Drawdown of reservoir

For LUSAS version:	21.0
For software product(s):	LUSAS Bridge plus or LUSAS Civil&Structural plus
With product option(s):	Geotechnical, Nonlinear, Dynamic

Problem Description

The factors of safety for a reservoir are calculated for different pore water pressure states, when it is full, when it is empty and for two different rates of drawdown. The problem geometry is shown in figure 1.

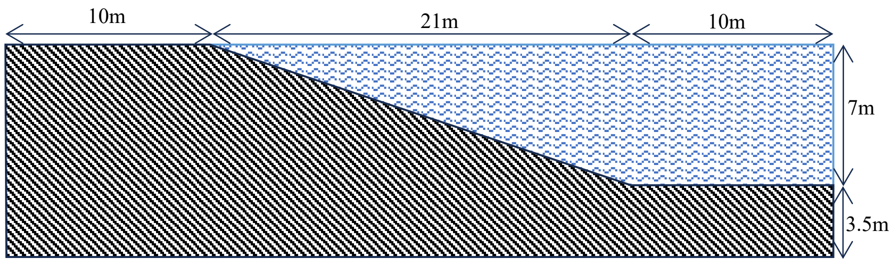


Figure 1: Problem geometry

Keywords

Pore Water Pressure, phi-c analysis, drained, undrained, transient.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.

- **drawdown_of_reservoir.lvb** carries out automated modelling of the example.

- Use **File > New** to create a new model of a suitable name in a chosen location.
- Use **File > Script > Run Script** to open the lvb file named above that was downloaded and placed in a folder of your choosing.

Objectives

The required output from the analysis consists of:

- ❑ Factor of safety of full reservoir
- ❑ Factor of safety of empty reservoir
- ❑ Factor of safety of reservoir at end of drawdown of 7 days
- ❑ Factor of safety of reservoir at end of drawdown of 70 days

Preparing the Model Features

Units of kN, m, t, s, C with a timescale of days.

Feature Geometry

A single surface is used to model the soil with a single line used to set the level of the phreatic surface (figure 2).

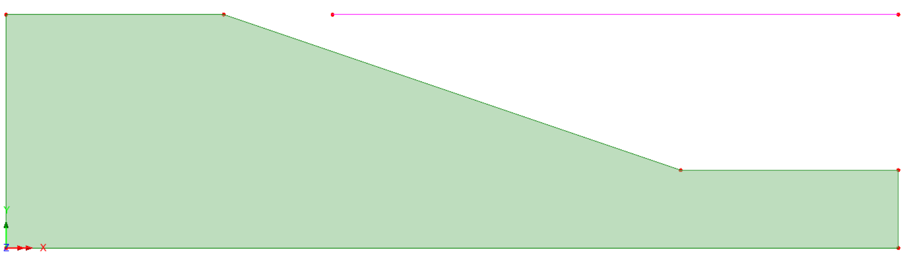


Figure 2: Problem modelled with single surface and line

Preparing the Model Attributes

Defining the Mesh

The model is meshed with triangular two-phase plain strain elements, TPN6P, with a length of 0.75m (figure 3).

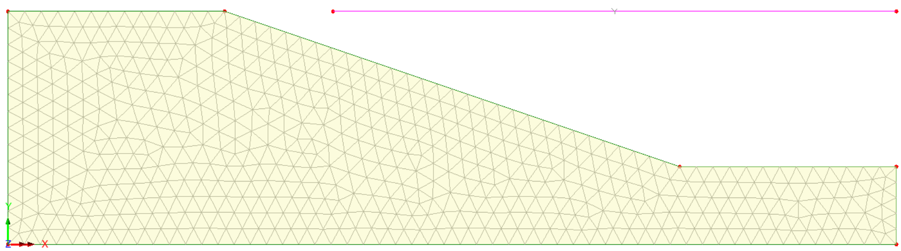


Figure 3: Mesh

Defining the Materials

The soil is modelled using a Modified Mohr-Coulomb with Rankine cut-off material. Properties are given in table 1. Water properties are given in table 2.

