SLOPE/W Tutorial – Getting Started

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Introduction

This example is designed to assist new users with developing a basic SLOPE/W analysis. This example highlights the main components of a stability analysis, including the slope geometry, material properties, trial slip surfaces, and pore water pressures. The analysis will consider the factor of safety of a 2:1 slope with ponded water at the slope toe. For the optimal learning experience, new users should attempt to reproduce this analysis by starting with a completely new project. Doing so will increase one's understanding of how to use SLOPE/W for other, user-specific analyses.

Background

SLOPE/W uses the limit equilibrium approach to assess the stability of a defined geometry. The limit equilibrium method divides a potential sliding mass, defined by a trial slip surface, into vertical slices. An iterative solution is used to determine the factor by which the shear strength of all slices must be reduced such that the sliding mass is just at the point of static equilibrium (before failure occurs). This reduction factor is referred to as the factor of safety. Equilibrium can be assessed with respect to moment or force equilibrium. Thus, SLOPE/W computes two factors of safety; one with respect to overall moment equilibrium and one with respect to horizontal force equilibrium. Another iterative solution determines the interslice force factor (lambda; the ratio of the interslice shear and interslice normal forces) generating the same factor of safety for both moment and force equilibrium. (More information on the limit equilibrium method is provided in the *SLOPE/W Engineering Book*.)

Key components of a SLOPE/W analysis include the slope geometry, slip surfaces, and material properties. Regions define the slope geometry and stratigraphy, and may be drawn or imported from a DXF or DWG file. Regions are formed with points and lines, where a point is a geometric object in space with x-y coordinates, a line is a straight object with points at both ends, and a region is a closed polygon with a point at each of the vertices. Similar to defining regions, there are multiple methods available for creating trial slip surfaces, including the Entry and Exit, Grid and Radius, and

Block-Specified methods (Figure 1). The material properties describe the shear strength of a soil, and are generally defined by unit weight, cohesion, and friction angle. Several material models are available in SLOPE/W for defining the shear strength parameters.

Pore water pressures can have a substantial impact on slope stability. Thus, another important aspect of SLOPE/W analyses is the pore water pressure definition. Pore water pressures may be specified by piezometric lines, spatial functions, Ru and $\bar{B}$ coefficients, or values computed by a corresponding finite element analysis (e.g., SEEP/W).

