Application of OpenFOAM to Coastal and Offshore Modelling

Gerald C J Morgan and Jun Zang

g.c.j.morgan@bath.ac.uk, j.zang@bath.ac.uk
Department of Architecture and Civil Engineering, University of Bath, Claverton Down, Bath, UK

Introduction

Computational Fluid Dynamics (CFD) simulations are powerful tools for analysing fluid-structure interaction. CFD is often passed over in practical design situations due to its high complexity and computational cost, despite its potential for much greater accuracy and detail than many traditional methods. As computers continue to increase in power and decrease in cost, however, CFD simulations are starting to become practical design tools in the design of coastal defences and offshore structures. This research is focussed on the assessment of how the CFD and continuum-mechanics library known as OpenFOAM performs when applied to a selection of common problems in coastal and offshore engineering.

OpenFOAM is a free, open-source library for continuum-mechanics problems written in C++ (Weller 1998). Its focus is on CFD solutions on unstructured, finite volume meshes and several pre-built CFD codes are available with OpenFOAM which have been found to be suitable for use in wide ranges of problems from complex fluid flow involving chemical reactions, turbulence and heat transfer, to solid dynamics and electromagnetics, as well as coastal and offshore problems. The solvers we used in our numerical simulations, known as the “interFoam” solvers, solve the incompressible Navier-Stokes equations using the PISO scheme. They solve for both the water and the air in a domain using a “Volume of Fluid” (VoF) approach to define the interface between the phases. A wide variety of turbulence models, discretisation schemes and other parameters can be specified.

This research presents preliminary results from three validation cases to test the ability of OpenFOAM for use in coastal and offshore eingineering: a simple, two-dimensional case of regular waves passing over a submerged breakwater; a much more complex, three-dimensional case for regular waves and focussed wave groups interacting with a vertical cylinder; and some preliminary results from a two-dimensional case for waves interacting with a porous breakwater.

Validation Test 1

To study the model’s ability to correctly model the propagation and transformation of surface water waves, a well-known test case for wave propagation was used. Beji & Battjes (1993) modelled the propagation of a regular wave over a submerged breakwater. The experiment was later repeated by Luth in 1994 and these later results are sometimes referred to in the literature as the “Dingemans” test case. It has been widely used for the validation of Boussinesq-type models.

The results from the model were compared with the experimental data in a number of ways. The experiment recorded water surface elevation time series from 11 wave gauge locations as shown in figure 1. Figure 2 shows the modelled water surface elevations (as solid lines) compared to the experimental water surface elevations (as dashed lines) for a particular wave at four locations. Figure 3 shows the corresponding amplitude spectra from these locations. The numerical predictions agree very well with the experimental measurements, including both wave forms and wave amplitude spectra—up to 6^{th} order harmonics have been correctly simulated.

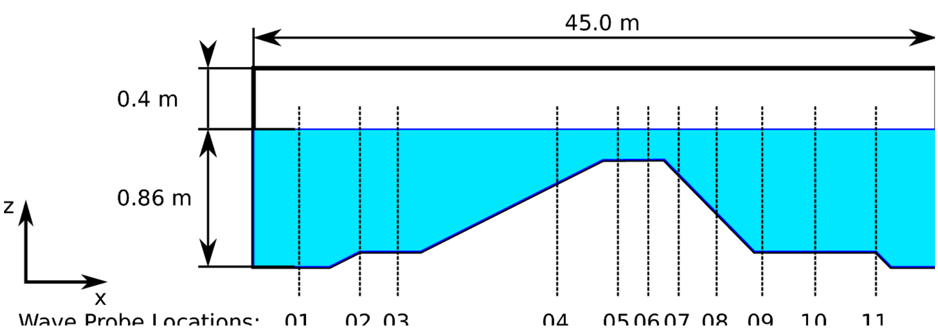

Figure 1: Breakwater geometry and wave gauge locations for the Dingemans test.

