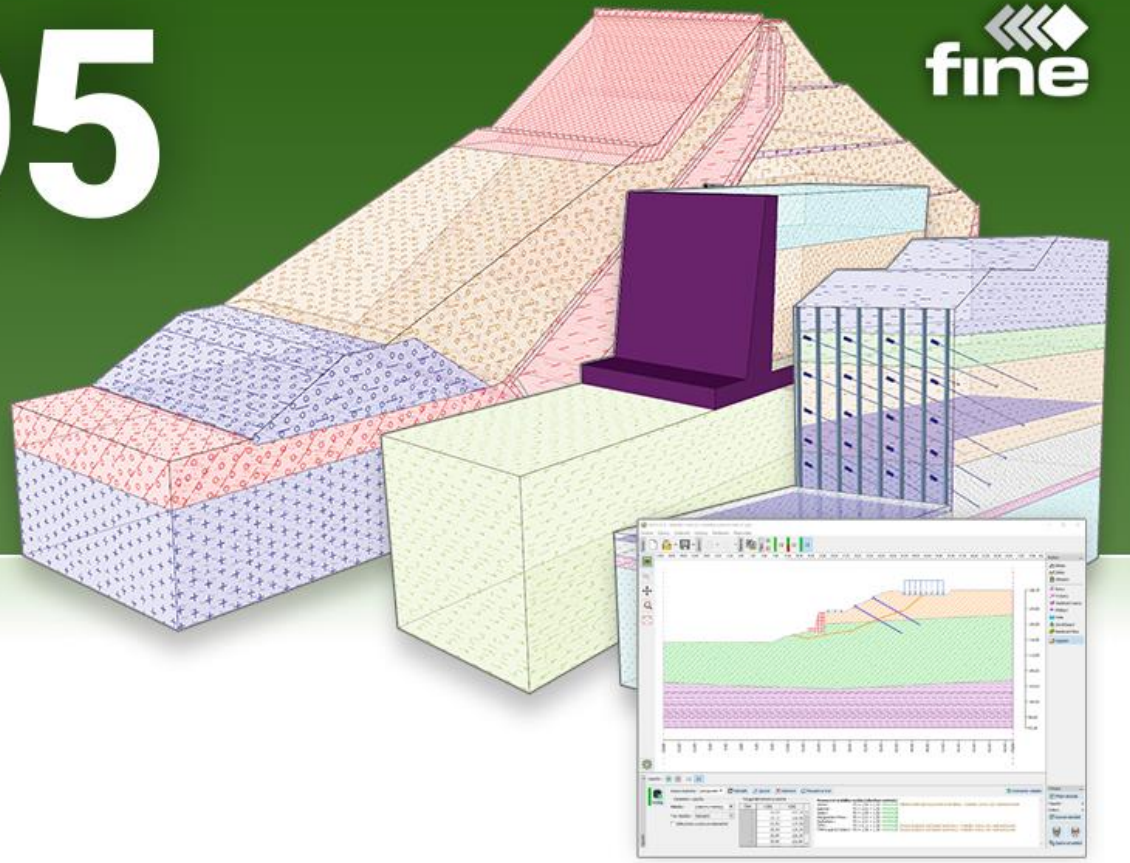
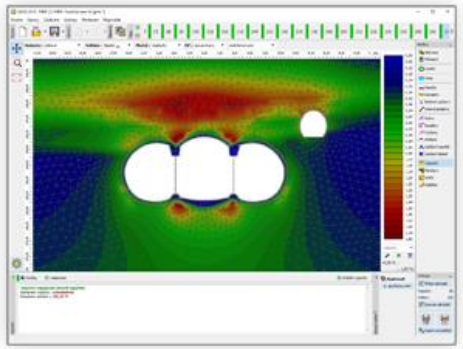
GEO5

