Water-Soil Interaction Simulation using Smoothed Particle Hydrodynamics

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Introduction

- Gravity base foundation for an offshore wind energy converter:
  - hollow structures made of concrete
  - manufactured onshore and transported to the construction site
  - lowered into a prepared foundation pit

- Jet grouting:
  - used since the 1970´s
  - method of ground improvement and stabilization
  - high presure streams to break up the soil

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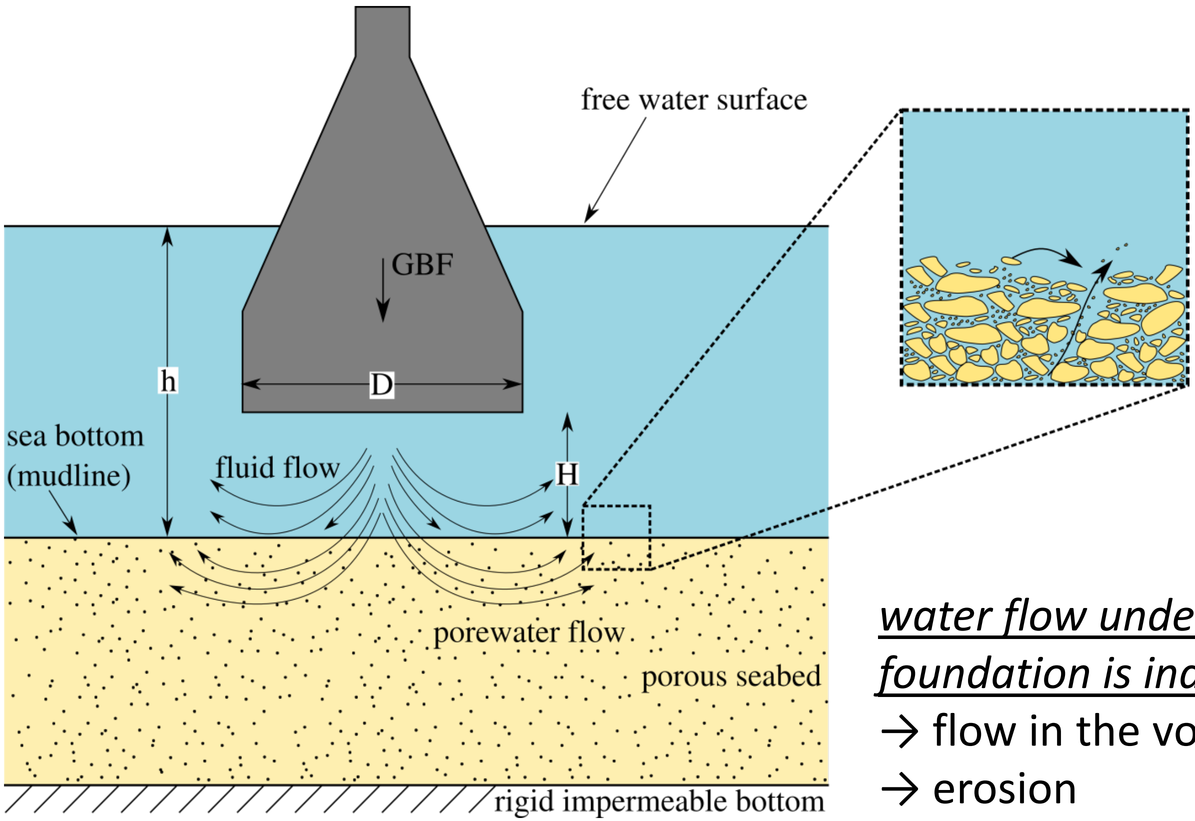
interaction between fluid and soil

Lowering of a gravity base foundation (GBF)



