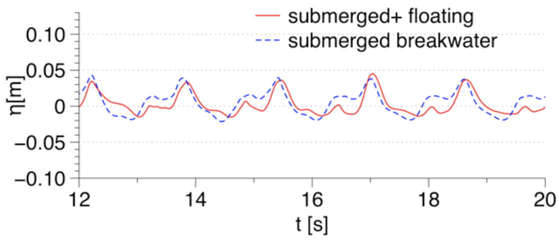

Figure 7 - Free surface elevation at WG6 at about L/2 from the toe of the leeward slope of the submerged breakwater, with and without the floating breakwater on the lee side.

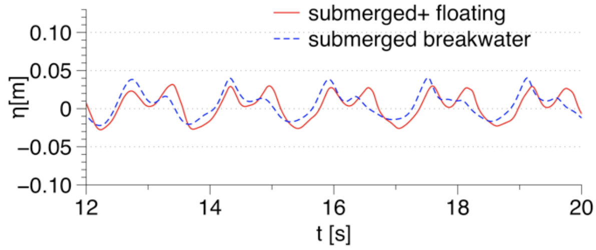

Figure 8 - Free surface elevation at WG7, a location just in front of the floating breakwater, with and without the floating breakwater on the lee side.

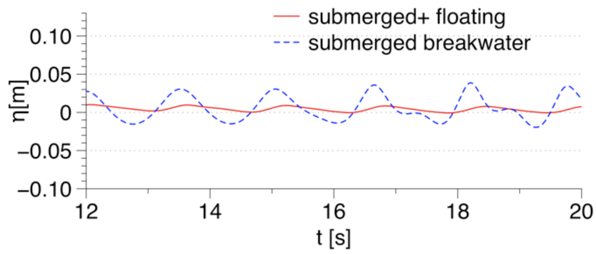

Figure 9 - Free surface elevation at WG8, a location just behind the floating breakwater, with and without the floating breakwater on the lee side.

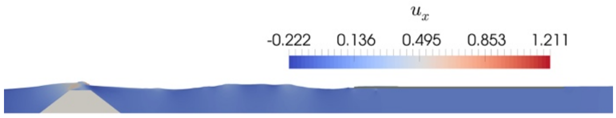

Figure 10 - Wave interaction with the submerged porous breakwater and the floating breakwater on the lee side. The thin floating breakwater is seen as a flat free surface due to its elongated dimensions.

CONCLUSIONS

The open-source CFD model REEF3D is used to simulate the interaction of regular waves with a submerged porous breakwater in combination with a floating breakwater. The model is validated for wave interaction with a submerged porous structure using experimental data. An effective reduction of about 87% of the incident wave height is calculated for the combination. Further studies can be carried out including the six degrees of freedom of the floating breakwater and the mooring forces.

REFERENCES

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