Three-node zero-thickness hydro-mechanical interface finite element for geotechnical applications

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Outline

1. Context
2. Modelling interfaces
3. Application
4. Conclusions

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1. Context
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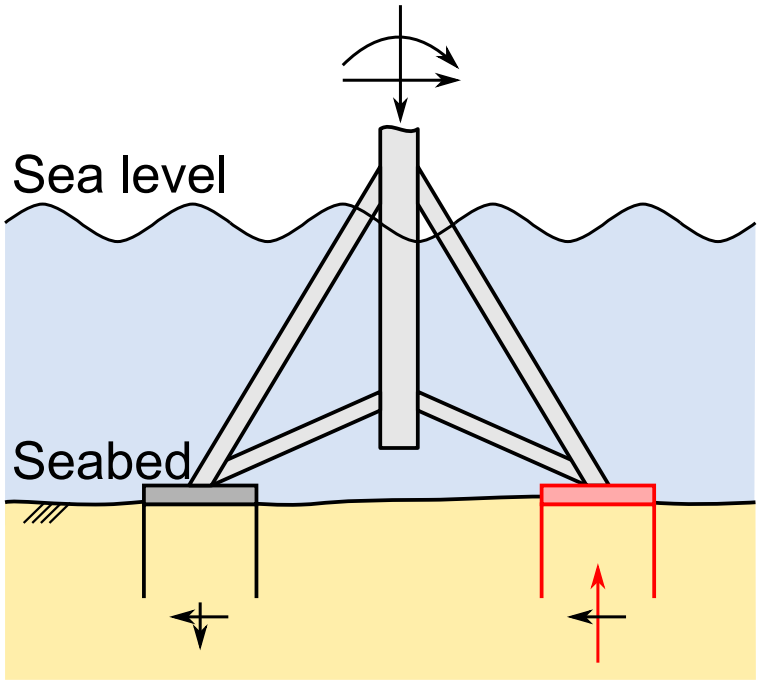
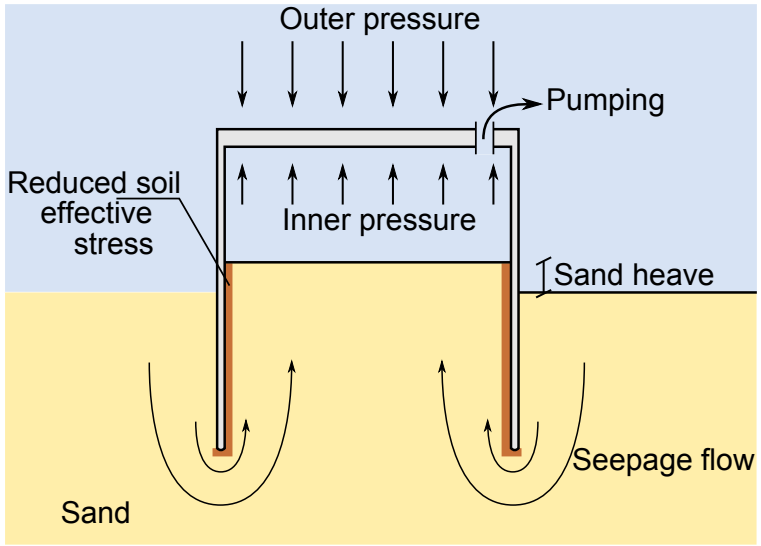
Suction caisson



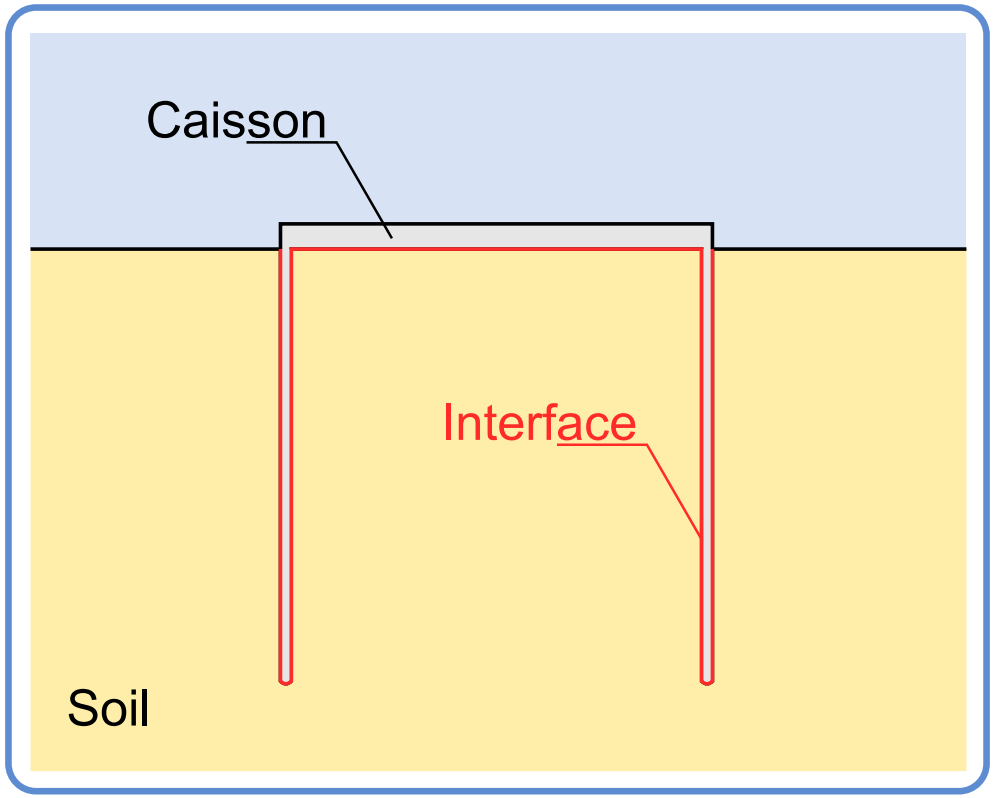
- Foundation for offshore structures
- Hollow cylinder open towards the bottom
- Made of steel



- Installed by suction
- Increased transient resistance to pull and push loads
- Crucial role of interfaces

Interface in geomechanics

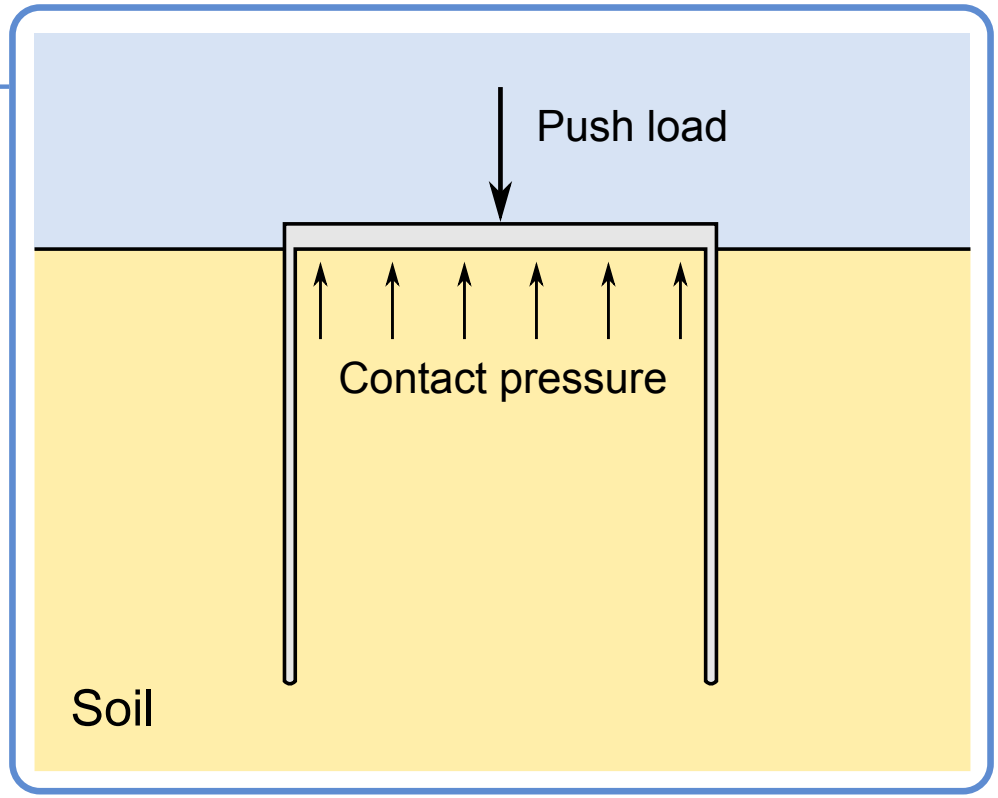
Interface — Surface between two media (=discontinuity)



Interface in geomechanics

Interface — Surface between two media (=discontinuity)