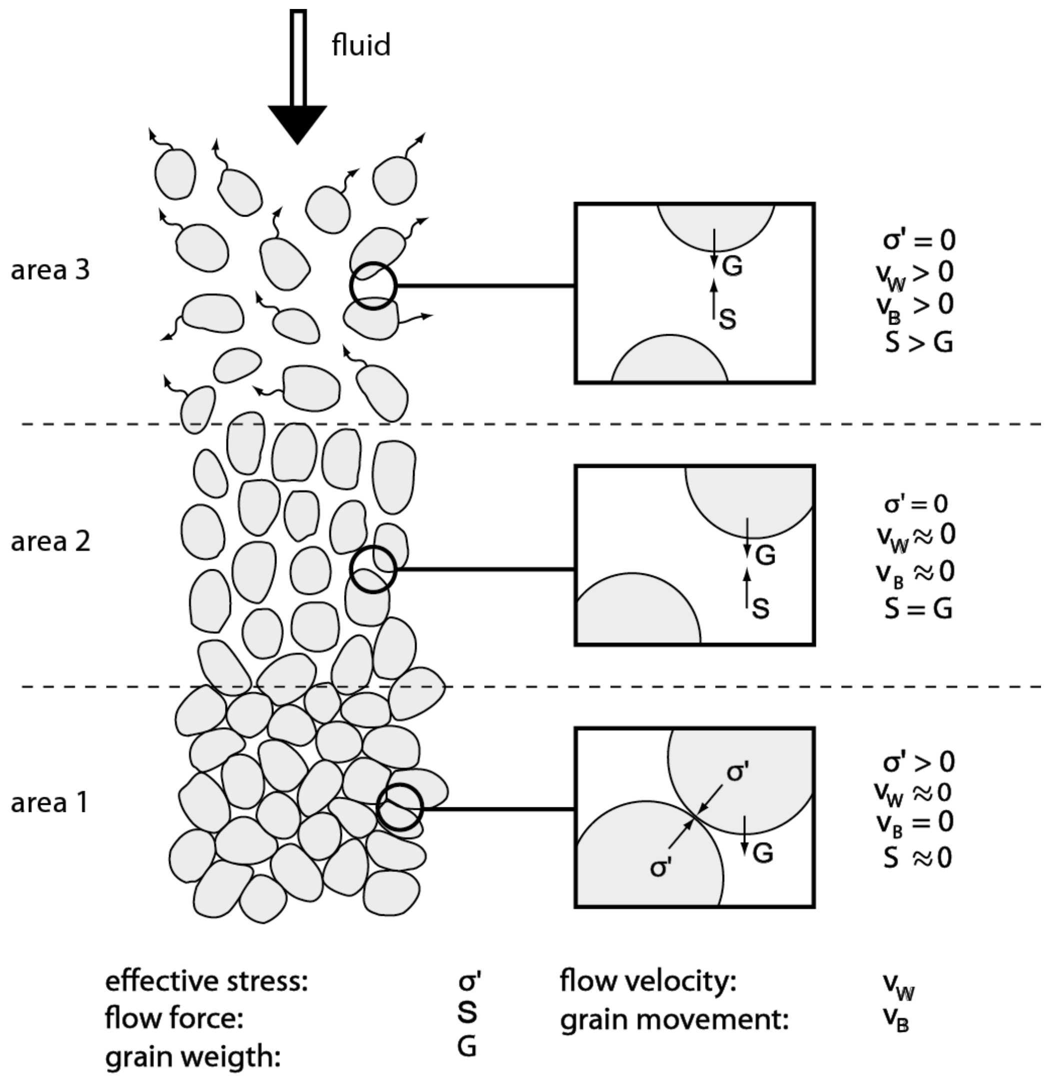
water flow underneath the foundation is induced:

