numgeo

A finite element code for geotechnical simulations

Tutorials
-
Series C: Infiltration of an initially unsaturated sand column (Plaxis example)

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1 Introduction

Validation of element formulations (and implementations) for simulations of partially saturated problems is difficult due to lack of analytical solutions. For this reason, we take validate the implementations in numgeo based on a comparison with calculation results obtained with the widely used FE program Plaxis. The boundary value problem (BVP) considered for this purpose is taken from the internal report of Plaxis (Vahid Galavi) "Groundwater flow, fully coupled flow deformation and undrained analyses in PLAXIS 2D and 3D".

The BVP considers a recharge situation of a soil column, which is filled from the bottom in opposite direction of the gravitational force. The soil column has a heigt of 2 m and is displayed in Figure 1. The displacements are constrained at all nodes (only the flow of water is investigated in this example). The initial pore water pressure is -10 kPa in the entire column leading to an initial degree of saturation of approximately 20 %.

Both the soil-water-retention curve and the dependence of the relative permeability on the effective degree of saturation are modelled using the well known van Genuchten model. The bulk modulus of pore water K^w and the hydraulic conductivity K are chosen such as described in the internal Plaxis report: $K^w = 4.875 \cdot 10^5$ and $K = 1.7604 \cdot 10^{-6}$ m/s. The paraemters for the van Genuchten model are $n^{vG} = 2.286$ and $\alpha^{vG} = 0.224$. The initial void ratio is $e_0 = 0.5625$

