

Drains in ZSoil v2026.

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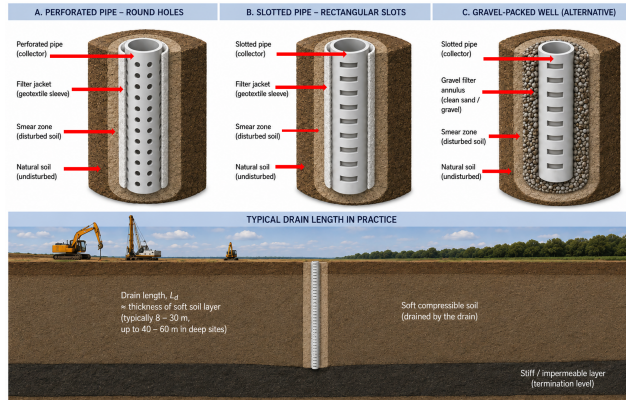
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- Main goal: solving seepage/consolidation problems for soft soils, dewatering of slopes
- Consolidation: standard method (drains + adding external loading) / vacuum consolidation
- Straining of drains is neglected
- Partial saturation is handled
- Soil models for weak soils are usually needed (MCC, Cap, Soft Soil Creep (in v2027))

- High aspect ratio ($L \approx 10..40\text{m}$, $D \approx 10..30\text{cm}$)
- Complex fluid flow related to the composite drain construction (perforated pipe, filter pack, smear zone caused by the installation procedure)
- Conclusion: full 3D modeling is not possible in the practice and we need a simplified formulation
- Drain elements are reduced to 1D FE elements arbitrarily embedded in the background continuum 2D/3D mesh (this may introduce some kind of singularities and may yield severe mesh dependency)

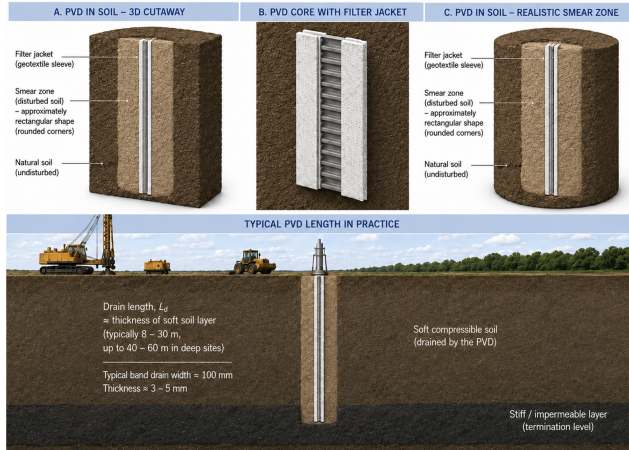
Drain type: circular shape



• Three formulations are foreseen for circular drains

- 1 With high level of complexity (perforated pipe (with holes/rect. slots)/filter pack and smear zone)
- 2 With medium level of complexity (perforated pipe (with holes/rect. slots)/filter pack and smear zone but permeability of the pipe+filter is defined in a simplified manner)
- 3 With low level complexity (perforated pipe and filter pack (treated together) and smear zone)

Drain type: PVD type



- One formulation is foreseen for PVD drains

- 1 With low level complexity (core and filter jacket (treated together) and smear zone)

Circular drains with 4 zones (soil, smear, filter, pipe): governing equations (strong form)

- Drain consists of a perforated pipe, a filter zone, a smear zone, and a **fictitious inner soil**
- The **fictitious inner soil** is represented as a **highly permeable porous medium** with a very large void ratio, providing a regularized Darcy-type approximation of the laminar water flow inside the pipe
- The axial hydraulic conductivity of the fictitious inner soil must be selected sufficiently large to make the hydraulic-head loss along the drain negligible in comparison with the radial hydraulic-head losses in the external soil, smear zone, filter, and perforated pipe wall
- At the same time, it should remain sufficiently limited to avoid the severe ill-conditioning that could result from using the full Hagen–Poiseuille conductance of the pipe
- The general fluid flow balance equation is expressed as

$$\underbrace{S \dot{u}_{k,k}}_{\text{cancel for the drain}} + v_{k,k}^f - c \dot{p} = 0$$

