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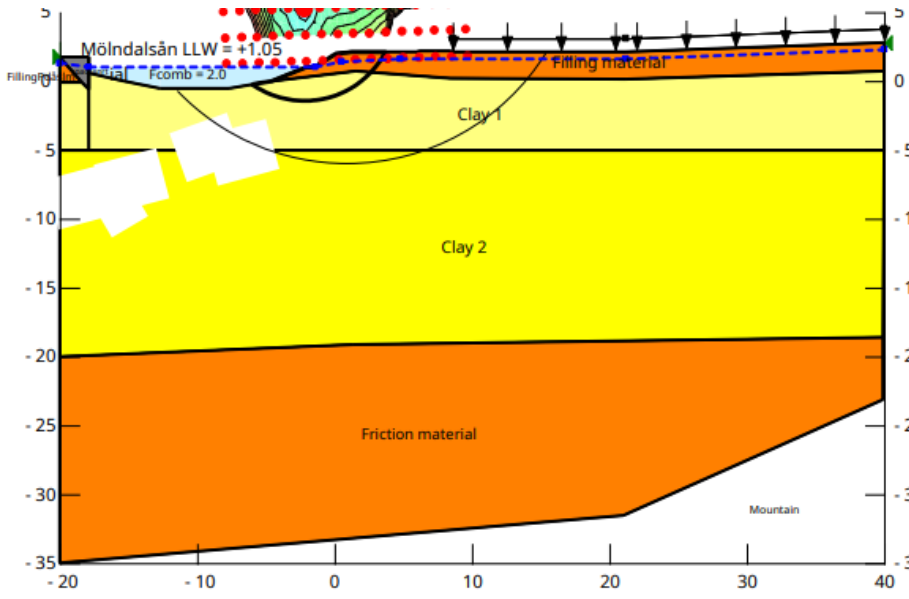
Effect of Bedrock Fault and Frictional Layer on Tunneling-Induced Ground Settlement: A Hydro-Mechanical Modeling Study in Composite Soil–Rock Systems

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Abstract ID : 349

Introduction: a complex geological system



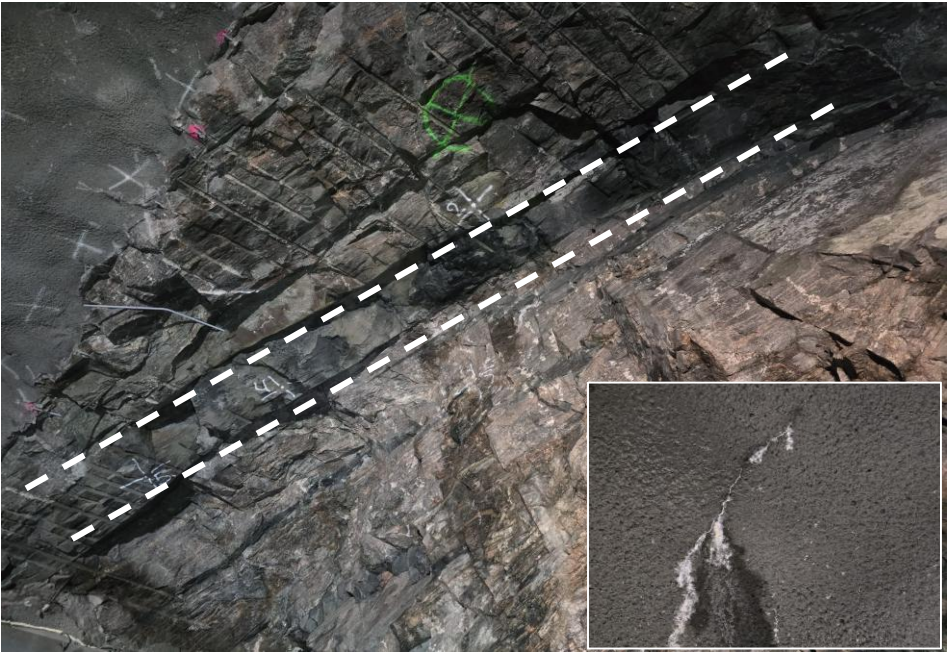
Layering sequence
Gothenburg city, Sweden



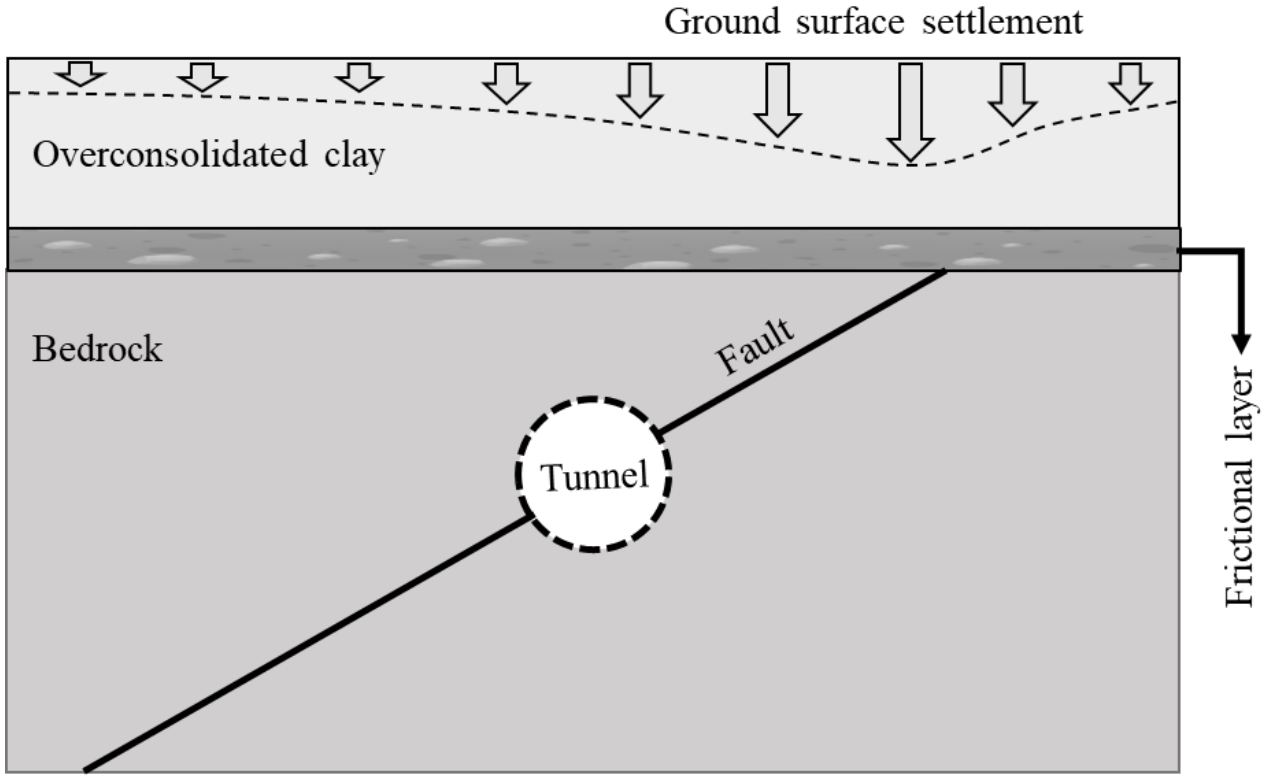
London Clay, an example of a complex geological system

