Transient Groundwater + Slope Stability

1. Introduction

This tutorial describes how to use Slide2 to calculate factors of safety for a dam subjected to time-dependent changes in pore pressure. As part of the tutorial, a transient groundwater analysis is performed using finite elements.

The finished product of this tutorial can be found by selecting **File > Recent Folders > Tutorials Folder >** ***Tutorial 19 Transient + Slope Stability.slmd*** in Slide2.

2. Model

We will open a model that has been partially prepared. Go to **File > Recent Folders > Tutorials Folder** in Slide2 and open *Tutorial 19 Transient + Slope Stability initial.slmd.*

In the Project Settings, note the following:

• In the **General** tab, the Failure Direction is set to Left to Right

• In the **Groundwater** tab, the Method is set to Steady State FEA. In this tutorial, we will perform a steady-state finite element analysis to get the initial state.

• In the **Transient** tab, we have checked the Calculate SF checkbox for each stage.

Click **Cancel** to close the dialog. Notice the three tabs at the bottom. One for Slope Stability, one for Steady State Groundwater, and one for Transient Groundwater. Note that geometry setup can only be done in the Slope Stability mode.

While in the Slope Stability mode, take a minute to look at the material properties. We have used Mohr-Coulomb in this case.

In this tutorial, we wish to restrict the search for slip surfaces to include only major failure surfaces extending from the top of the dam to the bottom. Notice that the slope limits have been changed. Details on how to do this can be found in Tutorial 1. Remember that the limits can easily be moved or edited by right-clicking on the limits and choosing the appropriate option.

3. Groundwater

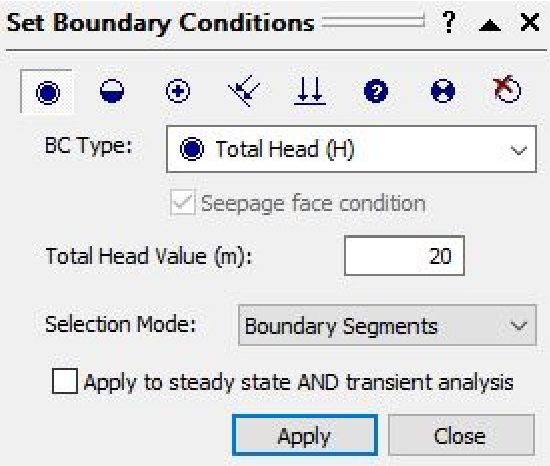
Now it is time to set up the finite element model for the calculation of groundwater behaviour. Go to the Steady State Groundwater tab and notice that the mesh has already been defined.

3.1 BOUNDARY CONDITIONS

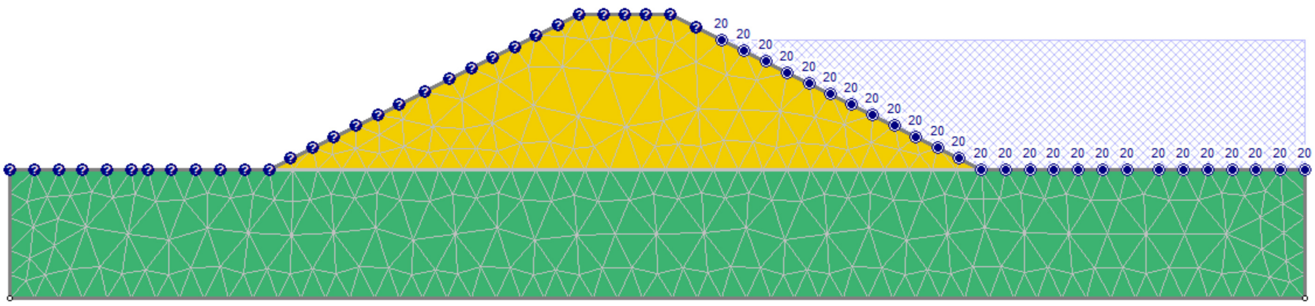
We will set up boundary conditions to simulate ponded water on the right side.

Select **Mesh > Set Boundary Conditions.**

For BC Type choose Total Head and set the Total Head Value to 20 m. Uncheck the box for 'Apply to steady-state AND transient analysis'.



