STABILITY OF MULTI-LAYER TETRAPOD MOUND BREAKWATERS AGAINST SOLITARY WAVES USING THE SMOOTHED PARTICLE HYDRODYNAMICS MEHTOD (SPH)

Alejandro Crespo, Universidade de Vigo, alexbexe@uvigo.es
Bonaventura Tagliafierro, Universitat Politècnica de Catalunya - BarcelonaTech, bonaventura.tagliafierro@upc.edu
Jun Mitsui, Fudo Tetra Corporation, jun.mitsui@fudotetra.co.jp
Corrado Altomare, Universitat Politècnica de Catalunya - BarcelonaTech, corrado.altomare@upc.edu
José Manuel Domínguez, Universidade de Vigo, jmdominguez@uvigo.es
Iván Martínez-Estévez, Universidade de Vigo, ivan.martinez.estevez@uvigo.es
Tomohiro Suzuki, Flanders Hydraulics, tomohiro.suzuki@mow.vlaanderen.be
Shinichi Kubota, Fudo Tetra Corporation, shinichi.kubota@fudotetra.co.jp
Moncho Gómez-Gesteira, Universidade de Vigo, mggesteira@uvigo.es

The purpose of employing artificial armour blocks in the construction of a mound breakwater is to enhance the overall stability of the system by maximising the interlocking effects among the units, offering distinct advantages over traditional rock structures of similar weights and apparent sizes (Figure 1). However, a balance must be achieved between the gaps and openings within the breakwater layout, as they play a crucial role in wave dissipation. On top of this, the coupled interplay between service and survival performance is challenging to explore in depth using conventional methods such as experiments and data-driven models. Here, high-fidelity numerical modelling can step in to complement research assessments. This study evaluates the effectiveness of an SPH-based fluid solver in modelling the behaviour of a fully deployed breakwater under extreme wave conditions. It leverages experimental data to validate the DualSPHysics software, which simulates the response of concrete Tetrapod (Daniel 1962) units that compose a breakwater when subjected to an modelled tsunami bore flow replicated using a solitary wave.

Figure 1 -Tetrapods in the Port of Molfetta (Italy). Source: Acquatecno Srl.

NUMERICAL MODELLING

In this work, the fluid phase is simulated using the Smoothed Particle Hydrodynamics (SPH) method, which offers a distinct advantage in simulating free-surface flows and capturing the complex nonlinear behaviour of wave-structure interactions and fluid-driven objects. Operating within a Lagrangian framework, SPH characterises fluid motion through *disconnected* entities known as "particles," enabling the representation of continuum properties with smoothed quantities. Based on such technique, the DualSPHysics framework (Domínguez 2022) is used to replicate the hydrodynamic response of Tetrapod units against a solitary wave. Additionally, for a more accurate representation of the surface properties of the blocks, the Discrete Element Method (DEM) from the Chrono library (Tasora 2016) is integrated in DualSPHysics (Martínez-Estévez 2023). Solid-solid interaction, which indeed dictates the stability of breakwaters, appears to be as important as the fluid-structure interaction due to the very complex shapes of Tetrapods, and the material properties of the block surface.

BACKGROUND

The stability of Tetrapod armour units against a solitary wave was assessed utilising the DualSPHysics code in Mitsui (2023). Focusing on a configuration involving a single row of Tetrapods placed on an impermeable mound, the work compared the physical motion of Tetrapod units under solitary wave conditions and the numerical results. The model successfully replicated the damage rate, defined as the percentage of Tetrapods displaced and the mean unit displacements, aligning closely with experimental findings. The results provided for the research highlight the strengths of the SPH-DEM coupling in capturing the wave impact on the units and in the induced motion. However, due to the particular breakwater layout, the validity of the outcome is limited as it only accounted for the interaction between each Tetrapod unit and the mound. In the proposed study, the collisions between Tetrapods represent an integral aspect of the broader problem and present a novel application of DualSPHysics to real-world engineering challenges. This study expands the scope to address not only Tetrapod-mound interactions but also Tetrapod-Tetrapod interactions, comprising normal and tangential contact forces.

