One-Dimensional Consolidation

Keywords

2D, Plane Strain Two Phase, Fully Saturated, Linear Elastic Model, Consolidation, Pore Pressure, Water Pressure Distribution, Automatic Time Stepping and Termination, open and drainage boundary conditions.

Problem Description

A fully saturated layer of soil 1 m thick rests on a rigid impervious base, consolidated by a uniform vertical load applied along its upper face. The problem is simulated through three stages: initial conditions, undrained loading and consolidation.

Discretisation

The soil is discretised by quadrilateral (QPN8P) elements. Figure 1 illustrates the boundary conditions used in the model. The main hydraulic conditions are the following:

- The pore pressure boundary condition is set to “Open” on the upper surface in the initial phase. As the model has not yet been solved, the pressure is zero throughout the soil and this value is fixed by setting the ‘Open’ boundary condition.

- All elements are assigned undrained status during the undrained loading phase. In undrained loading all porewater pressures freedoms are automatically set to ‘Closed’.

- The pore pressure boundary condition along the upper surface is set to “Drainage” in the consolidation phase. This restores the pressure at the boundary to the value of the pressure prior to the undrained loading, in this case 0.

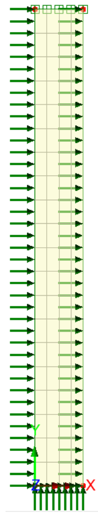

Figure 1: Mesh and boundary conditions

Material Properties

The soil is modelled as a linear elastic material, the following parameters in tables 1 and 2, are prescribed for this example:

Table 1: Elastic material properties

Mass density	Young's modulus, E	Poisson's ratio, ν
1.5 t/m^3	1.0E3 kPa	0.0

Table 2: Two-phase material properties

Balk modulus of fluid phase	Porosity	Hydraulic conductivity	Fluid Density
2.2E6 kN/m^2	0.5	1.0E-3 m/day	1 t/m^3

Loading Conditions

A constant surface load, 1 kPa, is applied on the layer first under undrained conditions, then we allow the model to consolidate until the dissipation of the excess pore water pressure becomes negligible.

Two approaches are used to solve the transient behaviour. In the first, the time is broken up into a number of stages of different duration with 10 steps per stage. The time at the end of each stage is listed below

stage	1	2	3	4	5	6	7	8	9	10
Time (days)	0.1	0.2	0.5	1.01	2.0	5.0	10.0	20.0	50.0	100.0

The second approach sets a target for the maximum change of porewater pressure in the increment and sets a termination value which stops the analysis once the maximum porewater pressure falls below it.

Initial timestep = 0.001 day

Target change in porewater pressure = 0.1 kPa

Termination value of porewater pressure = 0.001 kPa

Theory

When load is applied to a low permeability soil, the water that exists in the pores of a saturated soil initially carries it, resulting in a rapid increase in pore water pressure. As water drains away from the soil's voids, the excess pore water pressure is dissipated and the load transferred to the soil skeleton, which gradually compresses, resulting in settlement. Consolidation continues until the excess pore water pressure is dissipated. Terzaghi established the one-dimensional consolidation theory. The problem of 1-D consolidation is described by the following differential equation

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial y^2} \qquad (1)$$

Comparison

The variation of the pressure at the bottom of the column is plotted against time in figure 2 using results from the given timestep analysis. The results are compared to those of PLAXIS and are in good agreement. Figure 3 compares the solutions using the given timesteps and the automatic timestep and shows that the automatic time stepping algorithm provides an accurate answer with the specification of a few simple parameters.

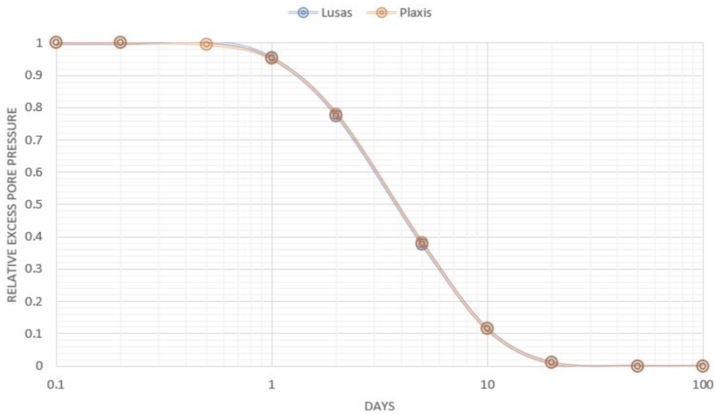

Figure 2: Comparison of pore pressure dissipation with time (LUSAS, PLAXIS)

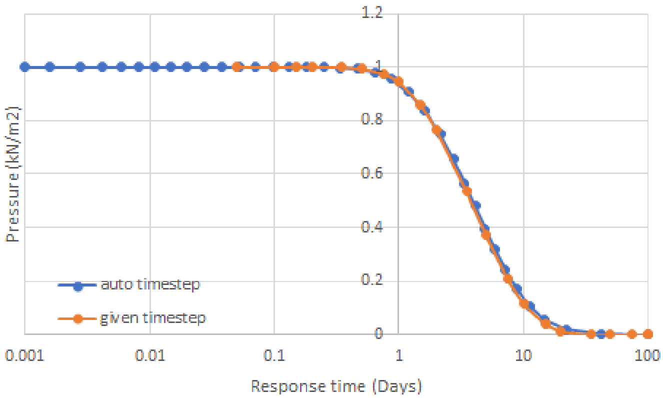

Figure 3: Comparison of given and automatic timestep solutions

References

[1] PLAXIS Manual, 2022.

Input Data

consolidation.lvb