PEER "Research Nuggets"

Title: Two-Dimensional Debris-Fluid-Structure Interaction with the Particle Finite Element Method

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Motivation: Field observations following recent tsunamis (Indian Ocean (2004), Chile (2010) and Japan (2011)) revealed significant structural damage due to debris impact. Physical experiments have quantified the forces imparted by debris objects on small structural models; however, the experiments can be difficult to replicate and require numerical models to inform future experiments and parameter variations.

Objectives: Simulations of debris impact in 2D fluid-structure interaction using the particle finite element method (PFEM) in OpenSees are compared with physical experiments and with numerical models that use the Smoothed-Particle Hydrodynamics- Finite Element Method (SPH-FEM). The OpenSees PFEM implementation is extended to 3D simulations in order to capture more realistic physics of debris impact and fluid flow around structures.

Methodology: Numerical simulations using the OpenSees PFEM are compared to experiments conducted by Ko et al. (2015) in the Oregon State University Large Wave Flume. The experiments included both in-air and in-water debris impact and were designed in a way that 2D simulations suffice for numerical simulations. To conduct simulations, a two-dimensional contact element was added to OpenSees for fluid-structure-debris interaction. Implementation of a three-dimensional contact element in OpenSees began with this research and preliminary 3D simulations of fluid-structure-debris interaction were conducted.

Results: The simulated results from OpenSees, e.g., as shown in Figure 1, matched the Ko et al. (2015) experiments as well as numerical models conducted with the SPH-FEM in LS-DYNA (summarized in a companion PEER report by Hasanpour et al. (2023)). In addition, the computational expense of the OpenSees PFEM simulations was quantified.

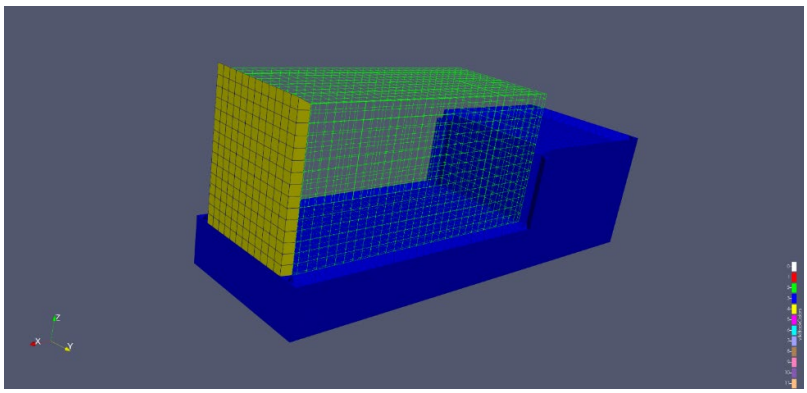

Figure 1: Simulation of debris impact on structural model.

Conclusions: The research showed that the PFEM in OpenSees is a promising approach for fluid-structure-debris simulations. Combined with its well-known earthquake engineering

capabilities, OpenSees continues to be an ideal framework for simulating the impact of multiple hazards on structural and geotechnical systems.

Future directions: Further development of the 3D modeling capabilities is required for the PFEM implementation in OpenSees. In addition, PFEM simulations are an ideal testbed for high performance computing applications with OpenSees.

Keywords: Fluid-structure interaction, OpenSees, finite element method, debris, tsunami

References

Hasanpour, A., Istrati, D., and Buckle, I. (in press). "Debris-tsunami-structure interaction and associated loads on coastal bridges." Report No. 2023/x, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.

Ko, H., D. T. Cox, H. R. Riggs, and C. J. Naito (2015). "Hydraulic experiments on impact forces from tsunami-driven debris." Journal of Waterway, Port, Coastal, and Ocean Engineering, 141(3).