

# Developer's Tips

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## Groundwater analysis using *Slide*

In this article we introduce the new groundwater/seepage analysis module, which was built into version 5.0 of *Slide*. The groundwater module uses a finite element formulation for modelling saturated and unsaturated steady-state flow. The distinctive feature of this new module is that it performs groundwater analysis on the same model used for slope stability analysis. The pore water pressures calculated from the new module can be automatically included in analyses by the slope stability engine in *Slide*. This means that with *Slide*, a model needs to be built only once; it is directly used for both groundwater and slope stability analysis.

Although the *Slide* groundwater module is geared towards the calculation of pore pressures for slope stability problems, it is not restricted to geometry configurations related to slopes only. It is a completely self-contained groundwater analysis program that can be used outside slope stability analysis.

## Background

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In slope stability analysis, pore pressure distributions, both negative and positive, play a major role in determining stability. They control the forces at the bases of the slices used in limit equilibrium analyses.

Generally the distribution of pore water pressures is either assumed or estimated using data obtained from installed piezometers. In most traditional slope stability programs, groundwater is usually defined as a 'hydrostatic line'. This assumption is simple to implement and requires minimal computational effort. In reality, however, groundwater flow is more complicated and depends significantly on geologic conditions, and properties of the materials that form the slope. For more accurate estimation of pore pressure distributions in a slope, more complicated seepage conditions must be input into a numerical analysis method.

The 'hydrostatic line' approach is conservative in some cases. This is especially true when conditions are such that an unsaturated zone can form in a slope (Rulan and Freeze, 1985). In layered soil problems, the approach becomes more conservative through overestimation of pore water pressures in certain zones. This overestimation seriously impacts the calculated shear strengths for the slice bases along the slip surface.

## Groundwater modeling

To perform groundwater analysis with *Slide*, a user must first set the *Groundwater Method* option in the Project Settings Dialog to *Groundwater Analysis* (see Figure 1 below).

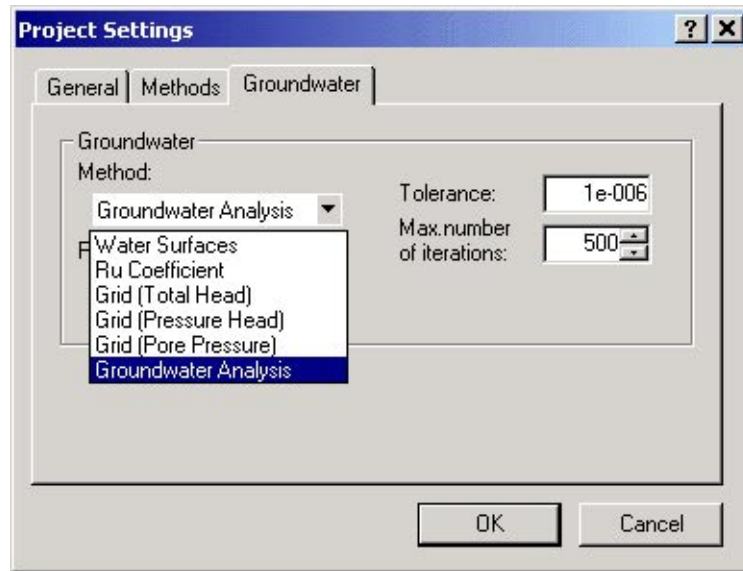


Figure 1. Project Setting dialog

Once this option has been set, the *Slide* Modeller can operate in one of two modes – Slope Stability mode or Groundwater mode (Figure 2). In Slope Stability mode you can build your model, complete with geometry and material properties. The Groundwater Analysis mode allows you to perform seepage analysis of your model.



Figure 2. Drop-down list on toolbar for selecting analysis mode

To create a model, users must first define the boundaries of their problem in Slope Stability Analysis mode. Also editing of the model can only be done in Slope Stability mode. Figure 3 shows a sample model created in *Slide*.

