

# Developer's Tip

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## Effective Stress Analysis With Phase<sup>2</sup> Using Seepage Analysis Results From Slide

Did you know that Phase<sup>2</sup> can be used for soil applications, as well as for the analysis of rock excavations? This Developer's Tip demonstrates how to use Phase<sup>2</sup> and Slide together to carry out a finite element slope stability analysis, using effective stress, in four easy steps:

1. Carry out a seepage analysis using the finite element seepage analysis capability of Slide.
2. Save the resulting pore pressure distribution within the soil to a PWP file.
3. Import the model boundaries from Slide into Phase<sup>2</sup>. Setup the appropriate boundary conditions for the Phase<sup>2</sup> model and import the PWP file containing the pore pressure distribution.
4. Carry out a finite element slope stability analysis using Phase<sup>2</sup> and compare the safety factor with the limit equilibrium safety factor calculated by Slide.

### STEP 1: Seepage Analysis with Slide

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Slide is two programs in one: a comprehensive limit equilibrium slope stability analysis program and a sophisticated, easy-to-use finite element seepage analysis program for performing saturated/unsaturated steady state seepage analysis. In the Slide User's Guide, a seepage analysis example is discussed in Tutorial 7 (Groundwater Tutorial). This example can be downloaded at:

[http://www.roscience.com/downloads/Slide/Slide\\_TutorialManual1.pdf](http://www.roscience.com/downloads/Slide/Slide_TutorialManual1.pdf)

The results of the analysis can be seen in Figure 1.

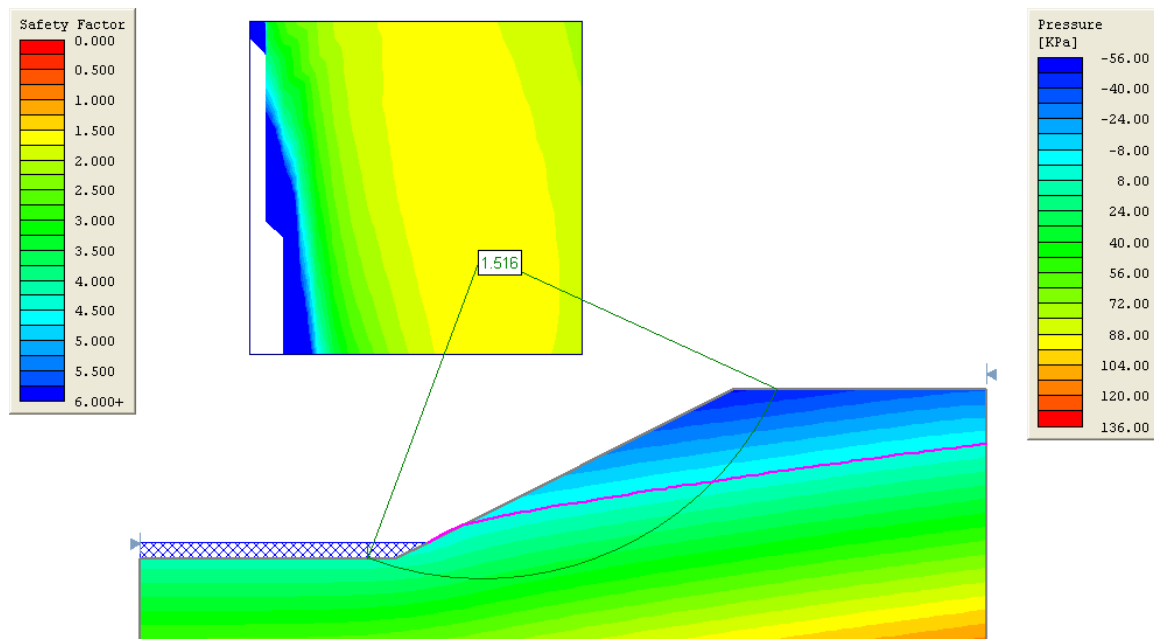


Fig.1: Safety factor contours and pore pressure contours obtained from Slide.

The contours within the slope represent the pore pressure distribution obtained from the finite element seepage analysis. The contours above the slope are the safety factor contours obtained from the limit equilibrium analysis (Bishop Method) using circular slip surfaces and a grid search (the minimum safety factor is  $FS = 1.516$ ).