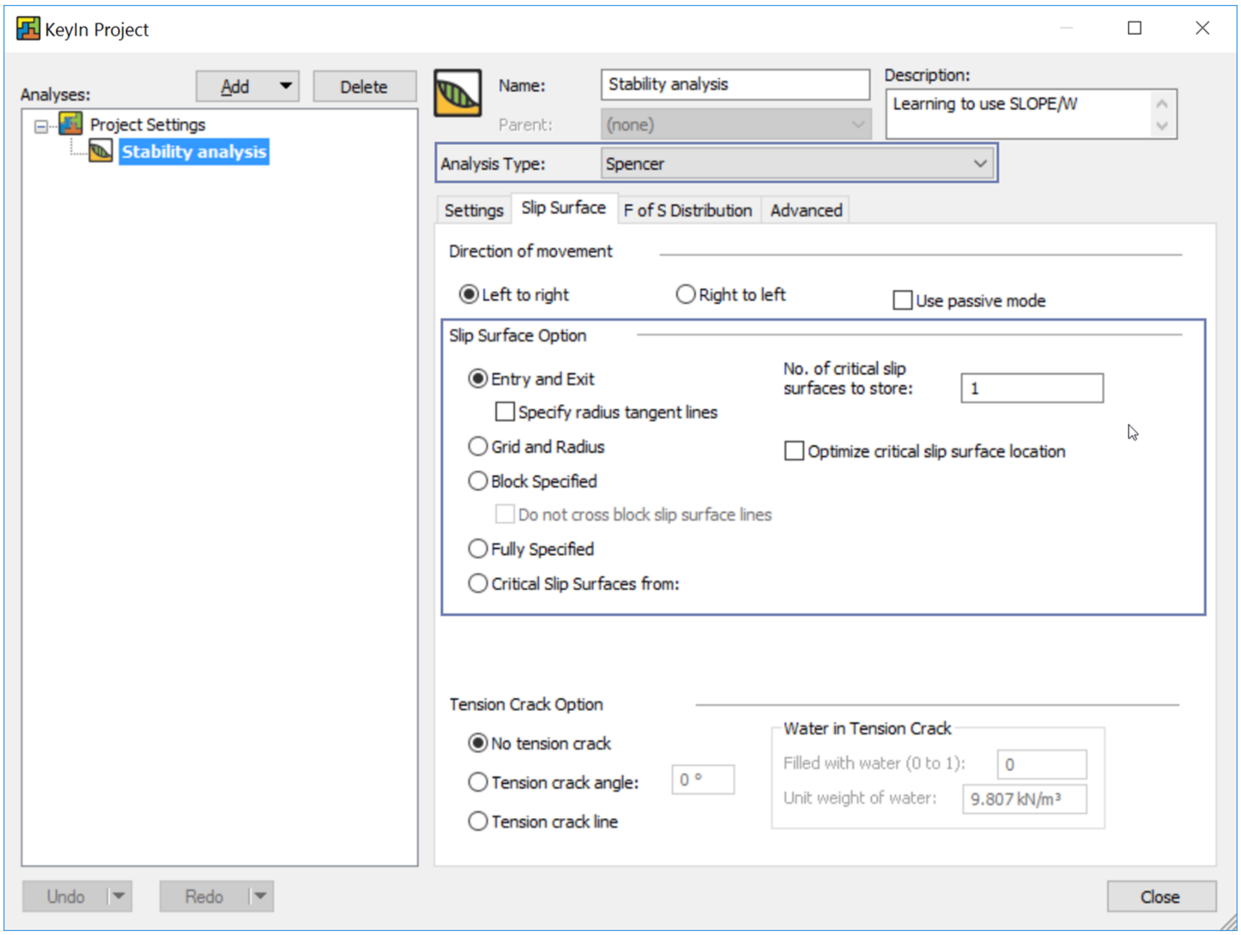

Figure 1: Analysis type and slip surface definition.

Numerical Simulation

A SLOPE/W analysis was created in the Define Analyses window, using the Spencer limit equilibrium formulation (Figure 1). In the Slip Surface tab, the Entry and Exit technique creates the trial slip surfaces with the direction of failure going from the left to right (Figure 1). Under the Settings tab, the Piezometric Line defines the pore water pressure conditions (Figure 2).