Contact

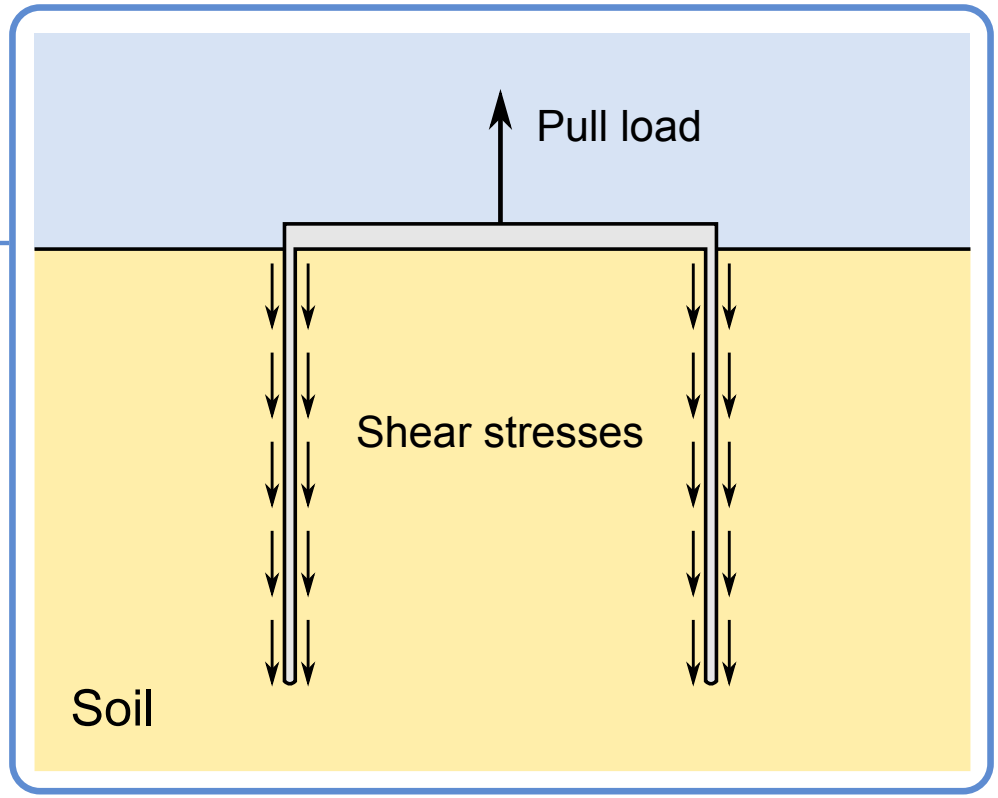


Interface in geomechanics

Interface — Surface between two media (=discontinuity)

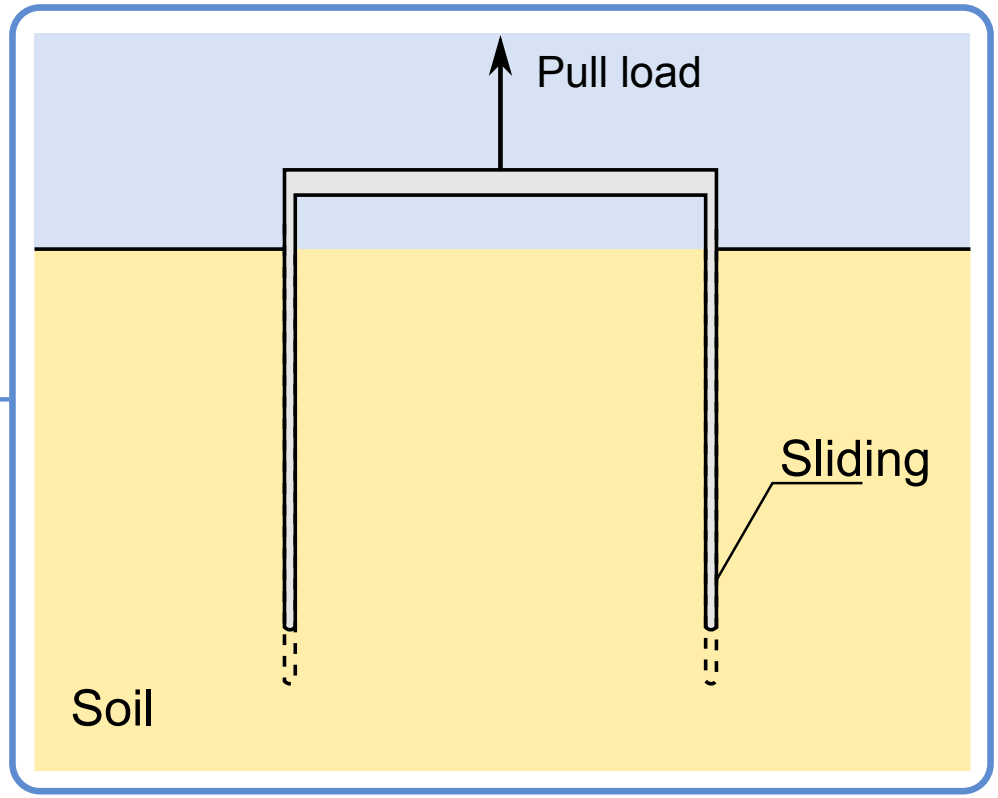
Contact

Shearing



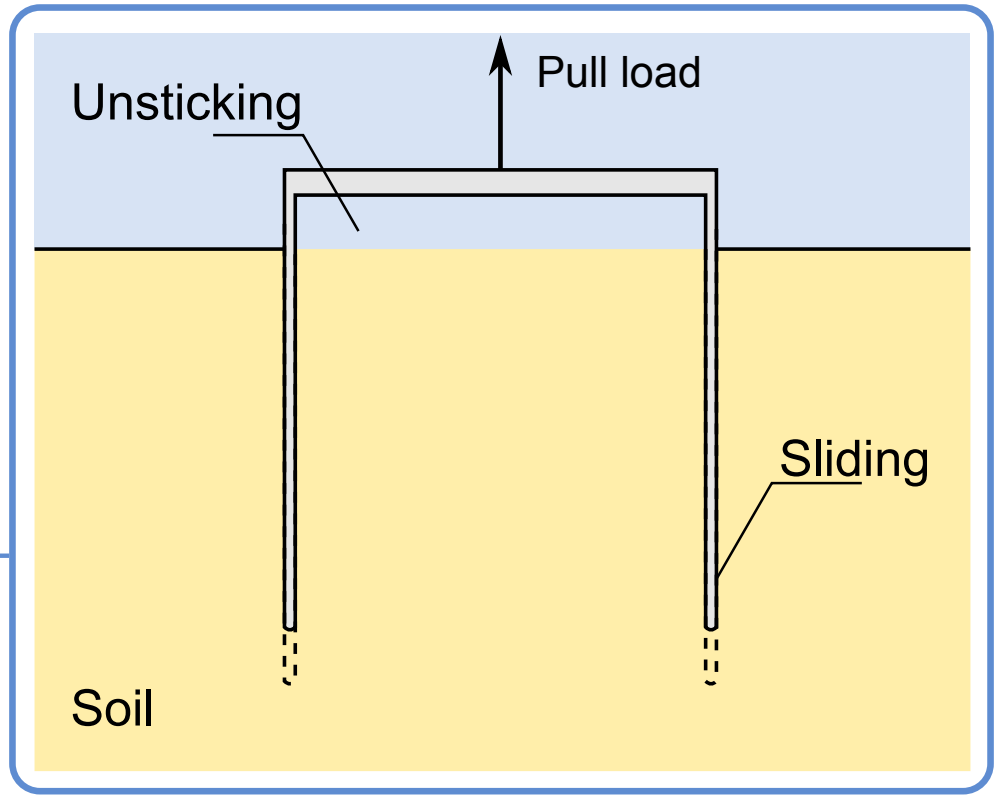
Interface in geomechanics

- **Interface** — Surface between two media (=discontinuity)
  - **Contact**
  - **Shearing**
  - **Sliding**



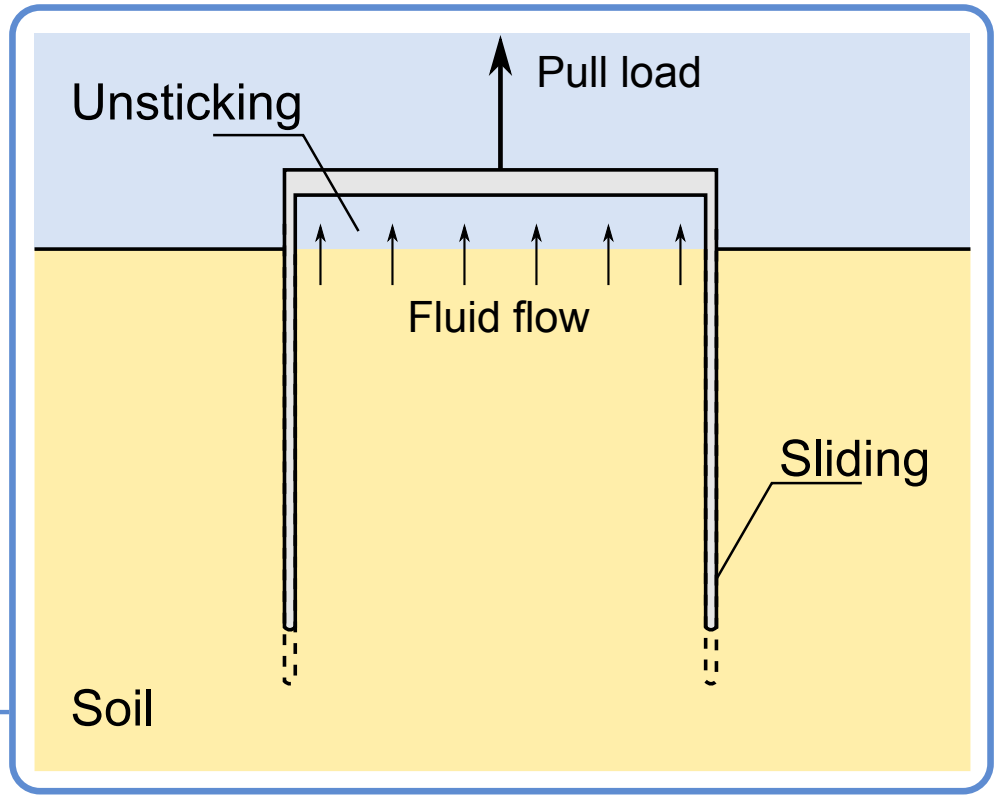
Interface in geomechanics

- **Interface** — Surface between two media (=discontinuity)
  - Contact
  - Shearing
  - Sliding
  - Unsticking



Interface in geomechanics

- **Interface** — Surface between two media (=discontinuity)
  - Contact
  - Shearing
  - Sliding
  - Unsticking
  - Flow



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- Hydraulic problem
- Coupled problem