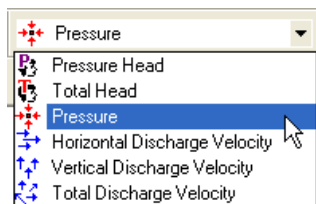
Slope stability analysis and the seepage analysis capabilities are fully integrated in Slide: the same model is used for both analyses, the stability analysis utilizes the pore pressures from the seepage analysis and slope stability and seepage results can be viewed simultaneously, if desired.

## STEP 2: Save Pore Pressure Values to a File

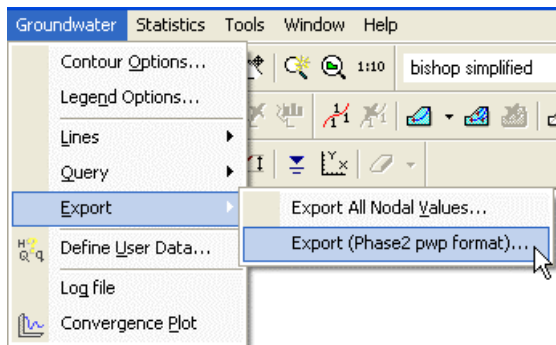
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The pore pressure distribution obtained from the Slide seepage analysis can be easily exported (saved to a file). This is done from the Slide *Interpret* program after the analysis has been run.

1. View the seepage analysis results in the Slide *Interpret* program (the Slide *Interpret* program is the program module used for viewing the results of the Slide analysis).
2. Make sure that you are viewing contours of pore pressure. Select the Pressure option in the drop-down list of groundwater data in the Slide toolbar.



3. In the Slide *Interpret* menu, select Groundwater > Export > Phase<sup>2</sup> PWP Format.

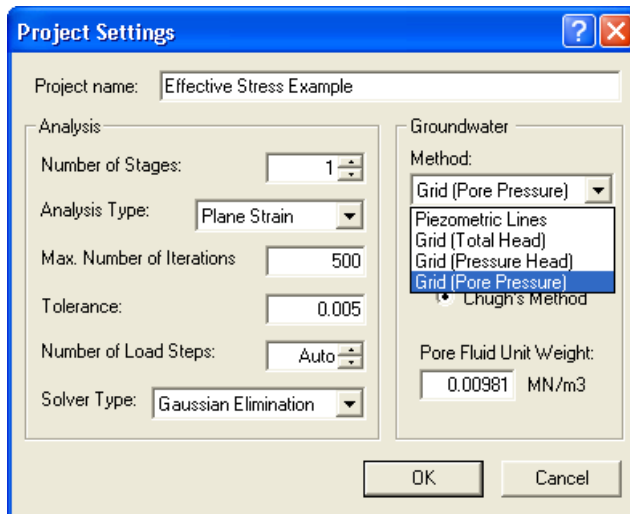


4. In the Save As dialog enter a filename and save the pore pressure data to a PWP file. This saves the pore pressure data at a grid of X-Y locations within the slope, where the grid is determined from the nodes of the finite element mesh.

### STEP 3: Setting Up the Phase<sup>2</sup> Model

Create the same model in Phase<sup>2</sup> by following these instructions:

1. Use the DXF Export feature in Slide to export the model boundaries to a DXF file.
2. Use the DXF Import feature in Phase<sup>2</sup> to read in the DXF File. (If you originally created your model in Phase<sup>2</sup>, you could just as easily import the model boundaries from Phase<sup>2</sup> into Slide, using the DXF Import/Export feature.)
3. Set up the appropriate boundary conditions and field stress for the Phase<sup>2</sup> model. The “ponded water” in the Slide model (at the toe of the slope) is modeled in Phase<sup>2</sup> as a distributed load.
4. In the Phase<sup>2</sup> Project Settings, set the Groundwater Method to Grid (Pore Pressure).



5. Import the PWP file from Slide. From the Phase<sup>2</sup> menu, select Boundaries > Water Pressure Grid.
6. In the dialog, select the Import button and read in the PWP file that you saved from the Slide seepage analysis.

The screenshot shows the 'Water Pressure Grid' dialog box. It contains a table with 10 rows and 4 columns: Point, x (m), y (m), and Pore Pressure (MPa). Below the table are buttons for 'Import...', 'Add Row', 'OK', 'Export...', 'Delete Row(s)', and 'Cancel'.