- The primary unknown is the water pressure in each of the drain zones (i is the inner soil, f is the filter, s is the smear zone, o is the outer soil):

$$p_k(s, t), \quad k \in \{i, f, s, o\}$$

Circular drains with 4 zones (soil, smear, filter, pipe): governing equations (weak form)

► Inner zone

$$\int w_i (-c_i(p_i)\dot{p}_i) A_i ds - \int k_i \left(\frac{1}{\gamma_w} p'_i + t^T b \right) w'_i A_i ds + \int w_i \beta_{if} (p_f - p_i) ds = 0$$

The cross section area is denoted here as A_i while in the Robin term the circumference is directly embedded in β_{if} .

► In discretized form an extra term is added to handle seepage type BC on top of the drain

$$k_v(p_o - p_i)$$

► Filter zone

$$\underbrace{\int w_f (-c_f(p_f)\dot{p}_f) A_f ds}_{\text{canceled}} - \int k_f \left(\frac{1}{\gamma_w} p'_f + t^T b \right) w'_f A_f ds + \int w_f \beta_{fi} (p_i - p_f) ds + \int w_f \beta_{fs} (p_s - p_f) ds = 0$$

► Smear zone

$$\underbrace{\int w_s (-c_s(p_s)\dot{p}_s) A_s ds}_{\text{canceled}} - \int k_s \left(\frac{1}{\gamma_w} p'_s + t^T b \right) w'_s A_s ds + \int w_s \beta_{sf} (p_f - p_s) ds + \int w_s \beta_{so} (p_o - p_s) ds = 0$$

► External soil zone

here extra term is added to preserve consistency

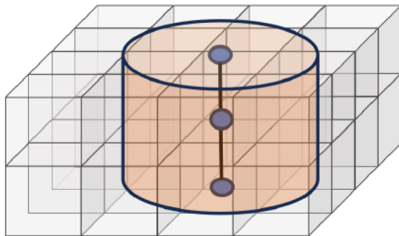
$$\int w_o \beta_{so} (p_s - p_o) ds$$

Flow between the inner fictitious soil and the outer boundary of the filter passes through two components connected in series:

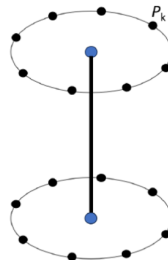
- ▶ the porous filter layer, governed by a linear Darcy-type relation,
- ▶ the perforated pipe wall, for which both viscous and inertial losses may contribute (this is the most complex part in fact)
- ▶ note that for series of components we can add resistances (inverses of conductances)

Nonlocal formulation for linking drains with background mesh

- The same idea that is used for heat exchangers is adopted here
- In the nonlocal formulation $\mathbf{p}_o = \sum_{i=1}^{\text{size}(S)} w_i^{\text{glo}} \mathbf{p}_{o,i}^S$
- Two possible strategies for w_i^{glo} are possible

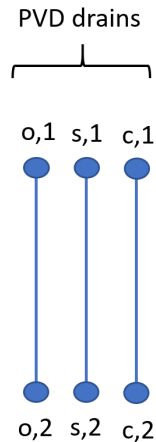
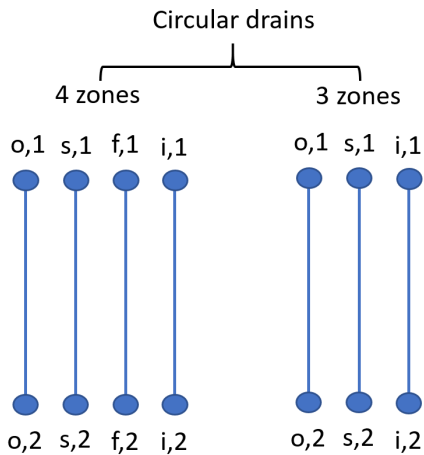


local version



nonlocal version

A. Truty. Nonlocal FEM modeling of piles as beam elements embedded within 3D continuum.
<https://doi.org/10.1016/j.engstruct.2022.115460>, Engineering Structures, Vol. 277, 2023