Click on the right side of the slope near the bottom, and the top of the foundation layer to the right of the dam. Click **Apply**. Click Close to close the dialog. The model should look like this:



3.2 TRANSIENT BOUNDARY CONDITIONS

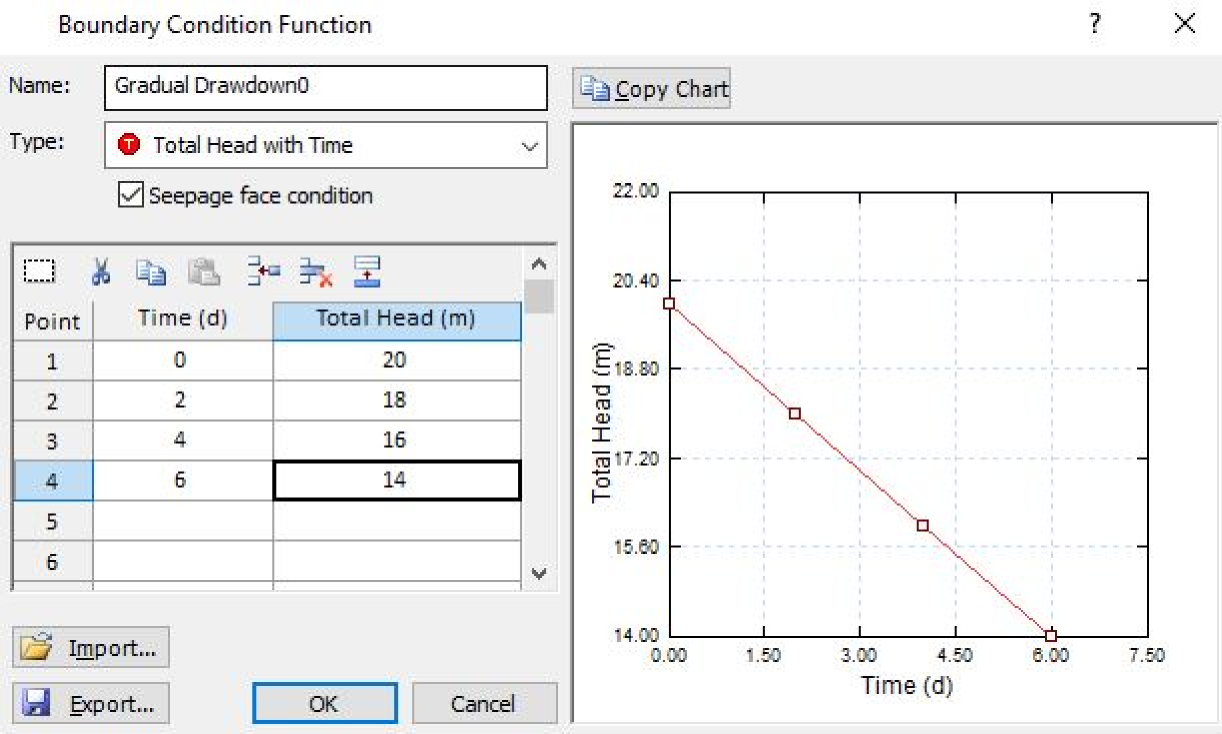
The ponded water model shown above represents the initial state. We will now implement transient boundary conditions to simulate a gradual drawdown of the water level.

Click on the tab for **Transient Groundwater** at the bottom of the screen.

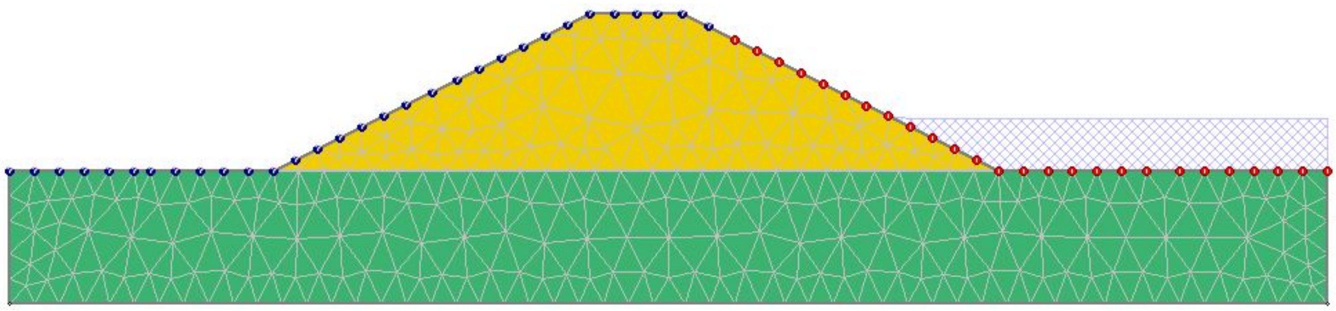
Select **Mesh > Set Transient Boundary Conditions**.