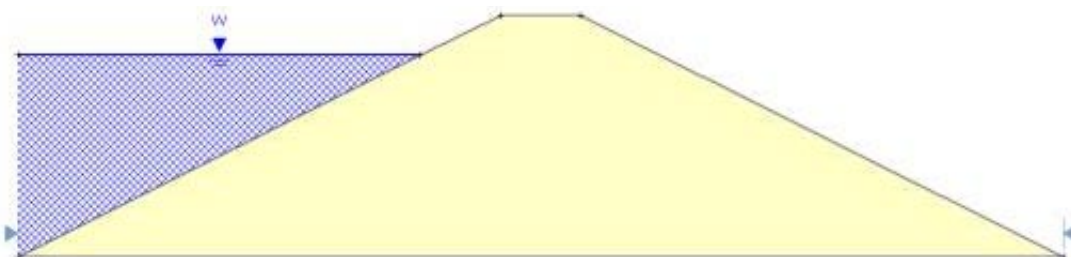


Figure 3. Sample problem: an isotropic earth dam

After creating the boundaries, users must switch to the Groundwater Analysis mode. In this mode they can create a finite element mesh of the model, apply the required set of boundary conditions, and define the hydraulic properties of the slope materials. Groundwater analysis in *Slide* uses the same powerful mesh generation technology that has proven itself well in *Phase<sup>2</sup>*, our finite element stress analysis program for geotechnical excavations.

Meshes can be generated with a single mouse click by selecting the Discretize and Mesh option on the toolbar (Figure 4). This option automatically creates a graded finite element mesh.



Figure 4. Mesh button in on Slide toolbar

Once the mesh is generated, users must proceed to set up the boundary conditions for the problem. This is done with the Set Boundary Conditions option. Selecting this option brings up the Boundary Conditions dialog shown in Figure 5. The dialog allows users to define boundary conditions for the model's boundaries or at any other node(s) of the mesh.

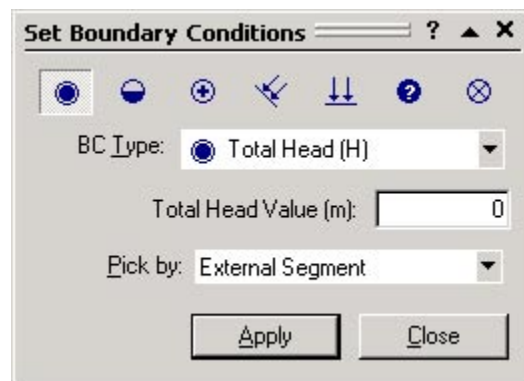


Figure 5. Dialog for setting boundary conditions in a Slide groundwater analysis

The following boundary conditions are available in Slide's groundwater module:







Symbol	Boundary condition	Units
	Total hydraulic head (H)	m (ft)
	Zero pressure boundary (P=0)	m (ft)
	Nodal flow rate	m <sup>3</sup> /sec (ft <sup>3</sup> /sec)
	Infiltration (Normal or vertical to the surface)	m/sec (ft/sec)
	Zero flow (Q=0)	
	Unknown boundary (p=0 or Q=0)	

Figure 6 below shows the mesh and applied boundary conditions for the sample dam model.

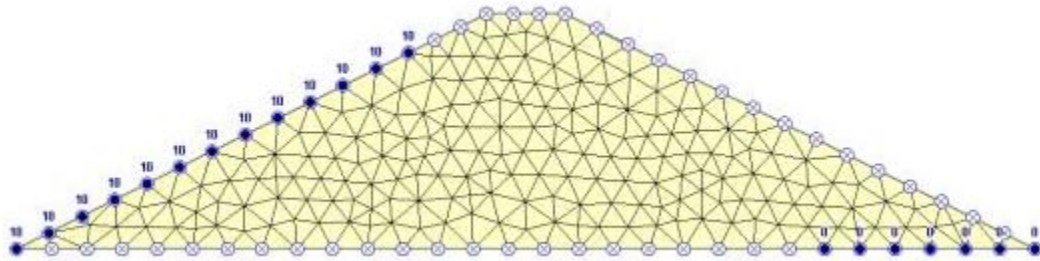


Figure 6. Mesh and boundary conditions for sample problem

To continue the analysis a hydraulic conductivity function has to be assigned to each material used in the model. A screen capture of the Hydraulic Properties dialog is shown on Figure 7. Users can choose from different closed-form equations (Van Genuchten, Fredlund & Xing, Brooks & Corey, Gardner) for hydraulic properties, or may define their own permeability functions.