Materials

Material definition

Bulk edit

Edit material in Virtual Lab

Add to database

Import material(s)

Update from database

#	Name	Continuum/Structure type	Material formulation
1	Mat. 1	Continuum	Elastic
2	Mat. 2	Continuum	Elastic
3	Mat. 3	Drain	Drain
4	No name	Seepage	Drain

Drain type

Circular

Drain data setup complexity level

High

Spacing in out of plane direction

1

[m]

Parameter	Value	Unit
Smear zone thickness	t_{sm} 0.1	[m]
Filter thickness	t_f 0.004	[m]
Outer pipe diameter	$d_{p,ext}$ 0.1	[m]
Pipe wall thickness	0.004	[m]
Perforation geometry	Circular	[]
Perforation diameter	0.002	[m]
Perforation ratio	0.4	[]
Discharge coefficient	0.7	[]
Dynamic viscosity	μ 0.0000000000...	[kN/m ² *day]

Fluid weight / unit volume

10

[kN/m³]

Fluid compressibility

Fluid bulk modulus

2000000

[kN/m²]

☒ Include air compressibility in fluid-gas mixture

Air stiffness bulk modulus at atmospheric pressure

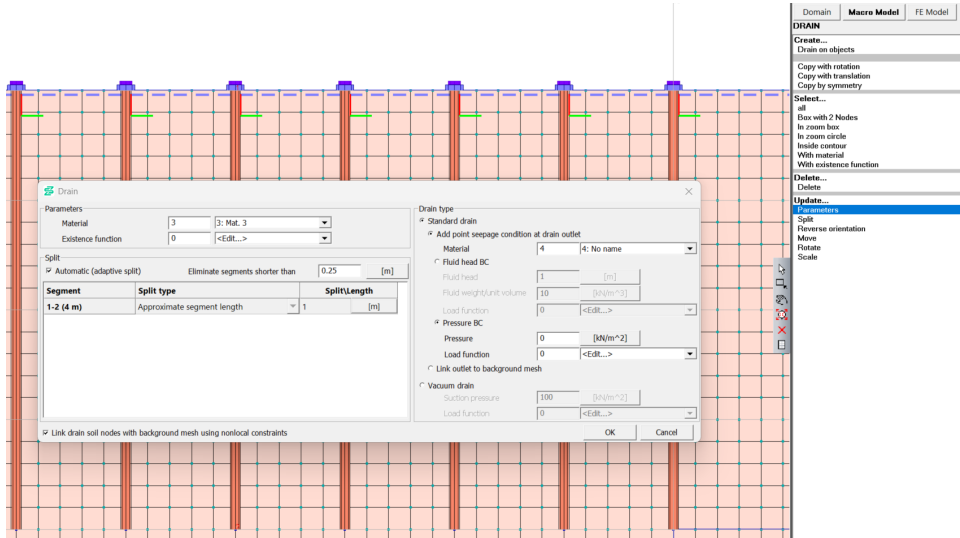
100

[kN/m²]

Parameter	Smear zone		Inner fictitious soil		Filter zone	
	Value	Unit	Value	Unit	Value	Unit
Inherit from adjacent soil	☒					
Scale permeability by factor	0.5	[]				
Isotropic flow	☒					
Darcy's coefficient k_x	k_x 1e-07	[m/day]	86400	[m/day]	8.64	[m/day]
Darcy's coefficient k_y	k_y 1e-07	[m/day]				
Initial void ratio	e_0 0.5	[]	100	[]	1	[]
Residual saturation	S_r 0	[]	0	[]	1	[]
Parameter related to the air entry ...	α 0.5	[1/m]	10	[1/m]	10	[1/m]
Measure of the pore-size distributi...	n 1.5	[]	2	[]	2	[]