Here we set up a function that will change the boundary conditions with time. Click the New button. Change the name to 'Gradual Drawdown' and set the Type to 'Total Head with Time'. Now fill in the Time and Total Head values as shown:

Point	Time (d)	Total Head (m)
1	0	20
2	2	18
3	4	16
4	6	14



Click **OK**. Now click on the bottom right part of the slope and the top of the foundation layer as before. Click Apply. The model should look like this:



Click **Close** to close the dialog. The plot now shows the height of the ponded water at the last stage of the analysis.

3.3 MATERIAL PROPERTIES (GROUNDWATER)

Select **Properties > Define Hydraulic Properties.** The hydraulic properties required for a transient analysis are the same as those for a steady-state analysis except that water content (WC) must now be specified.

Click on the link for Dam material. For the Model, choose Simple. This is a simple built-in function that relates permeability and water content to matric suction. To view the relationships, click on the graph icon to the right. Set the permeability Ks to be 1e-5 m/s. Leave the water content WC as the default value of 0.4.

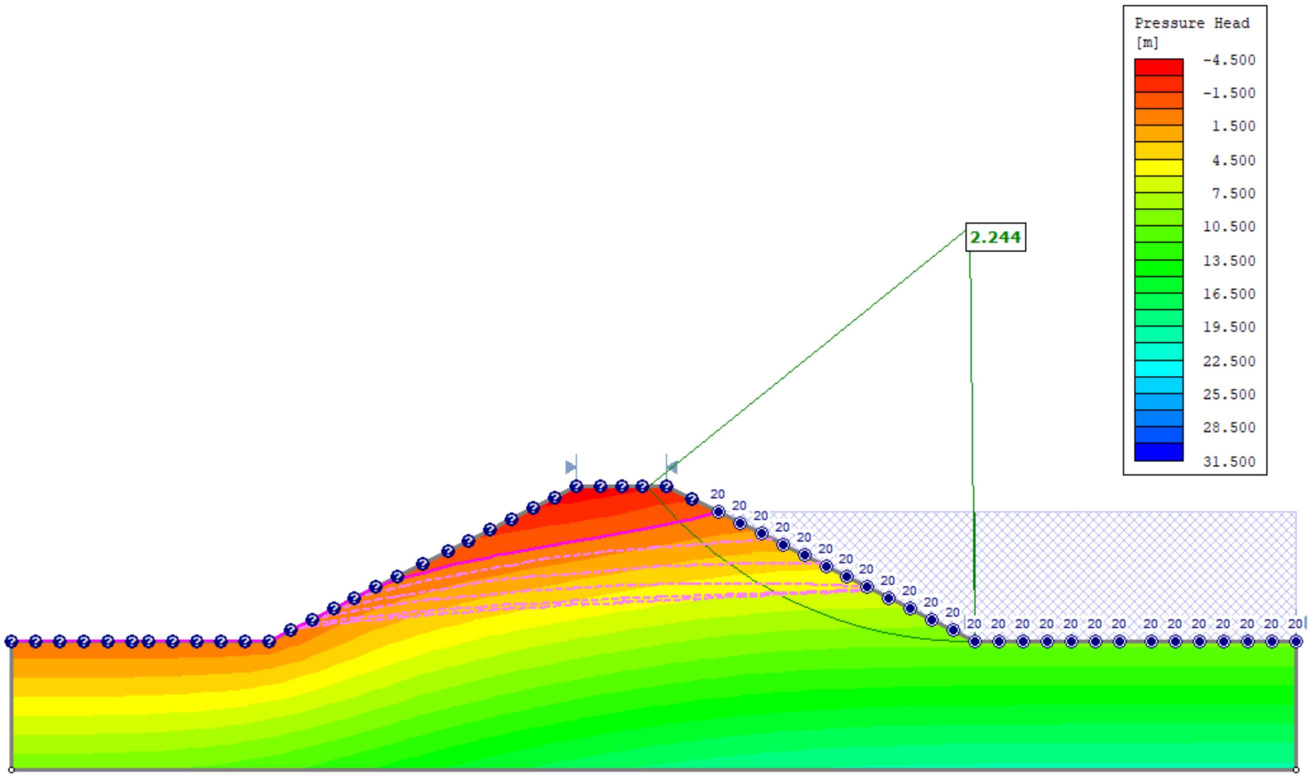
Click on the link for the **Foundation material**. Set Ks to 1e-8 m/s. Click **OK** to close the dialog.

