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Modelling physical wave tank with flap paddle and porous beach in OpenFOAM

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ABSTRACT

The capability of a numerical model to mimic the operation of a physical wave tank allows us to carry out complementary numerical tests to explore various aspects or to investigate the insights of the physical tests, which are otherwise not feasible with limited measured data. The numerical model could also be extended beyond the physical limitation of a laboratory facility, such as "full-scale" tests with realistic conditions at lower cost and shorter turnaround time. In this paper, we present a construction of such a numerical model of a physical wave tank with flap paddles and porous beaches. The model is built based on the Navier-Stokes solver and the Volume of Fluids method in the open-source software Open Field Operation and Manipulation (OpenFOAM). The paddles and the beaches are explicitly modelled to mimic the behaviours of the physical counterparts in the tank. High quality laboratory experiments of regular and focused waves were conducted for the validation of the numerical model. Extension of the numerical model to a three-dimensional wave tank with individually controlled paddles is also demonstrated.

1. Introduction

Offshore structures such as floating platforms and oil derricks in the oceans are exposed to impacts of extreme waves. Due to the harsh operational conditions in the ocean, modern offshore structures are often designed with high safety factor and undergone rigorous model testing. A common avenue of testing offshore structures is by conducting experiments in laboratory wave tanks. Such model tests are costly and subject to instrumentation limitations and physical limitations of the wave tank. On the other hand, with the rapid development of supercomputers and numerical methodologies, numerical studies are less expensive and are able to a produce full range of data in the studied domain. However, model simplification and assumptions are necessary in numerical simulations, rendering the numerical results to many sources of uncertainties. Therefore, combinations of laboratory experiments and numerical simulations, which exploit the strengths while complementing the weaknesses of each approach, are more commonly adopted: experimental data is used to validate numerical models, while numerical results complement experiments where data is lacking (for example, missing data points at certain locations due to inaccessibility of physical measuring devices). Furthermore, validated numerical models can be used to evaluate various designs of offshore structures and "test" them under different environmental conditions without the need to repeat the physical experiments. Numerical models can also be extended to conduct full-scale simulations beyond the physical limit of the laboratory facilities. Such numerical experiments are time-effective and cost-saving.

A common physical wave tank uses moving paddles to generate waves and uses beaches to absorb waves. In a numerical wave tank, waves can be generated and absorbed with several methods. The most straightforward approach to generate waves is to apply pre-defined surface elevations at the lateral open boundaries of the computational domain. Generated waves are allowed to transmit freely across the lateral boundaries by using an appropriate boundary condition. This simple approach is suitable for modelling long waves in oceans such as tides and tsunami (Pang and Tkalich, 2003; Tang et al., 2009). The computational domain could be extended to include relaxation zones at the lateral boundaries for better wave generation and absorption (Jacobsen et al., 2012). In the relaxation zones, pre-defined surface elevations are relaxed to known analytical solutions for wave generation, while unwanted waves are forced to decay gradually for wave absorption. The requirement to extend the computational domain renders this method unsuitable for large numerical models, which are often the case for enclosed

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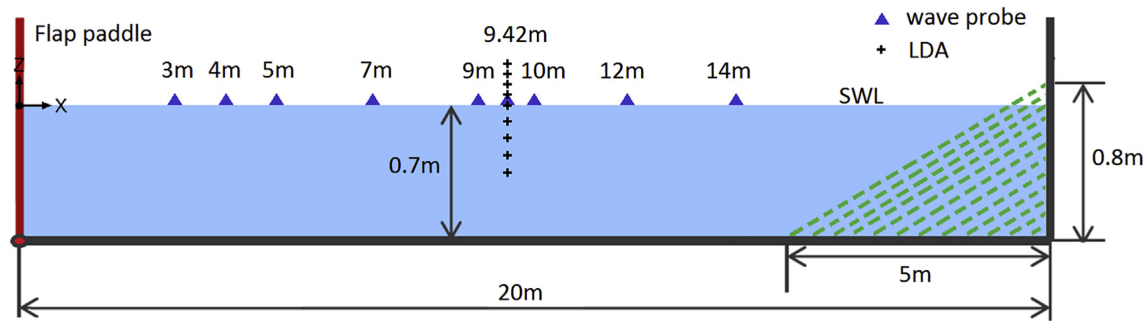

Fig. 1. Wave tank in the University of Aberdeen with a 5 m × 0.8 m porous beach. Selected locations of wave probes and LDA measurements were marked with triangles and crosses.