Point	x (m)	y (m)	Pore Pressure (MPa)
1	15	23.75	0.0220725
2	15	22.5	0.034335
3	15	21.25	0.0465975
4	15	20	0.05886
5	16.1364	20	0.0588855
6	17.2727	20	0.058914
7	18.4091	20	0.0589493
8	19.5455	20	0.0589964
9	20.6818	20	0.0590611
10	21.8182	20	0.0591504

For this example, we've prepared the final Phase<sup>2</sup> model for users – it can be downloaded from:  
[http://www.rocscience.com/downloads/phase2/Phase2\\_eff\\_stress.zip](http://www.rocscience.com/downloads/phase2/Phase2_eff_stress.zip)

## STEP 4: Slope Stability With Phase<sup>2</sup> Using Effective Stress

Finally, carry out a slope stability analysis with Phase<sup>2</sup> and compare the results (safety factor) obtained from the Slide limit equilibrium analysis. A more thorough discussion of finite element slope stability using Phase<sup>2</sup> can be found in the following article, available at:

<http://www.rocsience.com/library/pdf/SlopeStabilityUsingPhase2.pdf>

However, briefly, a finite element slope stability analysis can be carried out as follows:

1. Assuming Mohr-Coulomb material properties, we divide both the Cohesion and tangent of the Friction Angle ( $\tan(\phi)$ ), by an assumed “strength reduction factor” (SRF).
  - $C / \text{SRF}$
  - $\tan(\phi) / \text{SRF}$
2. Calculate the new friction angle ( $\arctan(\tan(\phi) / \text{SRF})$ ) and enter the new values of Cohesion and Friction Angle, as the material properties for your slope.
3. Run the finite element analysis. View the Total Displacement contours and record the Maximum value of the Total Displacement. The Maximum Total Displacement is listed in the Status Bar at the bottom left of the Phase<sup>2</sup> *Interpret* application window, when you select Total Displacement.
4. Repeat steps 1 – 3, using increasing values of SRF.
5. Plot SRF versus the Maximum Total Displacement. At a certain value of SRF, the finite element analysis will not achieve convergence and the Maximum Total Displacement will increase significantly. This value of SRF can be taken as the Factor of Safety for the slope.

For this example, we will start with a  $\text{SRF} = 1.48$ , just below the Factor of Safety determined from the Slide limit equilibrium analysis ( $\text{FOS} = 1.51$ ). We will then increase the value of SRF in increments of 0.01, until instability occurs. The following table summarizes the values of SRF, C (reduced),  $\phi$  (reduced) and the corresponding values of Maximum Total Displacement, which resulted from the analysis.

Original strength parameters: C = 11 kPa, Phi = 28 degrees			
SRF	C (reduced)	Phi (reduced)	Max. Total Displacement (m)
1.48	7.432	19.761	.01254
1.49	7.382	19.639	.01263
1.5	7.333	19.518	.01287
1.51	7.285	19.398	.01316
1.52	7.237	19.28	.03319

Table 1: Reduced strength parameters used for Phase<sup>2</sup> slope stability analysis

As can be seen from Table 1, instability occurs between a SRF of 1.51 and 1.52. The Maximum Total Displacement increases suddenly from a steady value of around 0.013, to a value of 0.033. Furthermore, for  $\text{SRF} = 1.52$  it was observed that the finite element solution did not converge within the specified maximum number of iterations (500), also indicating that instability occurs at this point.

The data in Table 1 is plotted in Figure 2 below.

The Factor of Safety obtained from this Phase<sup>2</sup> analysis (1.51) agrees very closely with the value determined by Slide (1.516), validating the stability analysis methods and the correctness of results produced by both Phase<sup>2</sup> and Slide.