→ flow in the voids of the soil

→ erosion

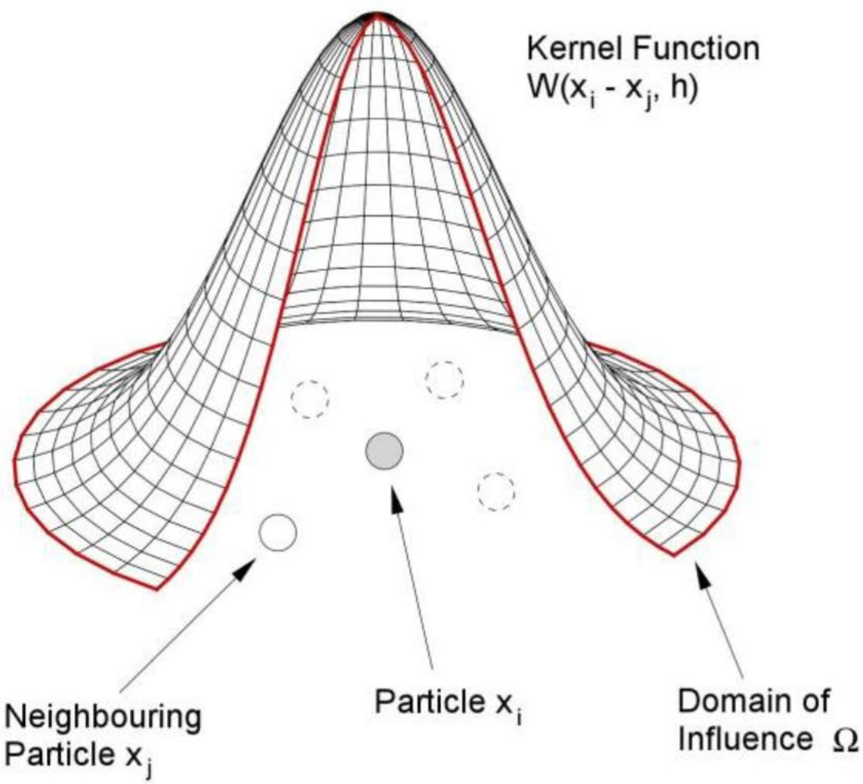
Soil interaction with a fluid jet

- high velocity and pressure
- different stages of interaction
- reduction of effective stress in the soil



Smoothed Particle Hydrodynamics (SPH)

- meshfree method
- uses particles that have the properties of the material
- originally applied in the 1970`s in the astrophysics
- nowadays used for different physical, hydrodynamic and also geotechnical calculations
- approximation for each particle using its neighbors



(fig. after Colagrossi, 2003)

Conservation equations in SPH

mass conservation

$$\underbrace{\frac{D\rho}{Dt} = -\rho\frac{\partial v^\beta}{\partial x^\beta}}_{Lagrangian\ formulation}$$

$$\Rightarrow \underbrace{\frac{D\rho}{Dt} = \sum_{j=1}^{N} m_j\,(v_i^\alpha - v_j^\alpha)\,\frac{\delta W_{ij}}{\partial x_i^\alpha}}_{SPH\ approximation}$$

momentum conservation

$$\underbrace{\frac{Dv^\alpha}{Dt} = \frac{1}{\rho}\frac{\partial\sigma^{\alpha\beta}}{\partial x^\beta} + \frac{f^\alpha}{\rho}}_{Lagrangian\ formulation}$$

$$\Rightarrow \underbrace{\frac{Dv_i^\alpha}{Dt} = \sum_{j=1}^{N}\left[m_j\left(\frac{\sigma_i^{\alpha\beta}}{\rho_i^2} + \frac{\sigma_j^{\alpha\beta}}{\rho_j^2}\right)\right]\frac{\delta W_{ij}}{\partial x_i^\beta} + \frac{f_i^\alpha}{\rho_i}}_{SPH\ approximation}$$