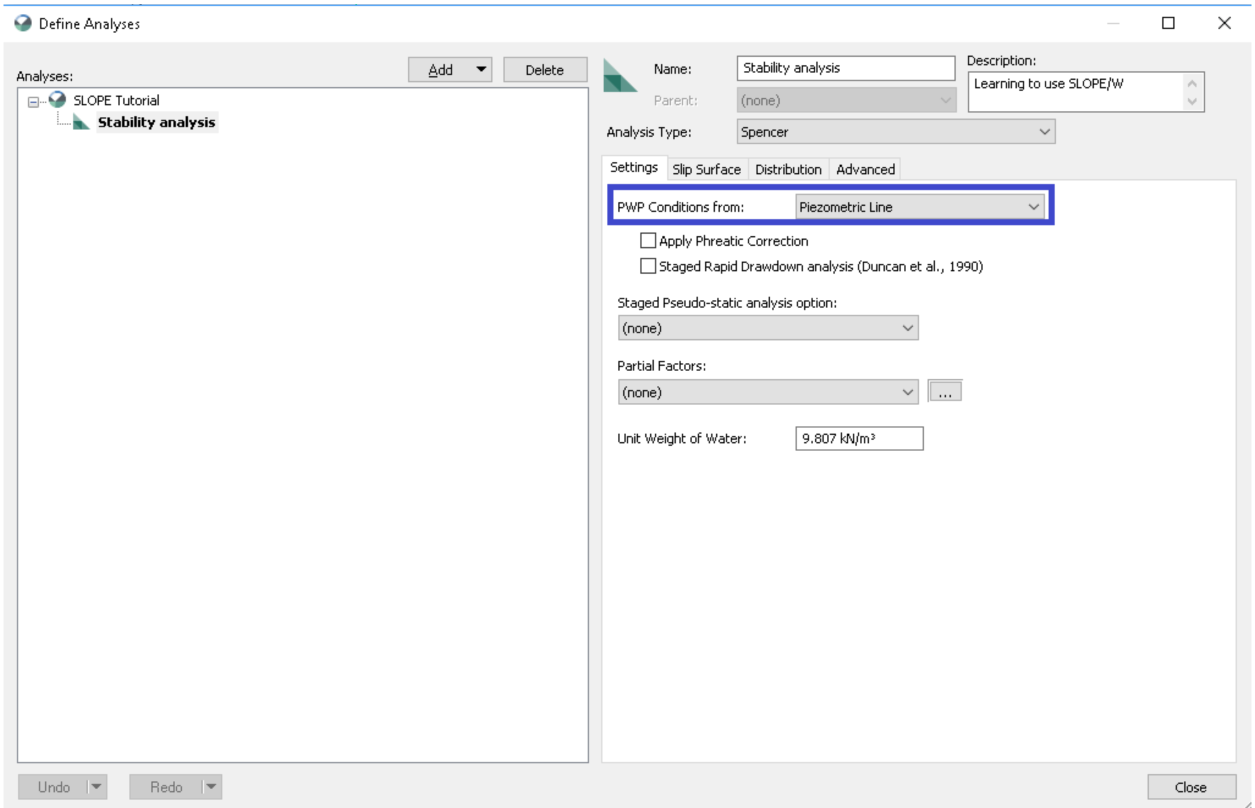

Figure 2: Pore-water pressure definition.

The modeled domain is comprised of two materials forming a 2:1 slope (Figure 3). Eight points define the two regions (Table 1), which can be entered in the Define Points window or drawn with the Snap-to-Grid option selected such that the point coordinates are at round numbers. The materials corresponding to the regions are defined in the Define Materials window with the Mohr-Colulomb material model. The parameter values, inputted in the Basic tab, are provided in Table 2. (Note: the parameters in the remaining tabs are not defined for this example.) Once the material definition is complete, the materials can be drawn onto the regions with the Draw Materials command. By default, SLOPE/W draws a green line to represent the ground surface after the materials are applied (Figure 4).

Table 1: Point coordinates defining the slope geometry.

Point Number	X (m)	Y (m)
1	0	14
2	10	14
3	20	9
4	0	9
5	30	4
6	40	4
7	40	0
8	0	0

Table 2: Material properties.

Material	Upper Layer	Lower Layer
Unit Weight	17 kN/m³	18 kN/m³
Cohesion	4 kPa	8 kPa
Friction Angle	20°	25°

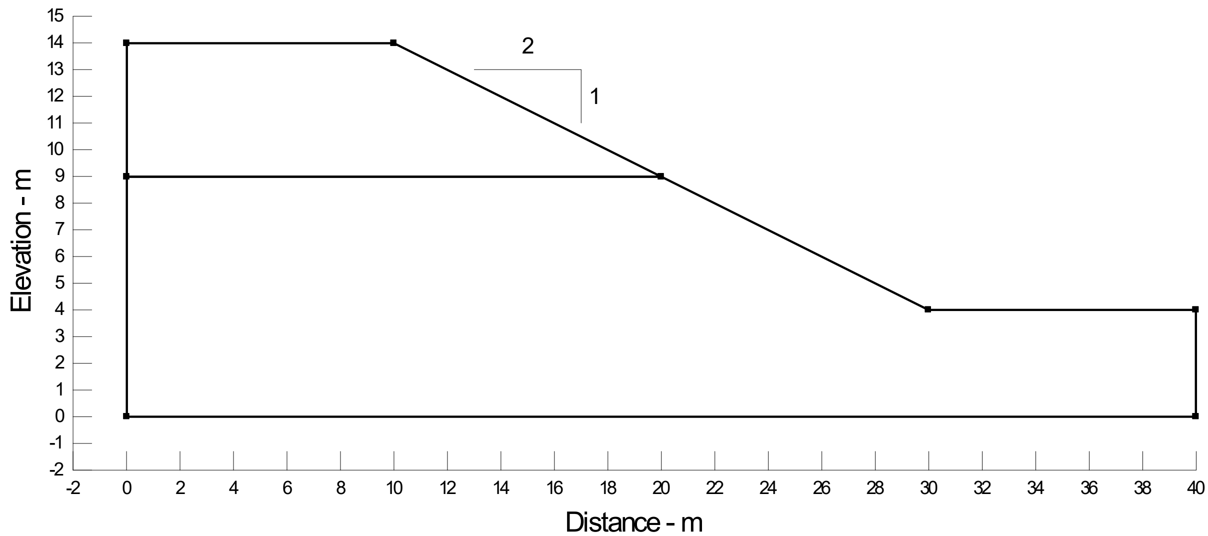

Figure 3. Slope geometry with two regions defined by eight points.