3 Application

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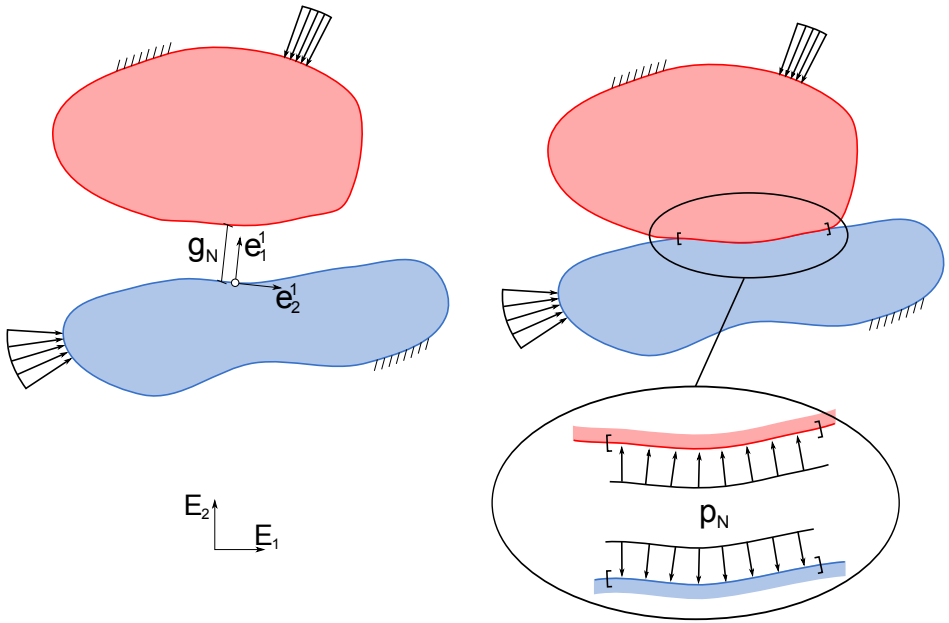
Normal behaviour

Contact

$$p_N \geq 0 \qquad g_N \geq 0 \qquad p_N\, g_N = 0$$



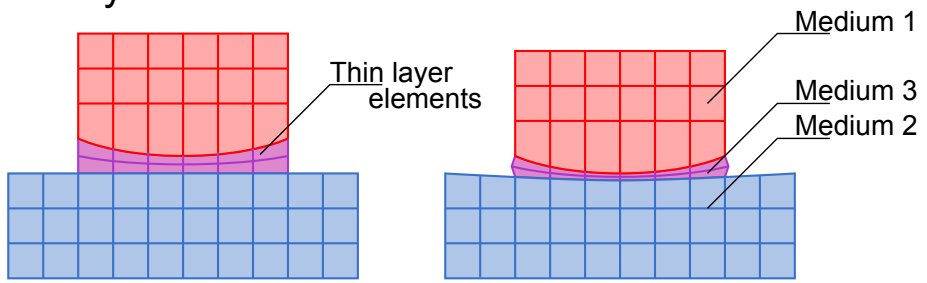
Normal behaviour

Contact

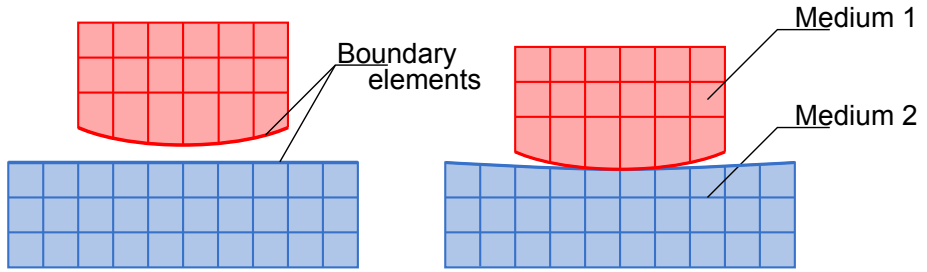
$$p_N \geq 0 \qquad g_N \geq 0 \qquad p_N\, g_N = 0$$