equation of state

$$p = \left(\left(\frac{\rho}{\rho_0}\right)^\gamma - 1\right)B$$

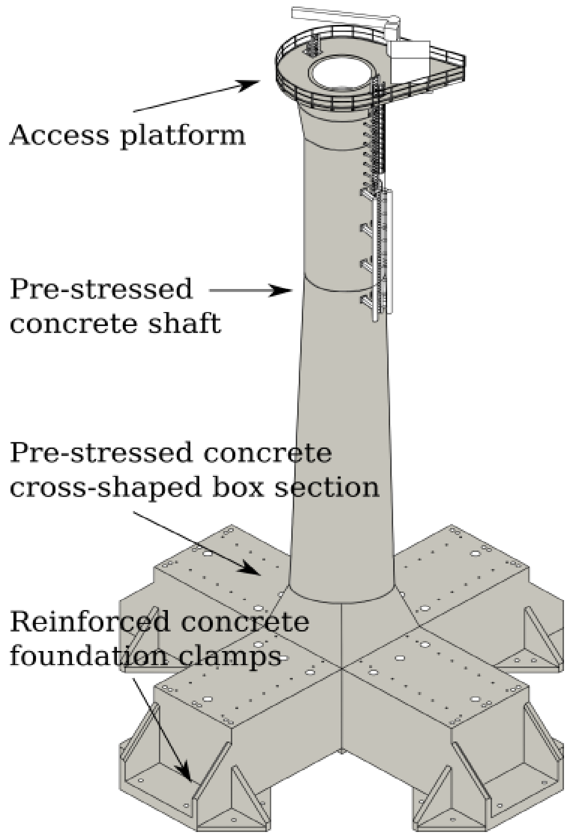
Implementation in SPH

- soil as a viscous fluid, using Gadget $^{H}2^{O}$ by C. Ulrich & T. Rung
  - viscosity μ as function of the angle of friction φ, cohesion c, pressure p and deviatoric strain rate $\dot{e}$:

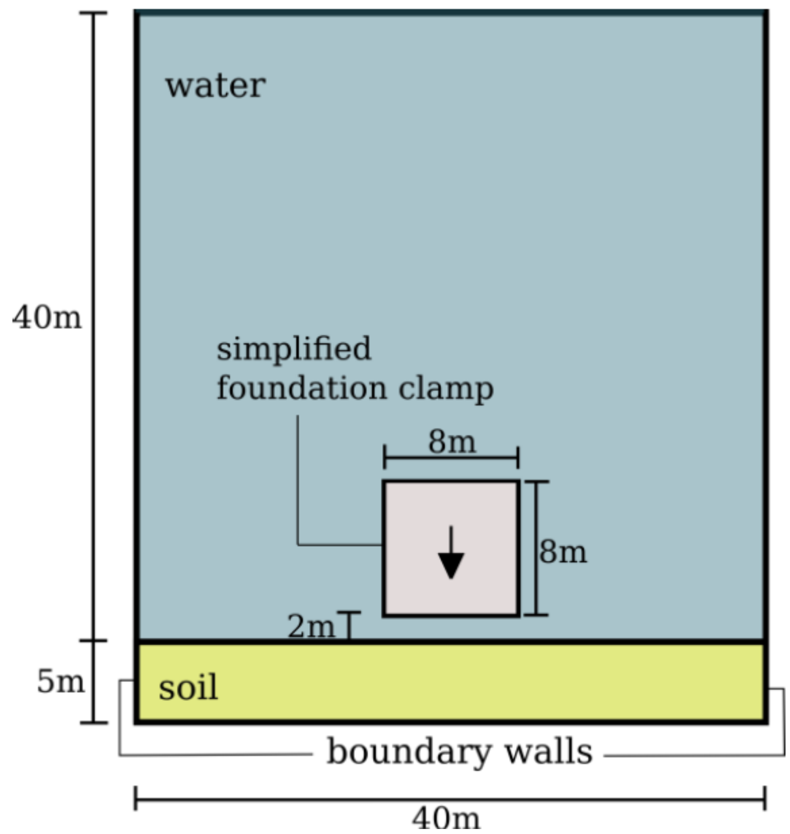
$$\mu = \frac{p\ \sin\varphi + c}{\|\ \dot{e}^{\alpha\beta}\ \|}$$

  - useful approach to study the applicability and feasibility of the models
  - for further geotechnical applications: more sophisticated treatment of soil needed

