CFD MODELING OF THE EFFECT OF ANTIFER UNITS USED IN THE ARMOR LAYER OF MOUND BREAKWATERS ON WAVE OVERTOPPING

Baris Ufuk Senturk, Middle East Technical University, ufuk@metu.edu.tr
Furkan Demir, Middle East Technical University, furkan.demir@plymouth.ac.uk
Berkay Erler, Middle East Technical University, erler.berkay@metu.edu.tr
Alperen Mulayim Korkmaz, Middle East Technical University, alperen.korkmaz@metu.edu.tr
Hasan Gokhan Guler, Middle East Technical University, goguler@metu.edu.tr
Cuneyt Baykal, Middle East Technical University, cbaykal@metu.edu.tr
Gulizar Ozyurt Tarakcioglu, Middle East Technical University, gulizar@metu.edu.tr
Dogan Kisacik, Izmir Institute of Technology, dogankisacik@iyte.edu.tr
Isikhan Guler, Middle East Technical University, isikhan@metu.edu.tr
Ahmet Cevdet Yalciner, Middle East Technical University, yalciner@metu.edu.tr
Aysen Ergin, Middle East Technical University, ergin@metu.edu.tr

INTRODUCTION

Accurate prediction of wave overtopping is crucial for designing mound breakwaters. It is a common practice to use empirical equations (e.g. EurOtop, 2018) to determine wave overtopping discharges for practical purposes. On the other hand, with the help of the exponential increase in computer technology, the use of computational fluid dynamics (CFD) tools for wave overtopping is becoming widespread (e.g. Chen et al., 2021). In coastal engineering CFD applications, it is a common practice to model the mound breakwaters using a macro porous media modeling approach, where the overall flow behavior through the porous media is mimicked (Guler, 2020). Volume-averaged Reynolds-averaged Navier-Stokes (VARANS) equations are an integral part of the macro porous media modeling approach. However, the appropriate application of VARANS equations strongly depends on the friction coefficients, especially when investigating the processes around the porous regions. These coefficients appear in the VARANS equations due to volume averaging based on the Darcy-Forchheimer Equation. Although Jensen et al. (2014) previously carried out an extensive study for the calibration of these friction coefficients under different conditions considering flow through rocks, the effects of different armor units, placement methods, and packing density have not been studied in the literature yet. This study delves into the calibration of friction coefficients within the VARANS equations for Antifer units used in the armor layer of mound breakwaters with different placement methods (closed pyramid, double pyramid, and irregular) and packing densities by comparing the results with the physical model experiments. Thus, this research aims to increase the accuracy of CFD assessments on wave overtopping, offering important opportunities for the design of coastal structures.

METHODOLOGY

A numerical solver, *ibmPorFoam*, established based on OpenFOAM® CFD library by Guler (2020) is used in the present study. It is capable of solving the fluid flow inside and outside the porous media, free-surface capturing in addition to wave generation/absorption based on the boundary conditions by Higuera et al. (2013). Flow properties inside the porous media are calculated by solving two-phase VARANS equations that are continuity and momentum equations. In these equations, three coefficients appear related to the porous media flow: linear (α) and non-linear (β) friction coefficients and added mass (C) coefficient. The linear (α) and non-linear (β) friction coefficients are calibrated for different armor unit placement methods in the context of this study. On the other hand, the added mass coefficient (C) is taken as 0.34 as suggested by Jesus et al. (2012).

In this study, two bichromatic wave series are used. The first bichromatic wave series is generated by superposing two monochromatic waves with a wave height of 13.3 cm and periods of 2.18 and 2.62 seconds, while the second one is generated using a wave height of 12.5 cm and periods of 1.91 and 2.29 seconds. The group periods of these wave series are obtained as 13.09 and 11.45 seconds, respectively. Here, we only present the results of the first bichromatic wave series for the sake of brevity.

