Trapezoidal Dam with Drainage Toe

Keywords

2D/3D continuum elements, Two-phase, phreatic surface, seepage boundary conditions, partially saturated, flow calculation.

Problem Description

This example illustrates water seepage through a trapezoidal earth dam draining into a granular filter in the downstream toe. The flow is unconfined, with the dam built on an impermeable foundation. The basic layout is shown in figure 1.

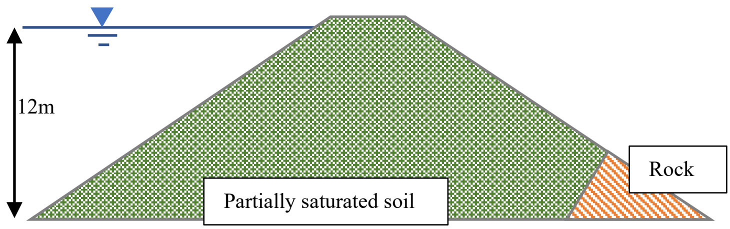

Figure 1. Dam layout

Discretisation

The 2D problem is meshed with quadrilateral plane strain elements (QPN8P) in 2D and tetrahedral elements (TH10P) in 3D. A phreatic surface is defined on the upstream side of the dam to set the level of the water in the reservoir. Seepage boundary conditions are applied to the downstream side along the lower edge of the toe. The base of the dam is fully restrained in the x and y directions.

Figure 2 shows the 2D mesh and boundary conditions. The elements in the dam have a length of 1m whilst those in the toe are 0.5m A finer mesh is required to improve modelling of the flow through the toe.

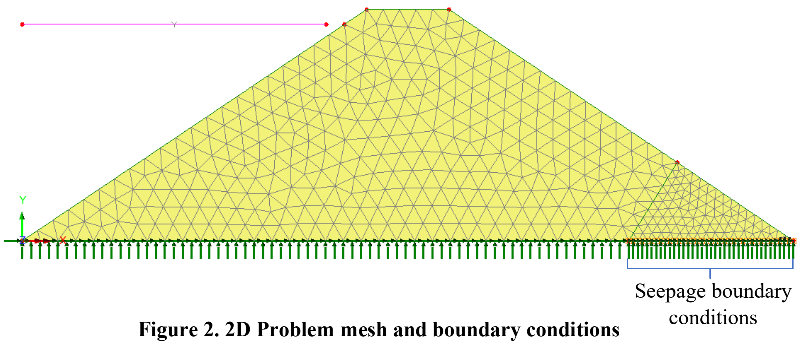

Figure 2. 2D Problem mesh and boundary conditions

Material Properties

The dam and fluid properties are listed in tables 1 and 2.

Table 1: Material properties

Material	Saturated density	Young's modulus	Poisson's ratio	Porosity	Hydraulic conductivity	Saturation	
						Residual	Full
Soil	2.0 t/m^3	50E3 kPa	0.2	0.3	1.52E-5 m/sec	0.0	1.0
Toe	2.0 t/m^3	80E3 kPa	0.2	0.3	0.3408 m/sec	0.0	1.0

Table 2: Additional flow parameters

Material	Van Ganuchten-Mualem			Simple flow
	Rate of water extraction	Air entry	permeability	Permeability factor in partial saturated zone
Soil	1.31	2.5/m	0.5	1E-3
Toe	3.19	3.5/m	0.5	1E-3

Loading Conditions

Gravity loading is applied.

Modelling Hints

This problem is slower to converge than normal, so the number of permissible iterations is increased to 20.

Comparison

The discharge volumes calculated using the Simple and van Genuchten properties describing flow in the partially saturated zone are compared.

The Simple flow parameters consist of the value of saturation when the soil is completed wet, and the residual saturation, when it is dry, and finally the scaling factor applied to the relative hydraulic conductivity in the zone above the phreatic surface. These conditions are closest to those used in traditional flowline solutions.

The van Genuchten-Mualem equations are commonly used and are examples of the empirical formulae used to define soil water characteristic curves (SWCC). They provide a continuous variation for the saturation and relative hydraulic conductivity in the partially saturated zone as opposed to the binary description of either fully saturated or fully dry for the Simple parameters.