Simulation of the lowering of a gravity base foundation

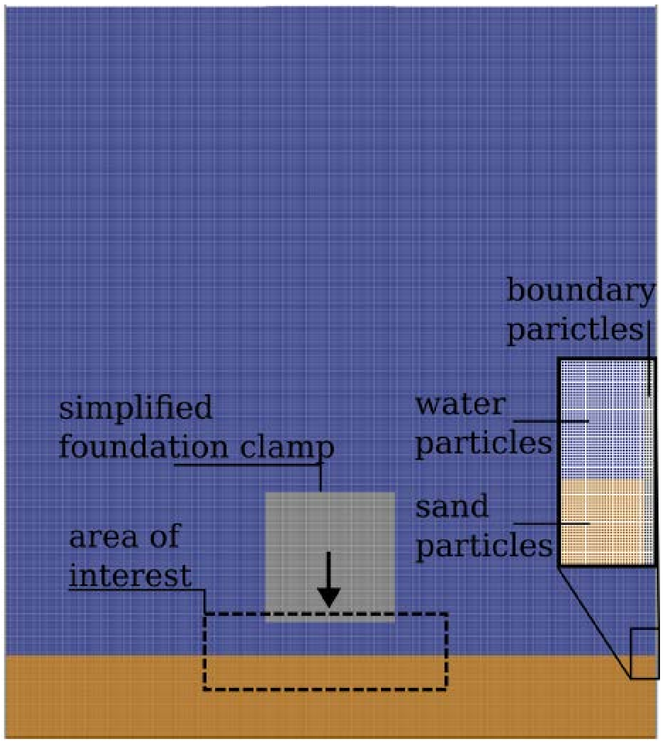


STRABAG Gravity Base (Weber, 2010)