Geological condition in a complex system

- Layered geological system
- The effect of frictional layer on ground surface settlement
- Effect of having a fault in bedrock on ground surface settlement profile



Tunnel roof, West Link Project, Gothenburg, Sweden

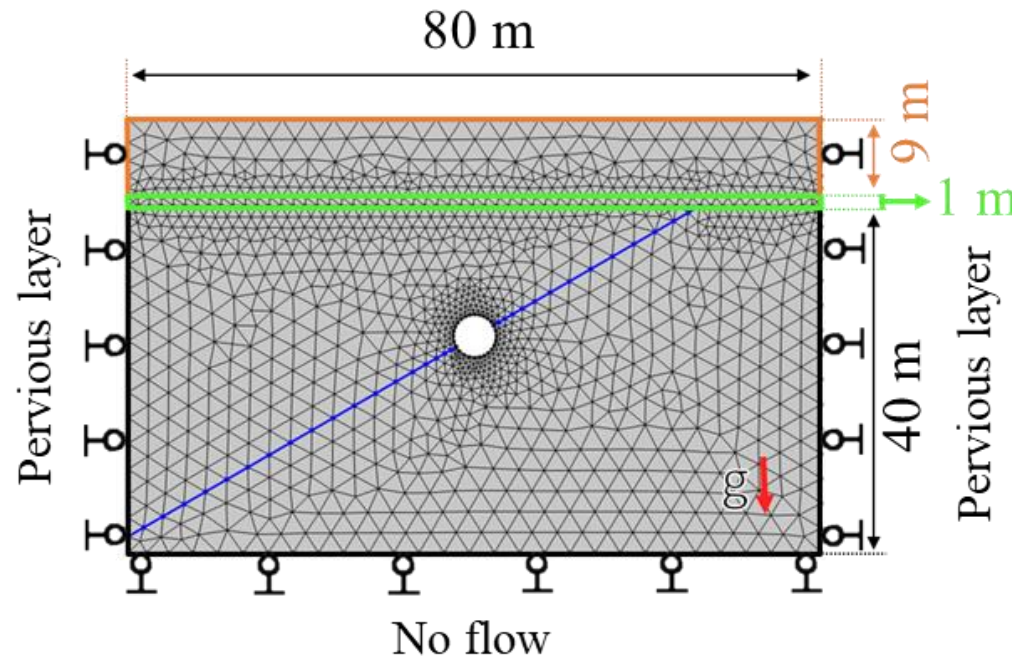
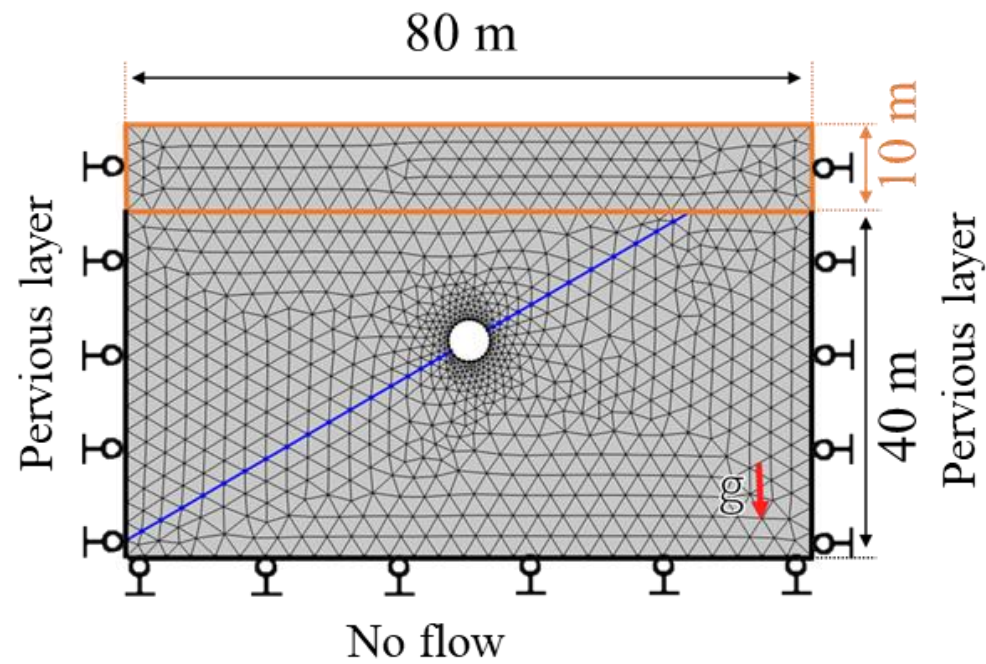


- Can a fault in a complex, layered system change the settlement profile?
- What is the effect of the frictional (granular) soil layer in this system?