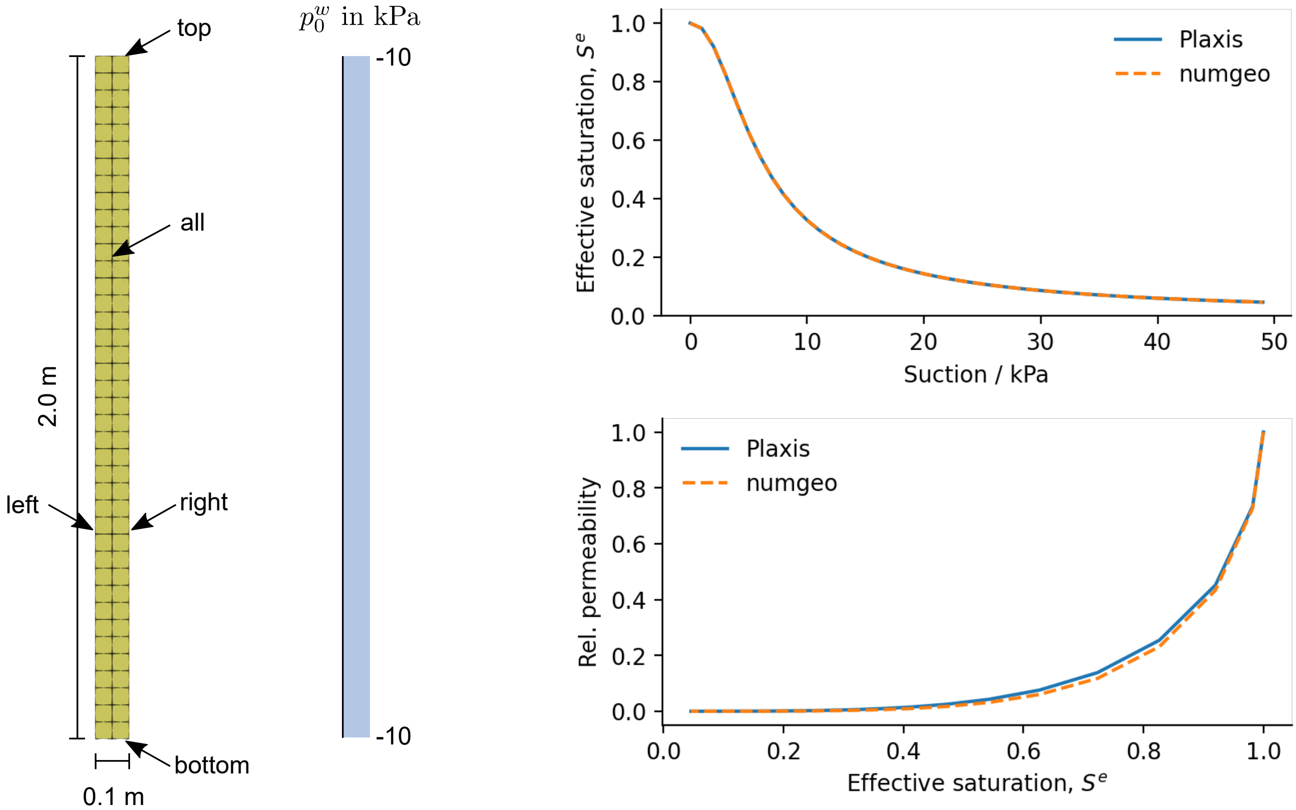

Figure 1: Left: finite element model of the BVP, Middle: initial distribution of pore water pressure, Right: comparison of soil-water-retention curve and relative permeabiltiy used in Plaxis and numgeo.

2 Numerical simulation

2.1 Material

For the solid a linear elastic constitutive model is chosen. As no soil deformation is considered in this simulation (an neither was observed in the experiment) this choice is completely arbitrary. The Young's modulus is $50 \cdot 10^3$ kPa and the Poisson's ratio 0.3.

Note that numgeo requires the prescription of the permeability K^s of the solid and the dynamic viscosity of the pore fluids μ^f instead of the hydraulic conductivity K^f, which are related as follows:

$$K^f = \frac{K^s \gamma^f}{\mu^f} \tag{1}$$

Therein, γ^f and μ^f are the specific weight and the dynamic viscosity of the fluid f, respectively.
The dynamic viscosity of pore water is $\mu^w = 10^{-6}$ kPa·s and of the pore air $\mu^a = 10^{-8}$ kPa·s. Assuming a specific weight of 10 kN/m^3 for the pore water, the permeability of the soil is calculated to $1.7604 \cdot 10^{-13}$ m^2.
The corresponding input commands are given in Listing 1.

```
*Material, name = elastic, phases = 3
*Mechanical = linear_elasticity
50d3, 0.3
*Density
2.65, 1.0, 0.0015
*Bulk modulus
4.875d5, 100.
*Dynamic viscosity
1d-6, 1d-8
*Permeability = isotropic
1.7604d-13
*Hydraulic = van Genuchten, Swr=0.06203
0.224, 2.286
*Relative permeability = van Genuchten
1d-6, 1d-6, 2.286
*Bishop effective stress = Crude-Switch
```

Listing 1: Definition of the material

2.2 Geometry and boundary conditions

For the back calculation of the experiments we simplify the geometry of the soil column as a planar (2D) situation, since no further information are given in the report. The entire model consists of one part named "Soil". On this part a total of 5 node sets and one element set were defined:

- top (Soil.top)
- bottom (Soil.bottom)
- left (Soil.left)
- right (Soil.right)
- all (Soil.all, element and node set)

The finite element mesh was created using the open-source software Salome [Ribes and Caremoli, 2007] and the numgeo-Python API. The column is discretised with 8-noded rectangular elements (quadratic interpolation). The nodal distance is approximately 0.05 m. For this simulation, changes in pore air pressure are judged as negligible, thus elements based on reduced set of governing equations are used - namely the up-formulation. These elements consider negative pore water pressures as suction $s = -p^w$ (instead of $s = p^a - p^w$). The geometry as well as some of the defined node sets are displayed in Fig. 1.

The input files as well as the Salome model (*.hdf) are included in the enclosed data.

2.3 Initial conditions

The initial pore water pressures is $p_0^w = -10$ kPa and constant over the height of the column. The initial void ratio is $e_0 = 0.5625$.
The corresponding input commands are:

```
*Initial conditions, type=stress, geostatic
Soil.all, 0.0, -21.12, 2.0, 0., 0.5, 0.5

*initial conditions, type=void ratio, default
```

```
Soil.all, 0.5625

*initial conditions, type=pore water pressure, default
Soil.all, 0.0d0, -10.0d0, 2.d0, -10.0d0
```

Listing 2: Definition of initial conditions

2.4 Calculation stages

The simulation is divided into 2 steps in total: one Geostatic step and one transient step.

