# **JGE05**

#### Geotechnical Software

Software

## FEM - Water Flow, Consolidation

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#### Outline

• 1 slide of water flow equations

• Terminology

- Steady state water flow
- Transient water flow
- Consolidation

• Recapitulation of Geo5 FEM



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### **Differential equation**

- Continuity equations:  $n \frac{\partial S}{\partial t} + \nabla [nS v^w] = 0$
- Darcy law:  $nSv^w = -\frac{K}{\gamma_w}(\nabla p \gamma_w i_g)$
- *n* porosity
- S degree of saturation
- *t* time

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- $v^w$  velocity of water
- K coefficient of permeability
- *p* water pore pressure

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• Darcy law:  $nSv^{w} = -\frac{K}{\gamma_{w}}(\nabla p - \gamma_{w}i_{g})$ 

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v<sup>w</sup> velocity of water
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*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 [-]





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#### 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!



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#### 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*



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#### Darcy law

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

 $v_s$  velocity of water particles in pores  $K_r$  relative coefficient of permeability  $K_{sat}$  permeability matrix

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

 $k_x$ ,  $k_z$  coefficients of permeability  $\nabla h$  gradient of total head



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### Coefficient of permeability

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

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



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#### Unsaturated soil

- Negative pore pressure suction
- Coefficient of relative permeability K<sub>r</sub>

•  $K_r = K_r(h_p)$ 







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#### Unsaturated soil

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



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GEO5

### **Boundary conditions**

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



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#### 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)

- Project parameters		– Design standards		- Advanced program options
Project type :	Plane strain	Concrete structures :	EN 1992-1-1 (EC2)	Advanced mesh generating parameters
Analysis type :	Stress	<ul> <li>Calculation of geostatic stress</li> </ul>	s (1st stage)	Advanced soil parameters
<ul> <li>Tunnels</li> <li>Allow to input water as the</li> </ul>	Steady state water flow Transient water flow Slope stability Consolidation	Analysis method :	Geostatic stress	<ul> <li>Advanced solitification</li> <li>Detailed results</li> </ul>
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#### 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.

I.	- Project parameters		- Design standards		<ul> <li>Advanced program options</li> </ul>
	Project type :	Plane strain	Concrete structures :	EN 1992-1-1 (EC2)	Advanced mesh generating parameters
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#### 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



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## 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









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