Model setup (geometry, BC, meshing)

- Two layer and Three layer systems
- 80 × 40 m domain
- 5 m tunnel diameter

- Pervious layer hydraulic BC
- Roller mechanical BC



- Free triangular
- 0.41 m – 3.46 m
- 2300 elements

Clay
 Bedrock
 Frictional layer
 — Discontinuity
 ⊕ Roller



- Overconsolidated clay
- Frictional layer
- Granite bedrock

Parameters to analyse:

- Fault permeability: 10^{-24} to 10^{-6} m²
- Frictional layer thickness
- Fault dip angle: 30°- 45°
- Time: 1 day -10 years

Parameter	Clay layer	Frictional layer	Bedrock
Density (kg/m ³)	1650	2000	2650
Permeability (m ²)	10 ⁻²⁰	10 ⁻¹²	10 ⁻¹⁸
Porosity	0.3	0.35	0.1
Poisson's ratio	0.3	0.25	0.35
Young's modulus (Pa)	5 × 10 ⁸	2.5 × 10 ⁷	7 × 10 ¹⁰
Biot's coefficient	0.9	0.7	0.75

	Equation	Parameters	
Solid deformation	$\nabla \cdot \sigma + f = 0$ $\sigma' = \sigma - \alpha pI = D : \epsilon$	ϵ_v : volumetric strain t: time α : Biot's coefficient ρ_w : water density Q: source term U: flux ϕ : porosity z: elevation S: storage coefficient g: gravity's acceleration	p: pore pressure μ_w : dynamic viscosity k: permeability f: body force σ : stress D: elastic stiffness matrix I: identity matrix σ' : effective stress
Groundwater flow	$\frac{\partial(\rho_w \phi)}{\partial t} + \nabla(\rho_w U) = Q - \rho_w \alpha \frac{\partial \epsilon_v}{\partial t}$ $U = -\frac{k}{\mu_w} (\nabla p + \rho_w g \nabla z)$ $\frac{\partial(\rho_w \phi)}{\partial t} = \rho_w S \frac{\partial p}{\partial t}$		

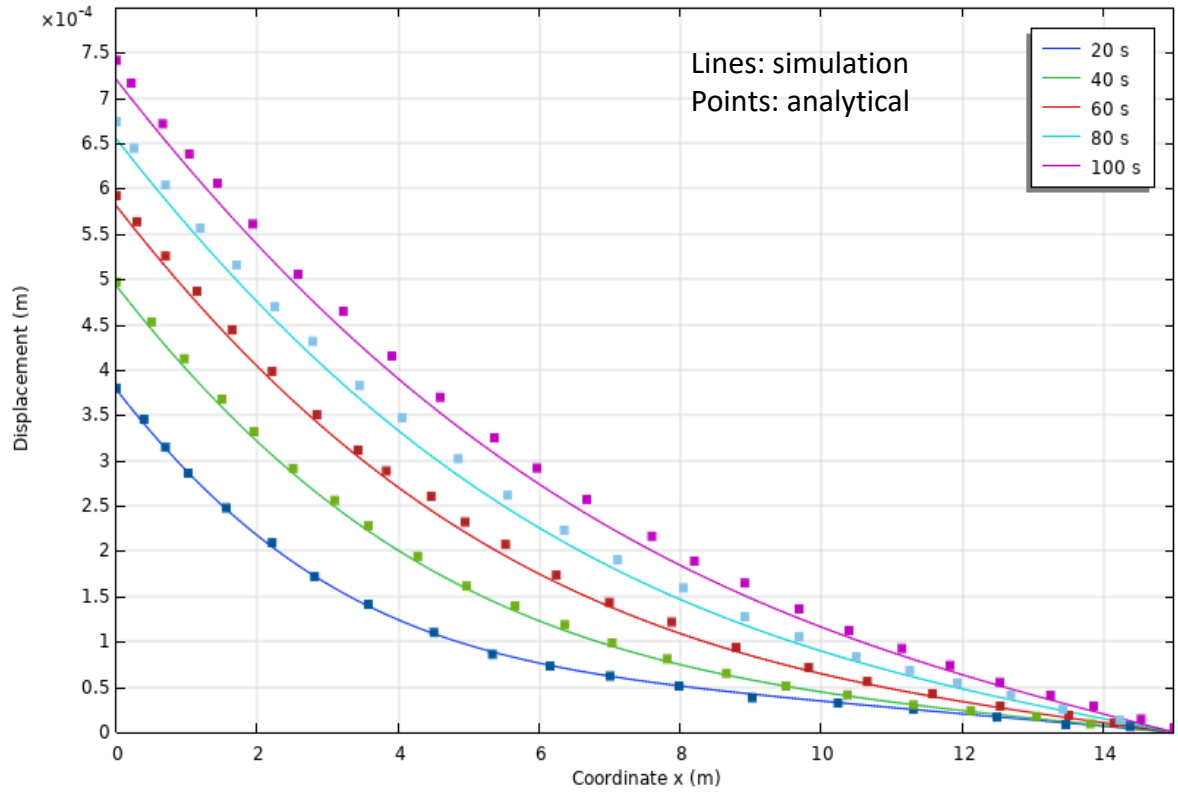
- Coupled HM
- Consolidation of a porous domain
- No gravity

Analytical solution of this problem

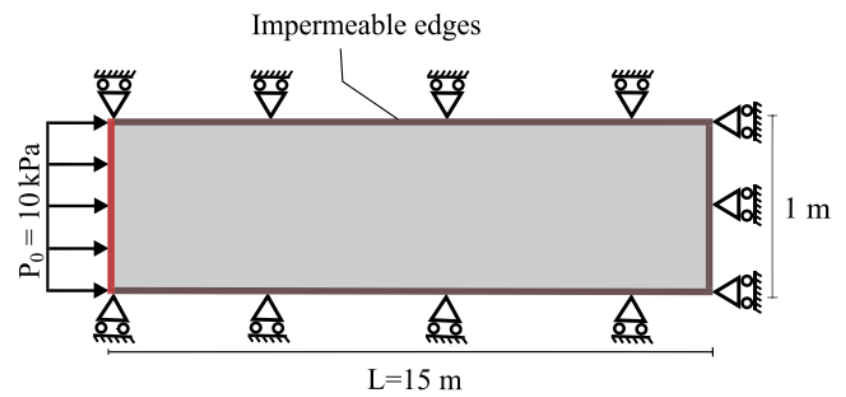
$$u(x, t) = c_m v P_0 \left\{ L - x - \frac{8L}{\pi^2} \sum_{m=0}^N a \frac{1}{(2m+1)^2} \exp \left[\left(-\frac{(2m+1)\pi}{2L} \right)^2 ct \right] \times \cos \left(-\frac{(2m+1)\pi x}{2L} \right) \right\} + b P_0 (L - x), \quad (62)$$