EXPERIMENTAL CAMPAIGN

A series of physical tests was conducted at the facilities of Fudo Tetra Corporation (Japan) to analyse the movement of Tetrapod units against a solitary wave. The testing campaign was designed to validate the proposed tool, with a focus on comparing the displacement of units during numerical simulations with physical experiments. The experiments took place in a wave flume measuring 50 meters in length, 1.0 meter in width, and 1.30 meters in height, equipped with a piston-type wave generator. The block models were cast-formed using mortar, scaling down the Tetrapod model to a convenient 1:50 scale, resulting in a block size of 7.70 cm in height, a volume of

128 cm^3 and a mass of 294 g, with a density of 2.30 g/cm^3. The friction coefficient between two Tetrapods in wet condition was physically measured at 0.65. The seabed was composed of a fixed bed of mortar, and the friction coefficient between the bed and the blocks was also determined. The Tetrapods were positioned 34.5 m from the wave paddle on a 1 in 30 slope. Two layers of Tetrapods were arranged as shown in Figure 2. The first layer consisted of 3 rows with 14 units, while the second layer comprised 13 units in 2 rows.

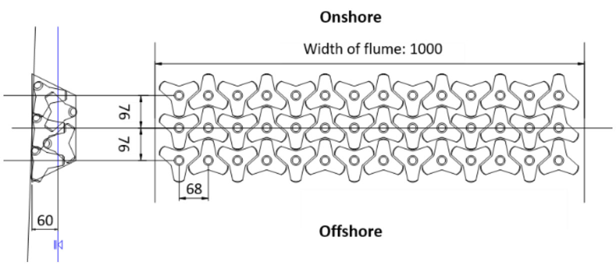

Figure 2 – Layout of the two-layer breakwater (unit in mm).

To ensure repeatability, the units were stacked in a very consistent manner, and the precise initial position of the blocks was used to initialize DualSPHysics (particles) and Chrono (blocks). The water depth offshore was 0.61 m, whereas at the breakwater location was 0.06 m, such that the first layer was almost completely submerged (side view in Figure 2). Various solitary waves were simulated, with wave heights ranging from 3 to 11 cm at a uniform water depth on the offshore side. The collected experimental data includes information on i) an incident wave without any structure, ii) wave elevations at different locations, iii) in-time unit displacement captured through video imaging techniques. It is important to note that the experiments were repeated three times under identical conditions.

RESULTS

As mentioned before, previous validations shown in Mitsui (2023) proved the capabilities of DualSPHysics to reproduce the hydrodynamic response of each Tetrapod unit under the action of different solitary waves, however only the interaction between each Tetrapod and the mound were solved using Project Chrono. New results are expected to be presented here where the two-layer breakwater (Figure 3) are simulated and the interaction between Tetrapod units are also numerically solved. Figure 3 shows the initial configuration in the experiment (top) and the initial setup for DualSPHysics (bottom). The new analysis will compute the damage rate for this simplified layout of a breakwater and will compare experimental and numerical individual displacements of its 68 units. Furthermore, the results will be presented, incorporating a convergence analysis to assess accuracy and performance across various numerical resolutions.

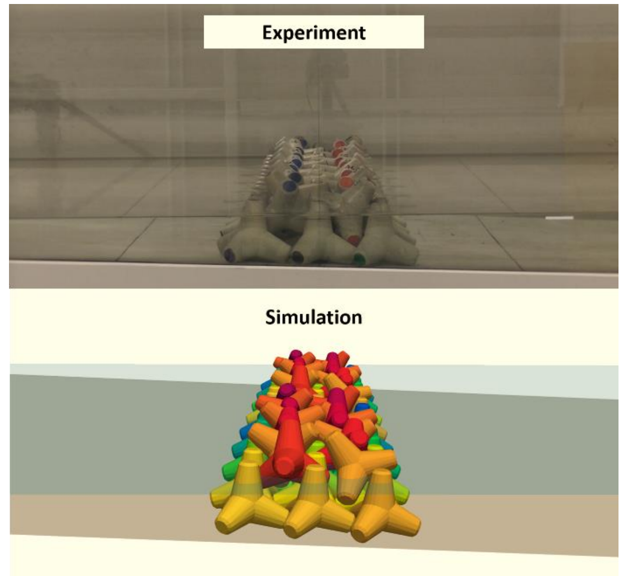

Figure 3 -Configuration of the two-layer breakwater in the experiment (top) and the setup for DualSPHysics (bottom).

To sum up, we aim to show that DualSPHysics can be used as an effective engineering tool to model the behaviour of a fully deployed breakwater under extreme wave conditions.

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