As indicated above, the pore water pressures in this example are defined by a piezometric line. Piezometric lines are composed of a series of x-y coordinates (Table 3). These coordinates can be created with the Draw Pore-Water Pressure command by clicking at desired locations, or may be entered in the Define Piezometric Lines window. A different piezometric line can be applied to each material; however, in this example, only one piezometric line is used (Figure 4).

Table 3: Coordinates defining the piezometric line.

X (m)	Y (m)
0	10
16	8
24	7
40	7

At the bottom of the slope, the defined piezometric line is above the ground surface. Consequently, there are positive pore water pressures or ponded water on the ground surface, indicated by the blue shaded region (Figure 4). The vectors drawn along the ground surface are a graphic reminder that the water weight is added to the weight of each slice in the analysis.

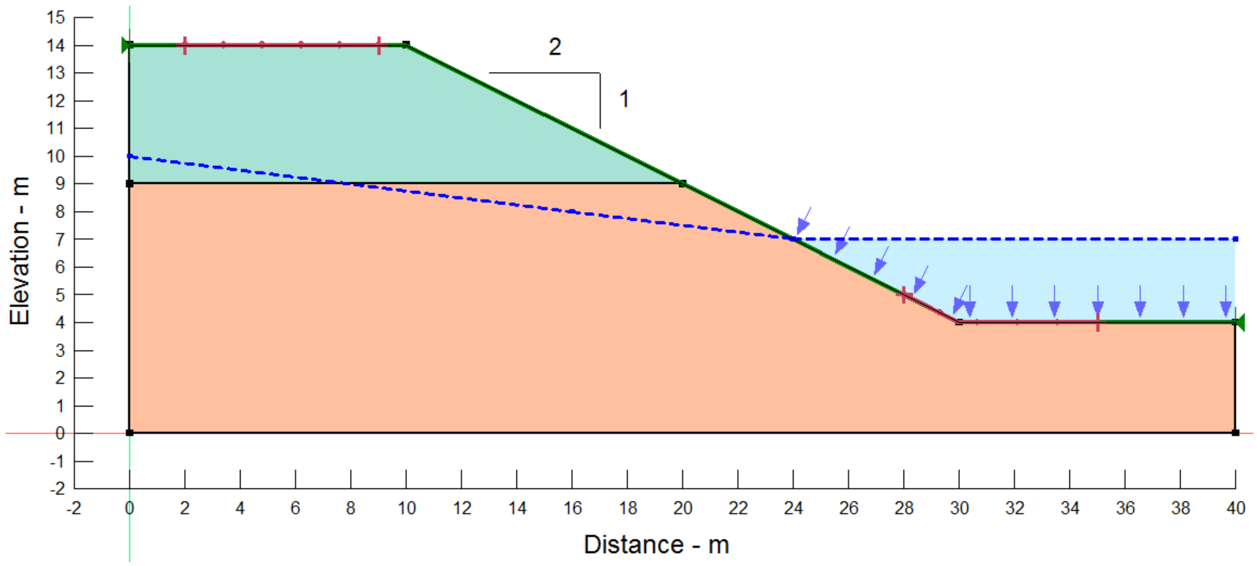

Figure 4. Problem configuration illustrating: (1) the materials applied to each region (orange and green areas); (2) the ground surface (green line); (3) the piezometric line (dashed blue line); and (4) the slip surface entry and exit points (red lines).

The trial slip surfaces are then created with the Entry and Exit method. The sections of the ground surface line where the slip surface must enter and exit are either drawn (in the Draw Slip Surfaces command) or entered into the Define Slip Surface Entry and Exit Range window (Figure 5). In this example, the Entry and Exit segments have 5 increments, making a total of 6 points on each segment, and the radius has 10 increments making a total of 11 points. Thus, the total number of trial slip surfaces is 396 (6x6x11). The slip surface definition is indicated by the red lines along the ground surface, as illustrated in Figure 4.

