ONE-DIMENSIONAL CONSOLIDATION

This document describes an example that has been used to verify the consolidation capabilities of PLAXIS. The problem involves the time-dependent solution of one-dimensional consolidation.

Used version:

- PLAXIS 2D - Version 2011
- PLAXIS 3D - Version 2012

Input: Figure 1 shows the geometry of the one-dimensional consolidation problem in PLAXIS 2D. The material properties of the soil layer are given in the Table 1. The layer surface (upper side) is allowed to drain while the other sides are kept undrained by imposing closed consolidation boundary condition.

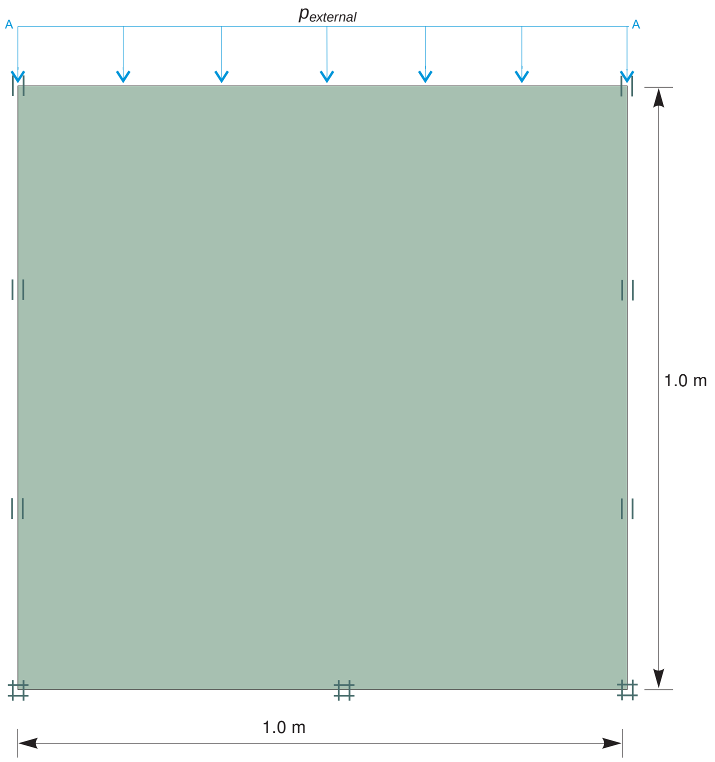

Figure 1 Problem geometry in PLAXIS 2D

Figure 2 shows the geometry of the one-dimensional consolidation problem in PLAXIS 3D. The material properties of the soil layer are given in the Table 1. The layer surface (upper side) is allowed to drain while the other sides are kept undrained by imposing closed consolidation boundary condition.

Materials:

Meshing: In the 2D model the *Medium* option is selected for the *Global coarseness*. In

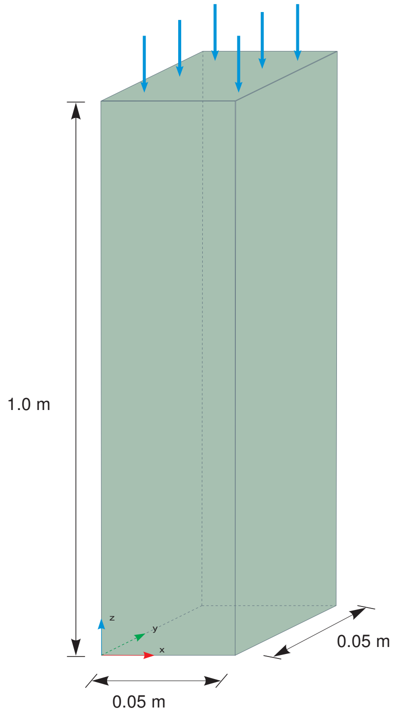

Figure 2 Problem geometry in PLAXIS 3D

Table 1 Material properties of soil

Parameter	Name	Value	Unit
Material model	*Model*	Linear elastic	-
Drainage type	*Type*	Undrained A	-
Young's modulus	*E'*	1000	kN/m^2
Poisson's ratio	ν'	0	-
Permeability	$k_x = k_y = k_z$	0.001	m/day

the 3D model the *Fine* option is selected as the *Element distribution*.

Calculations: In the Initial phase zero initial stresses are generated by using the K0 procedure with Σ -*Mweight* equal to zero. The distributed load is activated in a separate phase (Phase 1). The calculation type is *Plastic analysis*. The *Reset displacements to zero* option is selected. In addition, ten consolidation analyses are performed to ultimate times of 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10, 20, 50 and 100 days respectively. The default value (0.01) is accepted for the *Tolerated error*.