3.4 COMPUTE

Save the model using the **Save As** option in the File menu. You could now choose **Compute (groundwater)** from the **Analysis** menu to perform the groundwater analysis. However, in this tutorial we want both the groundwater and slope stability results to be computed. So select the tab at the bottom for Slope Stability. Now select **Analysis > Compute**. This will compute both the groundwater results and the slope stability results. It may take a few minutes to perform the calculations. When it is finished, choose Interpret from the Analysis menu to view the results.

3.5 INTERPRET

You will now see the pressure head for the initial state and the corresponding factor of safety.



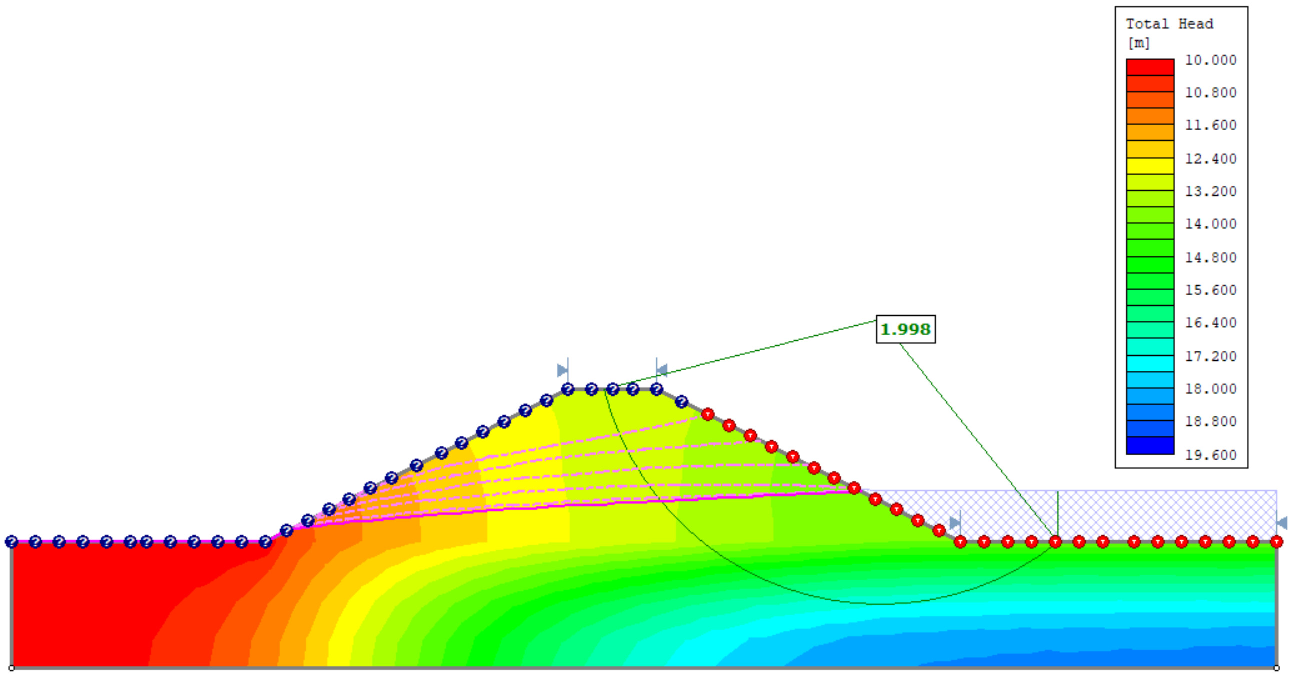
Factor of Safety and Pressure Head contours at initial stage

You can see that the slope is quite stable at this time.