$$p(x, t) = \frac{4v P_0}{\pi} \sum_{m=0}^N \frac{1}{2m+1} \exp \left[\left(-\frac{(2m+1)\pi}{2L} \right)^2 ct \right] \times \sin \left(-\frac{(2m+1)\pi x}{2L} \right), \quad (63)$$

where $a = 10^{-8}$ Pa, $\alpha = 0.5$, $S = 1/(6.06 \times 10^3 \text{ MPa})$, $k = 10^{-12} \text{ m}^2$, $b = \frac{a}{1+\frac{a\alpha^2}{S}}$, $v = \frac{a-b}{a\alpha}$, $c = \frac{k}{(a\alpha^2+S)\mu_w}$, and $c_m = \frac{a-b}{v}$.



Settlement profile over time

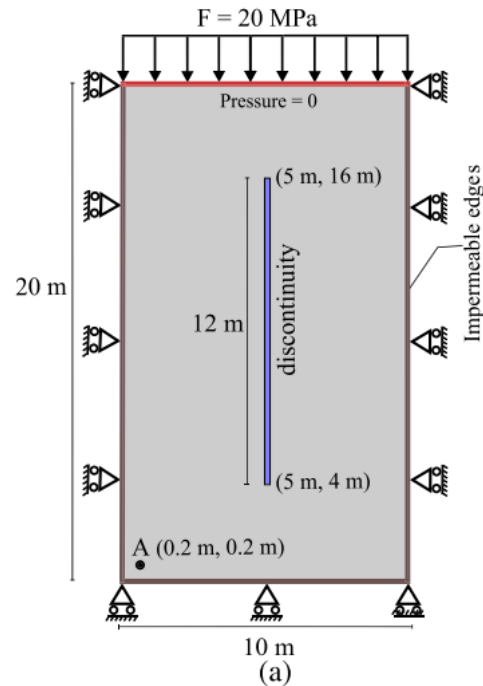


Material properties.

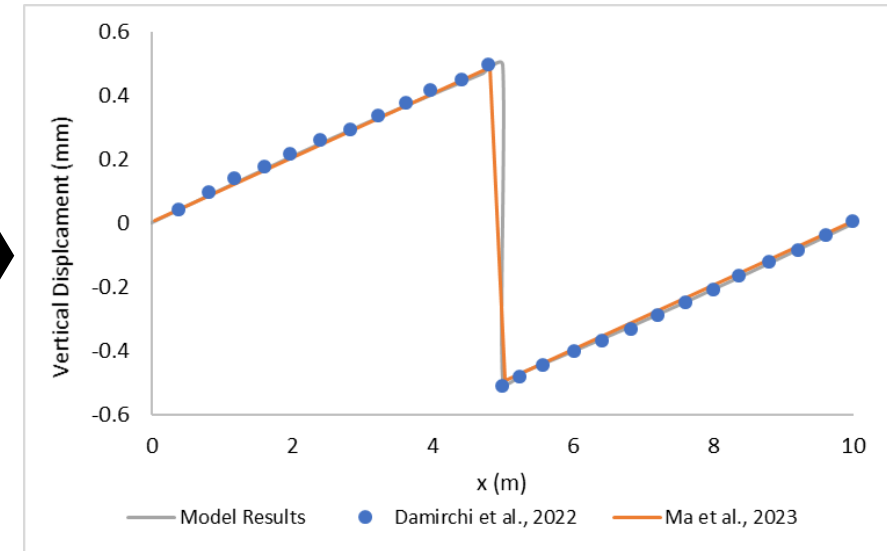
Parameter	Value	Parameter	Value
Young's modulus (MPa)	100	Storage coefficient (M^{-1})	$1/(6.06 \times 10^3 \text{ MPa})$
Poisson's ratio	0	Matrix permeability (m^2)	10^{-12}
Biot's coefficient	0.5	Fluid viscosity (Pa s)	10^{-3}

Model Verifications

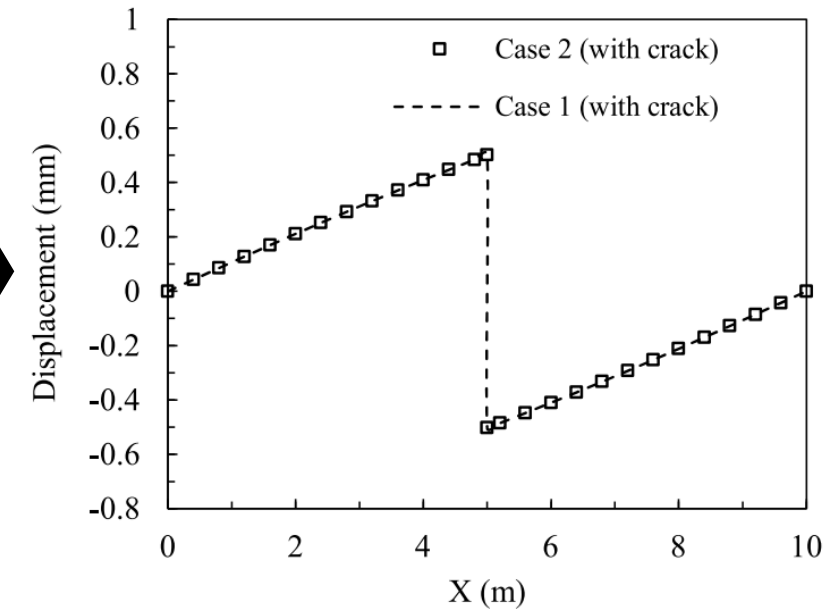
- Porous block with a vertical discontinuity
- 10 m × 20 m



Model Results



(Damirchi et al., 2022)

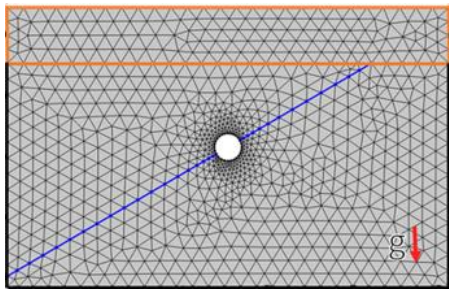


(Damirchi et al., 2022)