Within the scope of numerical modeling studies, a two-dimensional computational domain shown in Figure 1 is generated, which is the same placement method as the physical model experiments by Erler (2023). The computational settings are determined based on the recommendations by Larsen et al. (2019). Accordingly, the ratio of the smallest wave height *(H)* in the bichromatic wave series to the vertical cell thickness in the vertical direction is fixed as $H/\Delta z$=12.5. Thus, even the smallest waves in the wave series can be resolved. As a result, the vertical cell thickness is determined as constant Δz=0.4 cm. In addition, the ratio of horizontal cell thickness to vertical cell thickness is taken as constant $\Delta x/\Delta z$=1.5 throughout the entire area. The breakwater toe, armor layer, rear-side armor layer, filter, and core layers are defined as porous media. The porosity and nominal mean grain diameter values for each layer are introduced to the model as the same values in the experiments.

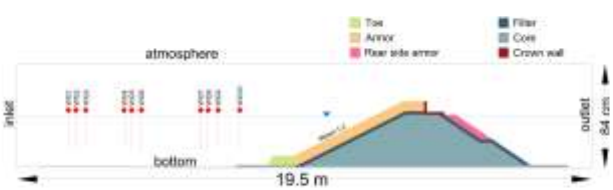

Figure 1 – Computational domain and the breakwater layers

In the experiments, free-surface elevations are taken from ten wave gauges (WG1-WG10) as shown in Figure 1. Furthermore, individual wave overtopping discharges are measured using several wave gauges and an overtopping box, as described in Erler (2023).

RESULTS

Although eight different armor layer placement methods with Antifer units are considered throughout the study, the results for the closed pyramid case having %54.8 packing density (see Fig. 2) are given in this abstract.

Figure 2 – Closed pyramid placement method with 54.8% packing density

As the first step, the free surface elevations are compared with the experimental results to validate the model. In this context, phase averaging methodology is applied to compare the results. For both experimental and numerical studies, the first two wave groups are considered as spin-up time, and the following three wave groups are phase-averaged. Phase-averaged results are given in Fig. 3, where it is seen that the numerical results are in reasonably good agreement with the experimental results.

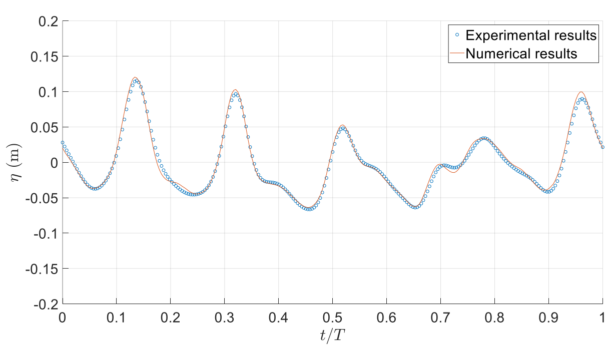

Figure 3 – Phase-averaged free-surface elevations taken from WG10.

The numerical results are obtained for different linear and non-linear friction coefficient combinations to calibrate them. In Fig. 4, snapshots from the numerical simulation during the wave passage of the highest wave are given.

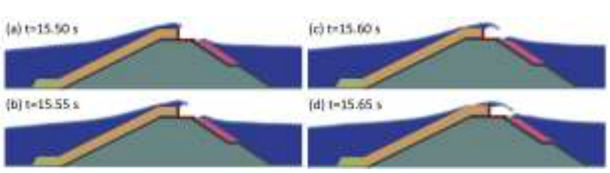

Figure 4 – Snapshots from the numerical simulation of wave overtopping

For the mean overtopping discharge comparisons, the first two wave groups are again assumed to be spin-up time, and the following three wave groups are considered in the calculations of both the experimental and numerical mean wave overtopping discharges and individual wave overtopping volumes. The numerical results are compared with the experimental data using absolute percentage error. For the closed pyramid placement method (with 54.8% packing density), mean overtopping discharge is measured as 2.15 l/s/m in the experiments, whereas it is predicted as 2.21 l/s/m using the linear and non-linear coefficients as α=200 and β=2.0, respectively, corresponding to 2.7% absolute percentage error. The comparisons of the experimental and numerical individual wave overtopping volumes will also be presented, where preliminary assessments show similar accuracy to the mean overtopping discharge comparisons.

Overall, the present study shows that the model is capable of simulating the propagation of bichromatic waves accurately. Furthermore, it is shown that the mean overtopping discharges can be predicted with reasonably high accuracy if the calibrated friction coefficients are used.

ACKNOWLEDGMENTS

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