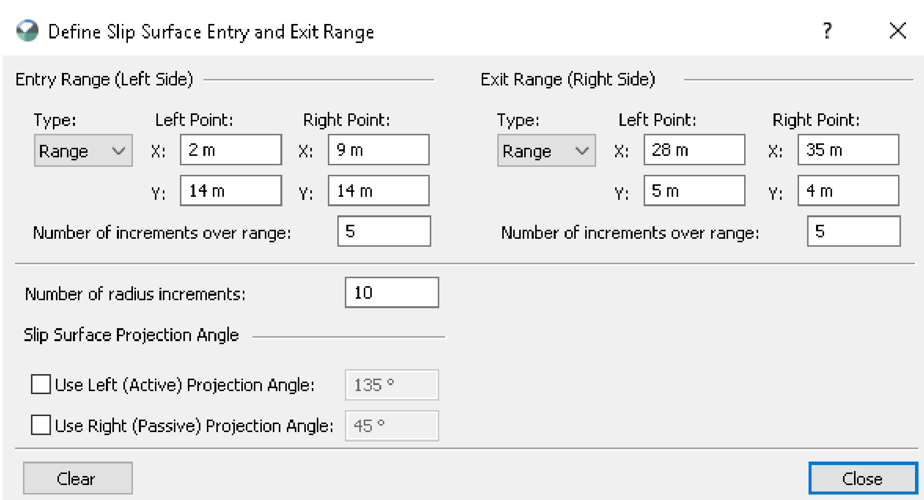

Figure 5. Entry and Exit slip surface dialog box.

Results and Discussion

The factor of safety for each of the 396 trial slip surfaces is computed when the SLOPE/W analysis solves. The slip surface with the lowest factor of safety, or the critical slip surface, is displayed in the Results view (Figure 6). This represents the potential sliding mass most likely to exhibit failure based on the inputted parameters. The factor by which the shear strength of each slice was reduced for the critical slip surface is 1.370.

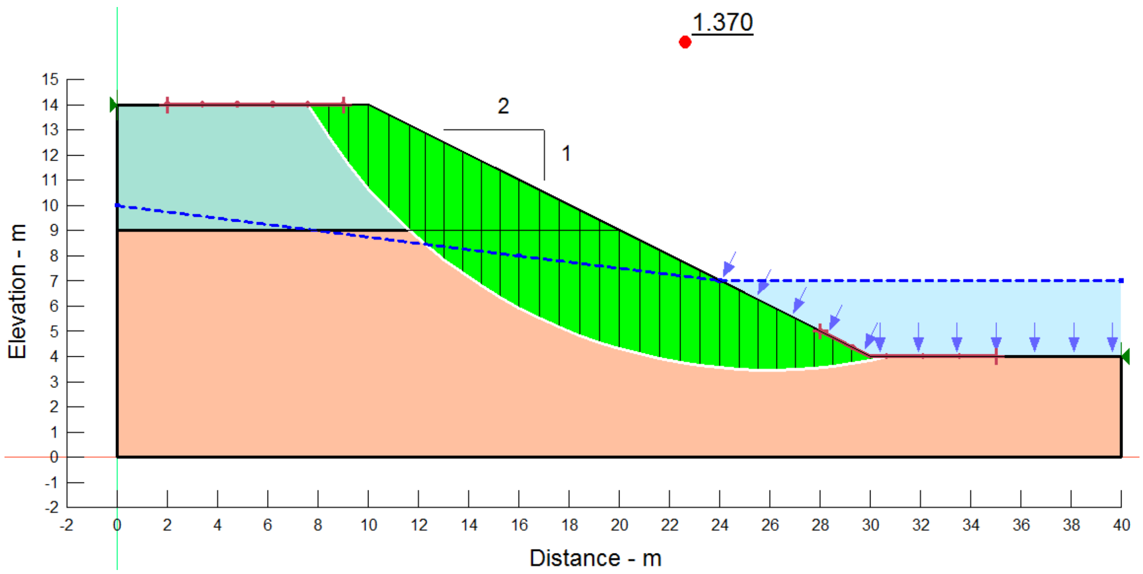

Figure 6. Resulting factor of safety for the SLOPE/W analysis.

The factor of safety of each trial slip surface can be drawn in Results view with a Slip Surface Color Map (Figure 7). The color map helps to visualize how many of the trial slip surfaces have a factor of safety close to the critical value, and the most likely shape of the failure zone.

