Particle-resolved simulations of piping erosion in suction bucket foundations

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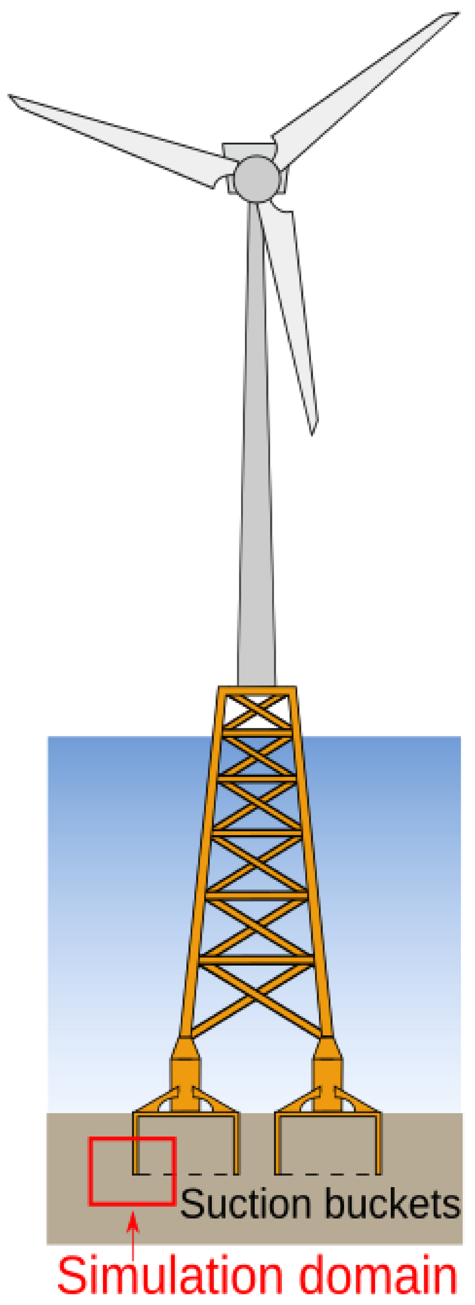
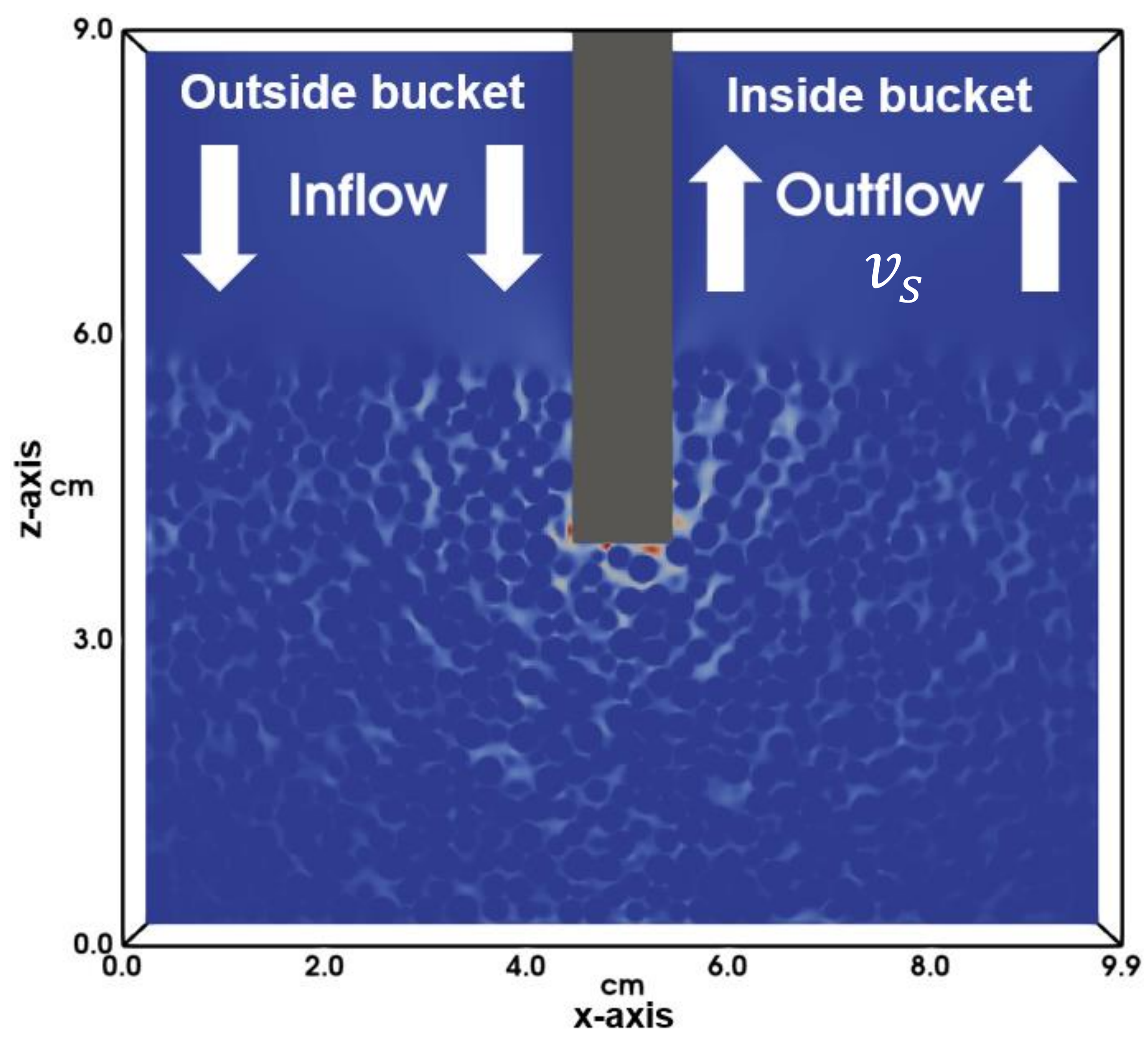
Suction-driven flow through granular bed under bucket wall

