Wave Run-Up and Overtopping Quantification at Different Coastal Structures

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ABSTRACT

With the sea level rise and all the processes associated with wave action, it is expected that the existing formulas for wave run-up and wave overtopping evaluation will be misfits, justifying further studies. In this work different methodologies to quantify wave run-up and overtopping will be evaluated by comparing the results obtained with traditional experimental tests made in a physical scale model, which consists of a sloped structure facing the direction of different irregular incident wave and tide level conditions. The first methodology is based on physical scale model films acquisition and an algorithm made in Matlab® consisting in digital images processing and analysis. The second methodology is based on numerical simulations using OpenFOAM®. Both methodologies show usefulness.

1. Introduction

The sea level rise due to climate changes and the consequent different conditions nearshore in the vicinity of coastal structures, will have an impact on those structures since extreme events become more frequent and more energetic. So, the knowledge of wave transformation close to coastal structures in those conditions become crucial for understanding physical processes (wave run-up and overtopping, in special) and to finally get a better design of those structures. Physical scale models and traditional experimental measurements have been crucial. However, they are expensive from the point of view of installed equipment and timely consumption of human resources. Digital methods and numerical methods can be an alternative. In this work, we will use digital images analysis using Matlab® to estimate wave parameters as well as numerical models based on the deterministic description of the hydrodynamics using advanced numerical models within OpenFOAM®. Both results (digital and numerical methods) are compared with measurements of free surface elevation acquired in the physical scale model with traditional methods.

2. Experimental Method

The physical model was built in the experimental facilities of the Department of Hydraulics and Environment (DHA) of LNEC, in the irregular wave channel of the Maritime Hydraulics Pavilion (COI1). The channel is 49.6 m long, 0.8 m wide and 1.0 m high and equipped with an irregular wave generator. The model, presented in Fig. 1a), is a real case and was built and explored according to Froude's law of similarity at a geometric scale of 1/90, to guarantee that the defined test conditions could be reproduced in the irregular wave channel with the available resources. This choice of scale implies that the time and volume scales were approximately 1:9.49 and 1:729000, respectively. A sloped structure 2.5:1 with height of 21.5 cm was implemented on the highest part of the bottom. Several equipment was installed in the flume, such as resistive probes measuring free-surface elevation along the channel and devices to measure the overtopping volume. We tested different water level with irregular wave train characterized by different combinations of the wave peak period and significant wave height.

3. Digital Analysis

Several films were performed under different light conditions to stablish the best conditions for the digital image processing and analysis procedure. Image analysis was carried out using different software: i) Free video to jpg converter to create a sequential of capture frames; ii) Matlab®, in which a set of scripts was created to automatically detect water height in several mark locations (Fig 1b1), where edge detection and distance between points from the edge has to be process in order to evaluate water height (Fig 1b2) and volume over the structure and define run-up and overtopping using different numerical techniques such as interpolation.

4. Numerical Model

OpenFOAM® is a widely used open source C++ toolbox, which includes different solvers, tools and libraries. It includes the solver interFoam and several boundary conditions, specially designed for coastal processes. InterFoam solver consists in solving Navier-Stokes equations / Reynolds-Averaged Navier-Stokes (RANS) equations governing the motion of the 3D incompressible and isothermal flows in which the free surface is described using a Volume-Of-Fluid method (VOF). Simulations require a detailed 3D model of the geometry that was constructed by coordinates to define the bottom and the structure using Salome to represent it through a stl ("stereolithography") file, to be used in OpenFOAM® snappyHexMesh tool to build a mesh in a parallelepiped cutted by the stl (Fig 1). Following guidelines of having 7 to 10 cells across the wave height and 100 cells along the wavelength (Carvalho et al., 2021), values of dx = dy = dz = 0.1 m were reached. Refinements parameters near the paddleboards, the sloped structure and the lateral walls were defined in snappyHexMesh Dictionary, using 2 levels for every surface-based refinement and 3 cells between levels. Data displacement from the paddle board generating a JONSWAP spectrum was extracted to define wave paddle boundary condition.

