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Quantifying the Predictive Capability of OpenFOAM 4.1: Focused Wave Interactions with a Fixed FPSO

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Numerical simulations of focused wave interactions with a fixed floating production storage and offloading (FPSO)-like structure are presented, representing an individual contribution to the CCP-WSI Blind Test Series 1, in which they are compared against both physical and alternative numerical solutions. The model is based in OpenFOAM with wave generation achieved via linear superposition of first-order wave components, derived from the empty tank data. This work focuses on comparing the "blind" estimation of accuracy, based on reproduction of the physical empty tank data (released before submission to the blind test), with the observed error in wave runup and pressure on the bow of the structure (following the release of the complete physical data set). The results imply that achieving a good reproduction of surface elevation based on the empty tank data does not necessarily correlate with good agreement when a structure is present.

INTRODUCTION

Two key issues limiting the routine use of high-fidelity models, such as computational fluid dynamics (CFD), are the uncertainty in the accuracy and the required time to obtain the numerical results. For the industry to benefit from the strengths of these methods, there is a need for a parametric understanding of their predictive capability and a reduction in the time taken to produce useable results. The required time to set up CFD simulations is a factor, often overlooked, that is sometimes significant in the overall time required to get a result. If a parametric understanding of the accuracy were achieved, the implementation time could be reduced greatly through increased confidence in prediction when using standardised, best practice implementations.

This paper presents work that was conducted as part of the CCP-WSI Blind Test Series 1 (Ransley et al., 2019), which focuses on the interaction of focused wave events with a fixed-scale model floating production storage and offloading (FPSO)-type structure. The scope of this work is to obtain a "blind" estimation of the numerical accuracy, based purely on the reproduction of available empty tank data, and compare this with the observed error in the prediction of wave runup and pressure on the bow of the structure following the release of the complete physical data set. A numerical evaluation was conducted using the open-source CFD software OpenFOAM; following that, the CCP-WSI Blind Test Series 1 was split into two parts, which are summarised in Table 1: Part 1 focuses on the role of wave steepness in both the pressure and runup on the bow of an FPSO hull through variation of the steepness parameter ka (whilst keeping the incident angle constant (0°)); Part 2 considers the effect of wave propagation direction through variation of the incident wave angle, θ (with the steepness kept constant at $ka = 0.17$). The paper structure is such that the numerical model and setup are first discussed. Work to obtain and optimise the blind estimation of error is then presented, followed by an assessment of the wave runup and pressure predictions (submitted to the blind test). Finally, the conclusions are drawn.

	Case	ka	θ	H_s	T_p
Part 1	$ka = 0.13$	0.13	0°	0.077 m	1.456 s
	$ka = 0.18$	0.18	0°	0.103 m	1.456 s
	$ka = 0.21$	0.21	0°	0.103 m	1.362 s
Part 2	$\theta = 0°$	0.17	0°	0.103 m	1.456 s
	$\theta = 10°$	0.17	10°	0.103 m	1.456 s
	$\theta = 20°$	0.17	20°	0.103 m	1.456 s

Table 1 Wave conditions used in the CCP-WSI Blind Test Series 1

NUMERICAL MODEL

This work utilises the open-source CFD software OpenFOAM, which is based on the finite volume discretisation. The interFoam solver, modified for wave generation, is used to solve the two-phase, incompressible, Reynolds-averaged Navier–Stokes (RANS) equations:

$$\frac{\partial(\rho\mathbf{u})}{\partial t} + \nabla\cdot(\rho\mathbf{u}\mathbf{u}) = -\nabla p + \nabla^2(\mu\mathbf{u}) + \rho\mathbf{g}, \quad \nabla\cdot\mathbf{u} = 0 \tag{1}$$

where p is the pressure, $\mathbf{u} = (u, v, w)$ is the fluid velocity, and $\mathbf{g}$ is acceleration due to gravity. The fluid density, ρ, and dynamic viscosity, μ, are determined using the volume of fluid (VOF) interface-capturing scheme:

$$\frac{\partial\alpha}{\partial t} + \nabla\cdot(\mathbf{u}\alpha) = 0, \; \rho = \rho_1\alpha + \rho_2(1-\alpha), \; \mu = \mu_1\alpha + \mu_2(1-\alpha) \tag{2}$$

where α is the colour function, representing the phase fraction of each mesh cell, and subscripts 1 and 2 represent air and water, respectively.

Wave Generation

The empty tank data supplied from the experimental campaign are a surface elevation time series at a finite number of spatial

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KEY WORDS: CCP-WSI Blind Test Series 1, error estimation, numerical modelling, extreme events, NewWave, optimisation.