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 pressure streams to break up the soil
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  \[ \text{interaction between fluid and soil} \]
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

**area 1**
- effective stress: $\sigma' > 0$
- flow velocity: $v_W \approx 0$
- grain movement: $v_B = 0$

**area 2**
- effective stress: $\sigma' = 0$
- flow velocity: $v_W \approx 0$
- grain movement: $v_B \approx 0$

**area 3**
- effective stress: $\sigma' = 0$
- flow force: $G$
- flow velocity: $v_W > 0$
- grain movement: $v_B > 0$

$S > G$
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**

\[
\frac{D\rho}{Dt} = -\rho \frac{\partial \mathbf{v}^\beta}{\partial \mathbf{x}^\beta}
\]

Lagrangian formulation

\[
\Rightarrow \frac{D\rho}{Dt} = \sum_{j=1}^{N} m_j (\mathbf{v}_i^\alpha - \mathbf{v}_j^\alpha) \frac{\partial \mathbf{W}_{ij}}{\partial \mathbf{x}_i^\alpha}
\]

SPH approximation

**momentum conservation**

\[
\frac{D\mathbf{v}_i^\alpha}{Dt} = \frac{1}{\rho} \frac{\partial \mathbf{\sigma}^\alpha_\beta}{\partial \mathbf{x}^\beta} + \frac{f_i^\alpha}{\rho}
\]

Lagrangian formulation

\[
\Rightarrow \frac{D\mathbf{v}_i^\alpha}{Dt} = \sum_{j=1}^{N} \left[ m_j \left( \frac{\sigma_i^{\alpha\beta}}{\rho_i^2} + \frac{\sigma_j^{\alpha\beta}}{\rho_j^2} \right) \right] \frac{\partial \mathbf{W}_{ij}}{\partial \mathbf{x}_i^\beta} + \frac{f_i^\alpha}{\rho_i}
\]

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 $^H2^O$ by C. Ulrich & T. Rung
  – viscosity $\mu$ as function of the angle of friction $\varphi$, cohesion $c$, pressure $p$ and deviatoric strain rate $\dot{\varepsilon}$:

\[
\mu = \frac{p \sin \varphi + c}{\| \dot{\varepsilon} \|^{\alpha \beta}}
\]

– 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)
Results for lowering of a gravity base foundation
Results for jet grouting

0.015s

0.03s

[m/s]
Results for jet grouting

![Diagram showing jet grouting results with particle and velocity representations at 0.015s and 0.03s. The color bar indicates velocity in [m/s].]
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!