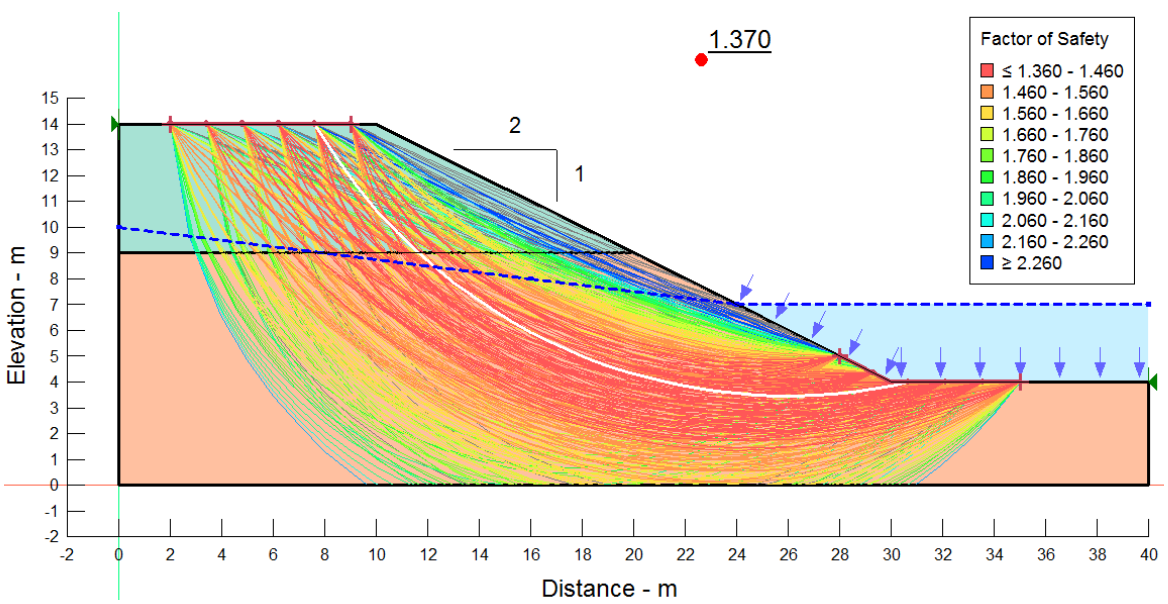

Figure 7: Color map indicating the factor of safety for each trial slip surface, and the critical slip surface in white.

For each trial slip surface, the factor of safety is computed with regards to both force and moment equilibrium over a range of lambda values (interslice force ratios). The results of these calculations produce a factor of safety versus lambda plot for each slip surface (Figure 8). The intersection of the red and blue plots provides the converged factor of safety for a given slip surface satisfying both force and moment equilibrium (Figure 8). The intersection point also indicates the lambda value resulting in a converged solution. The lambda value providing a converged factor of safety for the critical slip surface is 0.28 in this example – thus, the interslice shear is 0.28 x the interslice normal for all slices in the slip surface.

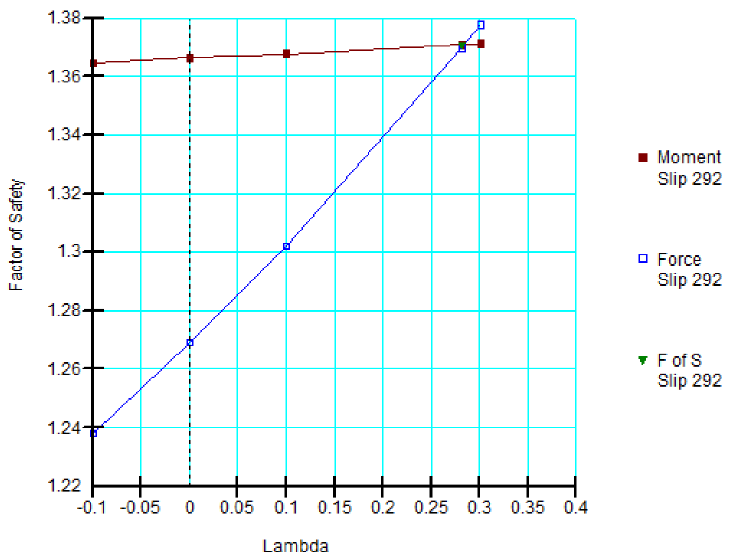

Figure 8. Factor of safety versus lambda plot for the critical slip surface.

Early limit equilibrium formulations (before personal computers), considered the factor of safety with respect to either force or moment equilibrium (not both), and ignored interslice shear (i.e., lambda of 0). The Bishop method satisfied only moment equilibrium. Thus, the Bishop factor of safety is where the moment plot intersects the y-axis (lambda = 0). For the critical slip surface, the Bishop factor of safety is 1.366 (Figure 8). Conversely, the Janbu method satisfies only force equilibrium but also ignores the interslice shear. The Janbu factor of safety is where the force plot intersects the y-axis (1.269 for the critical slip surface; Figure 8). These methods are available in SLOPE/W; however, the newer methods provided in SLOPE/W (e.g., Morgenstern and Price, Spencer methods) are more rigorous as they satisfy both force and moment equilibrium.