Approaches

Thin layer



Zero-thickness



No contact Contact

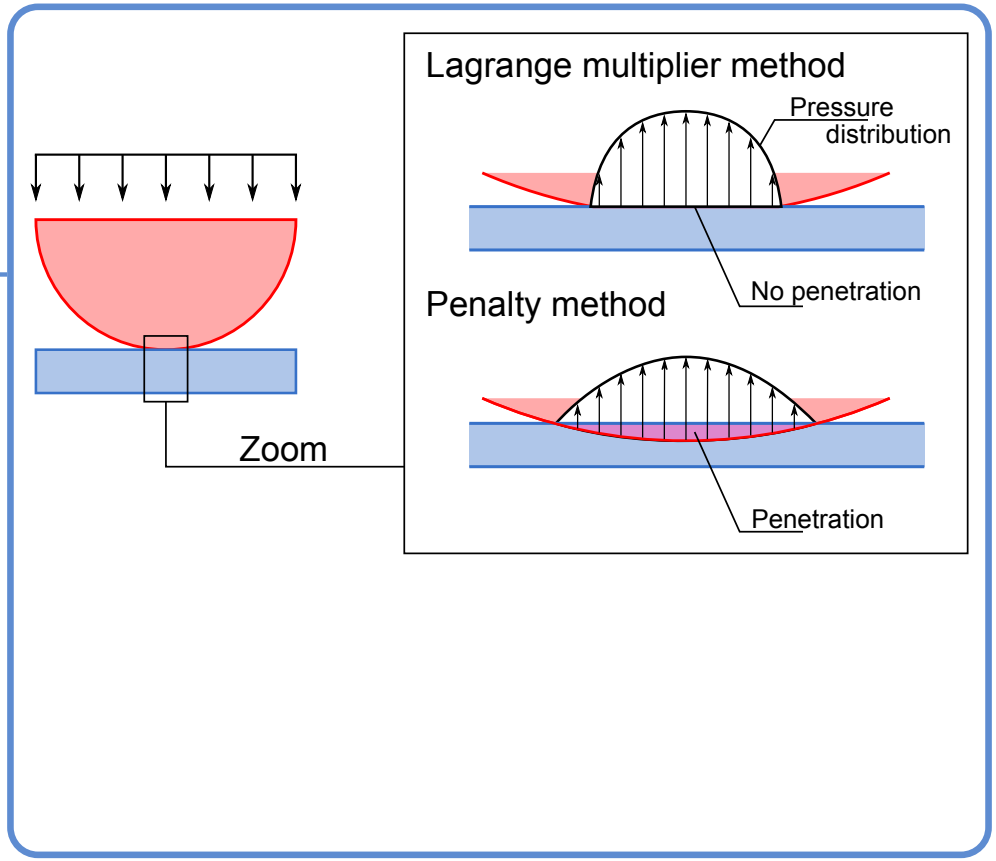
Normal behaviour

Contact

$$p_N \geq 0 \qquad g_N \geq 0 \qquad p_N g_N = 0$$

Approaches

Regularisation



Normal behaviour

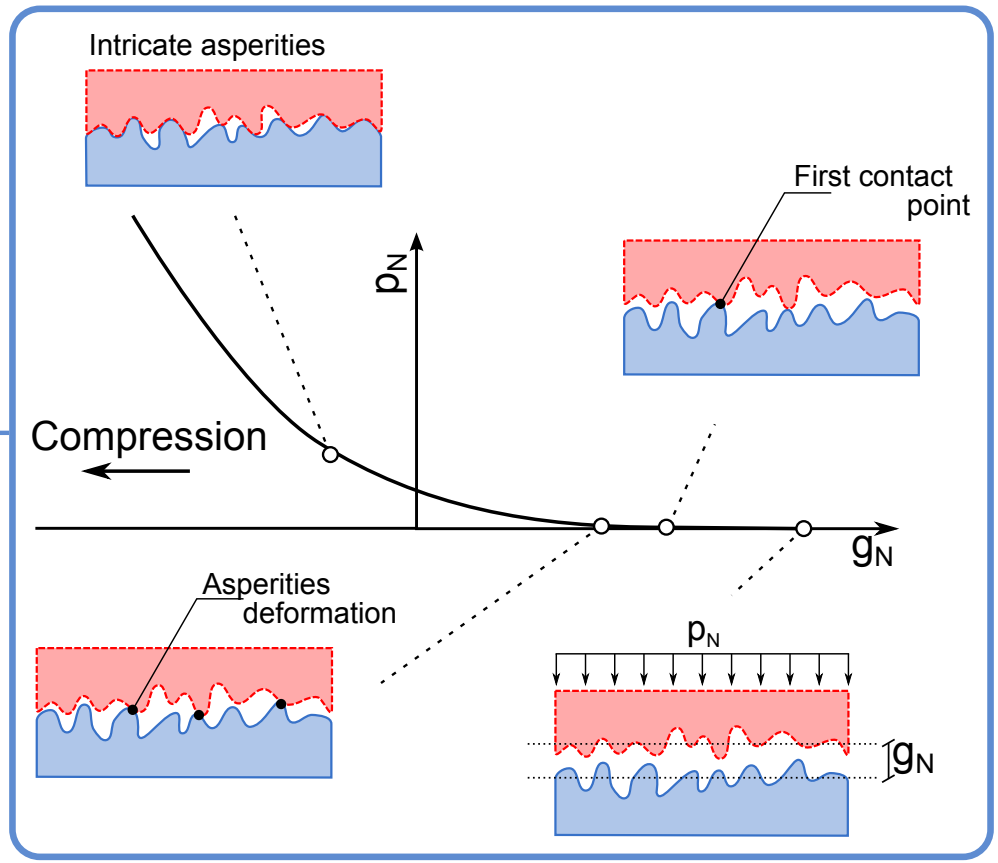
Contact

$$p_N \geq 0 \qquad g_N \geq 0 \qquad p_N\, g_N = 0$$

Approaches

Regularisation

$$p_N = f(g_N)$$



Normal behaviour

Contact

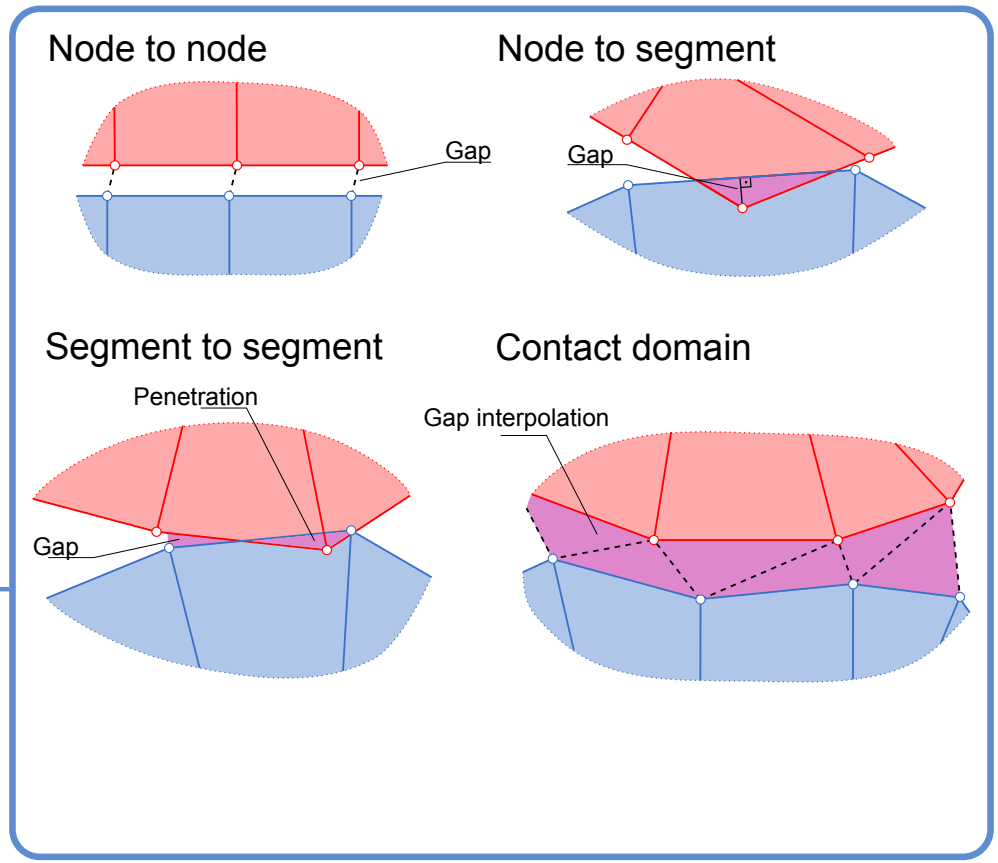
$$p_N \geq 0 \qquad g_N \geq 0 \qquad p_N\, g_N = 0$$