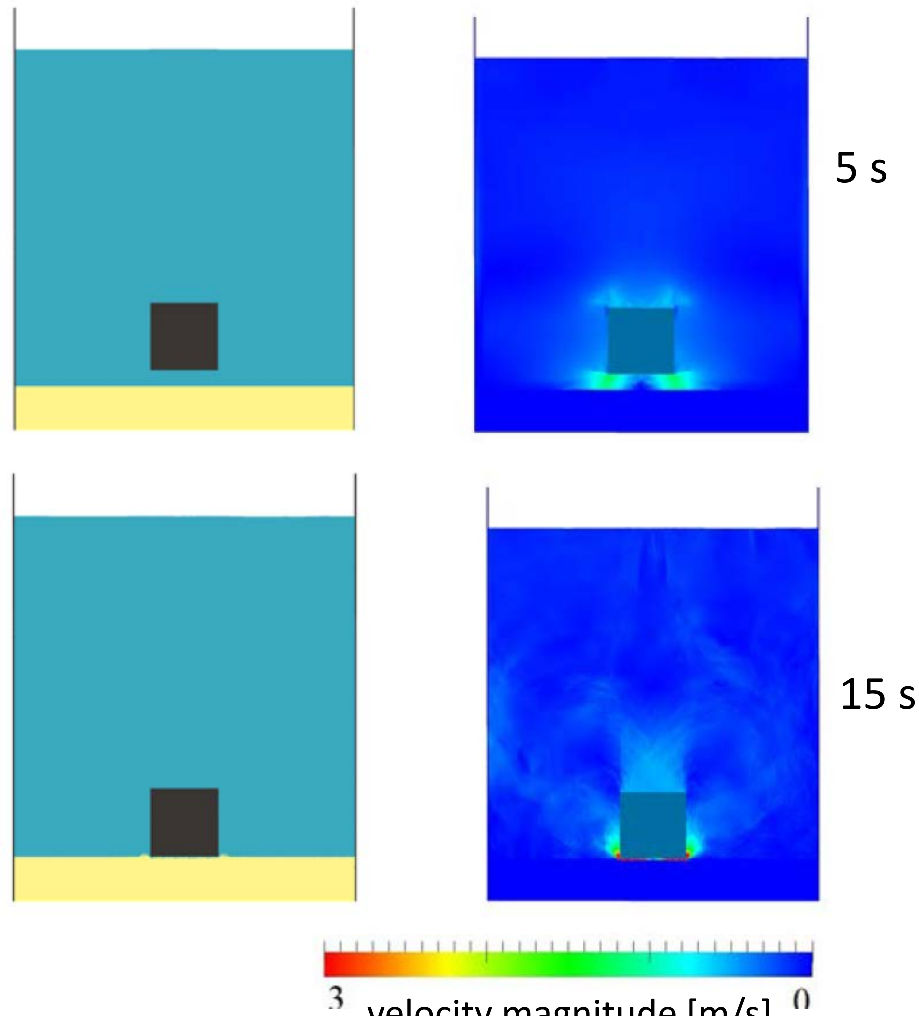


Model setup

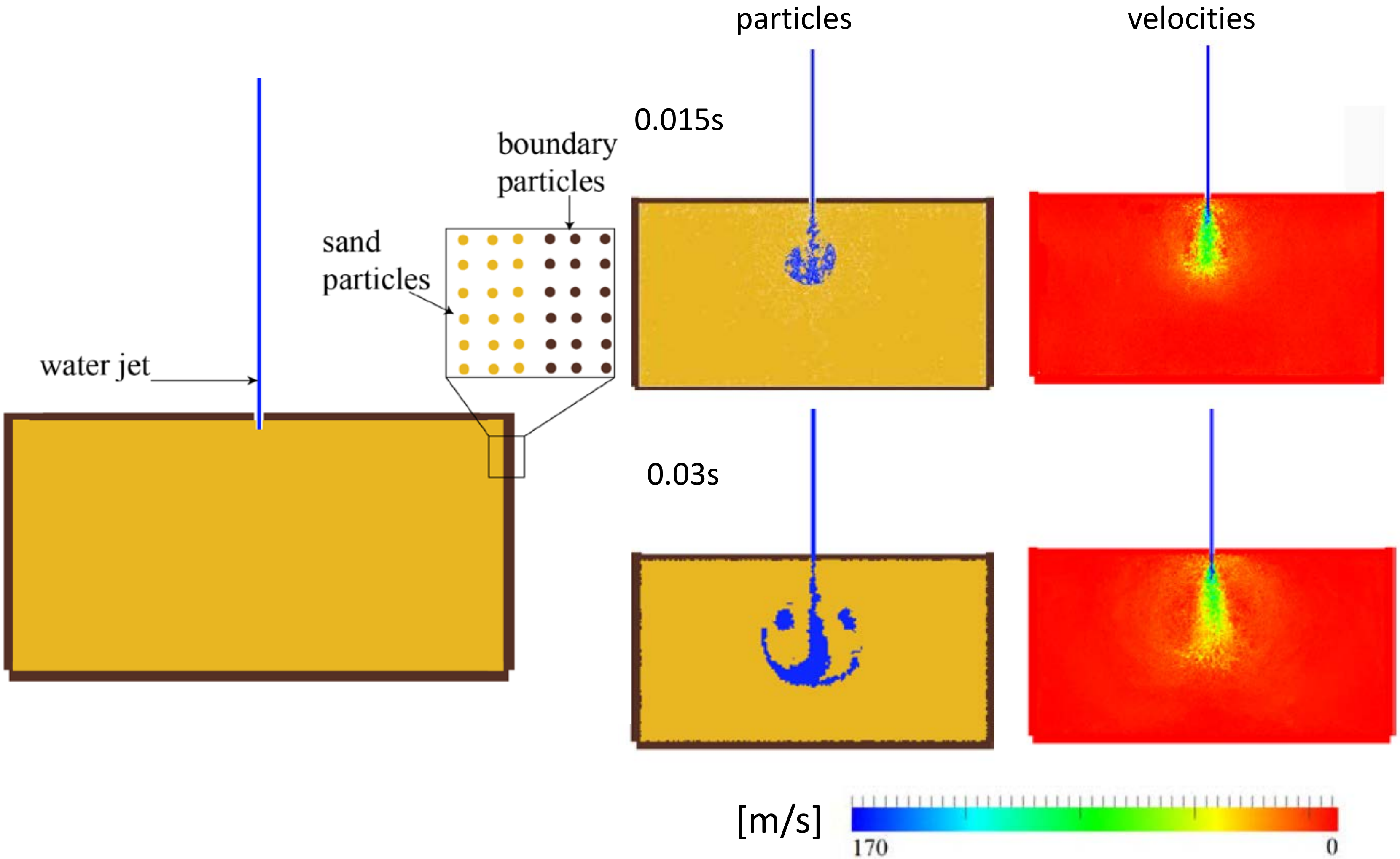
Results for lowering of a gravity base foundation