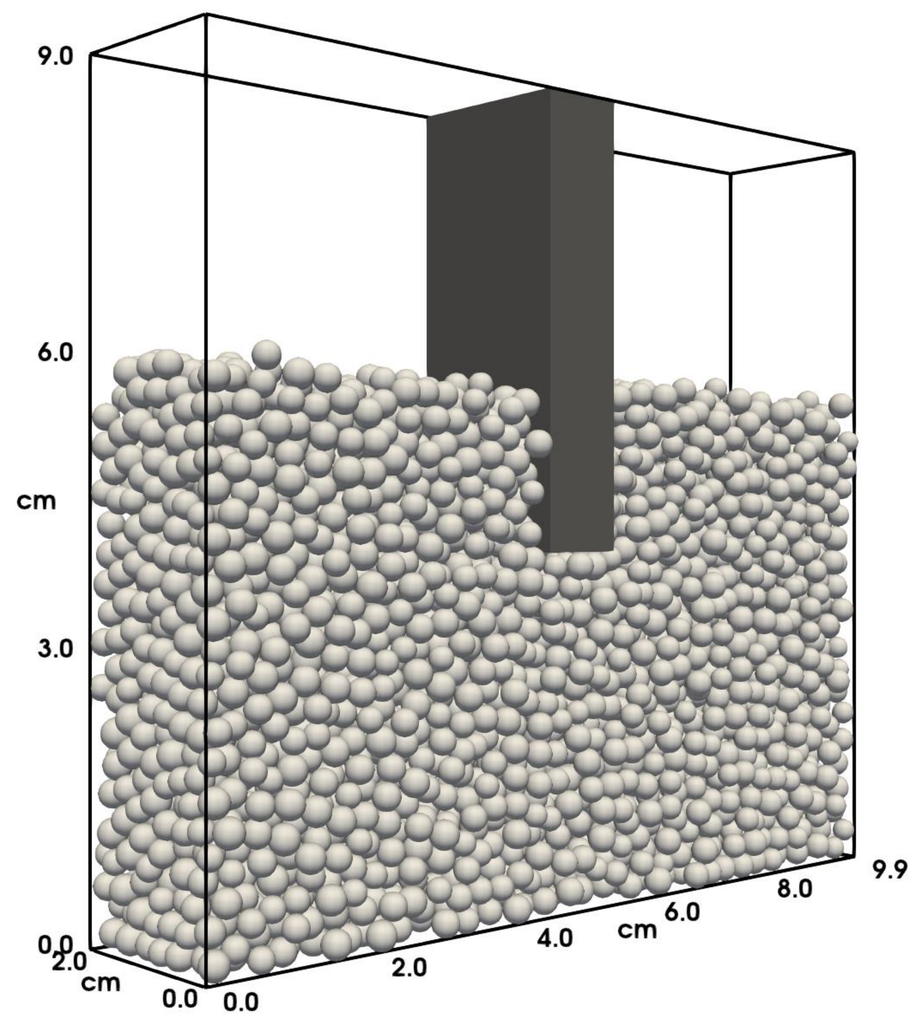
- **Context**: suction buckets promising for offshore wind turbine foundations
- **Problem**: risk of installation failure due to piping[1]
- **Goal**: better understand triggering conditions for piping