Geotechnical Software

fine



FEM - Water Flow, Consolidation



Tomáš Janda

Outline

- 1 slide of water flow equations

- **Terminology**

- Steady state water flow
- Transient water flow
- Consolidation

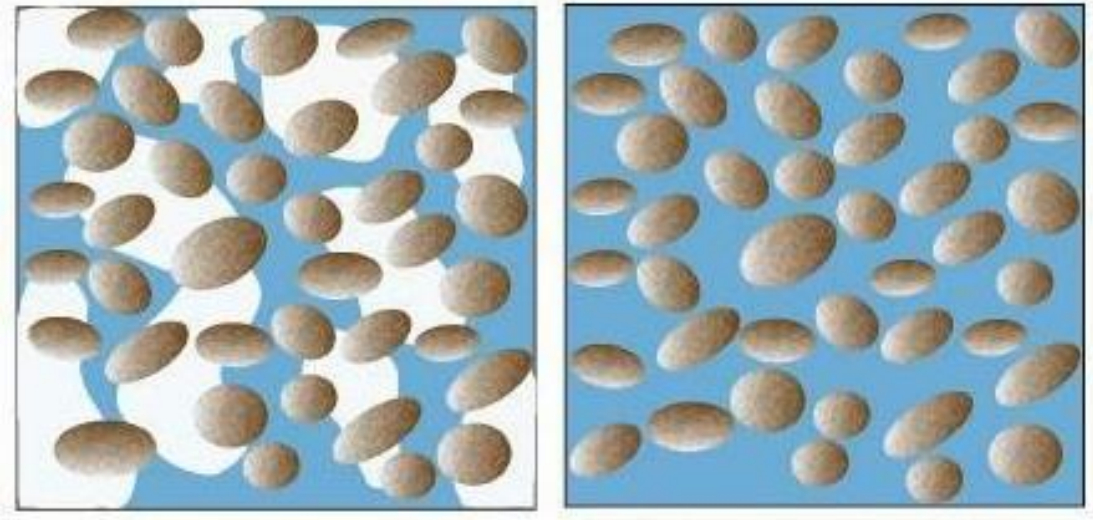
- Recapitulation of Geo5 FEM

Differential equation

- Continuity equations: $n\frac{\partial S}{\partial t} + \nabla[nS\boldsymbol{v}^w] = 0$
- Darcy law: $nS\boldsymbol{v}^w = -\frac{\boldsymbol{K}}{\gamma_w}(\nabla p - \gamma_w \boldsymbol{i}_g)$
- n porosity
- S degree of saturation
- t time
- $\boldsymbol{v}^w$ velocity of water
- $\boldsymbol{K}$ coefficient of permeability
- p water pore pressure