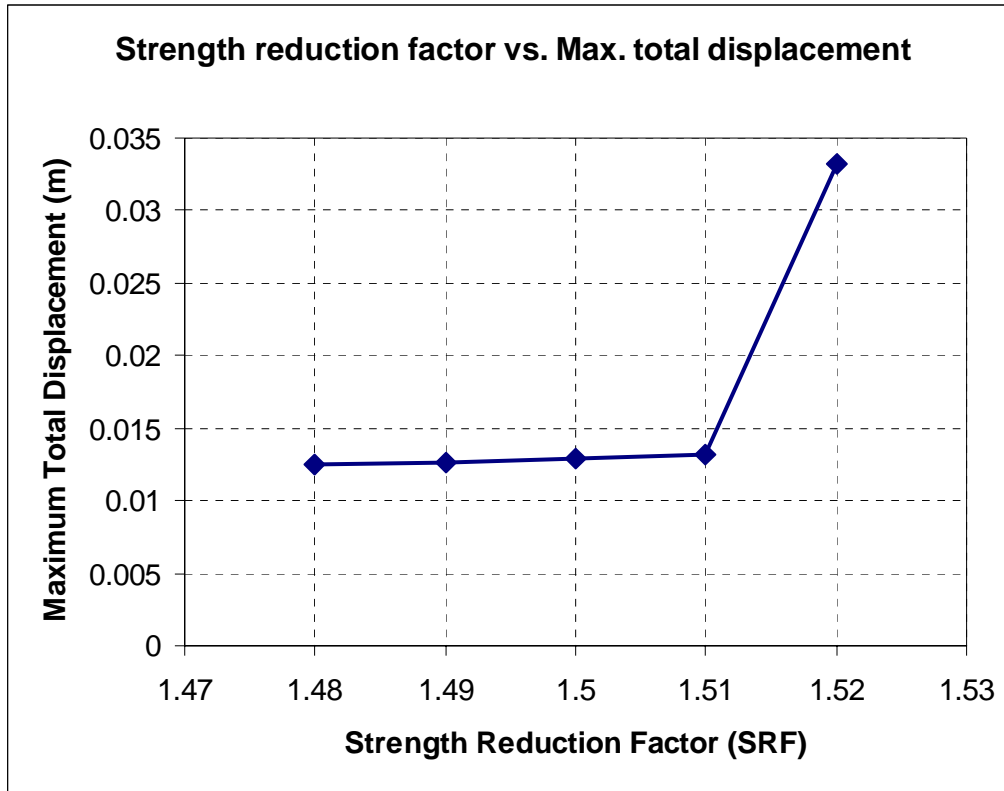


Fig. 2: Strength reduction factor vs. maximum total displacement

Figures 3 and 4 show the Total Displacement contours and the Maximum Shear Strain contours, respectively, for reduced C and Phi values corresponding to SRF = 1.52. Notice that the Maximum Shear Strain contours clearly indicate a “slip” region corresponding to the slip circle with the minimum safety factor determined by Slide (see Figure 1).

You can view contours of Effective Stress (Effective Sigma 1, Effective Sigma 3), as well as Pore Pressure, in the drop-down list of contour data in the Phase<sup>2</sup> *Interpret* program. When you include pore pressure in a Phase<sup>2</sup> stress analysis, the Effective Stress contours will be available for viewing.