Approaches

Regularisation

$$p_N = f(g_N)$$

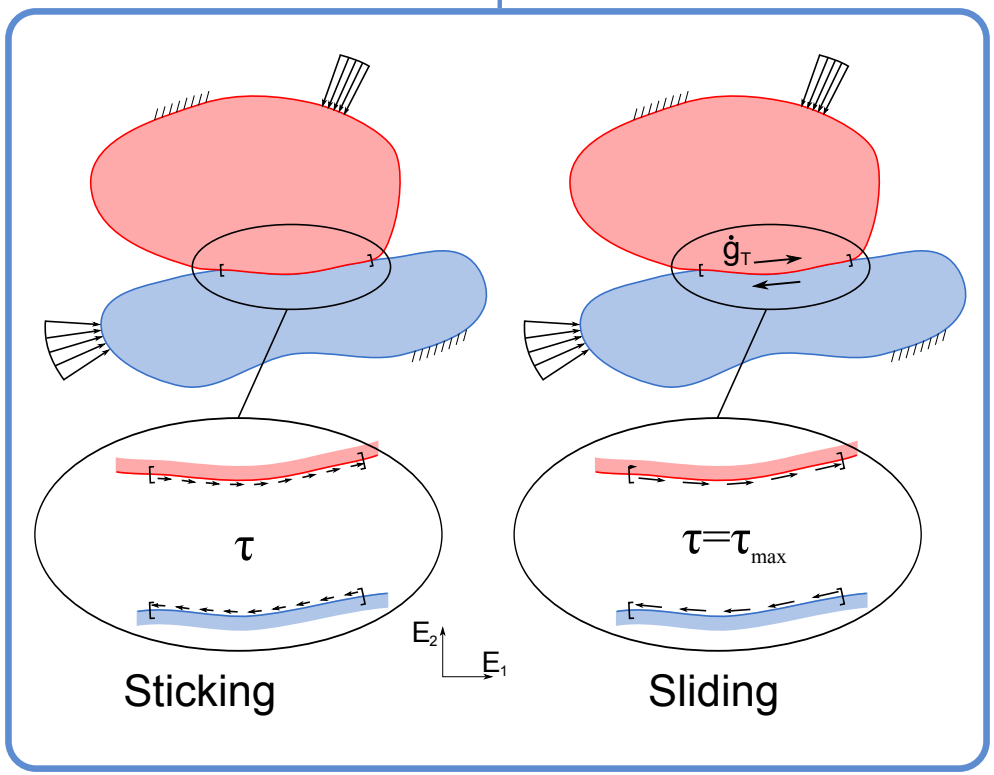
Discretisation



Tangential behaviour

Shearing

$$\tau \geq 0 \qquad \dot{g}_T \geq 0 \qquad \tau\, \dot{g}_T = 0$$

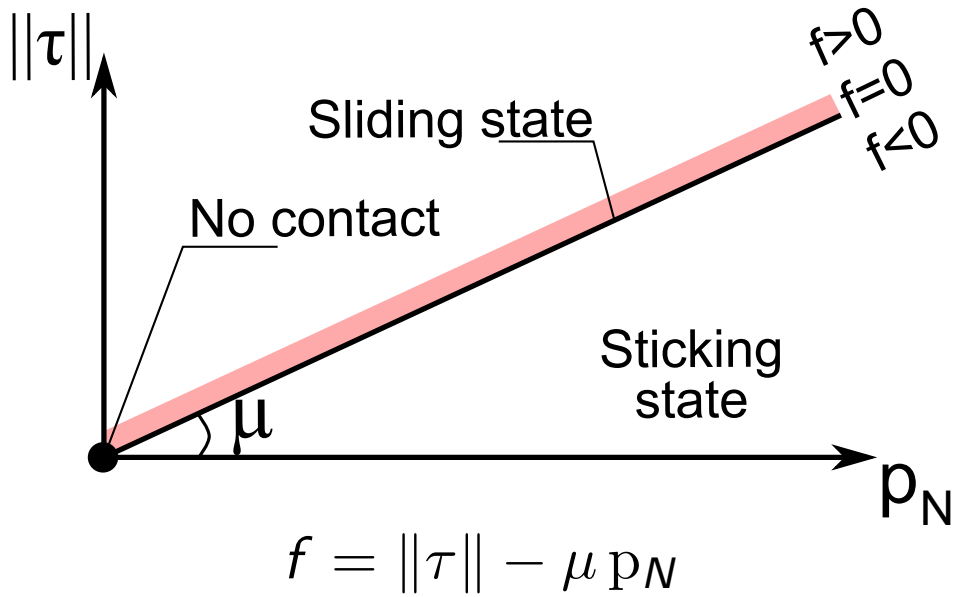


Tangential behaviour

Shearing

$$\tau \geq 0 \qquad \dot{g}_T \geq 0 \qquad \tau\, \dot{g}_T = 0$$

Criterion

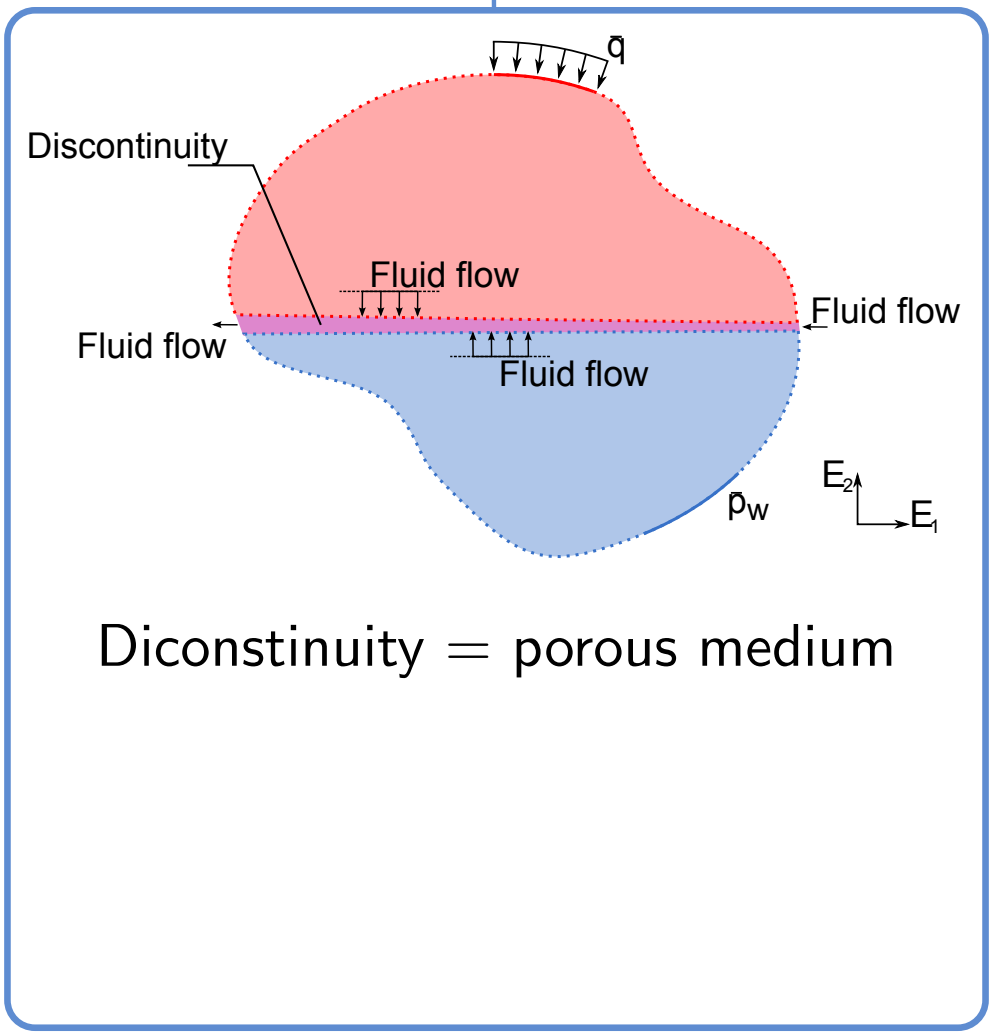


$$f = \|\tau\| - \mu\, p_N$$

Fluid flows

Interface

Longitudinal and transversal flows



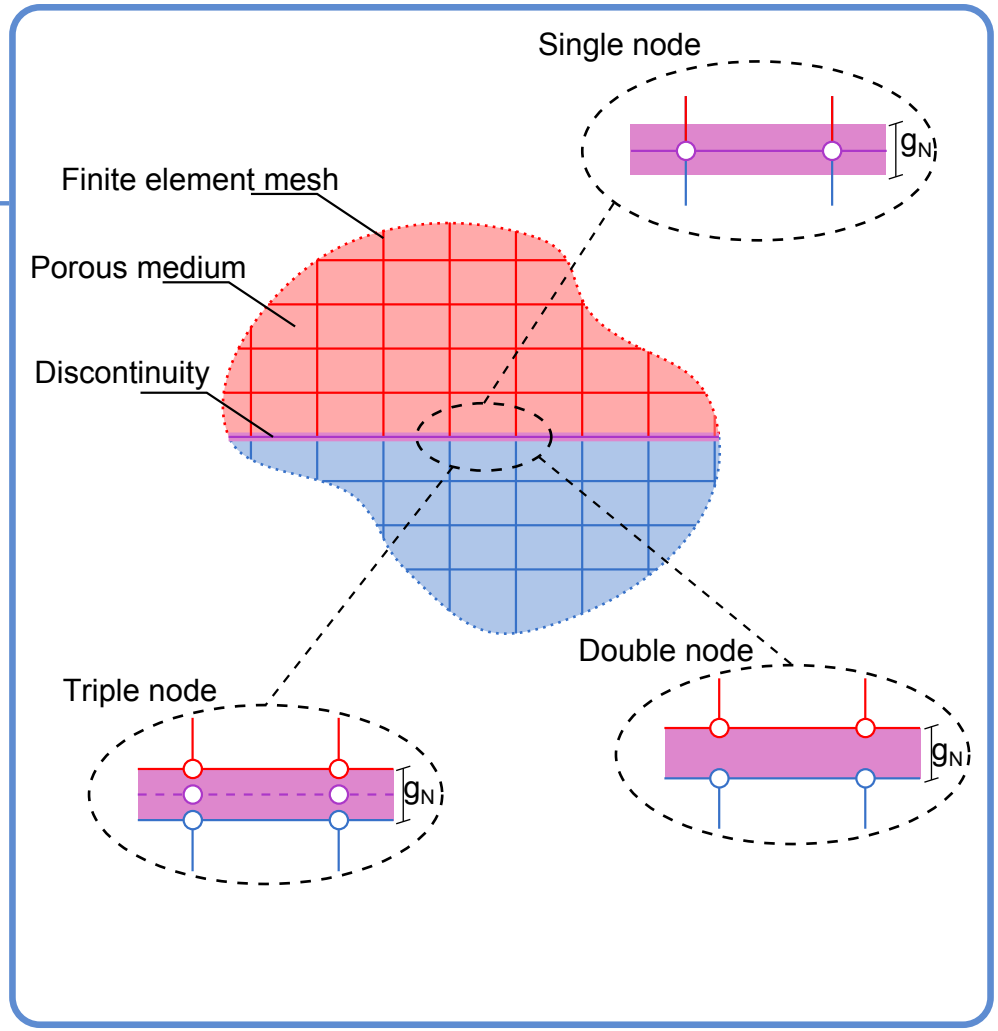
Diconstinuity = porous medium

Fluid flows

Interface

Longitudinal and transversal flows

Discretisation



Couplings

Hydro-mechanical couplings

Effective pressure

Terzaghi's principle

$$p_N = p'_N + p_w$$

- p'_N, effective pressure (mechanical behaviour)
- p_w, fluid pressure inside the interface

Couplings

Hydro-mechanical couplings

Effective pressure

Permeability

Cubic law

$$k_l = \begin{cases} \dfrac{(D_0)^2}{12} & g_N \leq 0 \\ \dfrac{(D_0 + g_N)^2}{12} & \text{otherwise.} \end{cases}$$

- k_l, longitudinal permeability
- D_0, residual hydraulic opening

Couplings

- Hydro-mechanical couplings
  - Effective pressure
    - Permeability
      - Storage

Stored water within discontinuity

$$\dot{\mathrm{M}}_f = \left(\dot{\rho}_w \, \mathrm{g}_N + \rho_w \, \dot{\mathrm{g}}_N + \rho_w \, \mathrm{g}_N \, \frac{\dot{\mathrm{L}}}{\mathrm{L}} \right) \mathrm{L}$$

- L, length of the discontinuity
- ρ_w, density of water

Summary

Mechanical problem

- Zero-thickness
- Segment to segment discretisation
- Penalty method to enforce normal and tangential constraints
- Coulomb criterion

Hydraulic problem

- Three-node discretisation
- Longitudinal flow
- Transversal flows

Coupled problem

- Effective pressure
- Permeability
- Storage (transient component)

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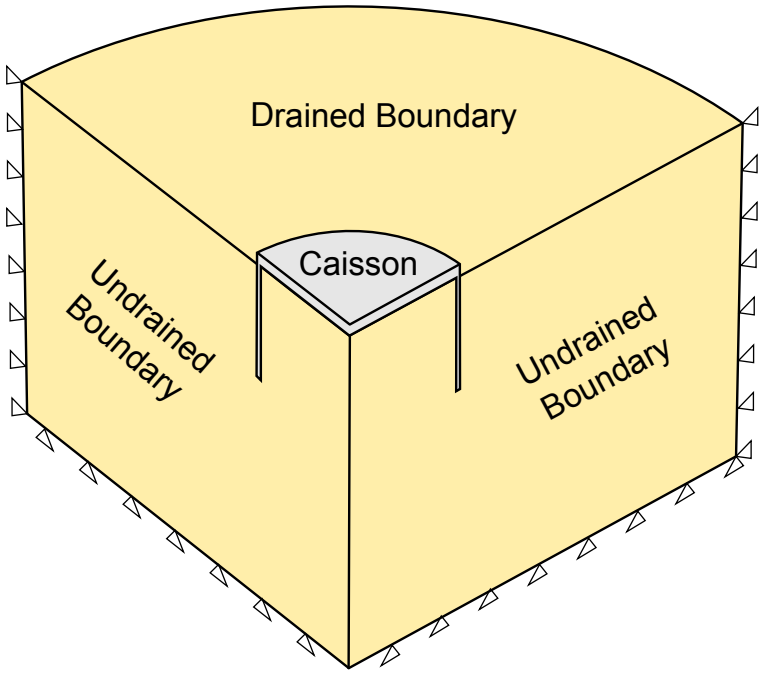
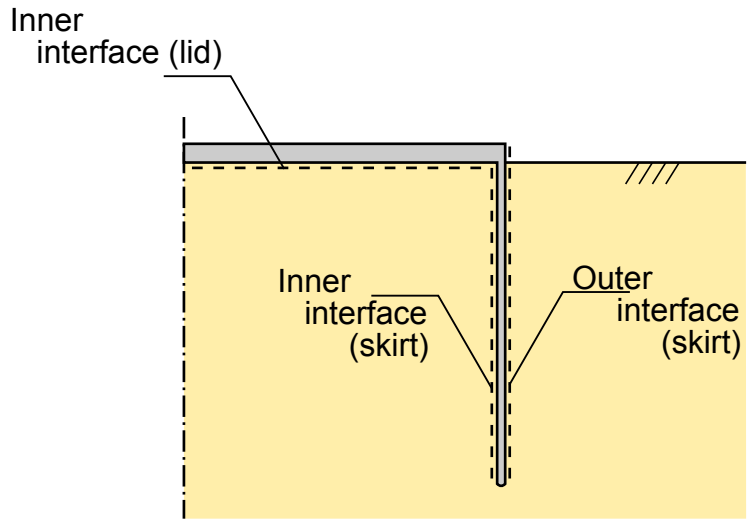
Statement of the problem

