Numerical Investigation of Scour Evolution Around Monopile Structures Using sedInterFoam

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INTRODUCTION

Scour around monopile structures critically affects offshore engineering by destabilizing foundations of wind turbines and marine installations. It results from complex wave and current interactions with the structure and seabed, creating intense flow patterns and turbulence that elevate bed shear stress, particularly upstream, forming a horseshoe vortex that initiates scour holes.

Accurate prediction of scour depth and morphology is vital for effective protection measures and structural integrity. This study uses sedInterFoam, an open-source OpenFOAM solver introduced by Mathieu (2024), to simulate sediment transport under combined wave and current conditions. By integrating multiphase flow dynamics with sediment equations, it analyses processes like bed shear stress, sediment entrainment, and deposition. Preliminary results show accuracy in predicting scour evolution, providing insights into sediment transport mechanisms and emphasizing the importance of advanced numerical tools for enhancing offshore foundation resilience against scour.

METHODOLOGY

Sediment transport and scour evolution around monopile structures are modelled using sedInterFoam, a three-phase OpenFOAM solver. Building on the two-phase Eulerian model sedFoam (Chauchat (2017)), it incorporates an air phase for free-surface dynamics, making it suitable for wave-driven coastal sediment transport. Governing equations are based on mass and momentum conservation principles applied to sediment and fluid phases (water and air). A k-ω SST turbulence model captures flow transitions, while the Volume of Fluid (VOF) method, coupled with waves2Foam, simulates wave generation, propagation, breaking, and seabed interaction. Advanced rheological models, including the Kinetic Theory of Granular Flows and μ(I) Rheology (Jop (2006)), ensure accurate sediment behaviour under varying flow conditions.

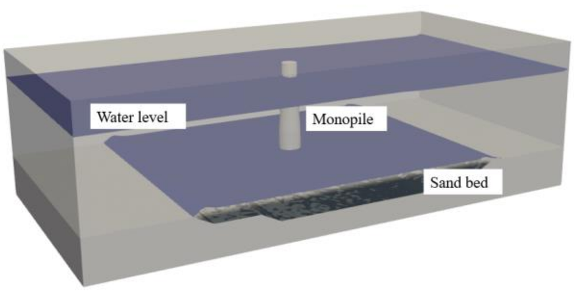

Figure 1. Computational Domain

Validation used experimental data from HR Wallingford's Fast Flow Facility, where a 1.75 m monopile was placed in a flume with a 0.3 m sand bed and 1.4 m water depth. The physical setup was meticulously replicated in OpenFOAM (Fig. 1) using a computational mesh of approximately 0.4 million hexahedral cells, ensuring high-resolution modelling of flow fields and sediment processes. Simulations were conducted under steady currents of 0.2 m/s over 600 seconds, comparing scour evolution and sediment transport against experimental results. Additional simulations explored higher current velocities (0.3 m/s, 0.4 m/s) and wave-current interactions, incorporating realistic wave parameters such as height, period, and direction to assess hydrodynamic and sediment transport responses under varied conditions.

RESULTS

Post-processing of the 600-second simulation results (Fig. 2) involved extracting a contoured surface from the volume fraction field to represent the water-sediment interface. This interface accurately captures morphological changes due to scour and deposition, enabling detailed characterization of scour depths and sediment accretion patterns around the monopile. The approach provides a clear depiction of the evolving sediment bed, facilitating quantitative analysis of erosion and deposition mechanisms near the structure.

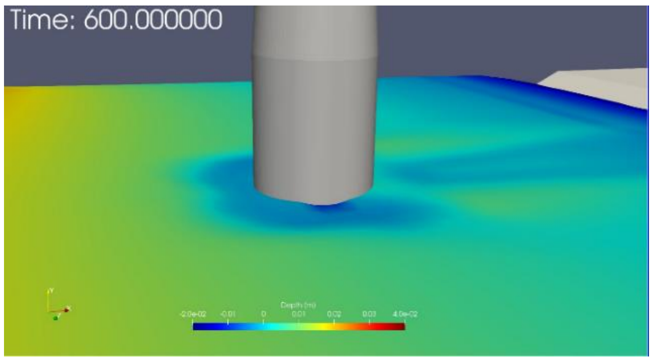

Figure 2. Scour Depth (m) around the monopile geometry using sedInterFoam

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REFERENCES

Chauchat, J., Cheng, Z., Nagel, T., Bonamy, C., & Hsu, T. J. (2017). SedFoam-2.0: a 3-D two-phase flow numerical model for sediment transport. *Geoscientific Model Development*, *10*(12), 4367-4392.

Jop, P., Forterre, Y., & Pouliquen, O. (2006). A constitutive law for dense granular flows. *Nature*, *441*(7094), 727-730.

Mathieu, A., Kim, Y., Hsu, T. J., Bonamy, C., & Chauchat, J. (2024). sedInterFoam 1.0: a three-phase numerical model for sediment transport applications with free surfaces. *Geoscientific Model Development Discussions*, 1-20.