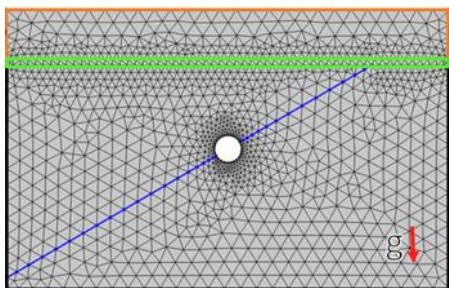
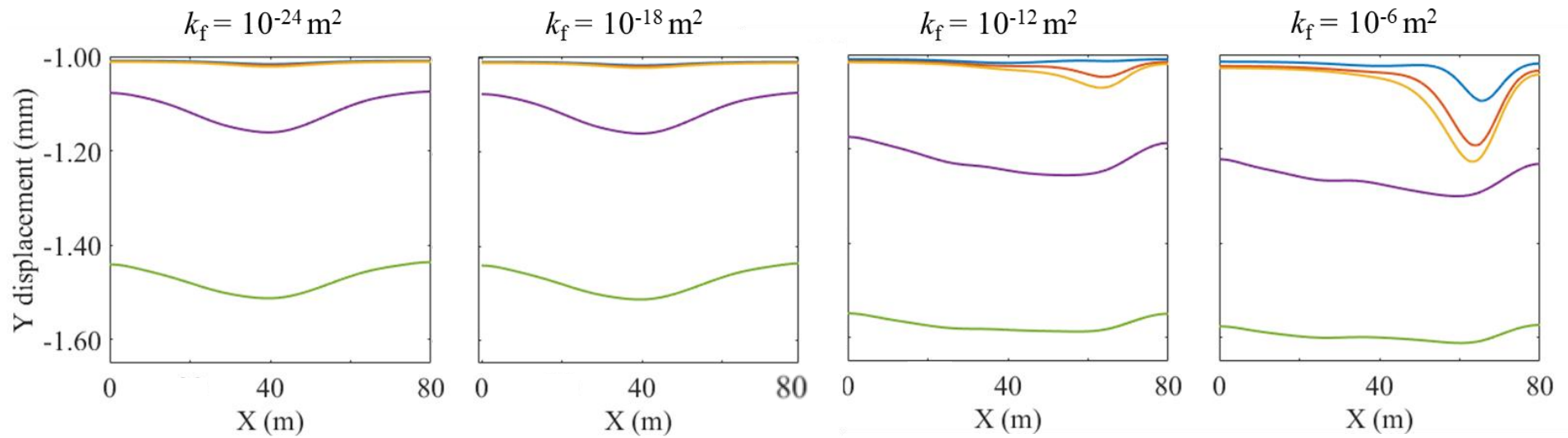
Parameters of the fractured porous medium.

Matrix		Fracture	
Young's modulus (GPa)	10	Permeability (m ²)	10 ⁻¹⁰
Poisson's ratio	0.2	Initial aperture (mm)	5
Biot's coefficient	0.75	Normal stiffness (MPa/mm)	4
Porosity	0.2	Shear stiffness (MPa/mm)	4

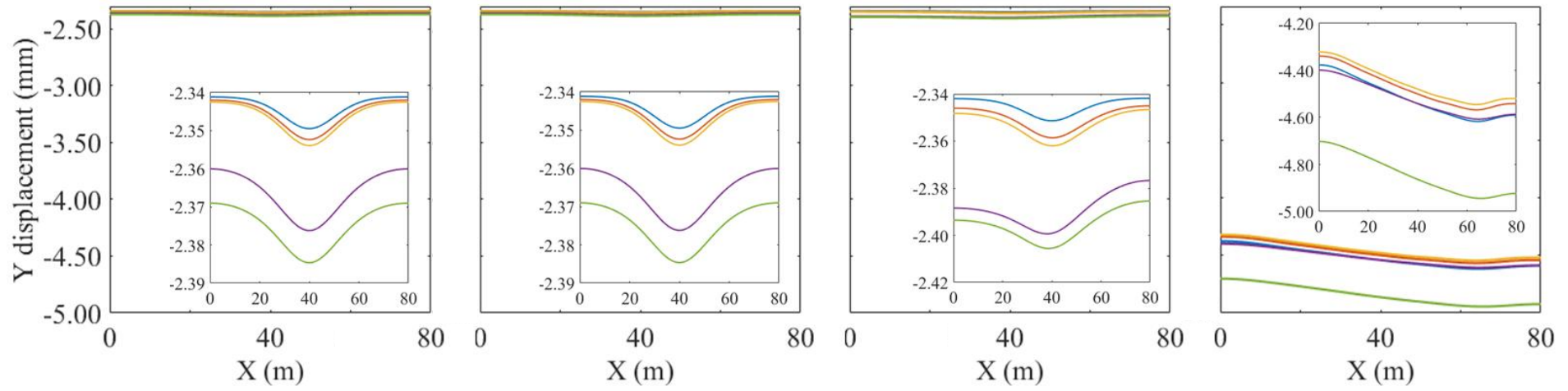
Results: ground surface settlement profiles