In addition to drawing the Slip Surface Color Map and considering the factor of safety versus lambda plot, there are many other ways to examine SLOPE/W results. Two common techniques are to review the slice details in the View Slice Information command, and to graph various parameters along the slip surface in the Draw Graph window. The View Slice Information command makes it possible to look at the details for each slice of a trial slip surface (Figure 9). The free body diagram on the left, gives an indication as to where the forces act on the slice. To the right of the free body diagram, the force polygon provides an indication of the slice force equilibrium – a closed polygon indicates the slice is in force equilibrium.

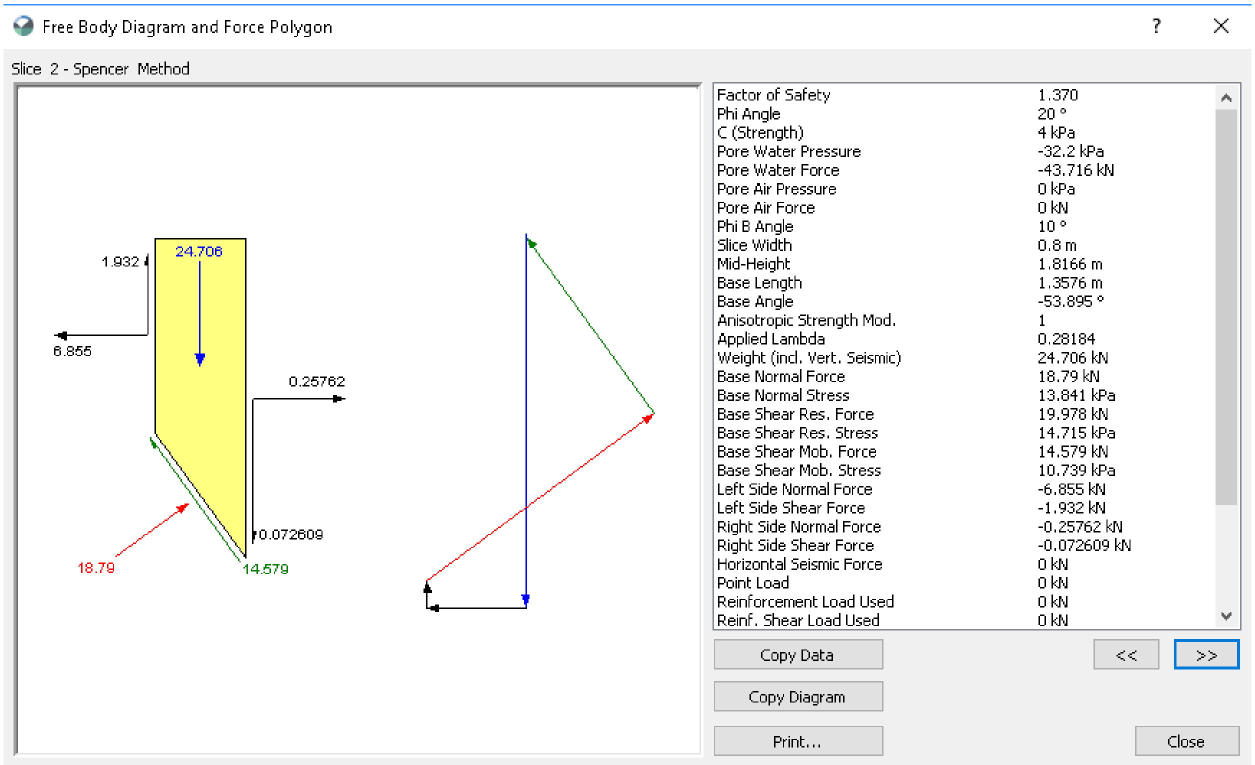

Figure 9. Slice force details and free body diagram.

Variables can be plotted over slice number in the Draw Graph window. Figure 10 compares the soil strength contributed by cohesion with the strength from friction, along the slip surface. The cohesive strength is not a function of the normal stress at the slice base, so it is constant within a material. However, frictional strength is a function of the normal stress at the slice base and, therefore, it varies by slice (Figure 10). A plot of pore water pressure versus slice number demonstrates that water pressure is negative for slices above the water table (Figure 11). Finally, shear resistance and shear mobilized can be plotted along the slip surface (Figure 12). Comparison of these plots shows that the shear resistance is multiplied by the same ratio to obtain the shear mobilized at each slice. This ratio represents the factor of safety.