Click through the other stages using the tabs at the bottom. You will see how the pressure head changes as the water table is lowered. After 6 days, the ponded water has reached its final depth (4 m above the foundation) but the pressure head in the dam continues to change as water flows from regions of high pressure to low pressure.

Click on the tab for **Stage 5 (50 days)**. This essentially represents the steady-state. You can show the progression of the water table with time by going to **View → Display Options.** Select the Groundwater tab and under FEA water, select **All Stages**.

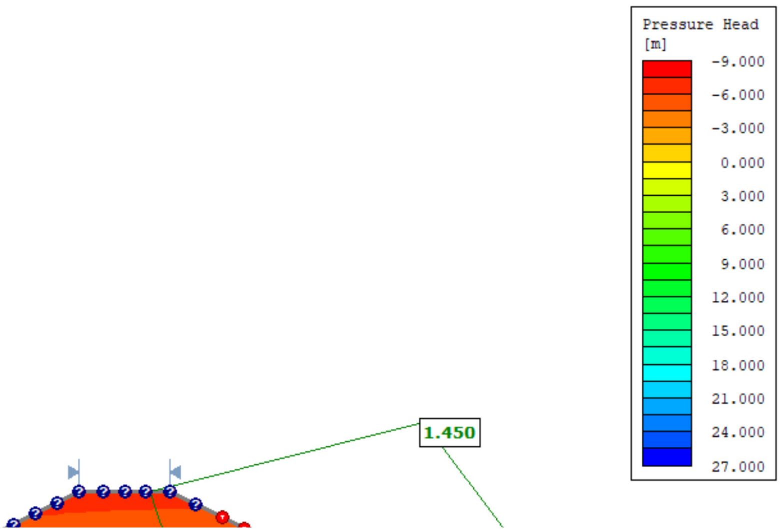
Click **Done**. The water tables at the different stages are now plotted as dashed pink lines. They are difficult to see on this plot so change the plot to show contours of Total Head using the drop-down menu at the top. The plot will now look like this:



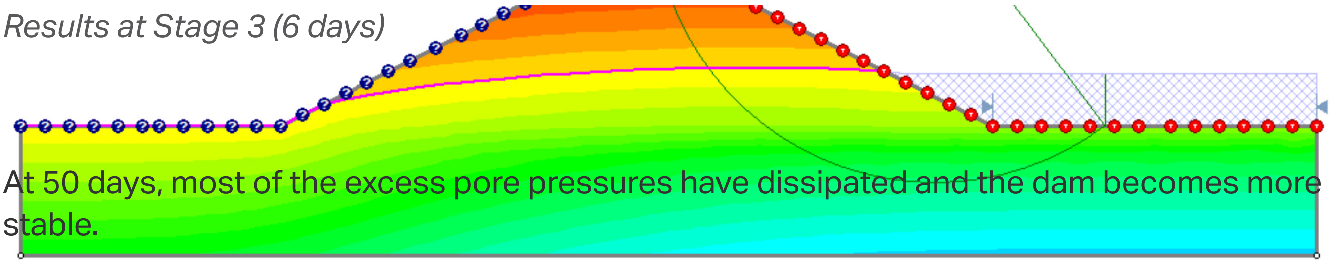
Progression of the water table and Total Head contours in Stage 5

You can see that the solid pink line represents the water table at 50 days and the dashed pink lines represent the water table at other stages. Go back to the Display Options and turn off the water tables. Change the contours back to the Pressure Head.