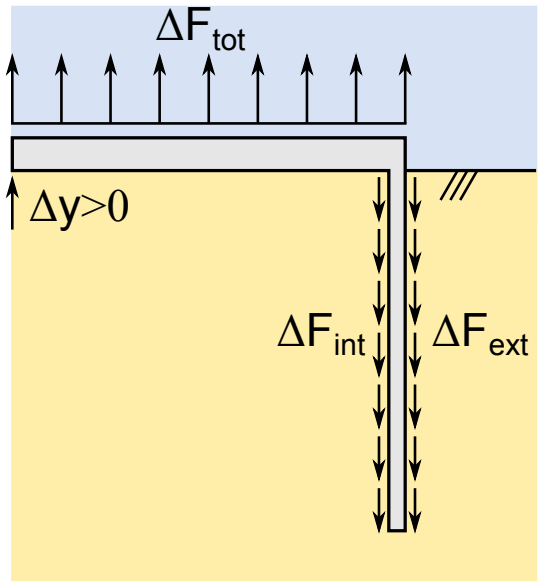




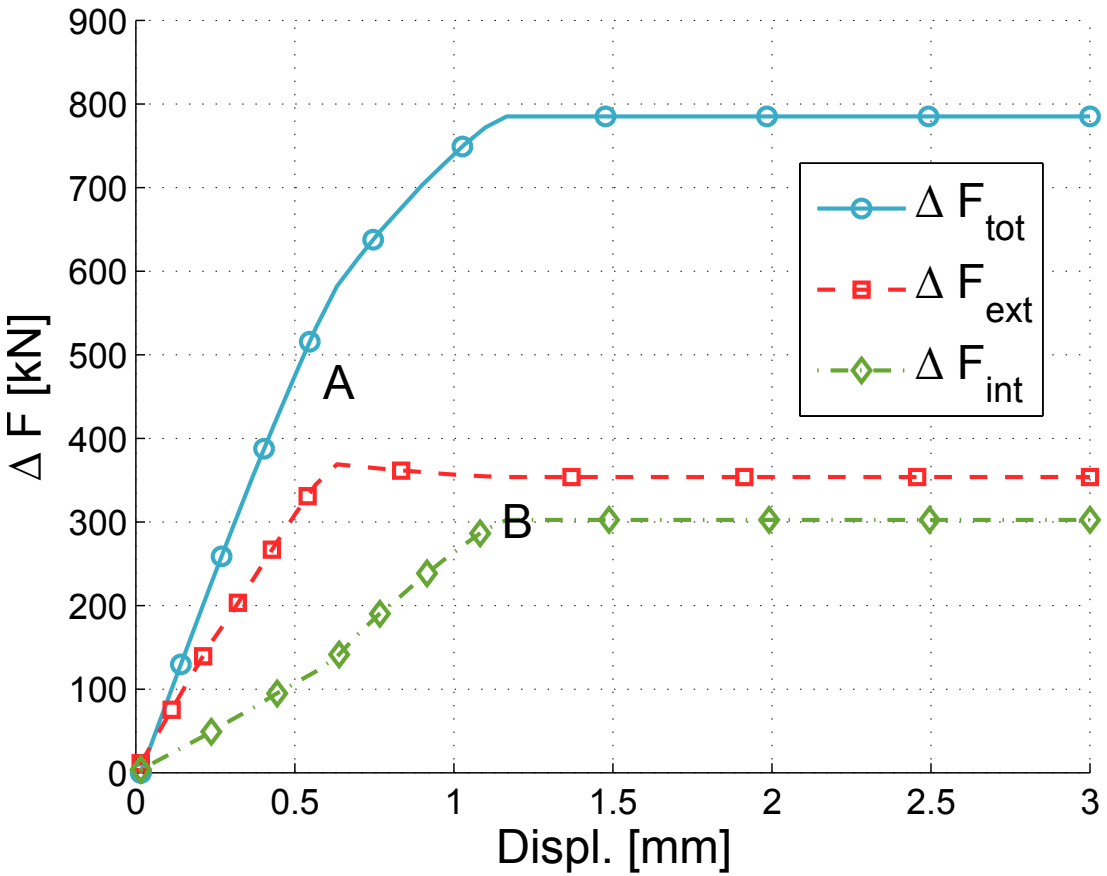
- Elastic soil and caisson
- Diameter 7.8m
- Water depth 10m
- Soil permeability 1.E-11m^2
- $\mathrm{K}_0 = 1$

- Friction coefficient 0.57
- Residual hydraulic aperture 1.E-5m
- Penalty coefficient 1.E10 N/m^3
- Conductivity 1.E-8m/Pa/s

Drained simulation (mechanical behaviour)



Shearing of the interface



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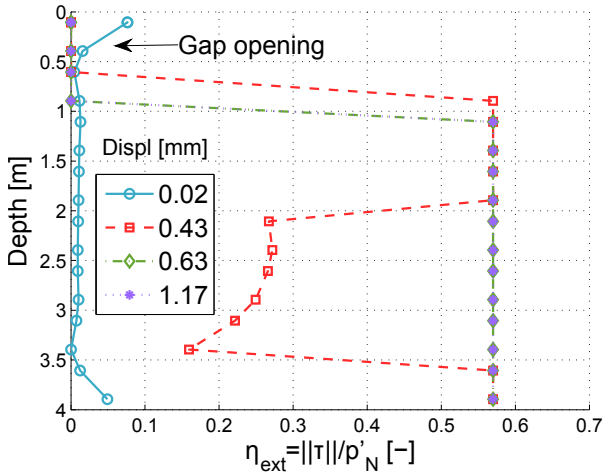
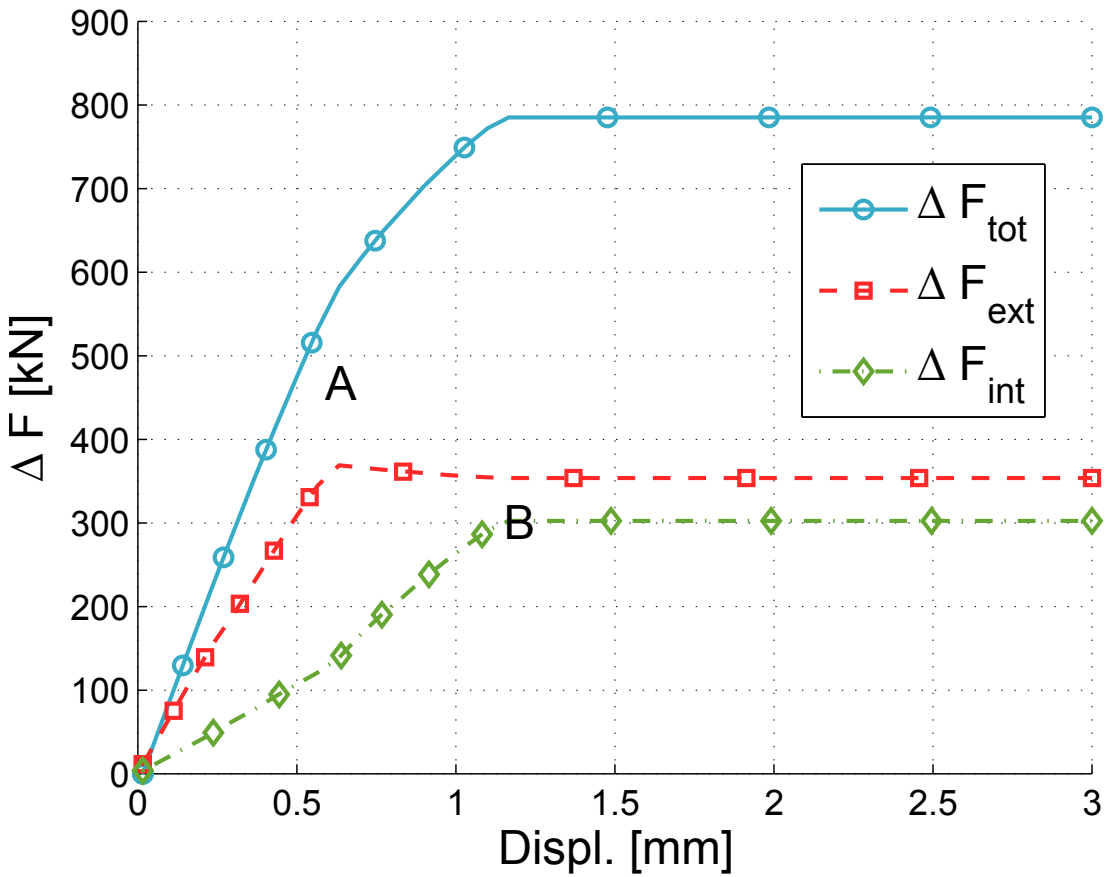
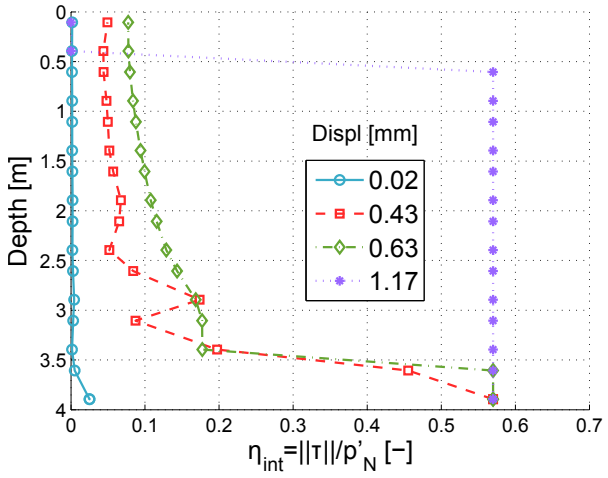


- Outer friction
- Gap opening

Shearing of the interface

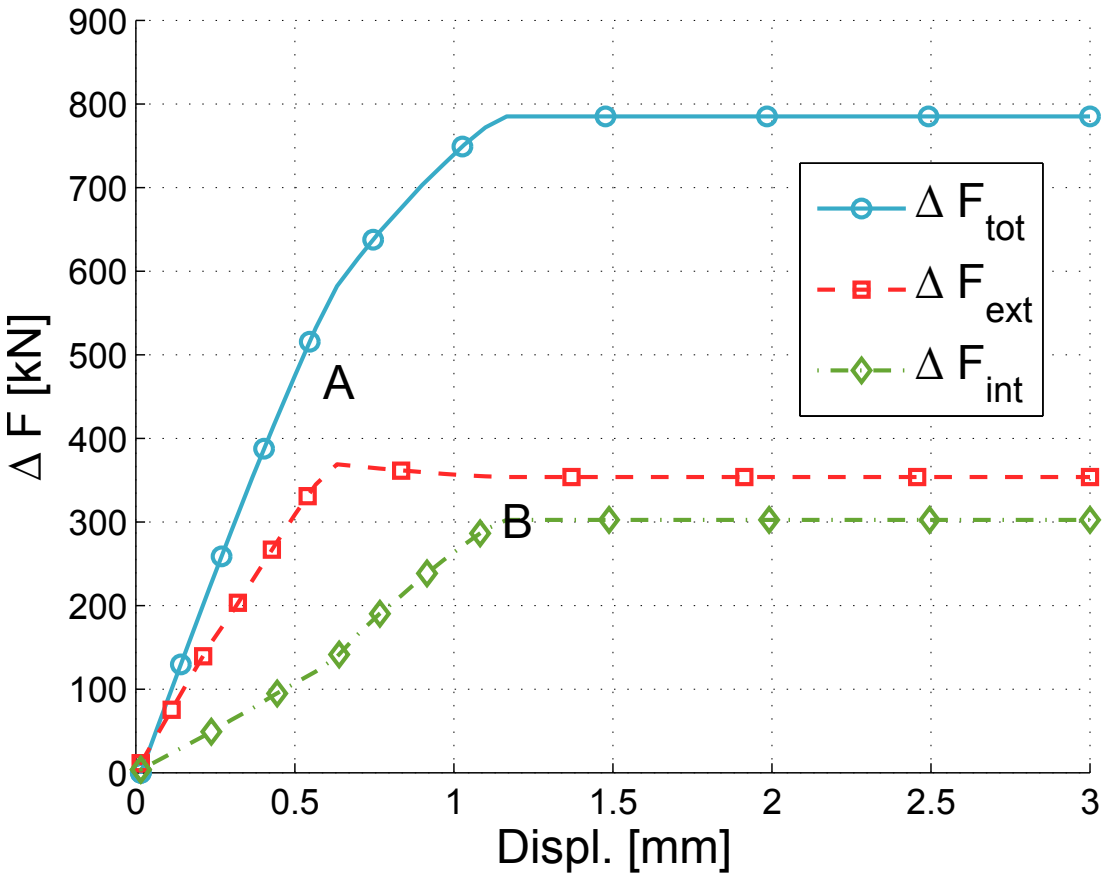


Drained simulation (mechanical behaviour)