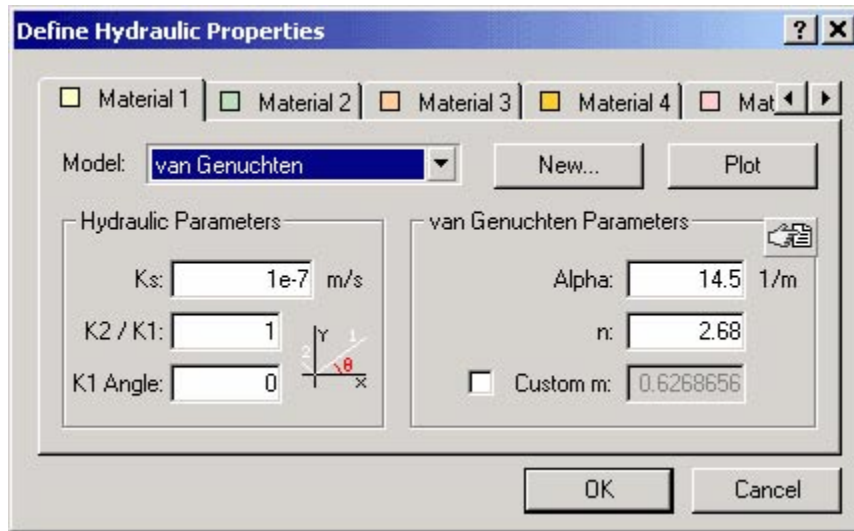


Figure 7. The Hydraulic Properties dialog in Slide's groundwater module

## Computing a groundwater analysis

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Although technically a separate program from Slide's slope stability engine, the groundwater analysis module can be run seamlessly from within *Slide*. As shown in Figure 8, it is invoked by simply clicking the Compute button in Groundwater mode. This arrangement allows users to run groundwater analyses independent of slope stability calculations.

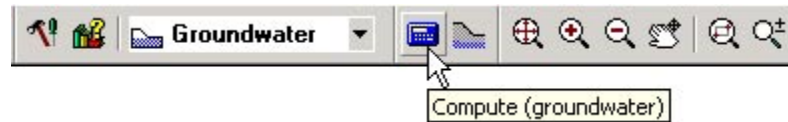


Figure 8. Selecting the Compute button while in Groundwater mode runs a groundwater analysis

After the groundwater analysis is completed, users can proceed with a slope stability analysis by switching to that mode on the toolbar.

## Interpreting groundwater results

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Users can view groundwater analysis results by selecting the Interpreter button while in Groundwater mode (Figure 9). This action calls up the Groundwater interpreter program.



Figure 9. The procedure for switching to the Groundwater Interpreter module

The primary means for interpreting data after a groundwater analysis is to view data contours superimposed onto a model. The Groundwater Interpreter program allows users to display contours of quantities such as heads and discharge velocities, obtained from the finite element analysis of a groundwater model. The data to be contoured is selected from a drop-down list on the toolbar (Figure 10).

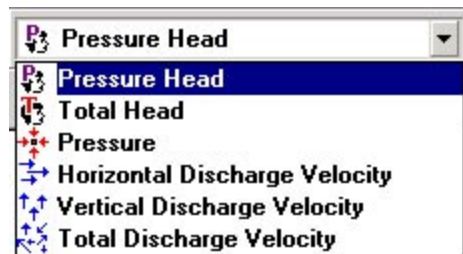


Figure 10. Drop-down list of quantities calculated in a Slide groundwater analysis

The Groundwater Interpreter functions just like the Interpreter in *Phase*<sup>2</sup>. Figure 11 below shows the pressure head contours calculated for the example dam model.