Contribution:

- 3D fluid-solid coupled micromechanical simulation
- Subdomain of bucket foundation
- Inflow: constant pressure
- Outflow: constant suction velocity v_s
- Periodic in out-of-plane direction







Direct numerical simulation

- Lattice Boltzmann method for fluid flow through granular soil
- Discrete element method to account for particle collisions
- Fluid-particle coupling via partially saturated method
- Integrated in open-source simulation framework WALBERLA[2,3] (www.walberla.net)

Simulation cases

Three cases with varying suction velocities v_s:

- **C1**: $v_s = 3 \cdot 10^{-3}\ \frac{m}{s}$
- **C2**: $v_s = 6 \cdot 10^{-3}\ \frac{m}{s}$
- **C3**: $v_s = 9 \cdot 10^{-3}\ \frac{m}{s}$

Particle properties:

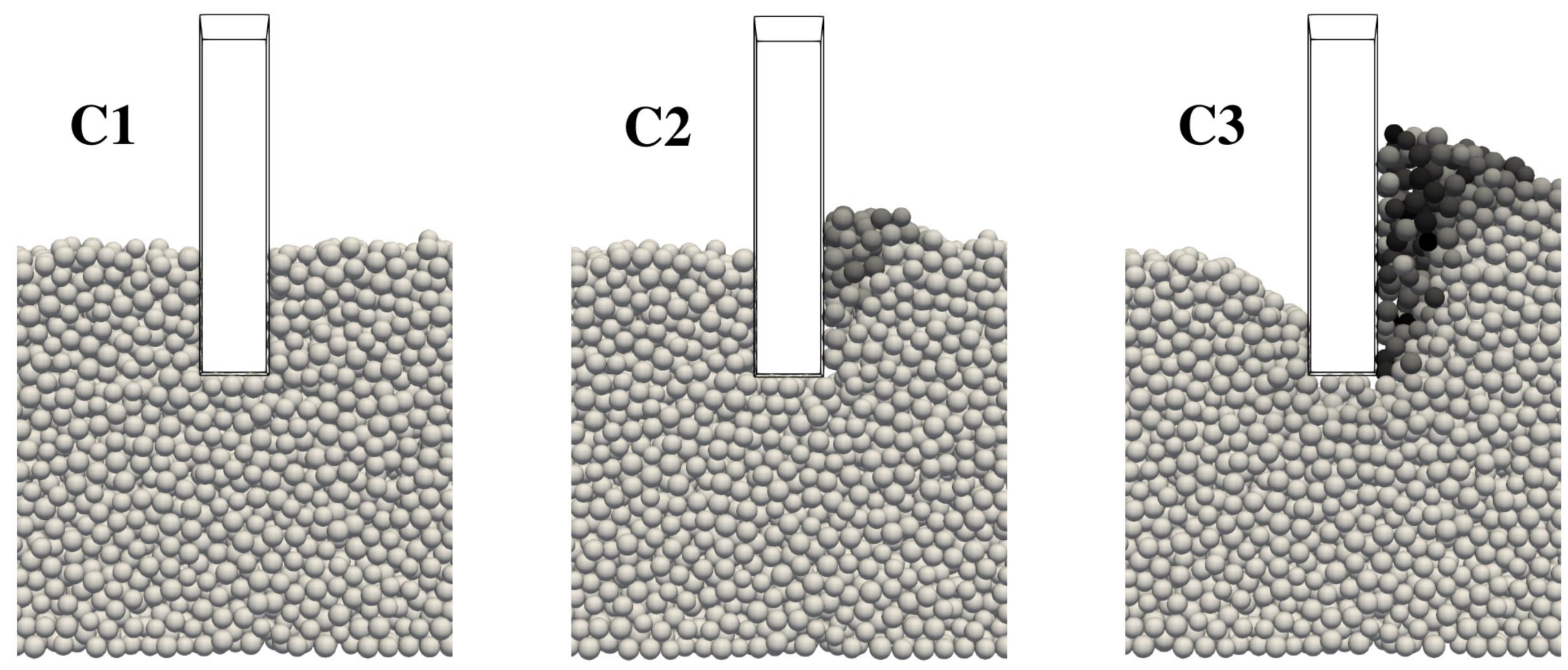
- Density: $\rho_p = 2650\ \frac{\text{kg}}{\text{m}^3}$
- Median diameter: $d_p = 3.0$ mm
- Bed: 5194 spherical particles (porosity: 0.39)