Table 1: material properties

Young's modulus	Poisson's ratio	Saturated density	Angle of friction	Angle of dilation	Cohesion
1000 kPa	0.2	2.0 t/m^3	20º	0º	10 kPa
Tensile cutoff	Porosity	Hydraulic conductivity	Saturation at residual water content	Saturation at full water content	
25 kPa	0.5	8.64E-4 m/day	0.0	1.0	

Table 2: Water properties

Bulk modulus	Density
2.1E6 kPa	1 t/m^3

Defining the Supports

The model is restrained in X and Y directions along its base and in the X direction on the lateral sides as shown in the figure 4.

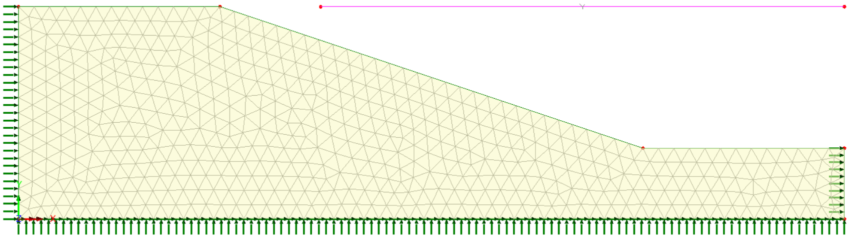


Figure 4: Boundary conditions

Defining the Loads

Gravity loading is used throughout. The phreatic surface is lowered at different rates using total prescribed displacement controlled by loadcurves.

Defining Other Attributes

The phreatic surface attribute is defined using **Attributes > Pore Water Pressure > Phreatic surface…** It is given the name reservoir level (figure 5).

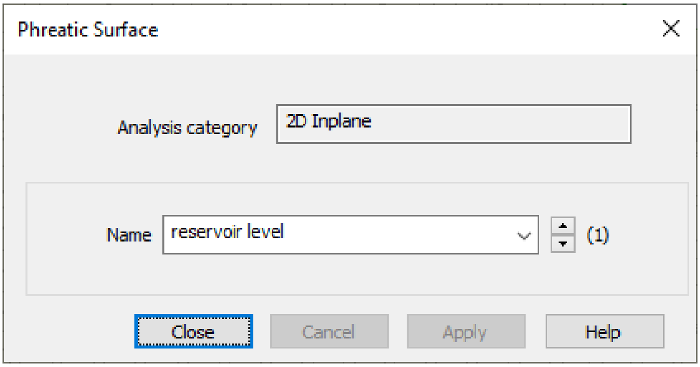


Figure 5: Definition of phreatic surface attribute

The phreatic surface attribute is assigned to the line in figure 6.

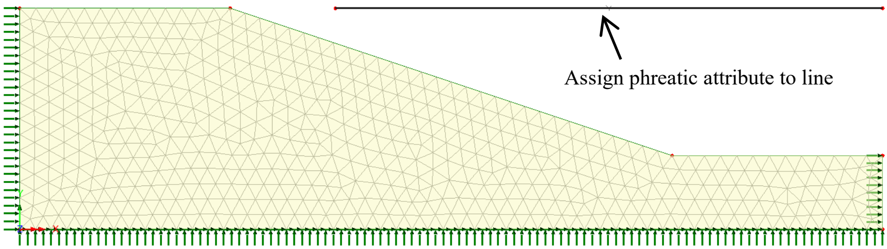


Figure 6: Assignment of phreatic attribute

A water pressure loading is then defined using **Attributes > Loading…**, selecting the radio button **Distributed load** and then the radio button **Water pressure distribution**. On the **Water Pressure Distribution** dialog ensure that the **Include face pressure** tickbox is checked (figure 7).