Without frictional layer



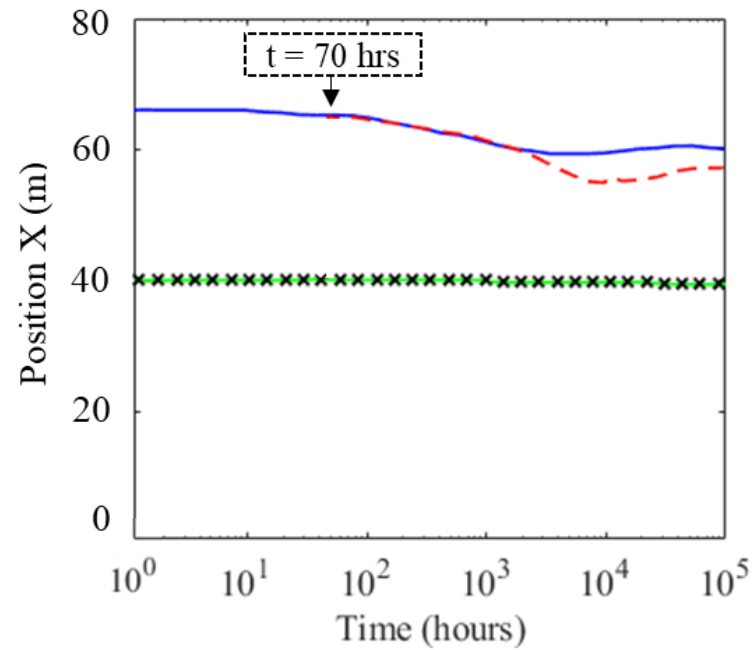
With frictional layer



— 1 day — 1 week — 1 month — 1 year — 10 years

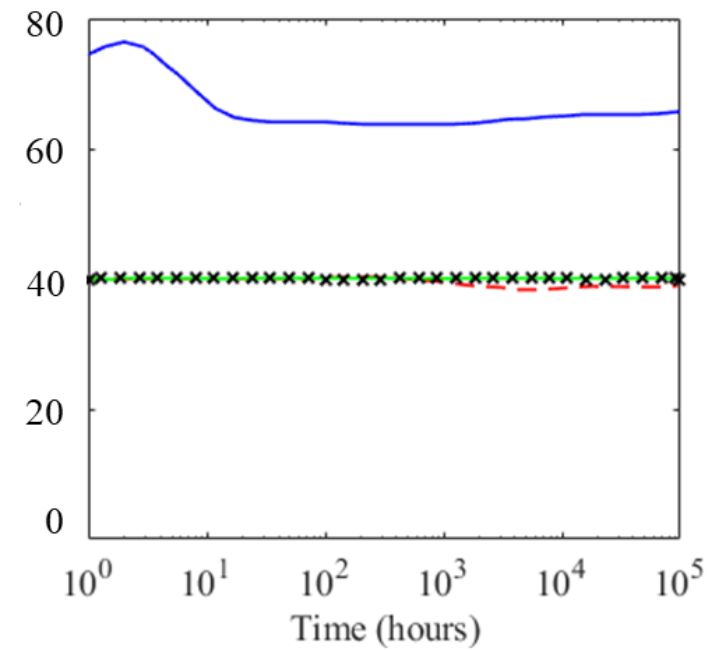
Location of the maximum settlement point over time

Without frictional layer

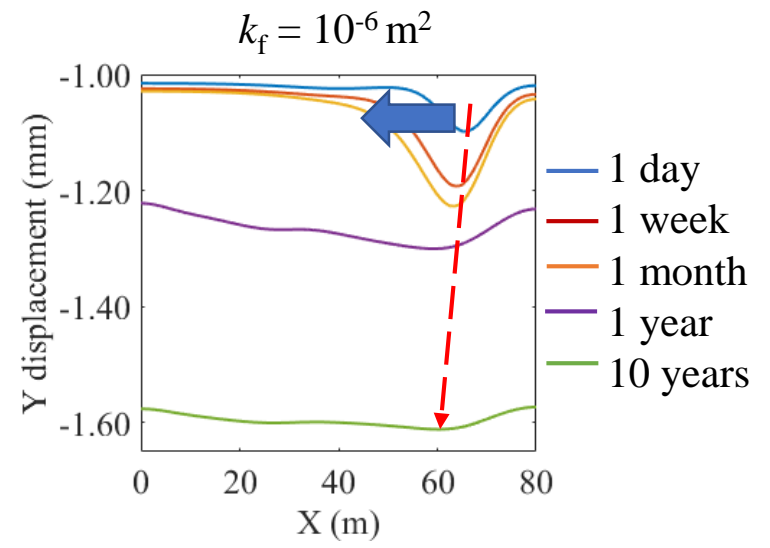
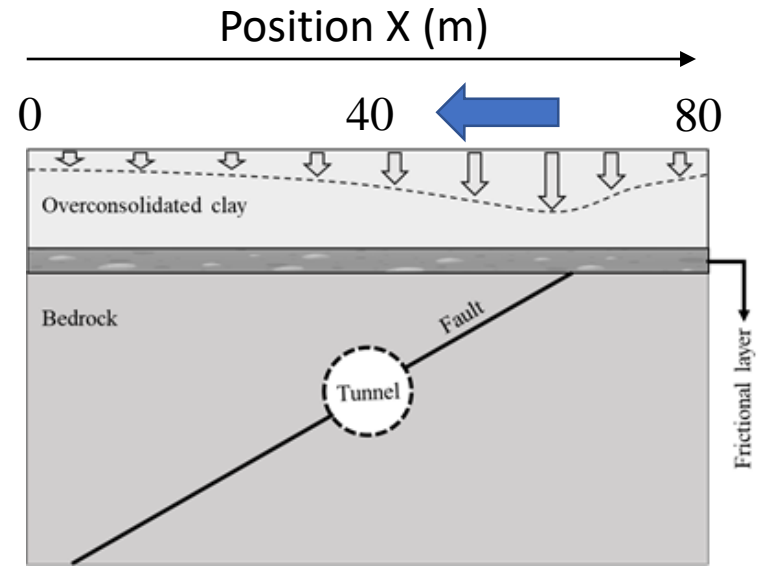