OK

Cancel



Permeability dependence on void ratio according to Taylor

- Taylor's empirical law assumes a linear relation between void ratio and logarithm of hydraulic conductivity:

$$e = e_0 + C_k \log_{10} \left(\frac{k}{k_0} \right).$$

- Equivalent exponential form used in computations:

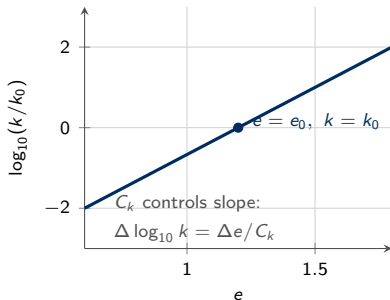
$$k(e) = k_0 10^{(e-e_0)/C_k}$$

where k_0 is measured at $e = e_0$ and C_k is the *hydraulic-conductivity change index*.

- Sensitivity needed for Newton linearization:

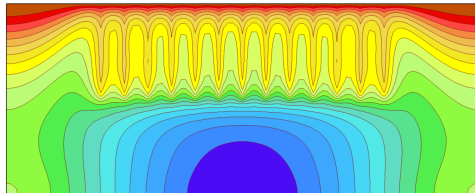
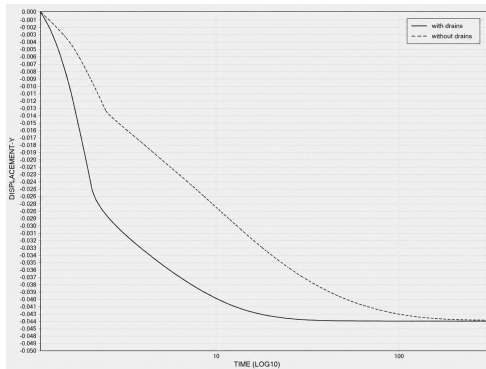
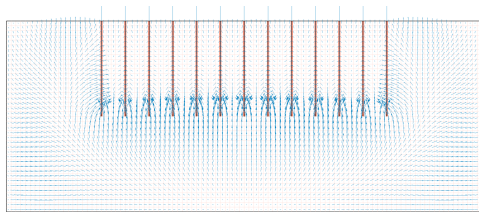
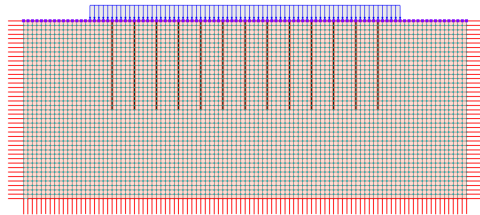
$$\frac{\partial k}{\partial e} = \frac{\ln 10}{C_k} k(e), \quad \delta k = \frac{\ln 10}{C_k} k \delta e.$$

log-linear Taylor law



Compression decreases e , hence k drops exponentially.
Use the law only within the calibrated void-ratio range.

Example (2D) of subsoil consolidation



Soft Soil Creep (SSC) model: equivalent pressure, cap and evolution law

- Mohr–Coulomb yield condition in principal effective stresses:

$$F_{MC} = \sigma'_1 - K_p \sigma'_3 - f_c = 0, \quad K_p = \frac{1 + \sin \varphi'}{1 - \sin \varphi'}, \quad f_c = \frac{2c' \cos \varphi'}{1 - \sin \varphi'}.$$

- Equivalent pressure associated with the current stress state:

$$p_{eq} = p' + \frac{\tilde{q}^2}{M^{*2} (p' + c' \operatorname{ctg} \varphi')}, \quad \tilde{q}^2 = M^{*2} (p' + c' \operatorname{ctg} \varphi') (p_{eq} - p').$$

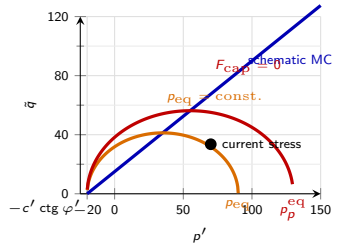
- Brinkgreve relation for the cap-shape parameter:

$$M^* = 3 \sqrt{\frac{(1 - K_0^{NC})^2}{(1 + 2K_0^{NC})^2} + \frac{(1 - K_0^{NC})(1 - 2\nu_{ur})(\lambda^* - \kappa^*)}{(1 + 2K_0^{NC})(1 - 2\nu_{ur})\lambda^* - (1 - K_0^{NC})(1 + \nu_{ur})\kappa^*}}.$$