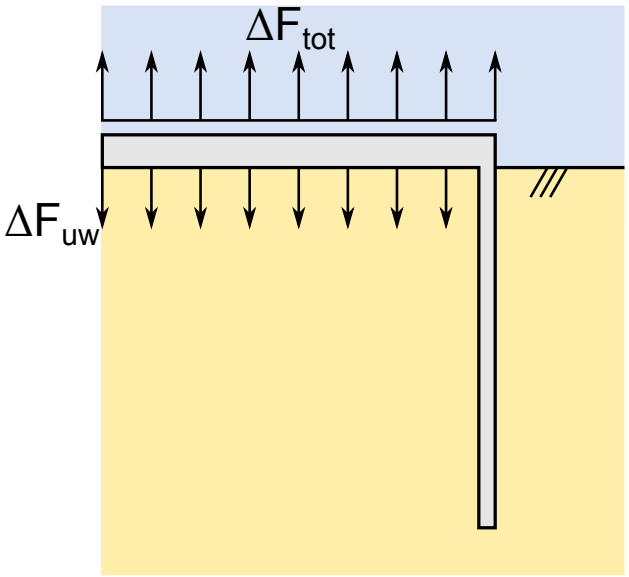


- Outer friction
- Gap opening
- Inner friction
- Failure

Shearing of the interface

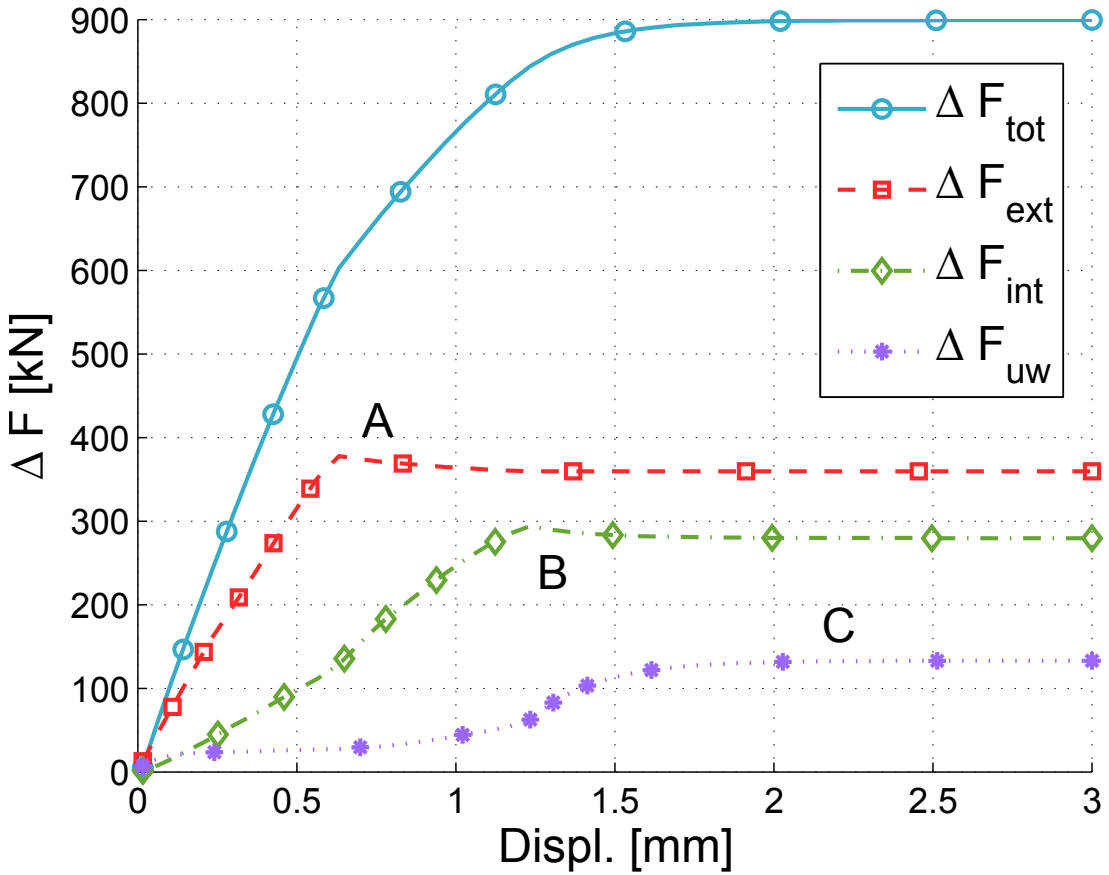


Partially drained simulation (hydraulic behaviour)



- Higher ΔF_{tot}

Suction effect



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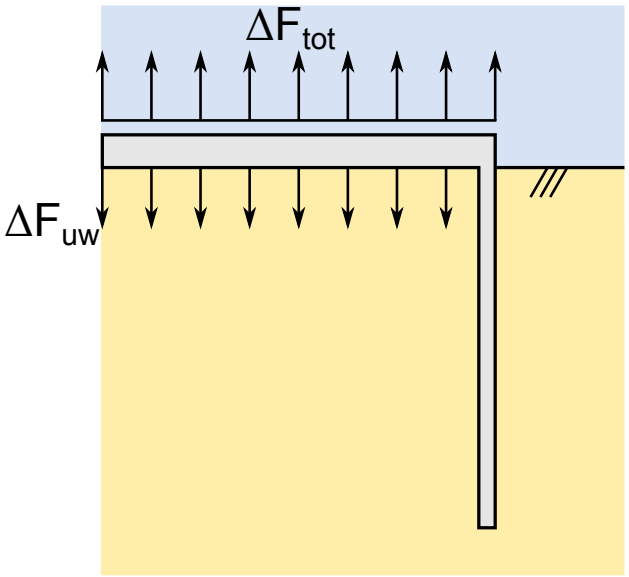
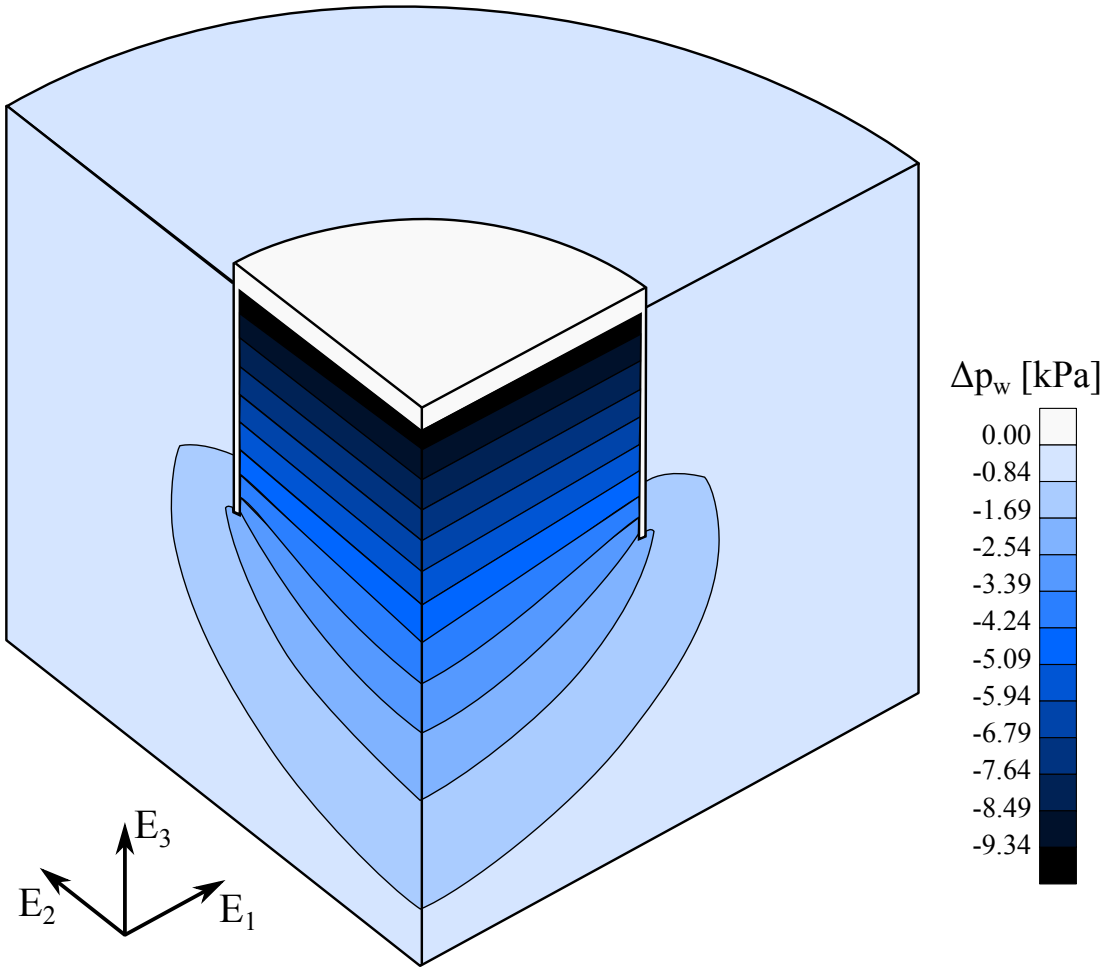
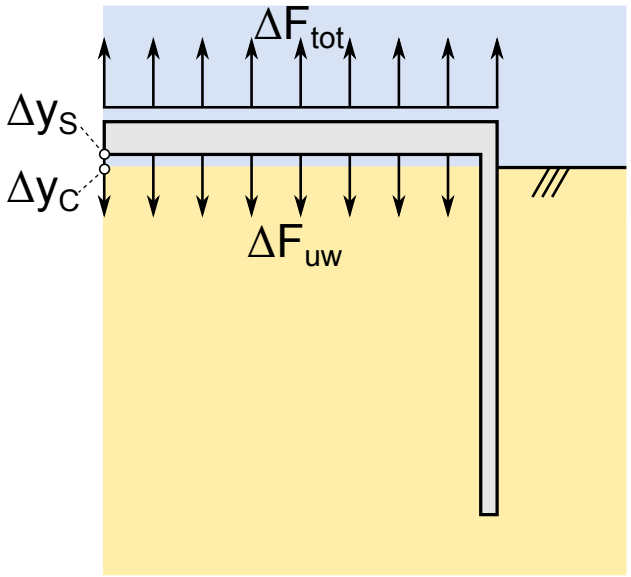