— $k_f = 10^{-6} \text{ m}^2$
 - - $k_f = 10^{-12} \text{ m}^2$

With frictional layer



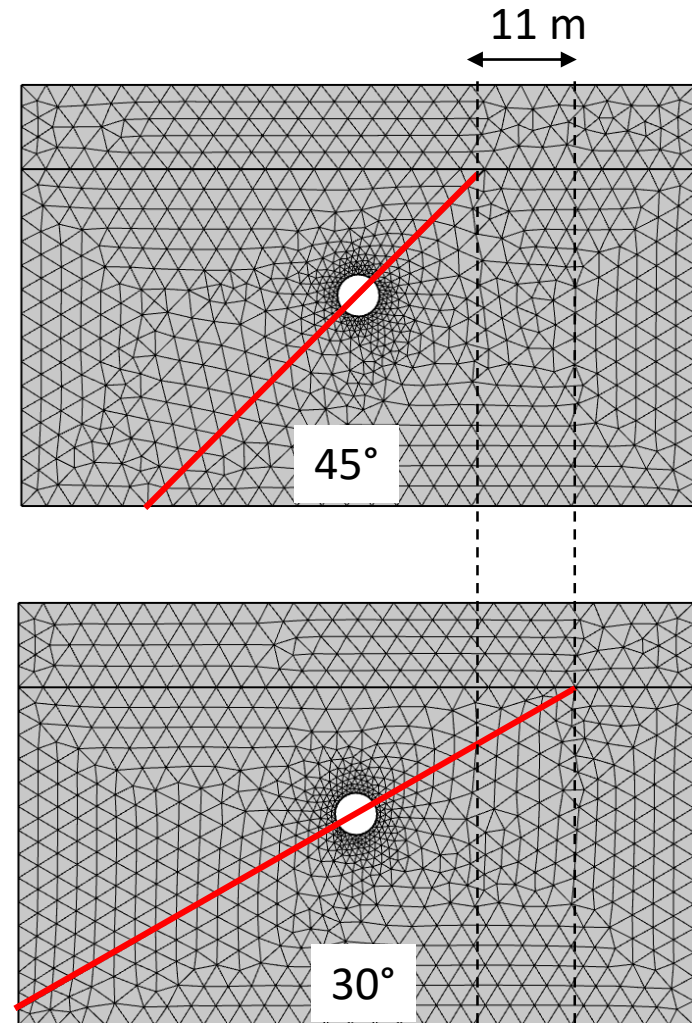
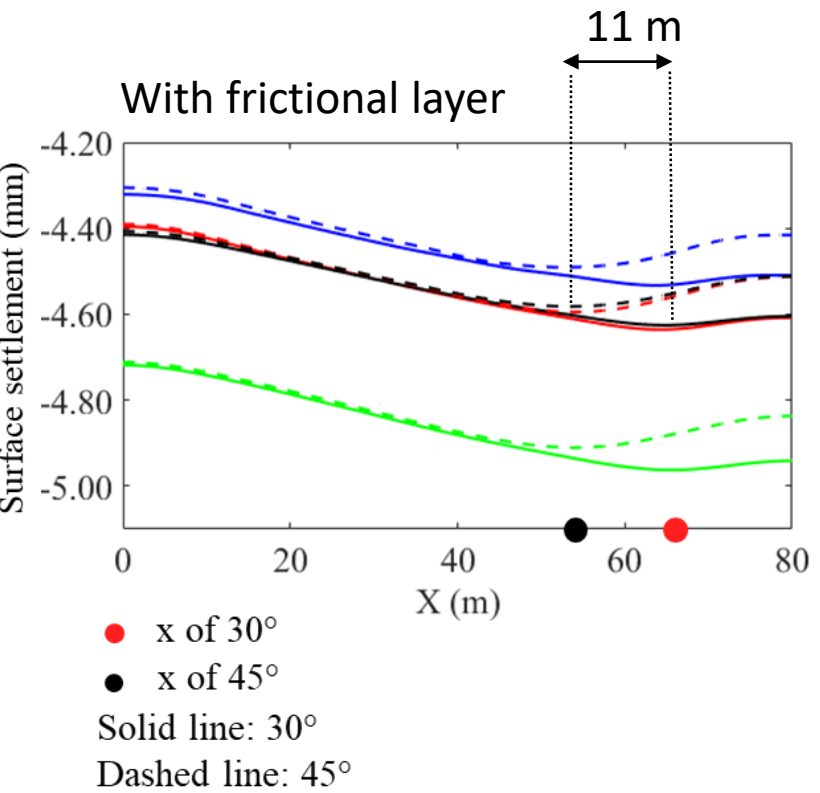
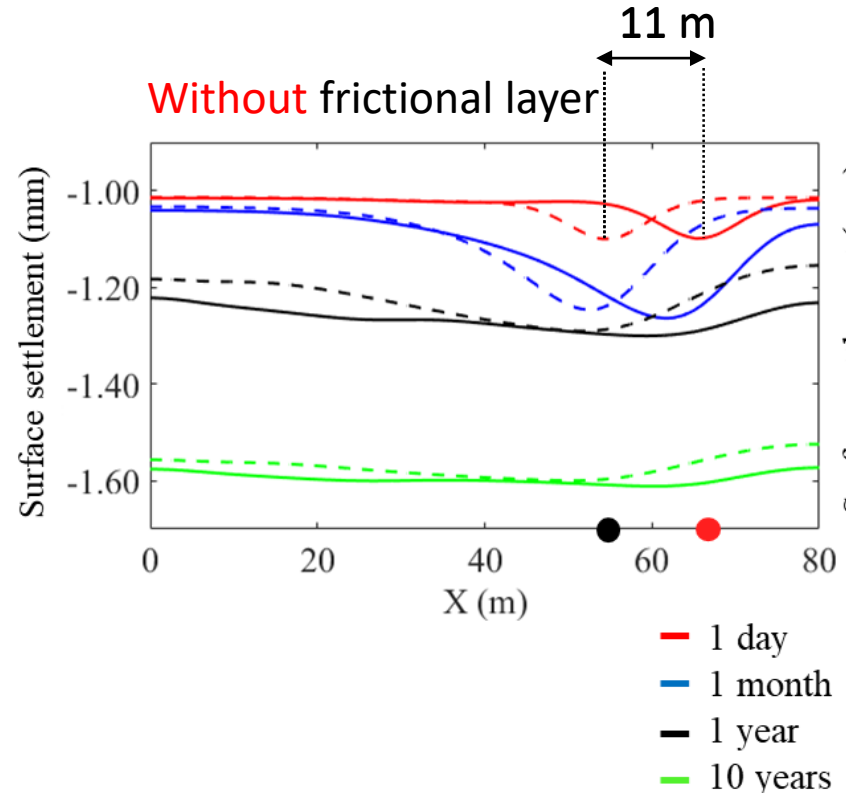
— $k_f = 10^{-18} \text{ m}^2$
 * $k_f = 10^{-24} \text{ m}^2$