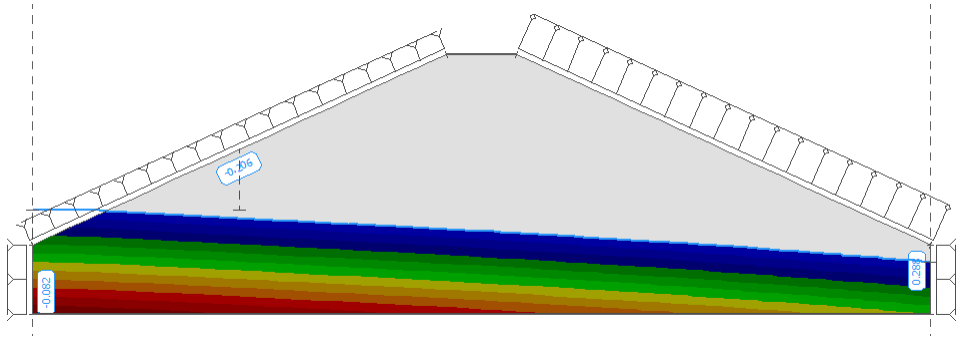
Degree of saturation S

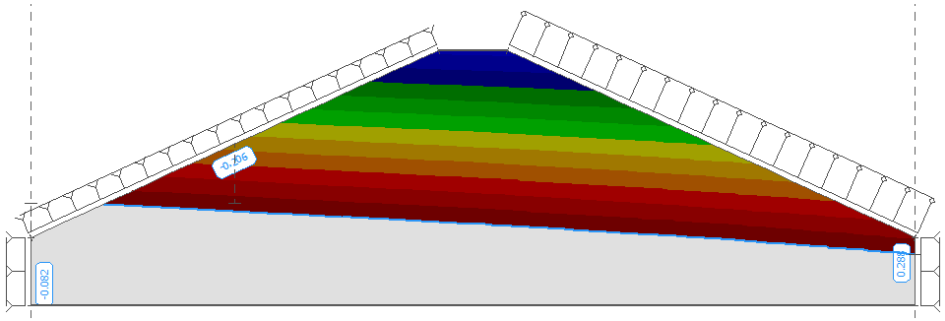
- Ratio of pores filled with water over all pores
- $S = \frac{V_w}{V_p}$
- Units [-]



Pore pressure u

- Units [kPa]
- Pore pressure at GWT is zero
- Negative pore pressure above GWT
  - "suction"
- Water does **not** flow from a point with higher pressure to a point with lower pressure!