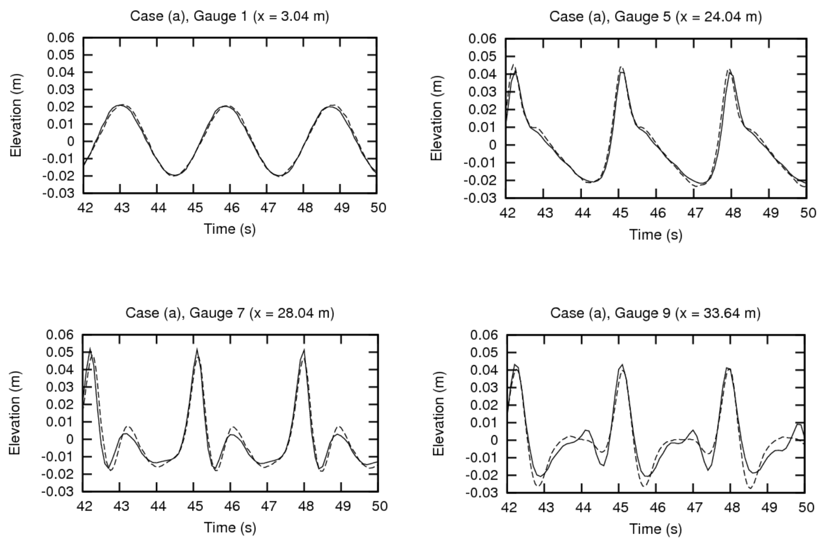

Figure 2: Graphs showing the observed (dashed line) and modelled (solid line) elevation time series at some wave gauges for case A of the Dingemans test.

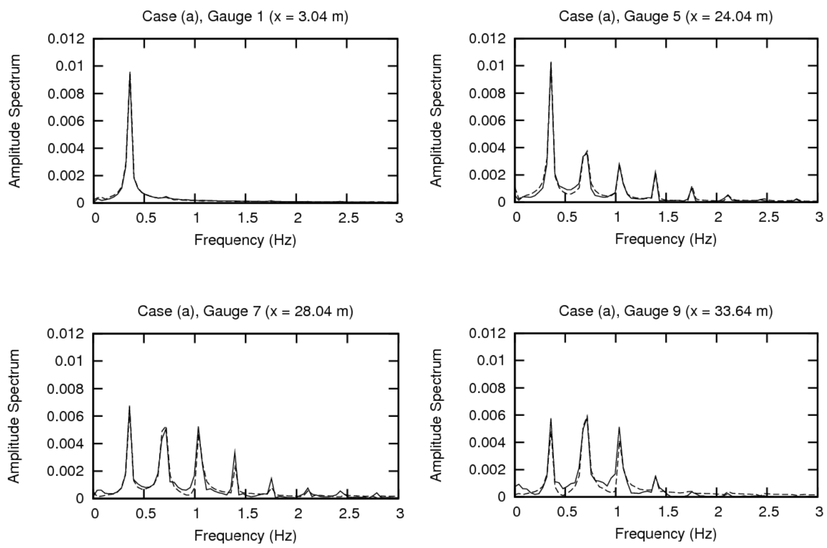

Figure 3: Graphs showing the observed (dashed line) and modelled (solid line) wave amplitude spectra at some wave gauges for case A of the Dingemans test.

Validation Test 2

To study the performance of the model for simulating three-dimensional wave interaction with a surface-piercing solid structure, the OpenFOAM was used to recreate a series of tests performed in the Danish Hydraulic Institute's shallow-water basin in the Autumn of 2009. The experiments on which this validation is based are extensive, with over 850 experimental tests being performed.

Two bed geometries were tested: a flat bed covered by a water depth of 0.505 m and a submerged, sloping beach with a gradient of 1/20 under a water depth of 0.8 m at the toe and 0.2 m at the tip. In the experiment, unidirectional waves were generated at a paddle which was positioned approximately 8 m in front of a cylinder of 0.25 m diameter. The water depth at the cylinder was 0.505 m.

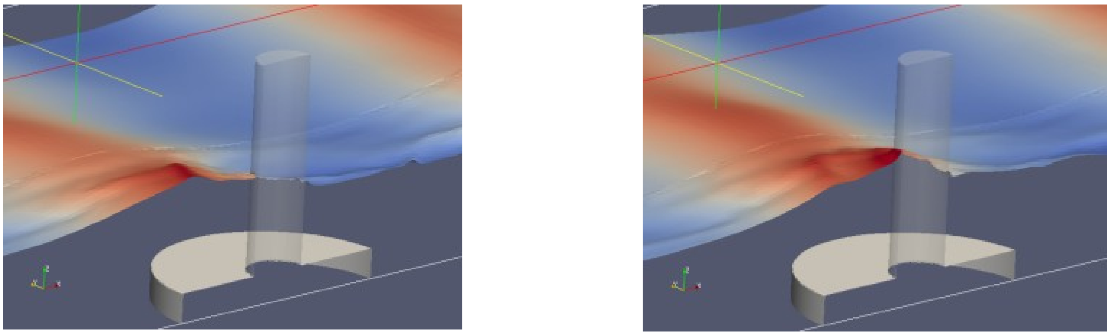

Figure 4: Images from the model of the crest of the wave group, just before and just as it is hitting the cylinder.