The *Iterative procedure* is manually defined. The *Desired minimum* is set to 2 and the *First time step* is defined as $\Delta t/100$ where Δt is the time interval for each consolidation phase. The default values of the remaining parameters are valid.

Output: Figure 3 shows the excess pore pressure distribution at the end of the Phase 6 in PLAXIS 2D and PLAXIS 3D.

Figure 4 presents the development of the relative excess pore pressure at the (closed) bottom.

Verification: The problem of one-dimensional consolidation can be described by the

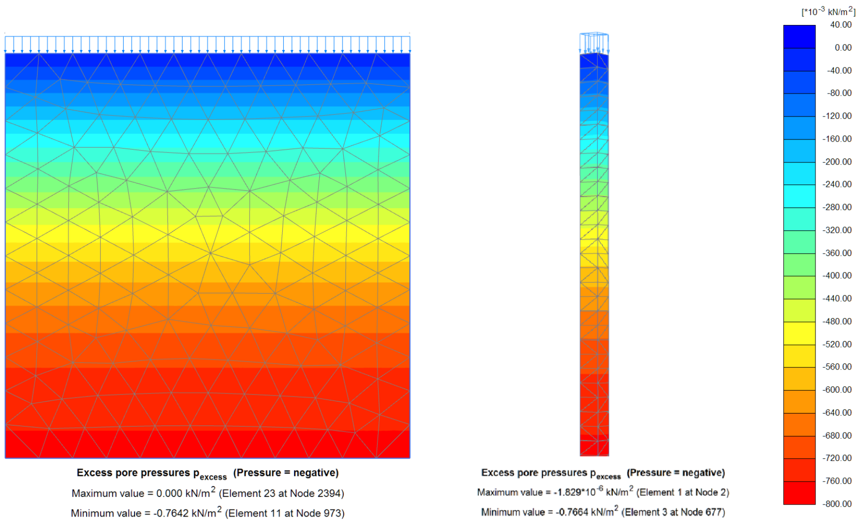

Figure 3 Excess pore pressure distribution (t = 1 day)

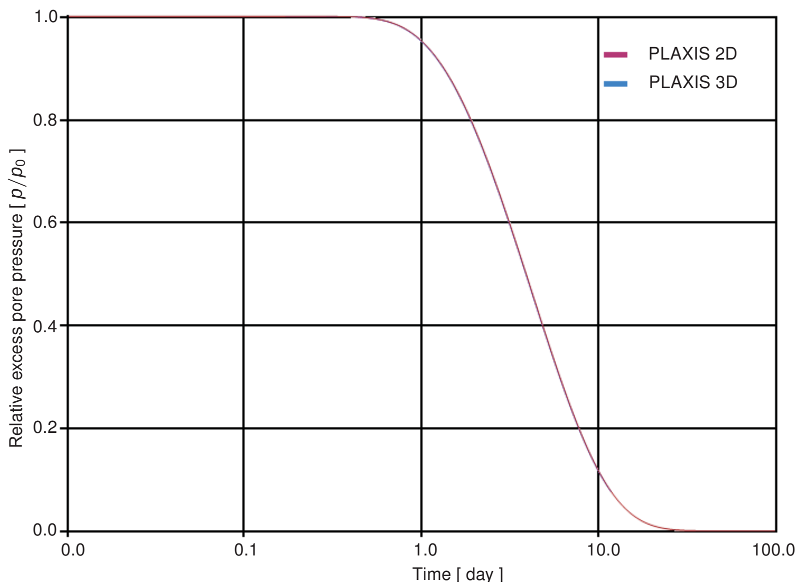

Figure 4 Development of excess pore pressure at the bottom of the sample as a function of time

following differential equation for the excess pore pressure p:

$$\frac{\partial p}{\partial t} = c_v \frac{\partial^2 p}{\partial z^2} \tag{1}$$

where:

$$c_v = \frac{k E_{oed}}{\gamma_w} \tag{2}$$

$$E_{oed} = \frac{(1-\nu)E}{(1+\nu)(1-2\nu)} \tag{3}$$

$$z = H - y \tag{4}$$

The analytical solution of this equation, i.e. the relative excess pore pressure, p/p_0 as a function of time and position is presented by Verruijt (2001):

$$\frac{p}{p_0}(z,t) = \frac{4}{\pi}\sum_{j=1}^{\infty}\frac{(-1)^{j-1}}{2j-1}\cos\left((2j-1)\frac{\pi}{2}\frac{y}{H}\right)\exp\left(-(2j-1)^2\frac{\pi^2}{4}\frac{c_v t}{H^2}\right) \tag{5}$$

This solution is presented by the continuous lines in Figure 5. It can be seen that the numerical solution is close to the analytical solution in PLAXIS 2D.