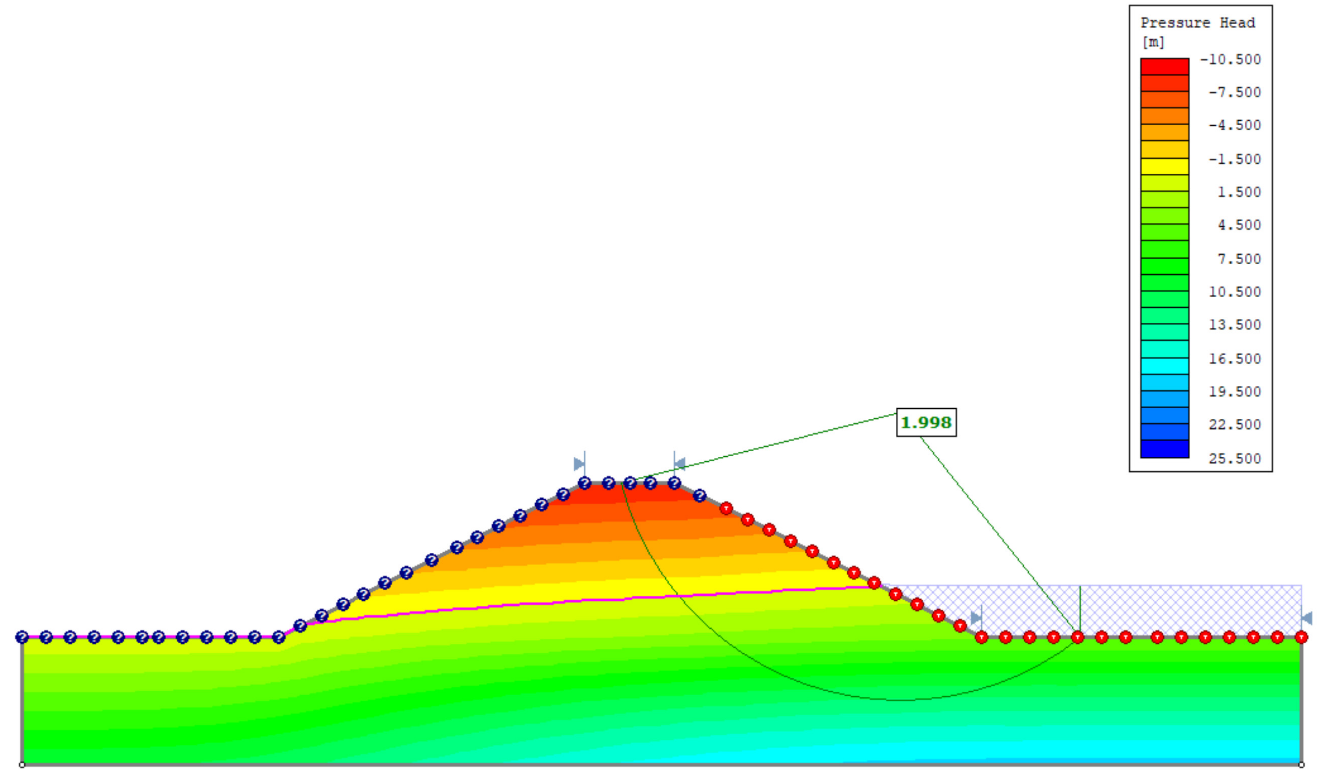
You can also see the changing factor of safety as the pore pressures change. When the water table is lowered, the factor of safety decreases dramatically since the weight of the water has been removed but the excess pore pressures have not yet dissipated. At 6 days, the factor of safety is lowest at just about 1.5.



Results at Stage 3 (6 days)

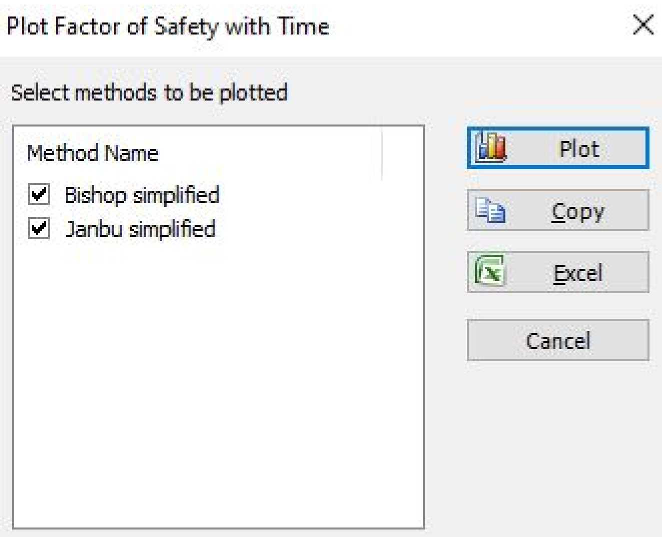


At 50 days, most of the excess pore pressures have dissipated and the dam becomes more stable.