For each test case, free surface elevations were recorded at 19 locations around the cylinder with a sampling frequency of 1 kHz. Figure 4 shows 3D wave profiles for a focused wave group passing the cylinder.

Validation Test 3

The third validation test presented in this research is designed to study the ability of the model to simulate the interaction of waves with coarse-grained fills and sands. This is generally done in CFD models by modifying the Navier-Stokes equations to incorporate additional momentum sinks based on the Darcy-Forchheimer equation (Troch 2000).

A simple, fast, two-dimensional model has been generated based on some tests in a wave flume conducted in Aalborg and reported by Troch (2000). Regular waves propagate along a flume for approximately 17 m before hitting a porous breakwater, constructed from coarse sand. Wave gauge measurements were taken, allowing the transmission and reflection coefficients of the breakwater to be calculated, and 15 pore-pressure time series from within the breakwater were also recorded, allowing the decay in wave energy through the breakwater to be observed.

As the model is relatively small and fast, it can be used as an approximate tool to investigate the dependence of the wave transmission and reflection properties of the breakwater on the porosity, Darcy-Forchheimer, and wave parameters without the need for as many physical experiments to be performed. Figure 5 shows how the wave amplitude decrease through the breakwater is affected by the Darcy parameter, α.

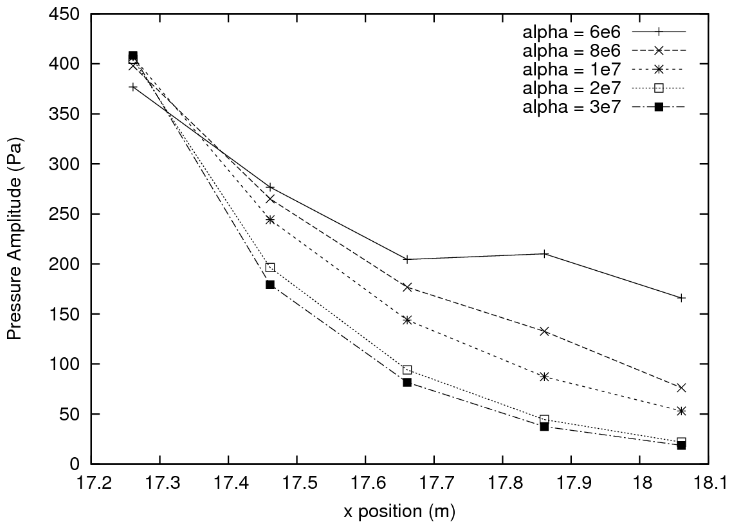

Figure 5: Graph showing how the wave amplitude decays through the breakwater in various model tests with different breakwater permeabilities.

Conclusion

These three validation tests, taken together with other work on OpenFOAM in other fields suggest that CFD tools such as OpenFOAM are able to produce results to a reasonable accuracy for a wide variety of wave conditions and geometries in coastal and offshore engineering. The fact that these results can be generated in a reasonable time makes OpenFOAM a potentially very useful tool for researchers and practising engineers & designers.

The research continues to progress and more results will be presented in the workshop.

Acknowledgements

This work was funded by the Great Western Research, Edenvale Young Associates Ltd., and the University of Bath whose support is gratefully acknowledged.

References

Beji, S. & Battjes, J. A. (1993). “Experimental investigation of wave propagation over a bar.” Coastal Engineering, 19 151–162.

Troch, P. (2000). “Experimentele studie en numerieke modelering van golfinteractie met stortsteengolfbrekers.” PhD Thesis, University of Ghent.

Weller, H. G., Tabor, G., Jasak, H. & Fureby, C. (1998). “A tensorial approach to computational continuum mechanics using object-oriented techniques.” Computers in Physics, 12 620–631.