Discretization:

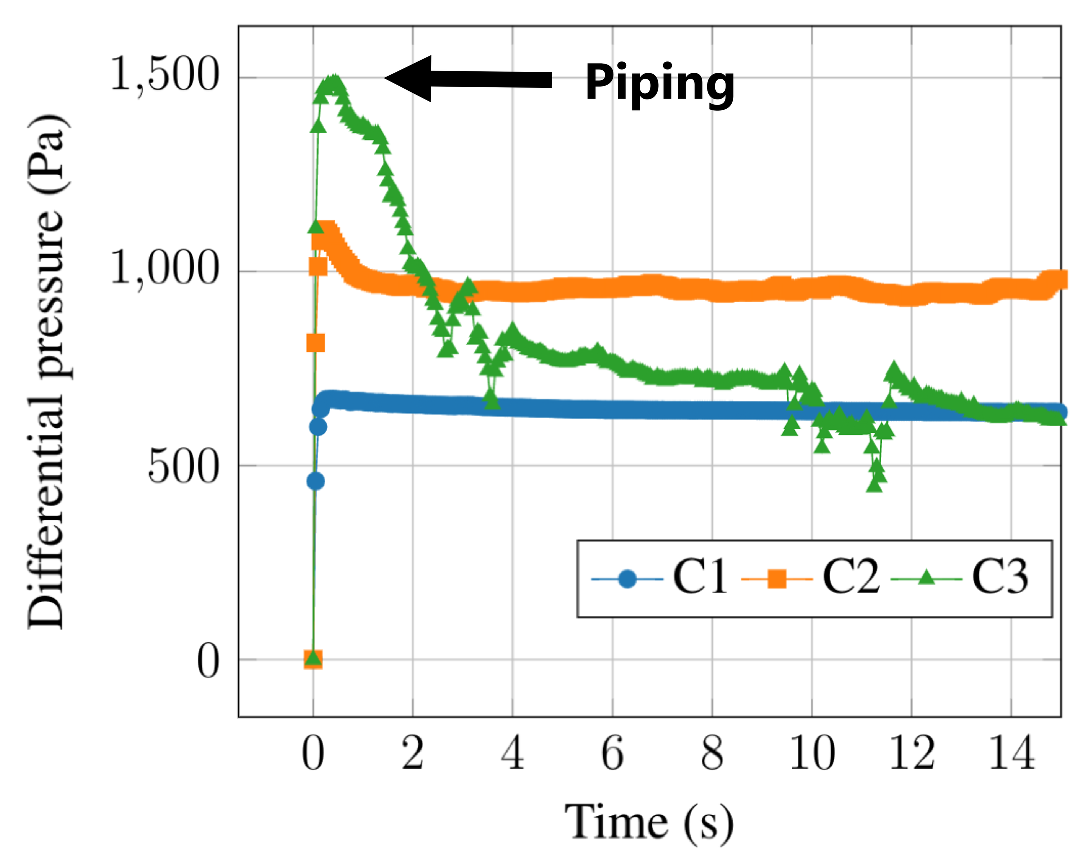
- Domain size: 660 × 140 × 600 fluid cells
- 20 fluid cells per particle diameter
- $3 \cdot 10^6$ time steps ($\Delta t = 5 \cdot 10^{-6}\ s$)