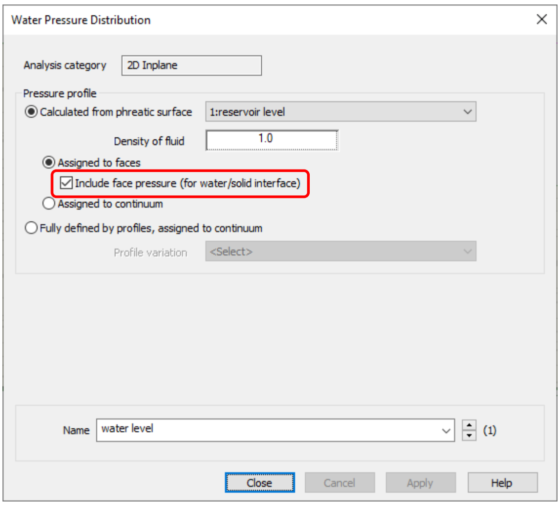


Figure 7: Water pressure distribution dialog

The water pressure distribution attribute is then assigned to the surface of the soil (figure 8).

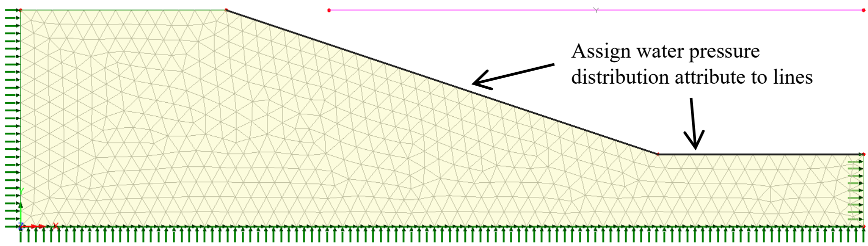


Figure 8: Assignment of water pressure distribution attribute

Running the Analysis

The safety factors for different states of the reservoir are calculated using the phi-c reduction method. An undrained phi-c reduction includes the bulk-modulus of water in the calculation of the stresses whilst for a drained analysis this is omitted. The undrained analysis is therefore applicable to the short term where the pore water pressures influence the slope stability as opposed to the drained analysis that considers long-term stability.

The phi-c analysis looks for the point at which the solution fails to converge. As failure is approached smaller and smaller changes to the safety factor are required to get a converged solution. The solution is considered to have converged once the incremental change to the safety factor falls below a given tolerance.

The actual solution process is governed by the choice of solution parameters and their influence on convergence which can lead to differing factors of safety. As the model gets closer and closer to failure one iteration may just satisfy the convergence tolerance and another iteration, marginally different, may not. As the slight differences accumulate the last solution at which convergence is achieved can change.

In this example the number of permitted iterations is increased to 20.

The displacements should be examined at a plot scale of 1 to see when the soil fails. Very large displacements can develop which, although mathematical solutions to the equilibrium equations within the given solution tolerances, are physically impossible.

Analysis 1 > Initial Phase

The initial stresses in the soil are established for the full reservoir.

Analysis 1 > Phi-C reduction of full reservoir

A drained phi-C reduction analysis is run on the full reservoir.

Analysis 2 > Fast drawdown 1m/day

A transient two-phase analysis is run to the draw the reservoir down in 7 days.

Analysis 2 > Phi-C reduction following fast drawdown

An undrained phi-C reduction analysis is run on the now empty reservoir.

Analysis 3 > Slow drawdown 0.1m/day

A transient two-phase analysis is run to the draw the reservoir down in 70 days.

Analysis 3 > Phi-C reduction following slow drawdown

An undrained phi-C reduction analysis is run on the now empty reservoir.

Analysis 4 > Initial Phase

The initial stresses in the soil are established for the empty reservoir.

Analysis 4 > Phi-C reduction of empty reservoir

A drained phi-C reduction analysis is run on the empty reservoir.

Viewing the Analysis

Contours for the pore water distributions at different times are shown in figure 9.