- ΔF_{tot}
- Coupling
  $p_N = p'_N + p_w$
- Transient Δp_w

Suction effect

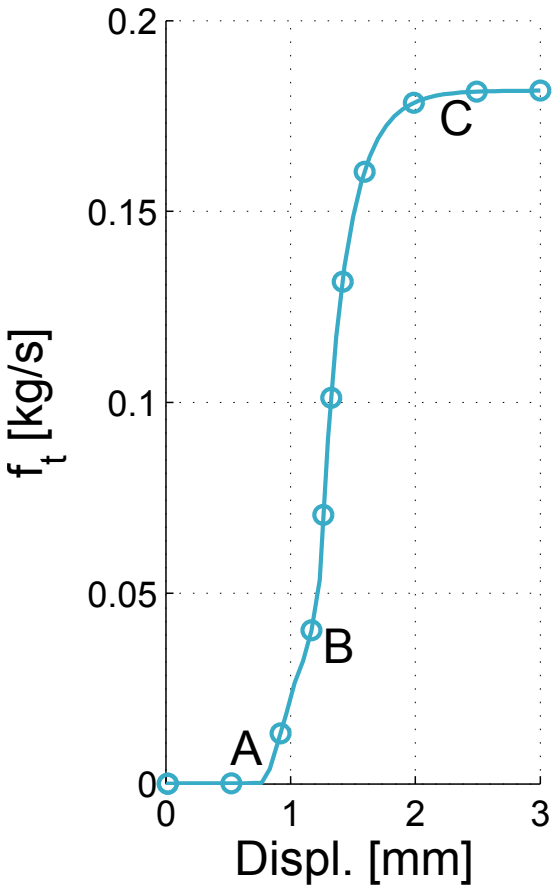


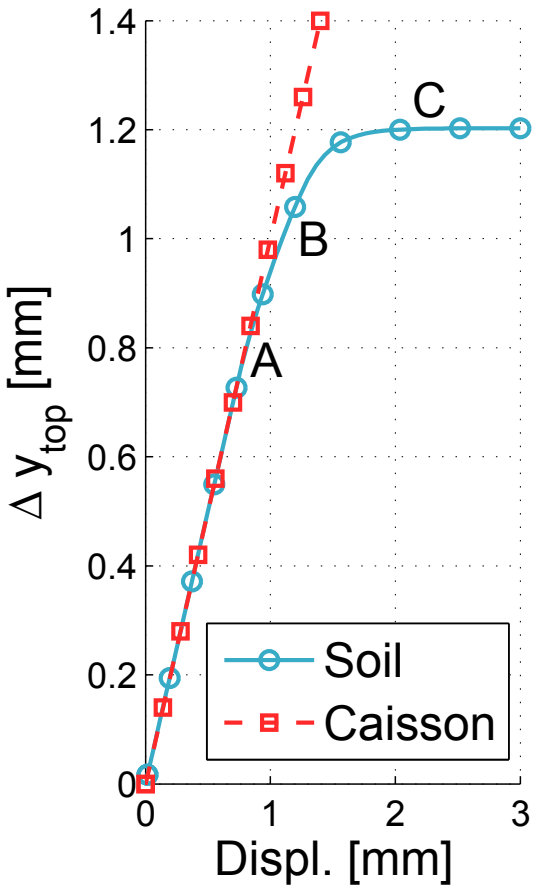
Partially drained simulation (hydraulic behaviour)



- Opening of a gap
- Transversal flow
- Transversal storage
- Stationary phase

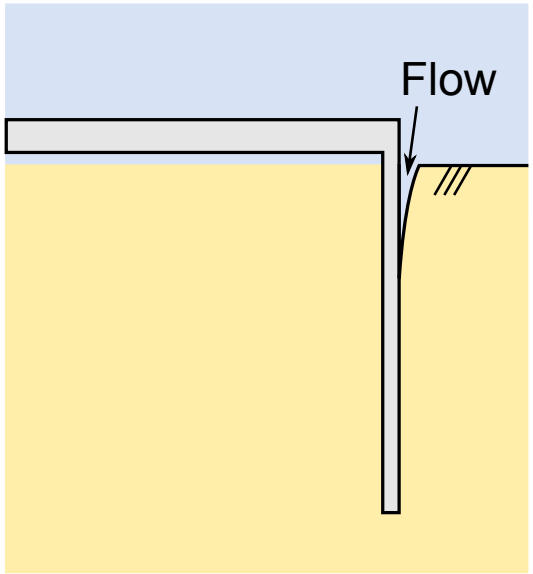
Top unsticking and storage





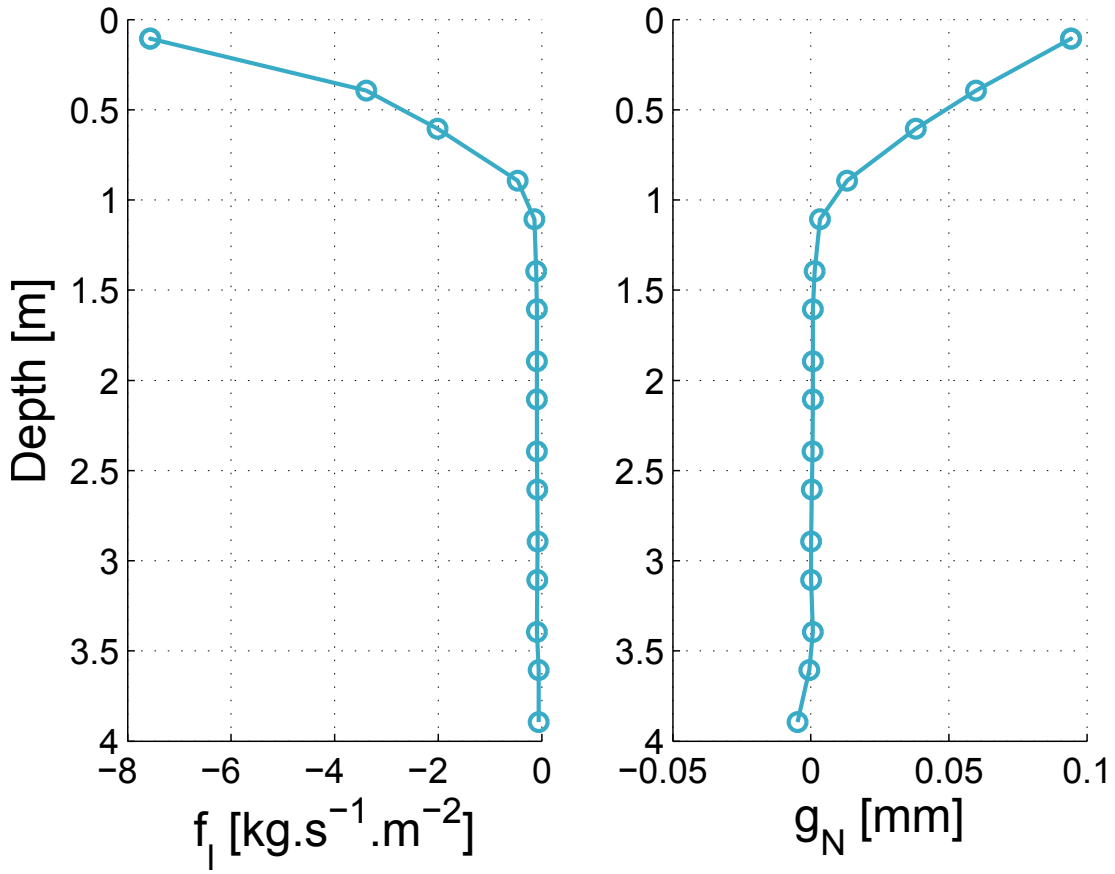
$v_p = 1$ mm/min

Partially drained simulation (hydraulic behaviour)



- Opening of a gap
- Coupling gap-permeability

Longitudinal flow f_l along the skirt



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1. Development of a coupled hydro-mechanical interface element
   - Zero-thickness
   - Three-node flow discretisation
2. Main features of mechanical behaviour
   - Shearing
   - Sliding
3. Main features of hydraulic behaviour
   - Transversal flows
   - Longitudinal flows
4. Hydro-mechanical couplings
   - Suction effect (Terzaghi)
   - Permeability (longitudinal flow)
   - Storage (Unsticking)

Related papers

- Cerfontaine B (2014) The cyclic behaviour of sand from the Prevost model to offshore geotechnics (2014). University of Liege.
- Cerfontaine B, Collin F and Charlier R (2015) Vertical transient loading of a suction caisson in dense sand. In *Proceedings of the 14th International Conference of International Association for Computer Methods and Recent Advances in Geomechanics*, *IACMAG2014*, pp. 929-934.
- Cerfontaine B, Levasseur S, Collin F and Charlier R (2014). In *Proceedings of the 8th European Conference on Numerical Methods in Geotechnical Engineering*, *NUMGE2014*, 2, pp. 1243-1248.
- Cerfontaine, B, Dieudonné AC, Radu JP, Collin F and Charlier R (2015 submitted) 3D zero-thickness coupled interface finite element : formulation and application, *Computers & Geotechnics*.