- SSC isotache creep law, cap evolution and flow direction:

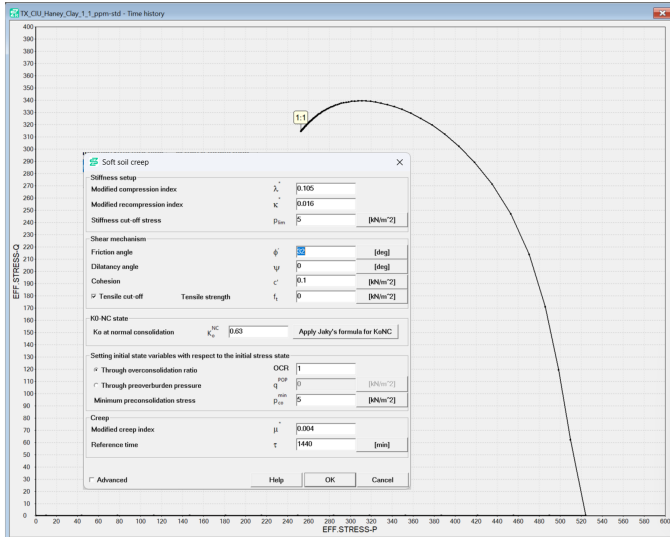
$$\dot{\varepsilon}_v^c = \frac{\mu^*}{\tau} \left(\frac{p_{eq}}{p_p^{eq}} \right)^{\frac{\lambda^* - \kappa^*}{\mu^*}}, \quad \dot{p}_p^{eq} = \frac{p_p^{eq}}{\lambda^* - \kappa^*} \dot{\varepsilon}_v^c,$$

$$p_p^{eq} = p_{p0}^{eq} \exp \left(\frac{\varepsilon_v^c}{\lambda^* - \kappa^*} \right), \quad \mathbf{n}_c \parallel \frac{\partial p_{eq}}{\partial \boldsymbol{\sigma}' }.$$

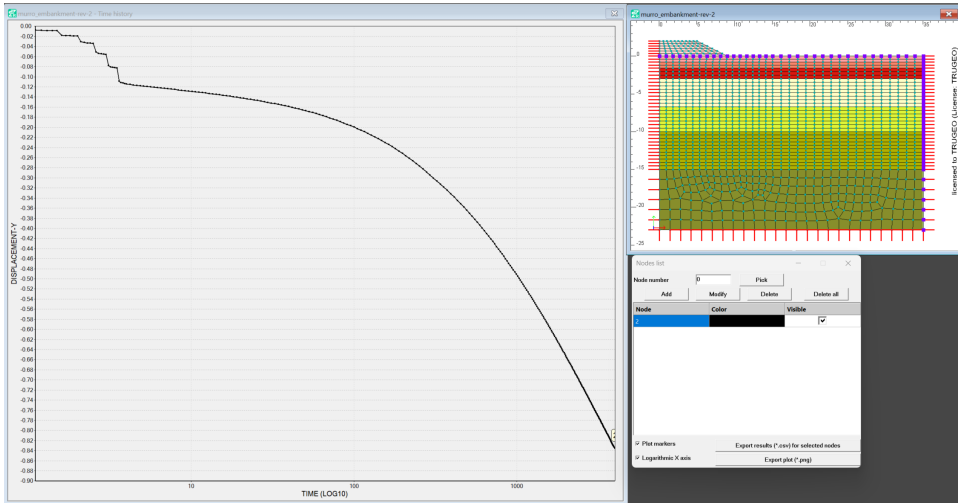


Schematic geometry in the p' - q plane.

SSC model: undrained test



SSC model: simulation of settlements of embankment on organic subsoil



Thank you for your attention