5. Results and Conclusions

Digital images taken from the physical model were processed to evaluate the water height at six different pre-defined "windows" using MATLAB scripts, which detect edges, define 2 points at the edges and calculate distance between them (Fig 1b1 and b2). Fig 1b3 shows the sequence of water depth in the selected six "windows". 100 frames from a video were tested and similarities between the results of the program and the ones from the probes of the canal can be noticed. The image quality still causes few data errors, which can be improved by new tests with different lighting conditions. Fig. 1c shows preliminary simulations with OpenFOAM®. Boundary condition to generate waves according the physical models should be improved.

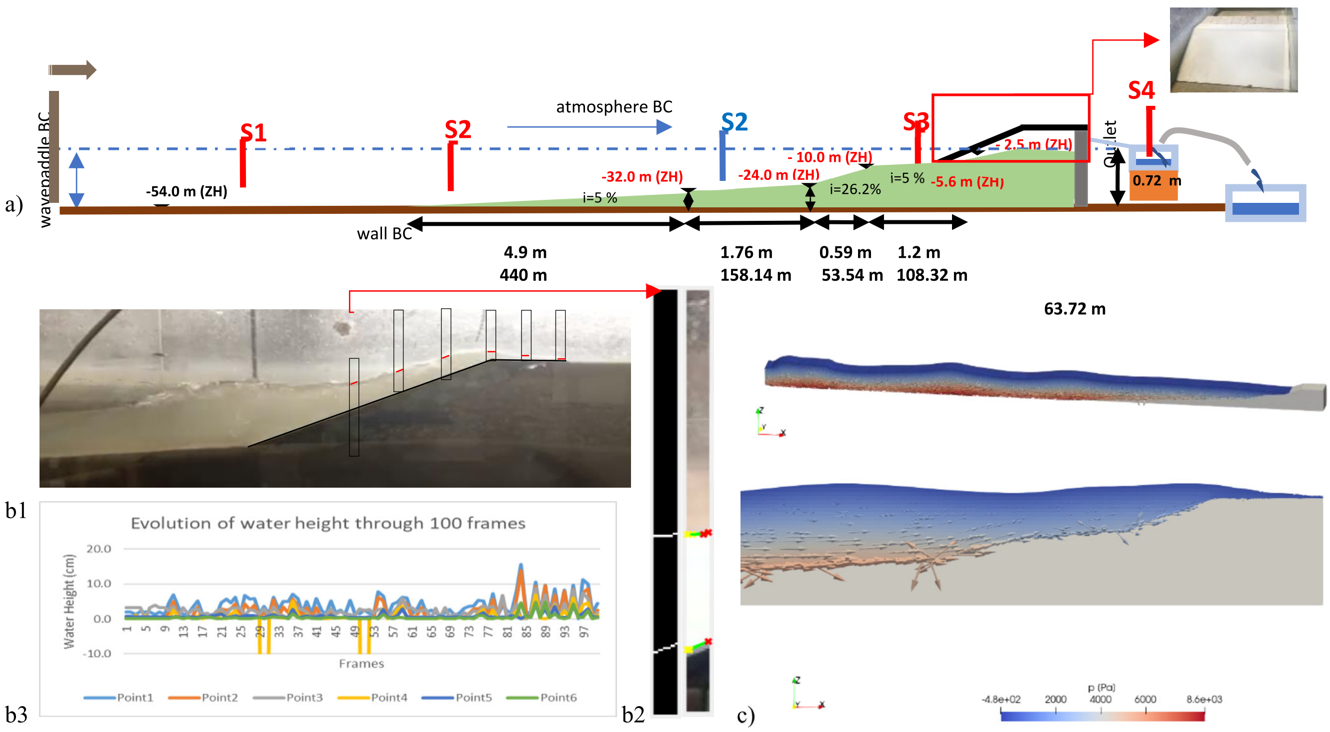

Fig. 1. Physical scale model: a) Bottom profile of the flume with the structure schema; b) images of the structure and run-up definition c) CFD preliminary simulations: 8s perspective and 9.5 s side view.

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