Two different analyses are run in the same model file, one with each set of material parameters.

In this example, we see that the simple parameters are not sufficient to provide an accurate description of the water flow and inaccuracies in the solution of the flow equations led to an imbalance between the water entering the dam and leaving.

The outflow is calculated by selecting the seepage nodes at the base of the toe and the inflow by selecting nodes on the upstream face.

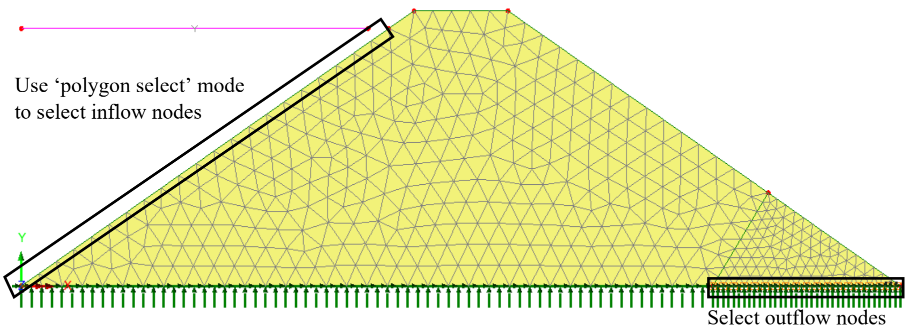

Figure 3. Selection of inflow and outflow nodes

First select the outflow nodes. Then select **utilities>graph wizard**. Choose the loadcase to plot and then for the x-axis the 'named' variable 'Loadcase ID'. For the y-axis choose 'nodal'. The selected nodes appear in the box as shown in figure 4.

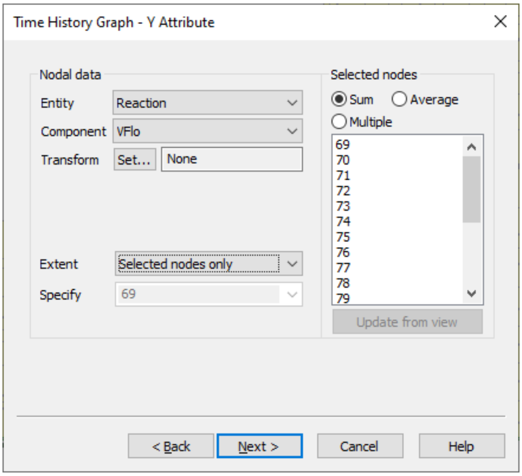

Figure 4. Graph dialog to sum nodal flows

The flow can then be read from the y-coordinate of the completed graph as shown in figure 5. The procedure was repeated for the inflow. Note that inflows are negative whilst outflows are positive.

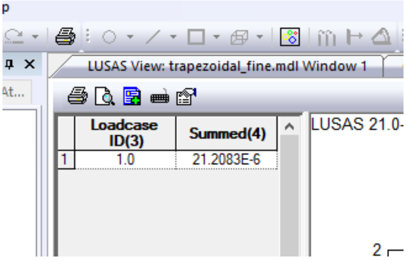

Figure 5. Summed outflow listed in graph point data

Table 2 examines the differences in inflow and outflow between the Simple and Van Genuchten equations. Flows are given in both seconds and days.

Using the Simple parameters, the inflow is greater than the outflow with the outflow being less than half the inflow. To reduce the error, the tolerance of the pressure norm was tightened from 0.1 to 0.01 without significantly changing this result. The solution did not converge for a tolerance of 0.001.

The difference in flows for the Van Genuchten equations is much less. At a tolerance of 0.1 the flows are identical.

Two-phase parameters	Pressure norm tolerance	Inflow ($m^3/s/m$)	Outflow ($m^3/s/m$)	Inflow ($m^3/day/m$)	Outflow ($m^3/day/m$)
Simple	0.1	53.0E-6	21.1E-6	4.58	1.82
	0.01	52.9E-6	21.2E-6	4.57	1.83
Van Genuchten	0.1	53.7E-6	53.7E-6	4.64	4.64

Table 2: Inflow and outflows for different solutions

Figure 6 shows the flow residuals at points throughout the dam for the Simple flow parameters using a pressure convergence tolerance of 0.1.