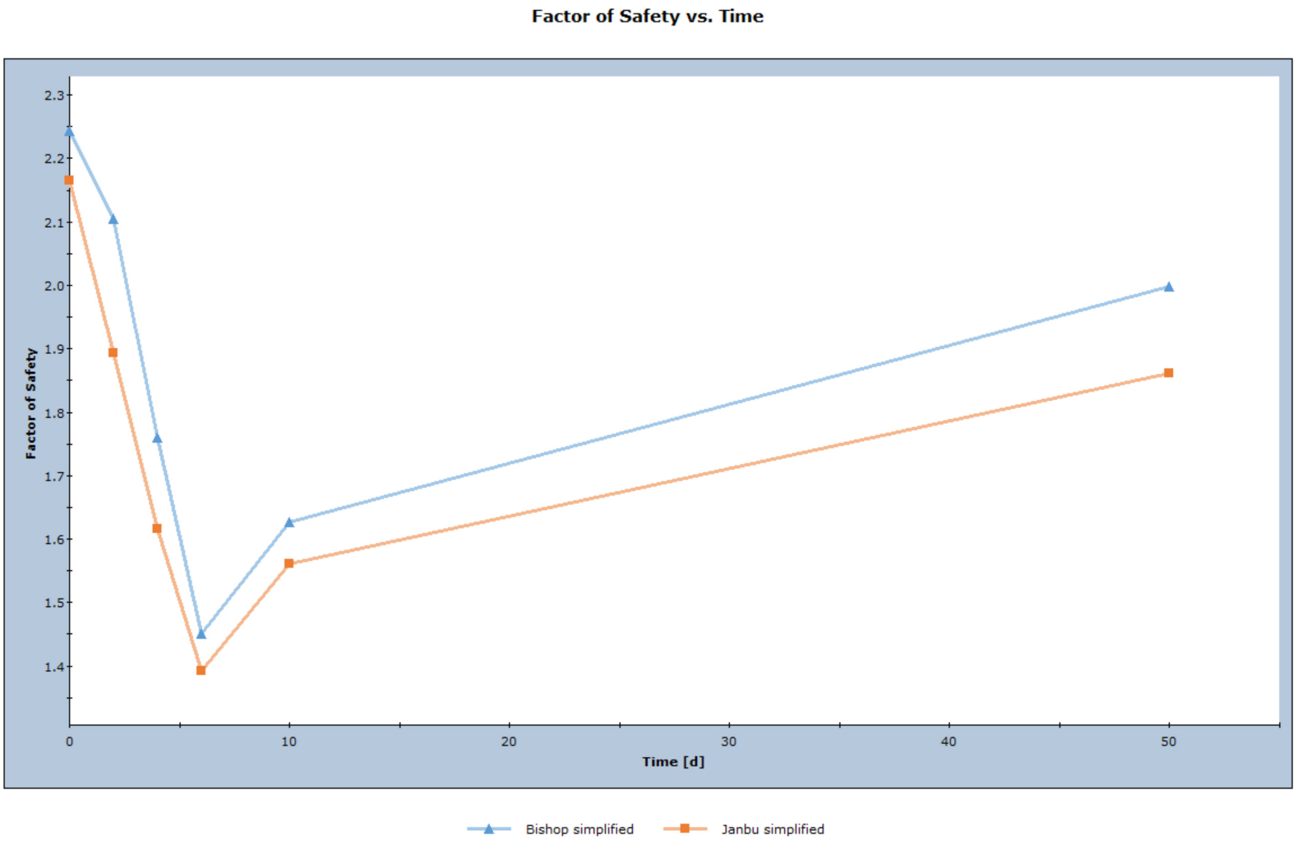


Results at Stage 5 (50 Days)

You can plot the factor of safety versus time by going to **Data > Graph SF with Time**. You can choose which method results to plot. Choose both the Bishop simplified method and the Janbu simplified method as shown.



Click **Plot** to see the graph. It should look like this:



Factor of Safety vs. Time for the Bishop and Janbu methods

Here you can clearly see the rapid decrease in factor of safety as the water table is lowered and the gradual increase as the excess pore pressures dissipate. This example shows the importance of a transient groundwater analysis since a steady-state analysis would suggest that the dam has a constant and stable factor of safety.

This concludes the tutorial.

4. Additional Exercise

At 50 days, the dam has not yet reached a steady-state solution. Try adding another stage (at say 100 days) to see the final steady-state factor of safety.