Geostatic step

During the Geostatic step, the self weight of the soil (grains and pore water) is applied without generating any deformation. As stated previously, no deformation of the soil skeleton is expected. We therefore constrain the displacements of all nodes in $x1$ and $x2$ direction. In addition, we use boundary conditions to prescribe the pore water pressure for each node. As in the initial conditions, the pore water pressure is prescribed as -10 kPa over the entire column. The corresponding input commands are given in Listing 3.

```
*Step, name=Geostatic, inc=1, maxiter=100
*Geostatic

*Body force, instant
Soil.all, grav, 10.0, 0., -1, 0.

*Boundary
Soil.all, u1, 0.
Soil.all, u2, 0.
Soil.bottom, pw, -10.0
Soil.top, pw, -10.0

*Output, field, vtk, ascii
*Frequency = 1
*Element, elset = Soil.all
S, sat_eff, void, sat
*Node, nset = Soil.all
pw, sat_eff, void, sat

*End Step
```

Listing 3: Definition of the Geostatic step

Transient step

During the transient step we simulate the water supply at the bottom of the soil column. This is done by prescribing the pore water pressure at the bottom nodes. The value is set to 15.0 kPa, which corresponds to a pressure head of 1.5 m. The total step time is 323136 seconds. Due to the strong nonlinearities resulting from the saturation-suction relation and the relative permeability function, we limit the maximum allowed time increment size to 2000 seconds. No ramp is used to increase the pore water pressure from its initial value of -10.0 kPa (`*Boundary, instant`). The corresponding input commands are given in Listing 4.

```
*Step, name=Saturation, inc=1000000, maxiter=50

*Transient
0.01, 323136, 0.01, 2000

*Body force, instant
Soil.all, grav, 10.0, 0., -1, 0.

*Boundary
Soil.all, u1, 0.

Soil.all, u2, 0.
Soil.bottom, pw, -10.0

*Boundary
Soil.top, pw, 20.0
```

```

*End Step
```

Listing 4: Definition of the transient step

2.5 Results

Figure 2 presents the distribution of the degree of saturation over the column heigt, The comparison of the simulation results obtained with numgeo and the results presented in the internal Plaxis report show a good agreement.

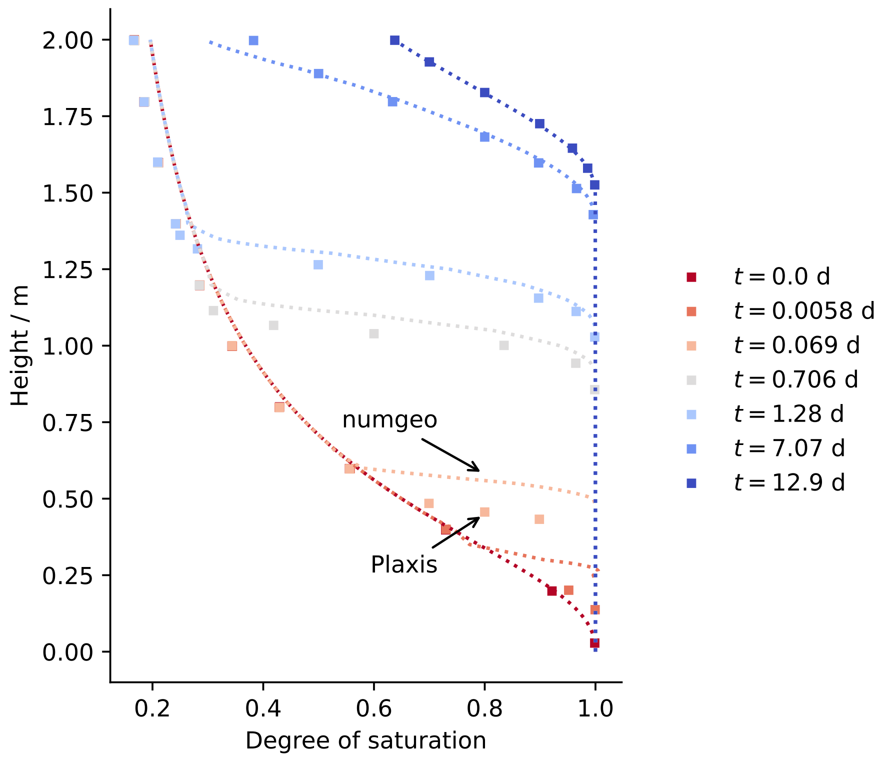

Figure 2: Distribution of degree of saturation along the column height for different time steps of the simulation. `numgeo` vs. Plaxis.

References

A. Ribes and C. Caremoli. Salome platform component model for numerical simulation. In *31st annual international computer software and applications conference (COMPSAC 2007)*, volume 2, pages 553–564. IEEE, 2007.