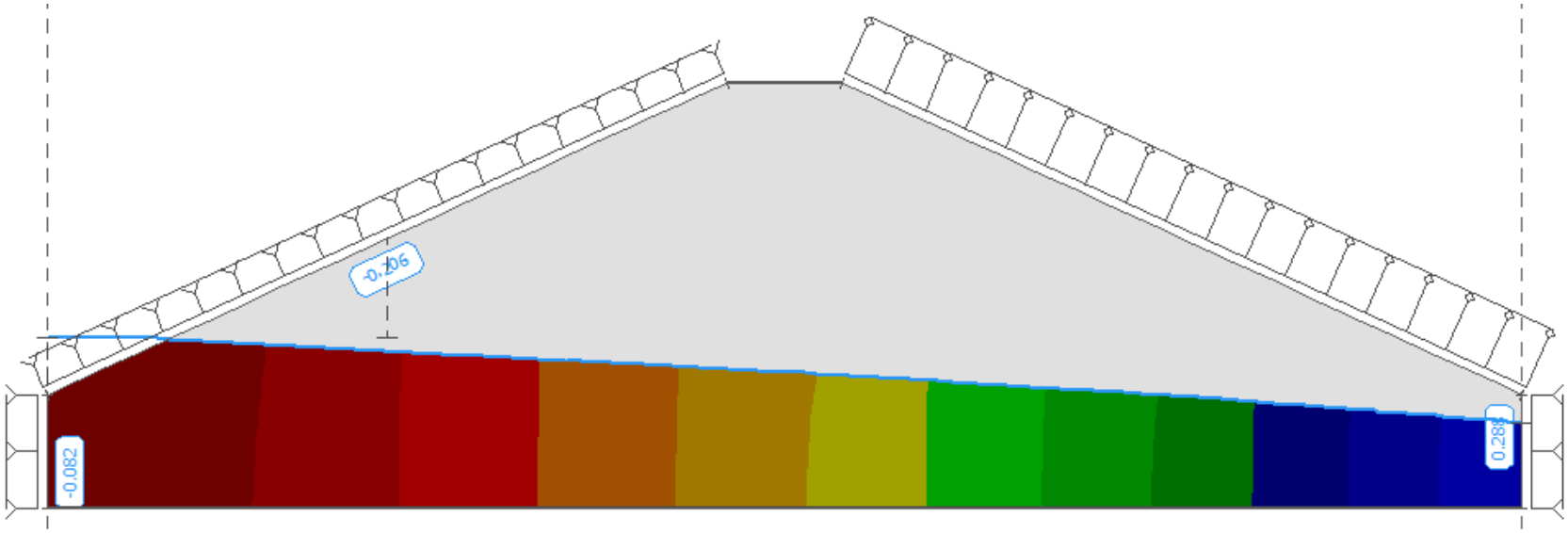


Total hydraulic head h

- Position of free GWT in piezometer

$$h = h_p + z = \frac{u}{\gamma_w} + z$$

- Water flows from point with higher h to point with lower h



Darcy law

$$\boldsymbol{v} = n\boldsymbol{v}_s = -K_r \boldsymbol{K}_{sat} \nabla h$$

$\boldsymbol{v}_s$ velocity of water particles in pores

K_r relative coefficient of permeability

$\boldsymbol{K}_{sat}$ permeability matrix

$$\boldsymbol{K}_{sat} = \begin{bmatrix} k_x & 0 \\ 0 & k_z \end{bmatrix}$$

k_x, k_z coefficients of permeability

∇h gradient of total head

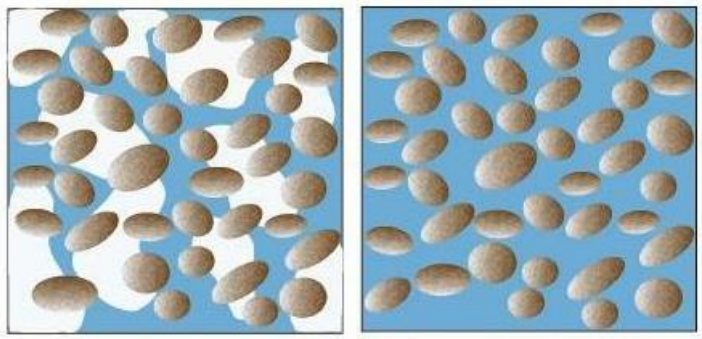
Coefficient of permeability

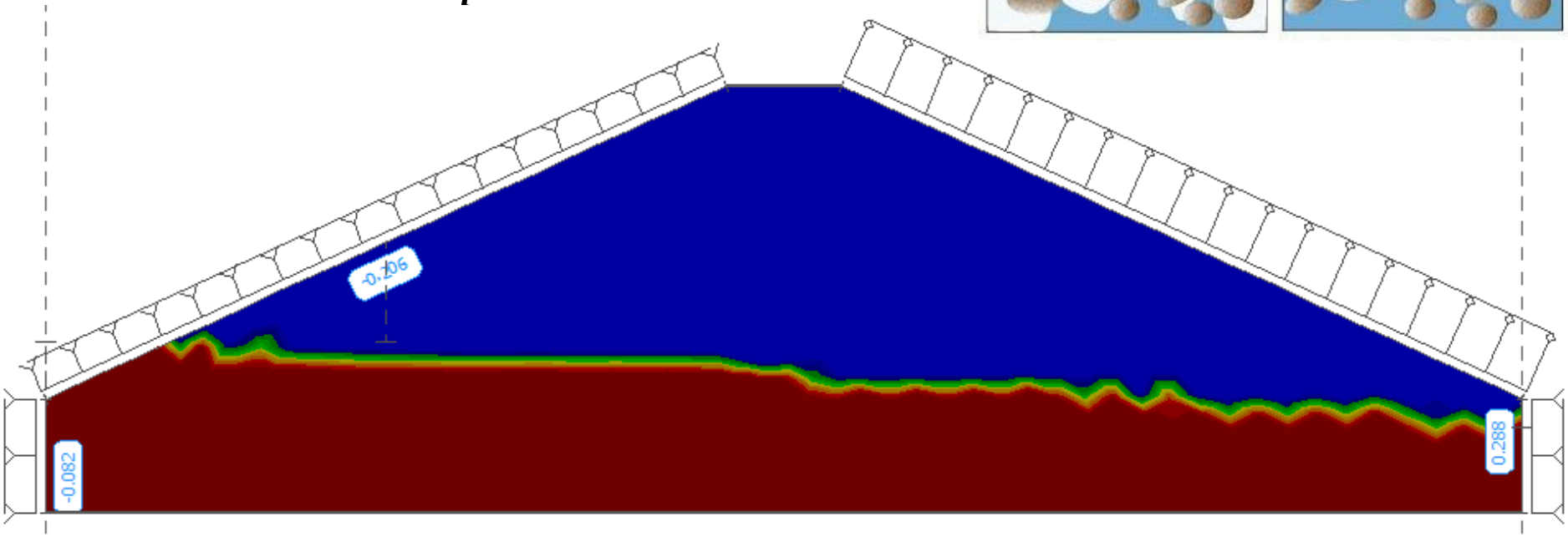
- Higher size of grains → higher k
- Empirical formulas based grain size
- Laboratory tests
- Table in GEO5 help pages

