Transient Groundwater Analysis with Slope Stability

This tutorial describes how to use Slide 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 in the Tutorial 19 Transient + Slope Stability.slim data file. All tutorial files installed with Slide 6.0 can be accessed by selecting File > Recent Folders > Tutorials Folder from the Slide main menu.

Topics Covered

- Transient groundwater seepage analysis
- Slope stability with transient groundwater

Geometry
Start the *Slide* Model program.

**Project Settings**

Open the **Project Settings** dialog from the **Analysis** menu. Set the Stress Units to Metric, set the Time Units to Days and the Permeability Units to meters/second. Set the Failure Direction to Left to Right as shown.

Click on the Groundwater link on the left side. For the Method choose Steady State FEA. Select the **Advanced** checkbox and choose Transient Groundwater.
The Method refers to the method used to obtain the *initial state* for the transient groundwater analysis. In this tutorial we will perform a steady state finite element analysis to get the initial state.

Now click on the Transient link on the left. Here we need to specify the times at which we wish to observe pore pressure results. Change the Number of Stages to 5. Enter the times for each stage as shown. Also select the Calculate SF (Safety Factor) checkbox for each stage.

This will set up the model to calculate factor of safety at each specified time as groundwater conditions are changing.

Click OK to close the Project Settings dialog.
Slope Stability

You will now see a blank screen with three tabs at the bottom. One for Slope Stability, one for Steady State Groundwater and one for Transient Groundwater. The first part of this tutorial involves setting up the model geometry. This can only be done in the Slope Stability mode, so click on the tab for **Slope Stability**.

**Boundaries**

The model represents a dam overlying a strong foundation holding back ponded water on one side. Here we will define the geometry of the problem.

Make sure that you are in ‘Slope Stability’ view. Select the **Add External Boundary** option in the **Boundaries** menu and enter the following coordinates:

\[
\begin{align*}
0, 0 \\
100, 0 \\
100, 10 \\
75, 10 \\
55, 20 \\
51, 22 \\
44, 22 \\
20, 10 \\
0, 10 \\
c
\end{align*}
\]

Hit Enter to finish entering points. The model will look like this:
Now we need to define the boundary between the dam material and the foundation. Select **Boundaries → Add Material Boundary**. Click on the point at (0, 10) and then on the point at (100, 10). Hit Enter to stop entering points. The model will look like this.

**Materials**

Select **Define Materials** from the **Properties** menu. Change the name of Material 1 to Dam. Set the Cohesion to 6 kN/m² and \( \phi_b \) to 35° as shown.
When in Slope Stability mode, only the slope stability parameters can be set. We will set the groundwater flow parameters later.

Click on the link for Material 2. Change the name to Foundation. Set the Cohesion to 15 kN/m² and set $\phi$ and $\phi_b$ to 30 degrees as shown.
Click OK to close the dialog.

**Assigning Properties**

By default, the entire model is assigned Material 1 (Dam). To set the foundation material, choose **Properties → Assign Properties**. Choose Foundation and click inside the bottom part of the model. Close the Assign Material dialog and the model should look like this.

![Model with assigned materials](image)

You could also simply right click inside the foundation area and choose Assign Material → Foundation.
**Slip Surfaces**

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. To do this, we need to add another set of Slope Limits.

Go to **Surfaces \(\rightarrow\) Slope Limits \(\rightarrow\) Define Limits**. Click the box for Second set of limits as shown.

It is possible here to specify coordinates of the limits but it is easier to do this graphically by dragging them along the slope surface, so click on OK to close the dialog. You will now see two sets of slope limits on the model.

We want potential slip surfaces to start from the top of the dam. So right click on the slope limit icon at \(x=33\) (second from the left) and select **Move Limits**. Now drag the icon to the right side of the flat top of the dam as shown.

Now drag the left icon at \(x=0\) to the top left of the dam.
Finally, drag the icon that is halfway down the slope at x=66 to the bottom of the slope. Hit Enter to finish moving the limits and the model should look like this:

Now that the slope limits are defined, we need to specify how Slide should search for potential failure surfaces. Go to Surfaces → Surface Options. Under Search Method, choose Auto Refine Search. This option means that we do not have to define a search grid.
Now it is time to set up the finite element model for calculation of groundwater behaviour. First we will set up the initial state that exists prior to the drawdown, so select the tab for **Steady State Groundwater** at the bottom of the screen.

**Mesh**

Before we can set up the boundary conditions we need to create a finite element mesh. This is easily done by selecting **Mesh → Discretize and Mesh**. The model should now look like this:
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:

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:

![Boundary Condition Function](image)

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:

![Model with Ponded Water](image)

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

**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 $K_s$ to be $1e^{-5}$ m/s. Leave the water content $WC$ as the default value of 0.4. The dialog should appear as shown.

Click on the link for the Foundation material. Set $K_s$ to $1e^{-8}$ m/s.

Click OK to close the dialog.
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 (groundwater)** from the **Analysis** menu to view the results.

Interpret

You will now see the pressure head for the initial state. To show the factor of safety as well, click the button on the toolbar for ‘Slope Stability and Groundwater’.

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 as shown.
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:
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 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 just above 1, indicating that the slope will likely fail.

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

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 method and the Janbu method as shown.
Click Plot to see the graph. It should look like this:

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 is stable.

This concludes the tutorial.

**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.