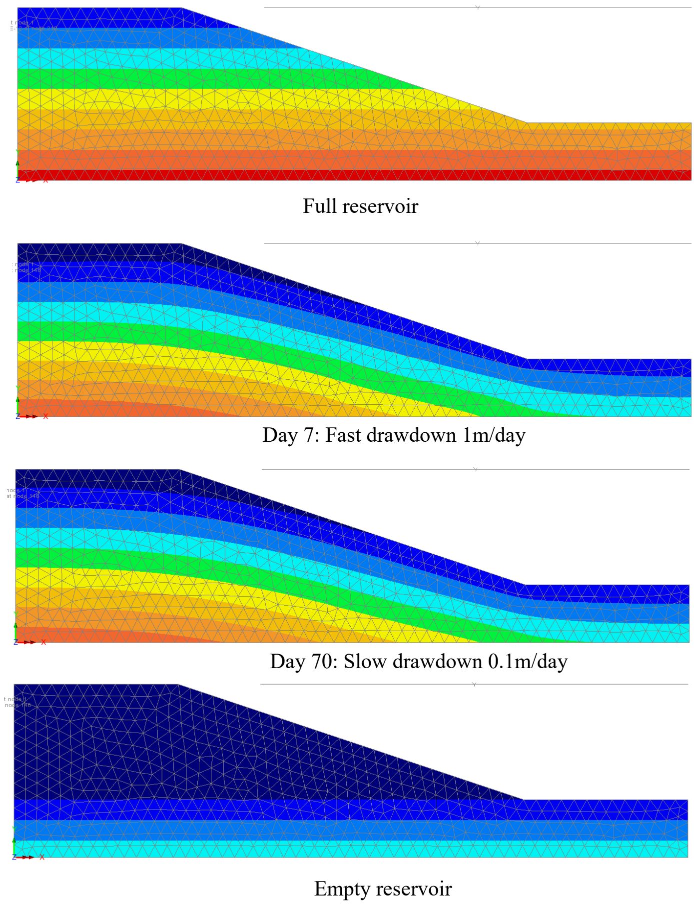
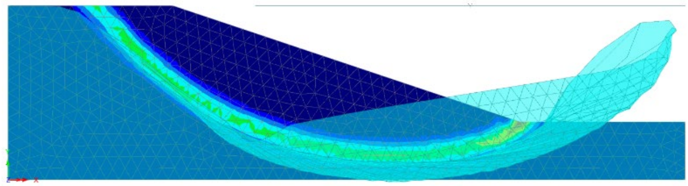
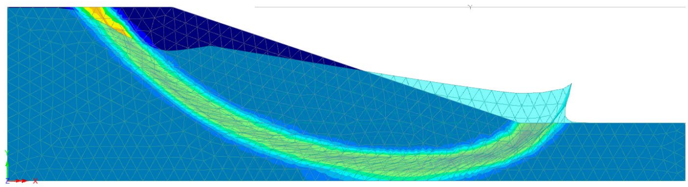


Figure 9: Pore water pressures for reservoir in different states

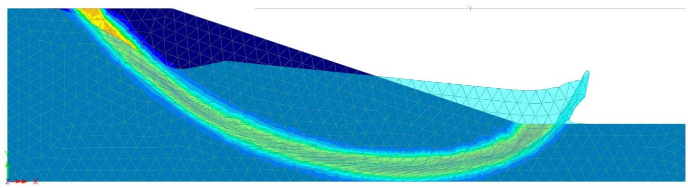
Figure 10 plots the final displaced shapes drawn at a scale of 1 at the end of each of the phi-c reduction analyses. For the first three plots the deformed shapes are obviously impossible but because linear (small displacement) theory is used the stresses can be successfully evaluated..



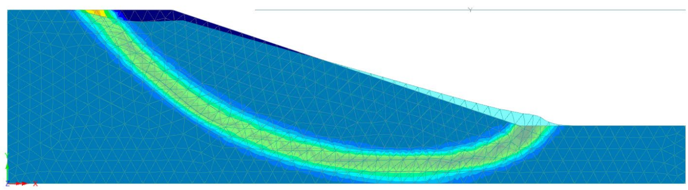
Full reservoir – drained – SF =2.66



Fast drawdown – undrained – SF = 1.43



Slow drawdown – undrained – SF = 1.46



Empty reservoir – drained – SF = 2.12

Figure 10: Contours of effective strain – displacements drawn at a scale of 1

The factors of safety for the fast and slow drawdowns do not change significantly. This is explained by the very low drainage rate resulting in only a small change in the position of the phreatic surface despite the slow drawdown taking 10 times longer than the fast one.