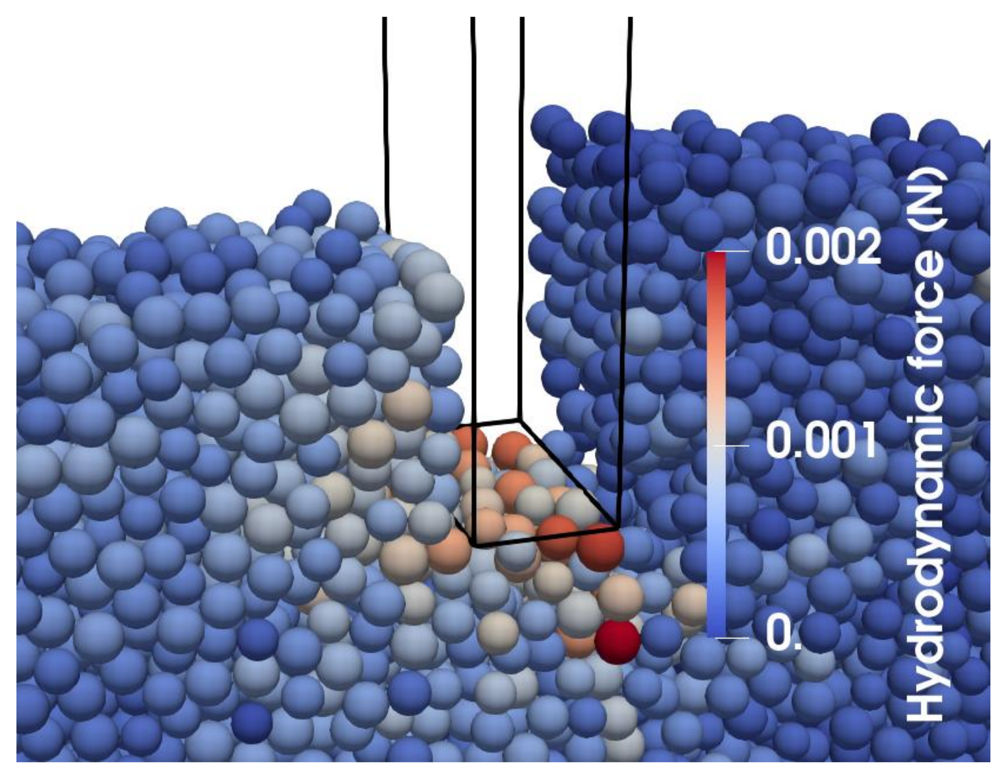
Validation of the numerical results

Grain displacement after 15 s:



Differential pressure (left) and **hydrodynamic forces** of C3 at piping onset at $t = 0.4\ s$ (right):





→ Successful **simulation of piping**

→ Enables campaigns with high-resolution simulations to study triggering conditions for piping

1. Sturm, H. (2017). Design aspects of suction caissons for offshore wind turbine foundations. Unearth the Future, Connect beyond. Proceedings of the 19th ICSMGE.
2. Bauer, M., et al. (2021). waLBerla: A block-structured high-performance framework for multiphysics simulations. *Computers & Mathematics with Applications*, *81*, 478-501.
3. Kemmler, S. et al. (2024). Efficiency and scalability of fully-resolved fluid-particle simulations on heterogeneous CPU-GPU architectures. arXiv:2303.11811.

Poster based on: Kemmler, S. et al. (2025). A fluid-solid coupled micromechanical simulation for the analysis of piping erosion during the seabed installation of a suction bucket foundation.

Corresponding simulation **videos** of **C1**, **C2** and **C3**