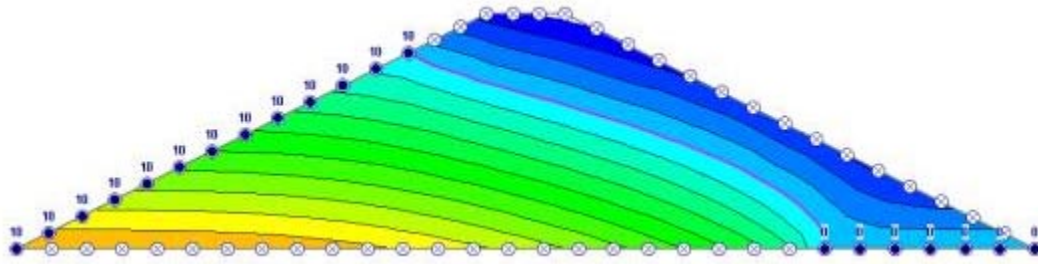


Figure 11. Pressure head contours

## Examples of groundwater analysis performed in *Slide*

The following are some groundwater analysis examples performed with *Slide*. Figures 12 and 13 below are examples of seepage within a layered slope (Rulan and Freeze, 1985).

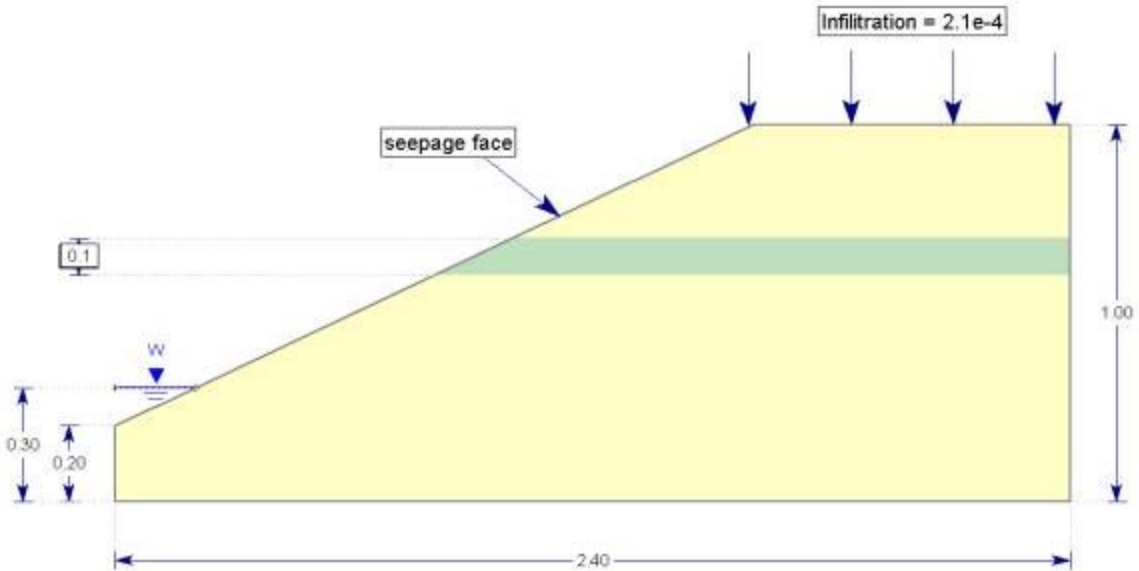


Figure 12. Geometry of the model

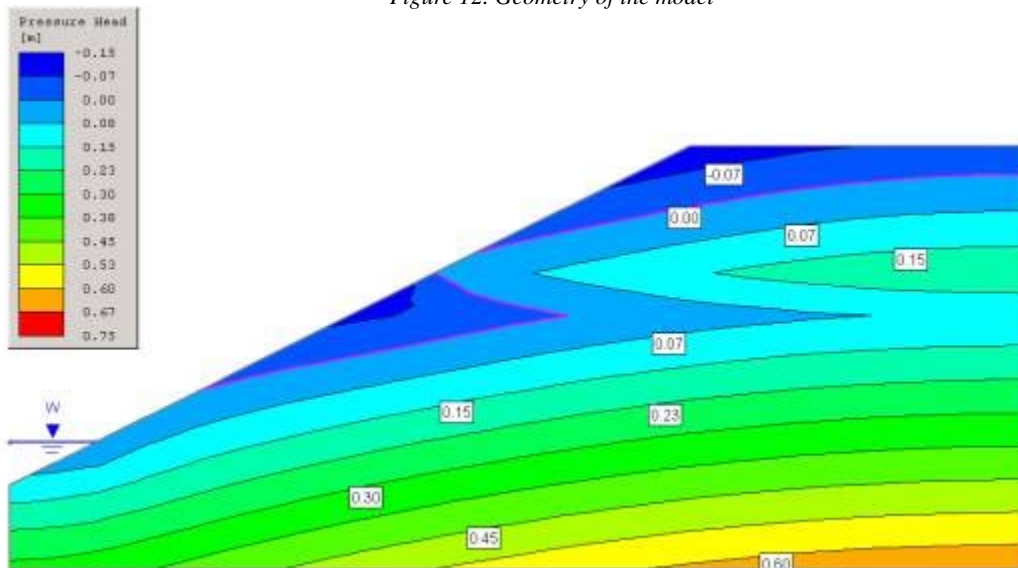


Figure 13. Distribution of pressure heads in the slope