Table 1
Wave parameters of the four experimental cases.

Case	Type	Focused Height (mm)	Peak Frequency (Hz)
R1	Regular	150	0.5
R2	Regular	120	0.9
F1	Focused	160	0.6761
F2	Focused	72	0.8399

deep-water wave tanks. The internal wave-maker method of Lin and Liu (1999) uses an internal source that periodically produces positive and negative fluxes in the governing equations to generate waves. This approach requires the source zone to be located in the middle of the computational domain (which requires domain extension) or at a symmetric plane (which geometrically limits the computational domain). A similar approach is used in the WAMIT code for wave generation (Lee, 1995). A velocity potential (the source) is used to represent the scattered waves generated by a body (the wave paddle) which is fixed at its undisturbed position. The most direct approach to generate and absorb waves in a wave tank is to explicitly model the physical wave paddles and the beaches. This method has the advantage replicating the exact movement of the physical paddles and the characteristics of the beaches in experiments, hence replicating their effects on the wave field. Another advantage of modelling the paddle movement is the ability to incorporate an active wave correction algorithm, which is available in some physical wave tanks such as the one used in this study. This algorithm receives real-time feedbacks from the wave tank to correct the input signals into the paddle, thereby fine-tuning the wave generation. Paddles with an active wave correction algorithm have also been used as wave absorbers. Despite its advantages, the approach of modelling the paddle movement has not been widely used, due to the need for dynamic mesh. Some studies that adopted this approach are reported in Grilli (1997), where a moving boundary was applied for a two-dimensional (2D) potential flow numerical wave tank and was later generalized to a three-dimensional (3D) tank in Brandini and Grilli (2001). Recently, Higuera et al. (2013, 2015) employed the dynamic mesh solver in OpenFOAM to model piston wave paddles for wave generation and absorption in their numerical wave tanks. Numerical simulations indicated a high degree of accordance with the experiments, proving the capability of simulating wave tanks using this method.

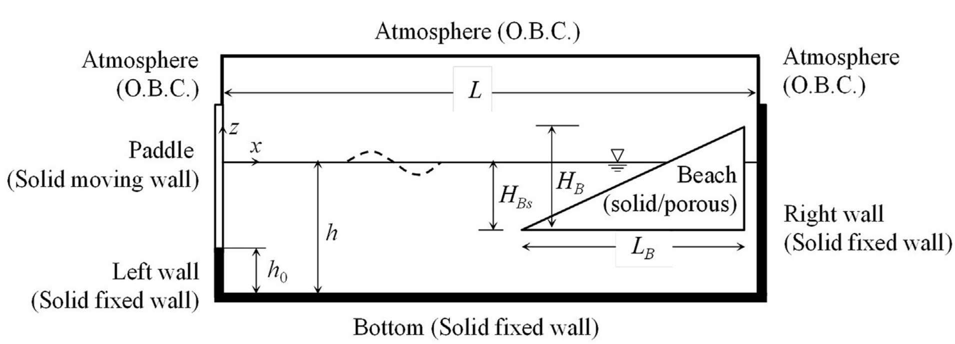

Fig. 2. Model concept of a wave tank with model boundaries and the associated boundary conditions (O. B. C. is open boundary condition).

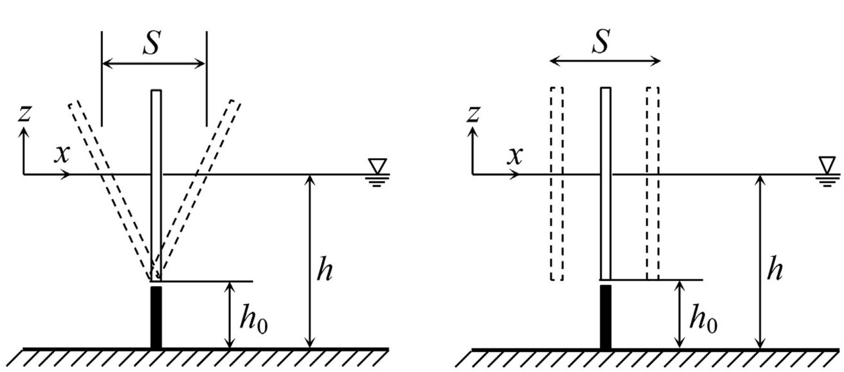

Fig. 3. Sketches of a flap paddle (left) and a piston paddle (right). The dash-line bars show the movements of the paddles. The hinge depth, h_0, is zero for paddles extending to the bottom.