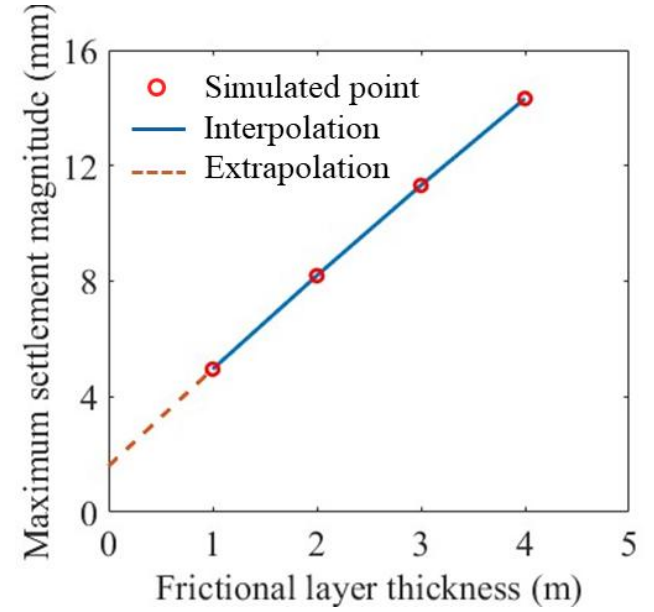
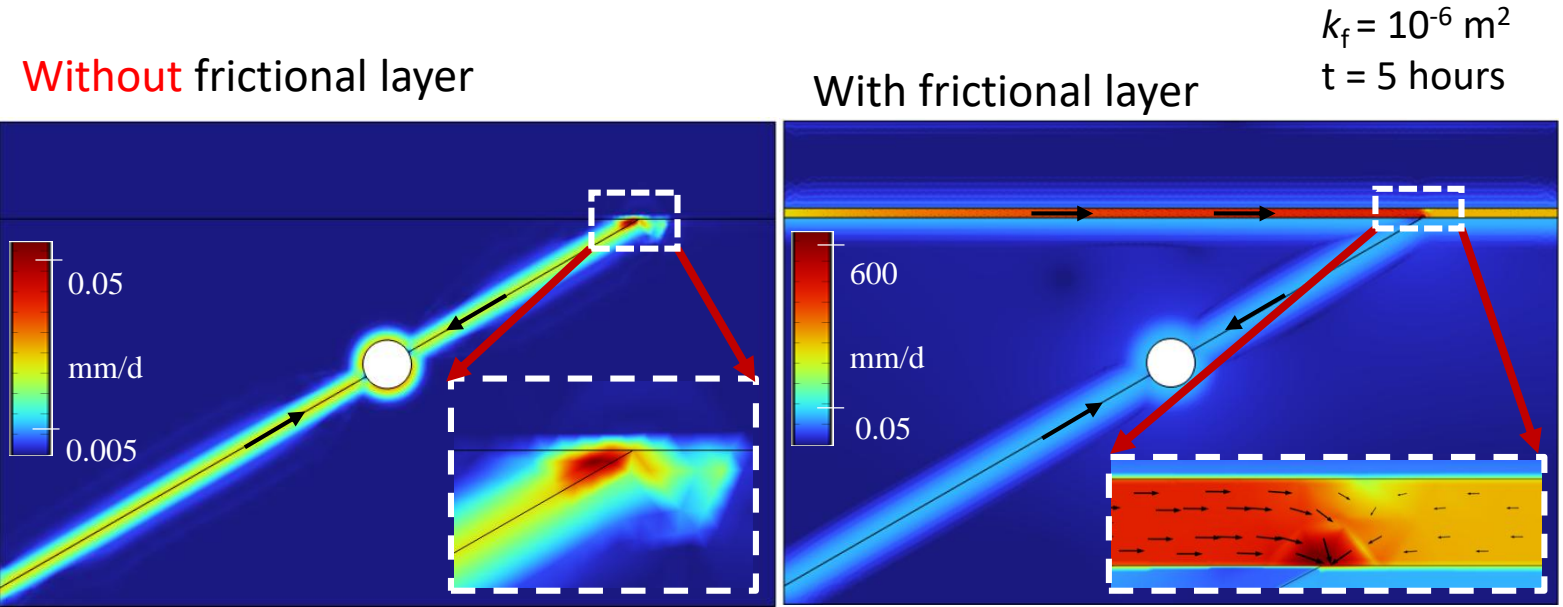
Effect of the fault's dip angle



Dip angles: 30° and 45°

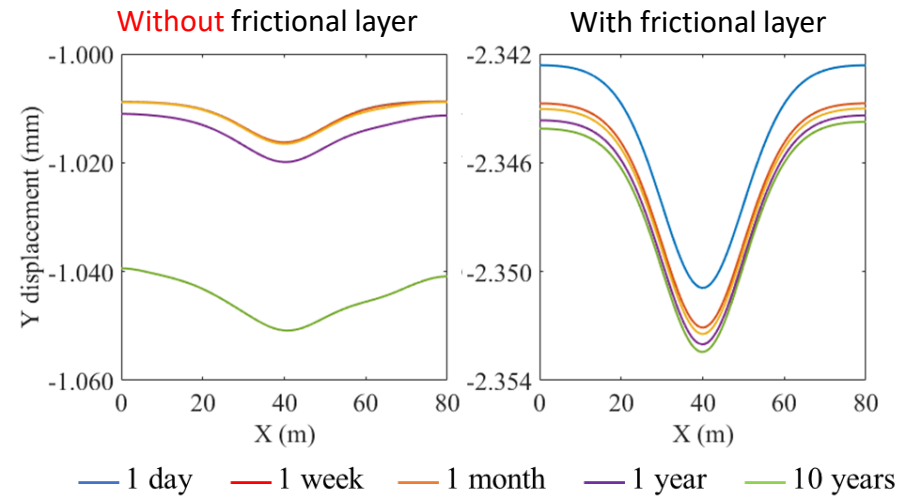


Darcy velocity magnitude distribution



Other parameters effect:

- No-flow boundaries : settlement **increases** (11%)
- Doubling FL thickness (1 m to 2 m): settlement **increases** (5 mm to 8 mm in 10 years)
- Effect of 20 cm thick concrete wall: settlement **decreases** (38%, 53%)



- Can a fault in a complex, layered system change the settlement profile?
 - ✓ High-permeability faults shift maximum settlement point away from the tunnel
- What is the effect of the frictional (granular) soil layer in this system?
 - ✓ Frictional layer presence amplify settlement magnitude

Acknowledgements

- Trafikverket (funding the project)



Thank you!