Type of soil	**Coefficient of permeability** k $[m/day]$	**Motion of water particle by** $1\ cm$ for hydraulic gradient $i = 1$ per time
Soft sand	10^{2} - 10	*6 s - 10 min*
Clayey sand	10^{-1} - 10^{-2}	*100 min - 18 hrs*
Loess loam	10^{-2} - 10^{-4}	*18 hrs - 70 days*
Loam	10^{-4} - 10^{-5}	*70 days - 2 years*
Clayey soil	10^{-5} - 10^{-6}	*2 years - 20 years*
Clay	10^{-6} - 10^{-7}	*20 years - 200 years*

Unsaturated soil

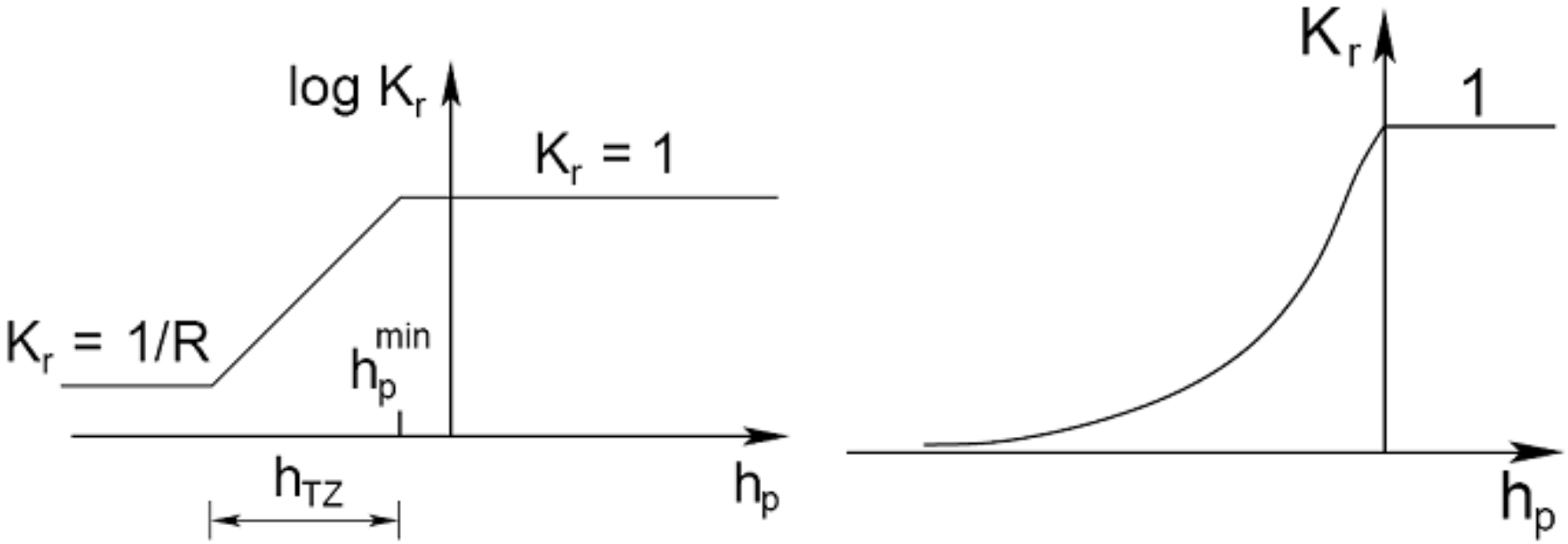
- Negative pore pressure – suction
- Coefficient of relative permeability K_r
- $K_r = K_r(h_p)$