Figures 14 and 15 below are examples of an anisotropic earth dam with a horizontal drain (Fredlund and Rahardjo, 1993).

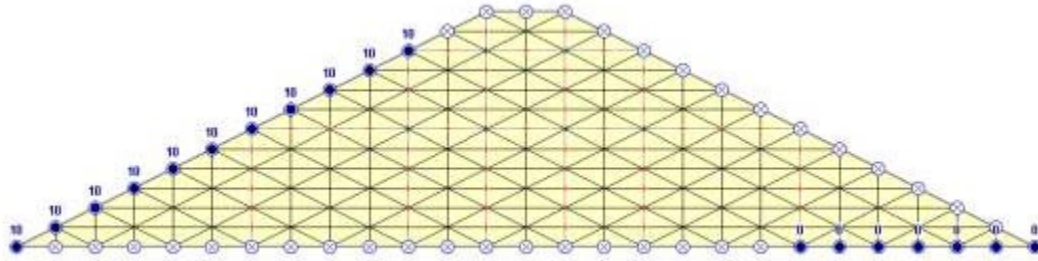


Figure 14. Mesh and boundary conditions for earth dam model

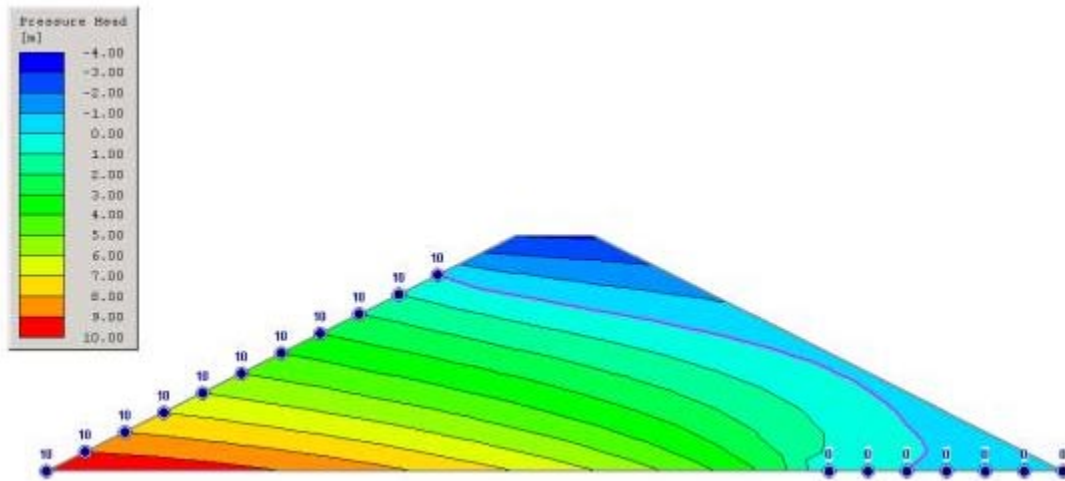


Figure 15. Pressure head distribution in dam

#### Reference:

1. Rulan, J.J. and R. A. Freeze (1985) Multiple seepage faces on layered slopes and their implications for slope stability analysis, *Can Geotech J.* **22** 347-356.
2. Fredlund, D.G. and H. Rahardjo (1993) *Soil Mechanics for Unsaturated Soils*, John Wiley