Figure 5 and Figure 6 show the calculated relative excess pore pressure versus the relative vertical position as marked. Each of the above consolidation times is plotted. The consolidation times are indicated by the time factor T calculated as $T = (c_v t)/(H^2)$.

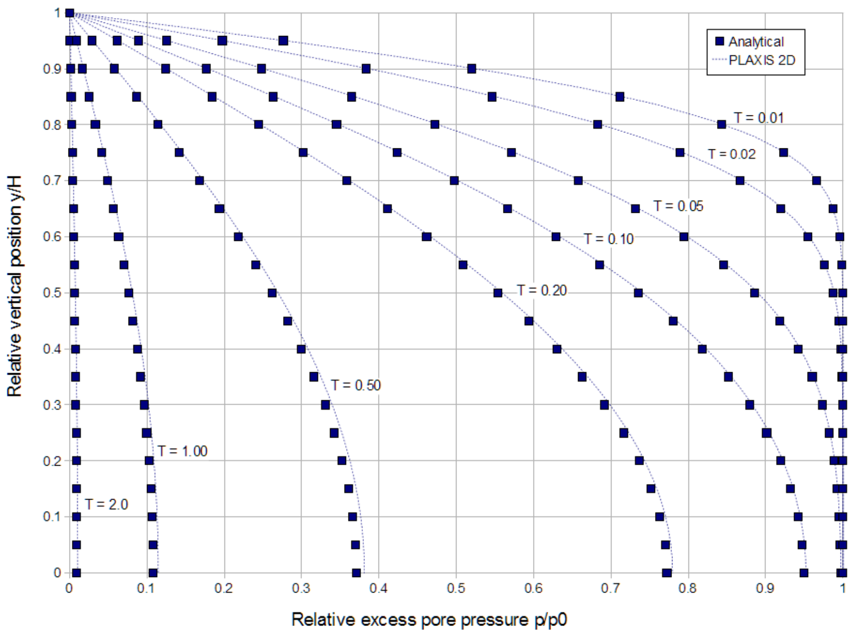

Figure 5 Development of excess pore pressure as a function of the sample height (PLAXIS 2D)

The settlement difference is mainly due to shear deformation, which is included in the numerical solution but not in the analytical solution. Apart from this, the numerical results are very close to the analytical solution. In PLAXIS 3D, the numerical solution has two distinct points of difference compared to the analytical solution. First, the excess pore pressure initially calculated is 0.98 $p_{external}$, instead of 1.0 $p_{external}$. This is due to the fact that the pore water in PLAXIS is not completely incompressible. See Section **??** of the Reference Manual for more information. Secondly, the consolidation rate is slightly lower than the theoretical consolidation rate. This is caused by the implicit integration scheme used.

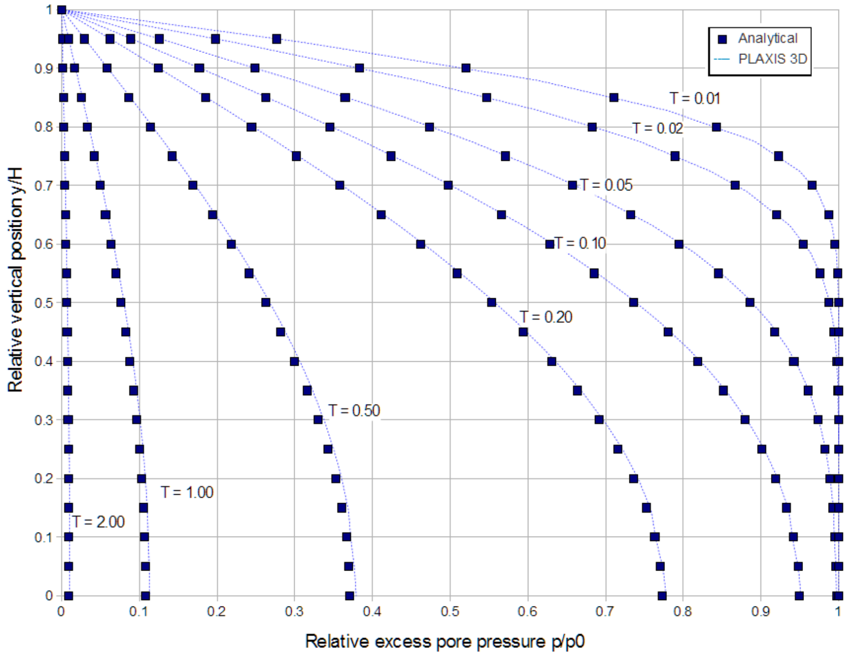

Figure 6 Development of excess pore pressure as a function of the sample height (PLAXIS 3D)

REFERENCES

[1] Verruijt, A. (2001). Soil mechanics. Delft University of Technology.