Unsaturated soil

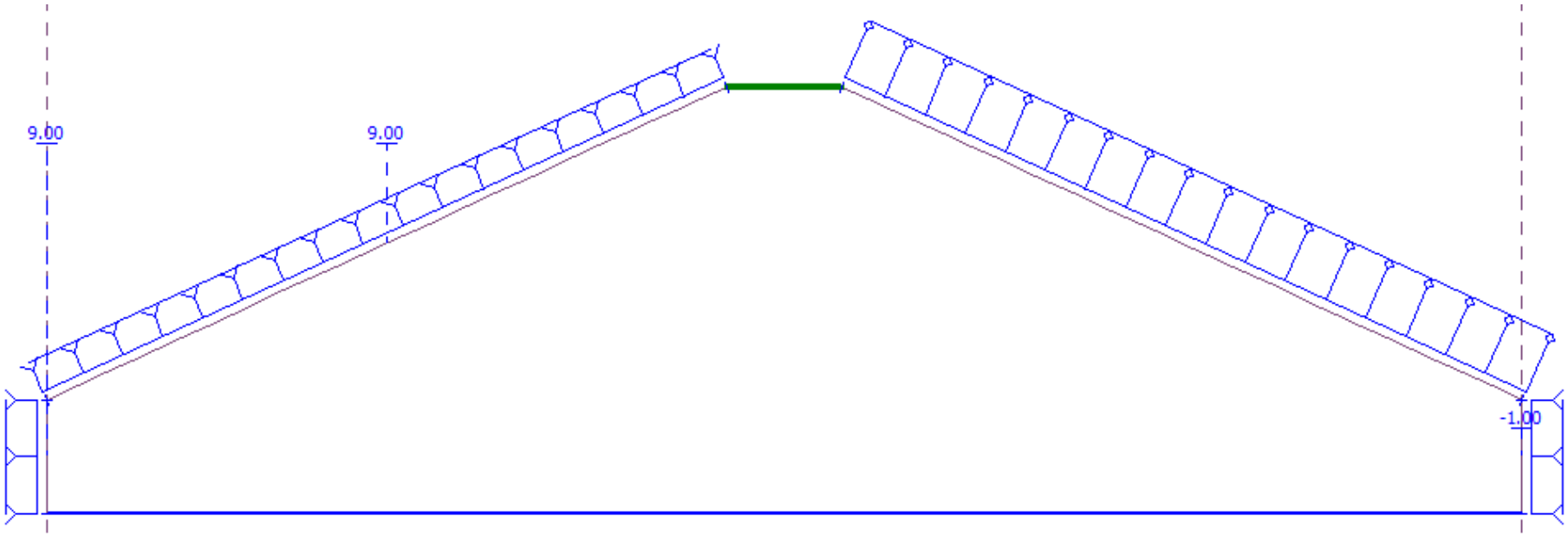
- Model for relative coefficient of permeability
- Below GWT $K_r = 1$
- Above GWT $K_r \rightarrow 0$



(a) Log-linear model [1], (b) Van Genuchten model [2]

Boundary conditions

- “Point flows” – inflow, outflow, drain, well
- “Line flows” – prescribed GWT level
- Seepage line – outflow only under GWT

