A NUMERICAL STUDY OF ARMOUR BLOCK PERFORMANCE AGAINST TSUNAMI FLOWS BY DUALSPHYSICS

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INTRODUCTION

In 2011, the tsunami generated by the Great East Japan Earthquake damaged many coastal structures. Coastal structures should be "resilient" to external forces beyond assumption. The armour blocks are usually installed to make stable of rubble mound under breakwaters. After Tohoku tsunami disaster high rubble mound has started installed behind breakwaters to prevent overturning and armour blocks were used on the high mound.

To estimate the required weight of armour blocks against waves, empirical formulas, such as Hudson (1959), van der Meer (1988), and Isbash (1932), are widely used. Their formulas cannot account for the shape of blocks, so the blocks have been developed by hydraulic model experiments for many years, but it requires many times and costs. If the displacement process can be simulated through numerical calculations, it would be a powerful tool for the development of new type blocks that have higher stability.

In the present study the Smoothed particle hydrodynamics (SPH) method is employed. SPH is a Lagrangian meshfree simulation method and a more applicable method to large deformation problems than mesh-based methods (Monaghan, 1992). This study calculates the behavior of armour blocks in tsunami flows by SPH model, DualSPHysics (Domínguez et al., 2022), and investigates the applicability for evaluating the performance by comparing with the hydraulic model experiments.

NUMERICAL MODEL

DualSPHysics is an open-source CFD model based on Weakly Compressible SPH method. DualSPHysics is coupled with the multiphysics library, Project Chrono (Martínez-Estévez et al, 2023). Project Chrono can calculate the interaction between rigid bodies using their geometry, not depending on the calculation particle size. Performing fluid flow simulations using SPH and rigid body calculations using Project Chrono can investigate fluid-structure interactions. Because DualSPHysics can perform calculations on both GPUs and CPUs, it is possible to calculate a large number of particles in a reasonable computational time.

Figure 1 shows the numerical wave tank when armour blocks are installed on high rubble mound behind a breakwater and the block shape. Oguma et al. (2020) conducted the hydraulic model experiments of armour block stability against tsunami overflow. In the experiment, the flow overflowing the breakwater is simulated by generating a steady flow using a submersible pump. The water level at harbour side and overflow height are changed, and investigate the limits that the blocks can remain stable. The blocks have holes that reduce the effect of buoyancy forces acting on them as Fig1 (c).

We assumed the breakwater and rubble mound as impermeable and fixed objects to concentrate on armour blocks' movement. The tsunami overflow is simulated by applying a certain flow to the inlet boundary and the outlet boundary as Fig.1(a). Red blocks are treated as fixed objects (no displacement allowed), while yellow objects are treated as floating objects in the SPH framework, see Fig.1(b). A floating object is a rigid body free to move under the action of the flow. We defined as "failure" when any blocks are scattered, and not scattered as "no failure".

We define the particle size as 2.0 mm in order to account for the behavior of water in the holes of the blocks. The initial particle count is approximately 10 million, and since the number of particles in the computational domain changes over time because of using open boundary conditions. The momentum equation employs the density diffusion term model proposed by Foutakas et al. (2019). In the continuum equation, the viscous term follows the Laminar SPS model as well (Gotoh et al., 2001). Modified Dynamic boundary conditions (English et al., 2020), called as mDBC, are applied to fixed boundary conditions. The mDBC is an improved version of the DBC used in DualSPHysics, improving the interaction between solid and fluid.

The computational time required for a 30-second real-time simulation is approximately 160 hours when utilizing the NVIDIA GeForce RTX 4090 GPU.

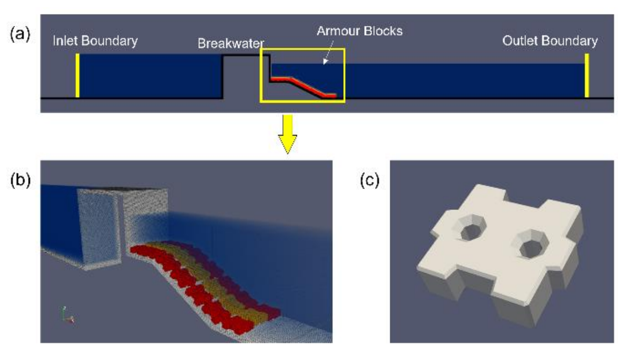

Figure 1 – Numerical wave flume. (a) shows overall view of numerical wave tank. (b) shows block on high rubble mound, red blocks are fixed while yellow blocks are floating objects. (c) shows block shape.

MAJOR RESULT

Figure 2 shows the snapshot of the simulation result of the low tide condition. The blocks were not scattered when the water level was high while the blocks were scattered when the water level was low.

Oguma et al.'s hydraulic model experiment showed that the stability of armor blocks is greater when the water level behind the breakwater is higher. The simulated failure process corresponds to the experimental results in which the armour blocks were slid and overturned. The edge of the mound is the location where a tsunami overflows a breakwater and enters the harbor side. The fluid force acting on armour blocks at the edge of the mound was greater than on the other blocks.

From these results, numerical simulation was able to reproduce the outcomes of a hydraulic model experiment and provide estimates the locations where blocks are likely to scatter. It was demonstrated that DualSPHysics is applicable for evaluating the stability of armour blocks.

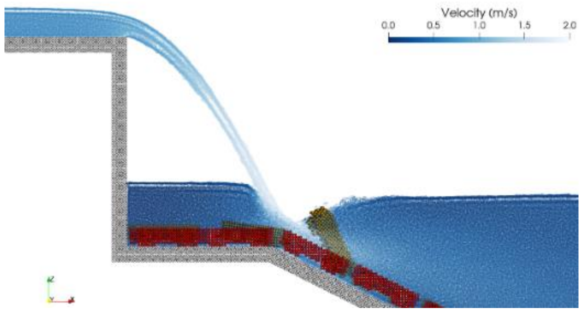

Figure 2 – Snapshot of the calculation results when changing the water level of harbor side.

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