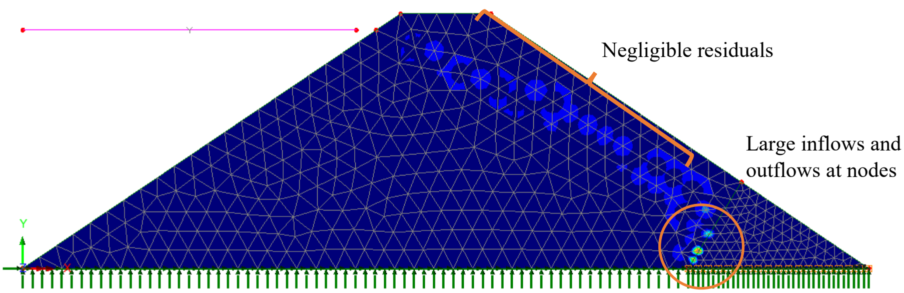

Figure 6: Flow residuals for the simple parameters

The nodal residuals correspond to both inflows and outflows. In the fully saturated and fully dry parts the residuals are zero. Along the upper length of the phreatic surface, they are negligible but at the toe/soil boundary there are large residuals with large outflows from two nodes in particular. A similar situation is found for the Van Genuchten solution but the residuals are smaller. For both cases, it is noted that after steady convergence the solution begins to oscillate unable to reduce the final residuals.

Figure 7 shows the pressure contours for both 2 and 3D meshes. The 3D dam has the same profile as the 2D mesh with a width of 10m. The water inflow for the 3D mesh is $46.5m^3/day$ inflow, slightly higher than the target $46.4m^3/day$ and the outflow is $46.6m^3/day$, a difference of less than 1%.

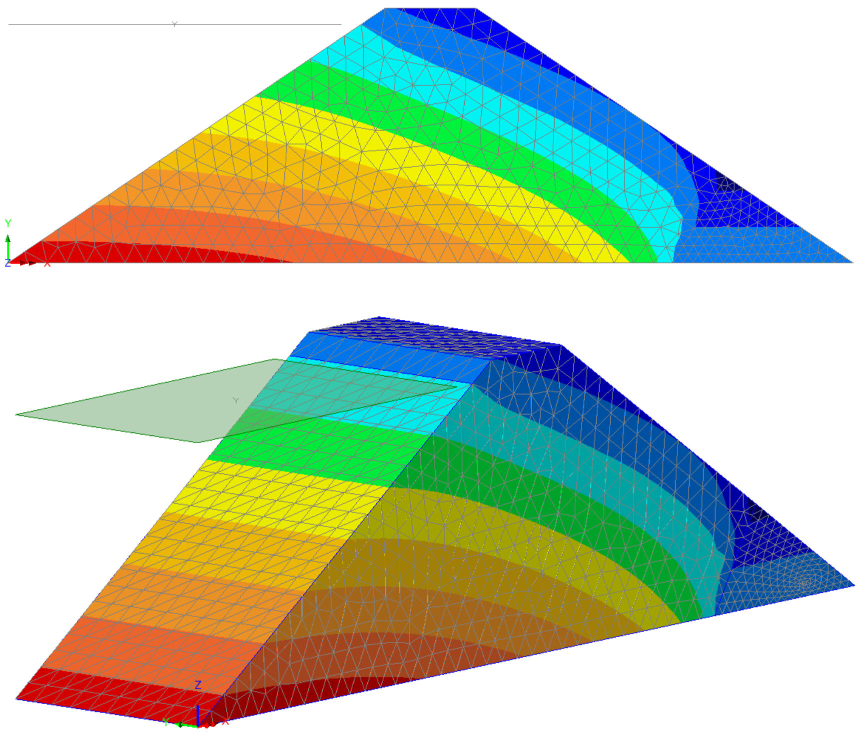

Figure 7. Pressure contour plots for 2 and 3D solutions

References

Input Data

Trapezoidal_dam_2D.lvb

Trapezoidal_dam_3D.lvb