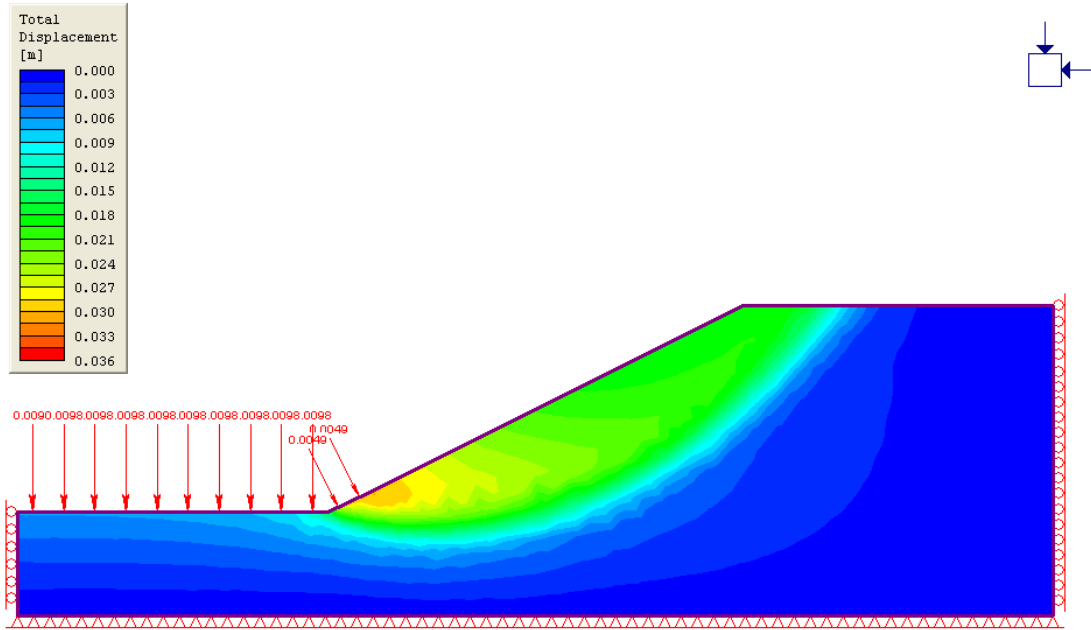


Fig. 3: Total Displacement for SRF=1.52

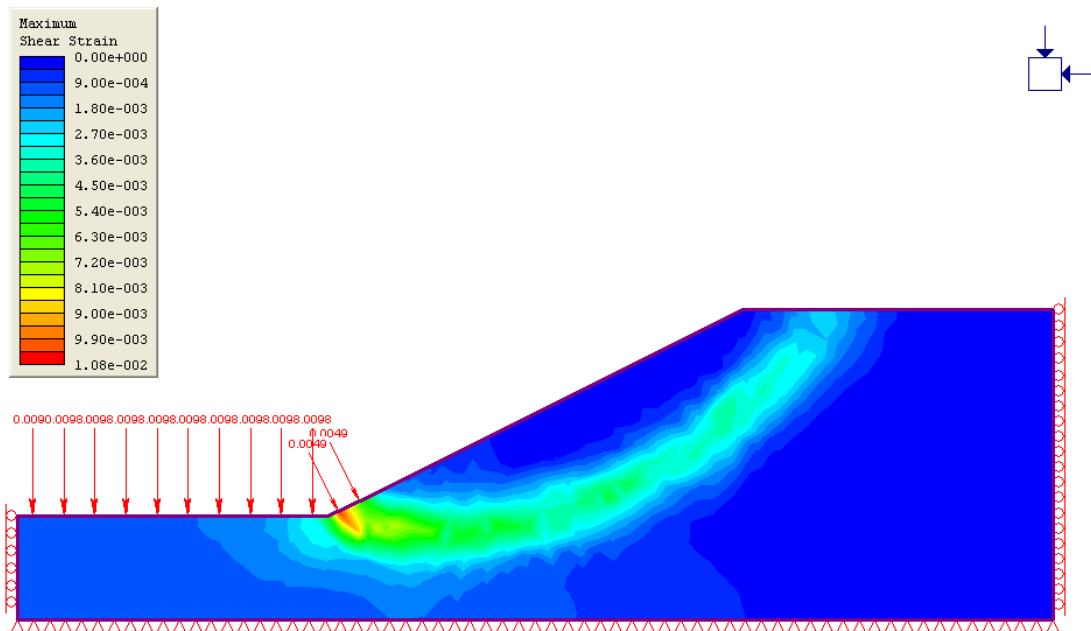


Fig. 4: Maximum shear strain for SRF=1.52

## Summary

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In conclusion, this Developer's Tip has demonstrated several important aspects of Phase<sup>2</sup> and Slide:

- Phase<sup>2</sup> and Slide can be used as complementary programs
- Phase<sup>2</sup> can be used to analyze soil problems, as well as rock
- Phase<sup>2</sup> can incorporate pore pressures for effective stress analysis
- Pore pressures from a Slide seepage analysis can be imported into Phase<sup>2</sup>
- Finite element slope stability analysis using effective stress can be carried out with Phase<sup>2</sup>

Pore pressure in Phase<sup>2</sup> can also be simply represented by a Piezometric Line (which may represent a Water Table or a Piezometric surface); it isn't necessary to import a pressure grid from Slide. This example was offered to demonstrate the possibility of using Phase<sup>2</sup> and Slide together, to combine a finite element seepage analysis with a finite element effective stress analysis. However, if you only require an approximate pore pressure distribution, you can easily draw a Piezometric Line directly in Phase<sup>2</sup> to approximately define your groundwater conditions and obtain effective stress analysis results.