initial configuration



Results for jet grouting



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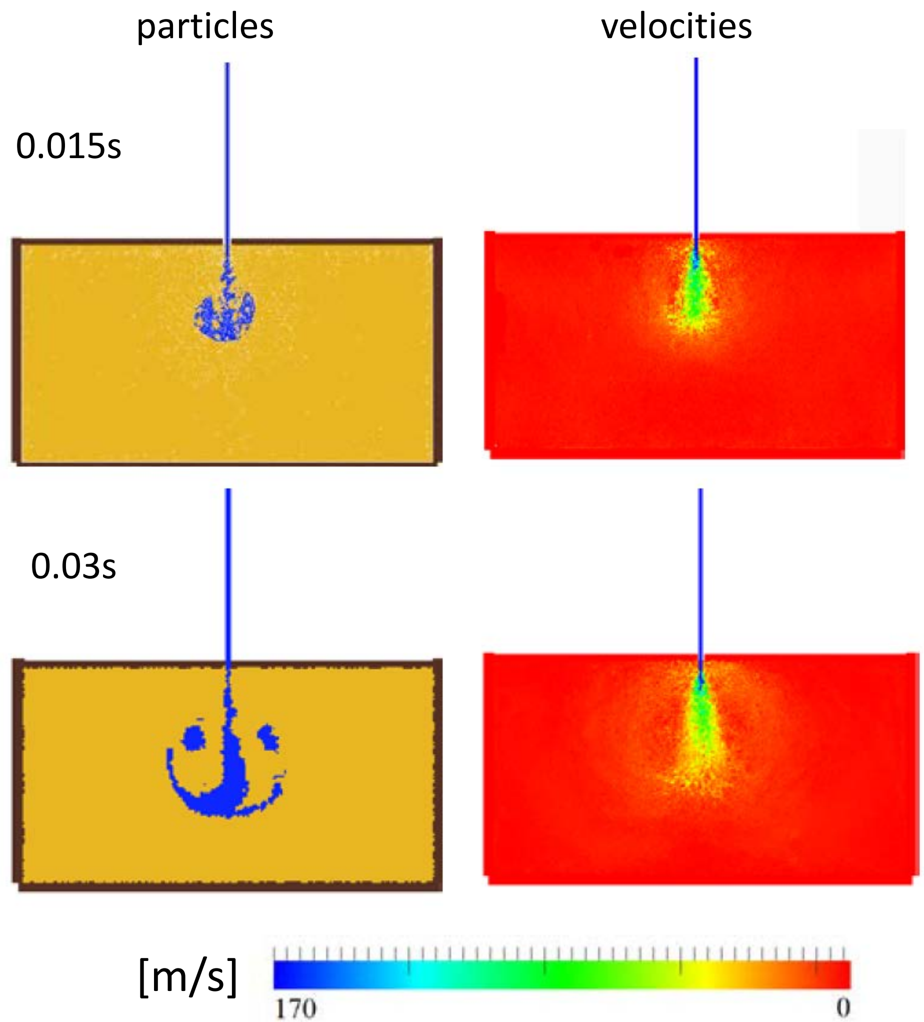

Conclusions & outlook

- soil-water interaction for two geotechnical problems was analyzed
- promising results
- future goals
  - two-phase-model in order to describe the soil-fluid-interaction
  - test cases for numerical analysis & variation of parameters
  - calibration and validation of the simulation results

THANK YOU FOR YOUR ATTENTION!

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