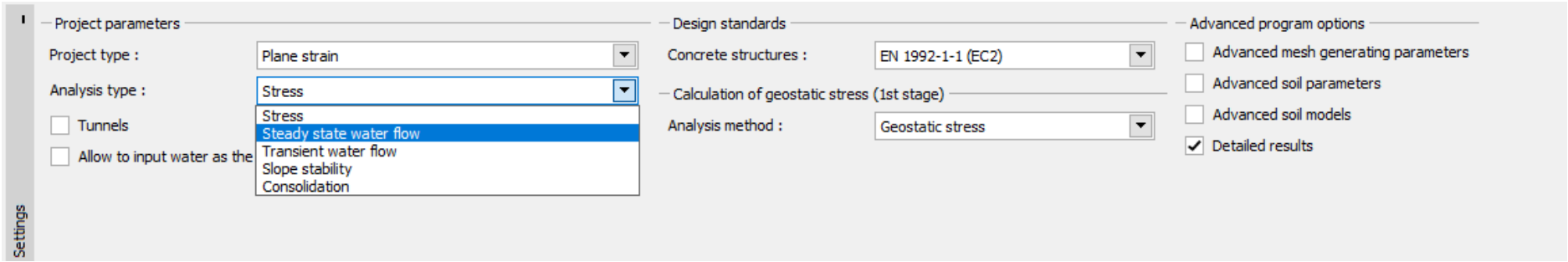


Steady state water flow

1. Find the position of GWT
2. Compute the amount of water going through the model

”construction stages” are **variants**

(order does not matter)



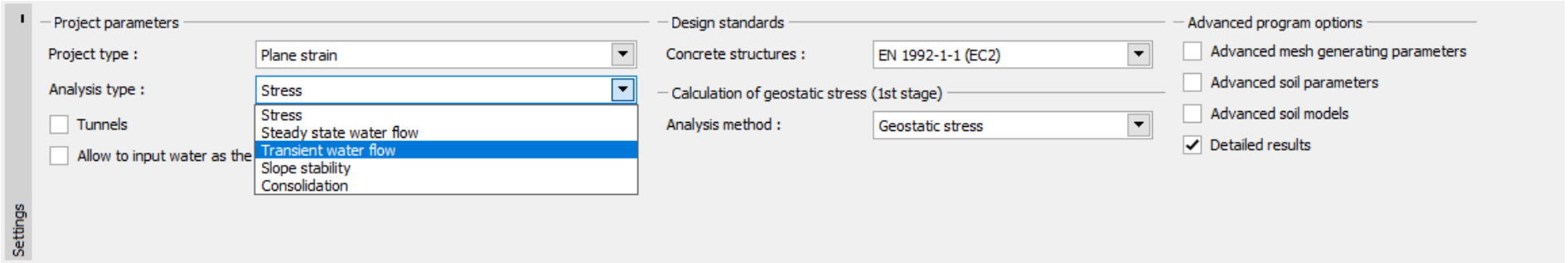
Transient water flow

1. How GWT changes in time
2. How the volume of water flowing through model changes in time

“construction stages” are **sequential**

(order matters)