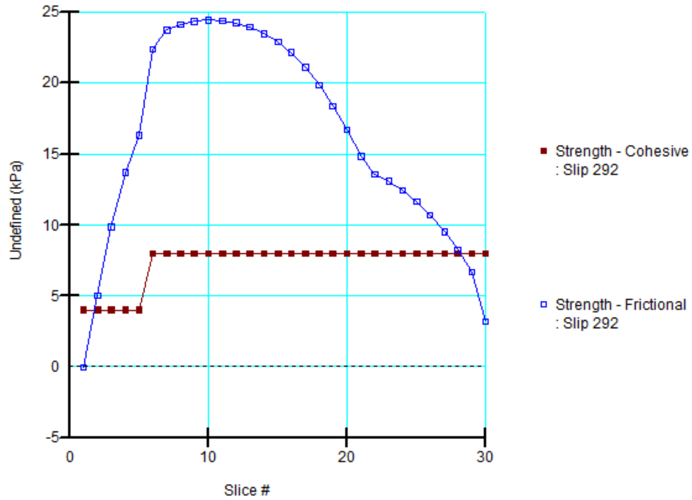

Figure 10. Frictional (blue) and cohesive (red) strength along the critical slip surface.

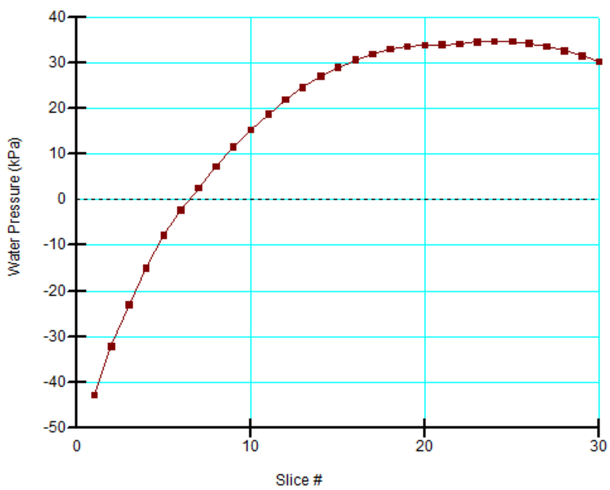

Figure 11. Pore-water pressure distribution along the critical slip surface.

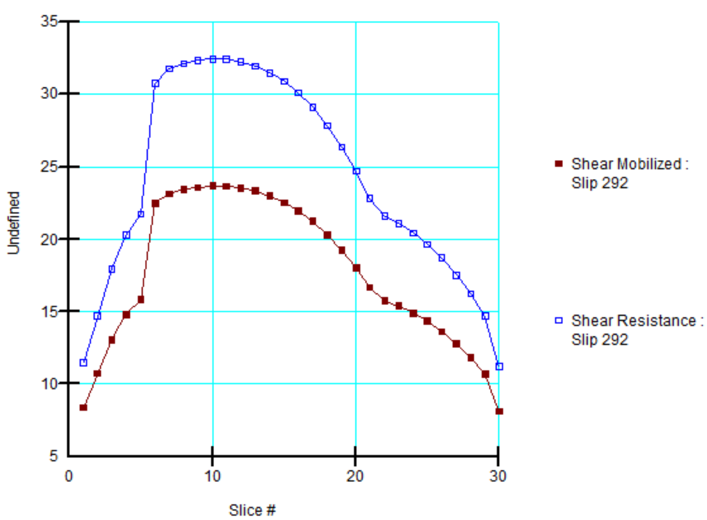

Figure 12. Comparison of mobilized and resisting shear along the critical slip surface.

Summary

SLOPE/W uses the limit equilibrium formulation to determine the factor of safety for a given slope geometry, applied materials and pore water pressures, and the defined slip surfaces. The slip surface associated with the lowest factor of safety is the critical slip surface. Multiple methods are available in SLOPE/W for interpreting the results, and can confirm that the defined soil properties are used as intended when computing the factor of safety. Replicating this example in a separate project file, will increase new users' fundamental understanding of SLOPE/W and ability to conduct future stability analyses.