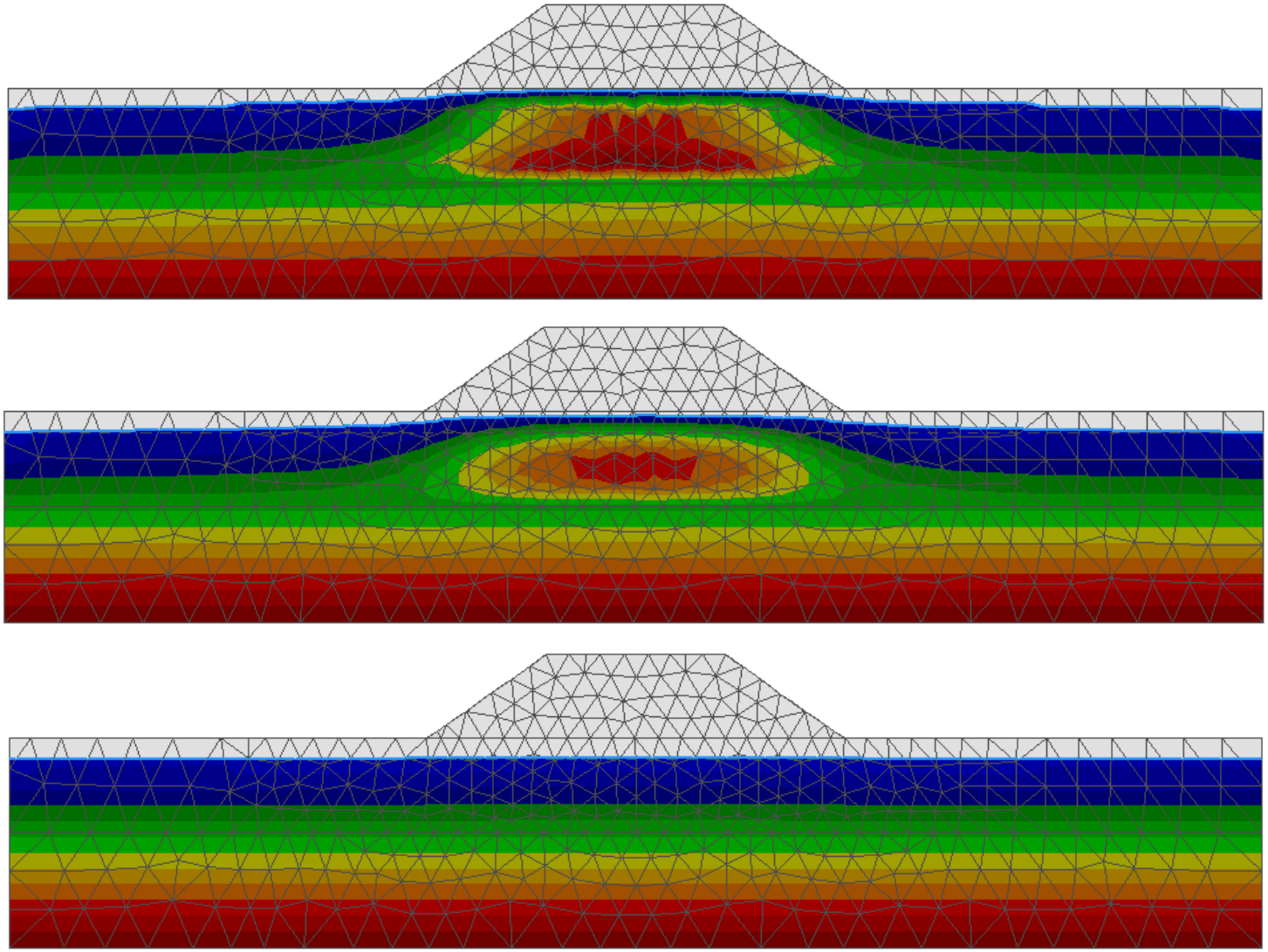
Stages have duration.



Consolidation

- Two phenomena together
  - Mechanical
  - Water flow
- Loading → excess in water pressure → flow → dissipation of pressure (takes time) → increase of effective stress → deformation
- GEO5 Settlement – only 1D flow
- GEO5 FEM Consolidation – 2D flow

Consolidation



Recapitulation of GEO5 FEM

- Analysis types
  - Stress (mechanical)
    - Deformation, plastic zones, anchored walls, tunnels, …
  - Stability
    - Factor of safety, failure mechanism
  - Steady state water flow
    - Position of GWT, amount of water
  - Transient water flow
    - Time dependent GWT, change after some event
  - Consolidation
    - Time dependent deformation

EISEKO COMPUTERS S.R.L.

Viale del Lavoro, 17
37036 S. Martino B.A. (VR)
tel. + 39 045 8031894
www.eiseko.it

Tel. 045 8031894

support@eiseko.com

Assistenza Remota