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GeoStudio Example File
Grid and Radius

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Introduction

In early limit equilibrium slope stability analysis, slip surfaces were defined by the Grid and Radius method. Even though new methods have been developed, the Grid and Radius method is still used by many. This example illustrates and discusses the use of a Grid and Radius method of specifying trial slip surfaces. In addition, this example highlights specific analyses where the Grid and Radius method is beneficial, and cases where obtaining a minimum factor of safety at the center of the grid is not possible.

Background

The limit equilibrium method (also known as the method of slices) for evaluating slope stability determines the slip surface with the lowest factor of safety (i.e., the critical slip surface) by computing the factor of safety for many trial slip surfaces. When this method was first developed, the factor of safety calculations were done by hand and, to keep the mathematics manageable, the trial slip surfaces were defined as the arc of a circle. Consequently, the circle radius and central coordinate were required. This led to the idea of using a grid of circle-centers and a range of radii to create many trial slip surfaces – referred to as the Grid and Radius method.

When using the Grid and Radius method, the computed critical slip surface should fall close to the middle of the grid, as this indicates that sufficient trial slip surfaces were analyzed to capture the one with the lowest factor of safety. Furthermore, a slope stability drawing with the lowest factor of safety within the grid was the only option available to graphically portray that many trial slips were analyzed and that the critical slip surface was found. This approach has become deeply entrenched in slope stability analyses and though it does have some disadvantages, it is still used by many (in spite of other available methods).

A typical Grid and Radius slope stability analysis is illustrated in Figure 1. The grid and radius definition utilizes boxes to define the coordinates for the circle centers (i.e., the grid intersection points) and the lines tangent to the circles (which establish the radii). The grid box is defined by three points: the upper left, the lower left, and the lower right corners. The tangent lines are defined by the corners of the radius box (see the Define Slip Surface dialog in Figure 2). The user can control the number of increments in both the x and y directions in the grid box and the number of radii increments.

SLOPE/W uses the x-y coordinates at the ends of each radius line to compute the equation of a straight line in space. Knowing the equation of the line and the x-y coordinates of a circle center, it is possible to compute the perpendicular distance between the line and the circle center. The perpendicular distance becomes the radius for the trial slip circle.

In Figure 1, there are a total of 36 circle centers (6 x 6) and six radii lines, resulting in 216 trial slip surfaces to be analyzed. An example circle generated by the Grid and Radius method is shown. The trial slip surface is created where the circle cuts through the ground.

GeoStudio Example - Grid and Radius

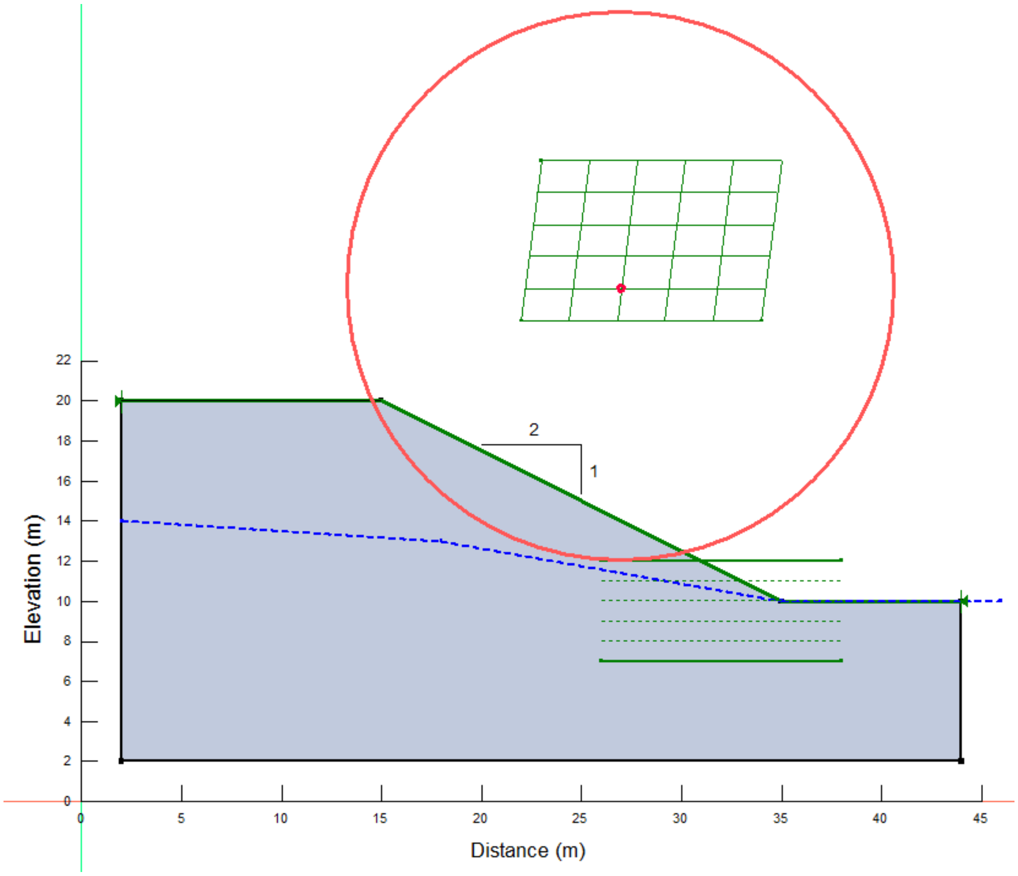

Figure 1. Grid and radius slip surface configuration and an example slip surface circle, which is tangent to the radius lines and is centered at the marked grid intersection point.

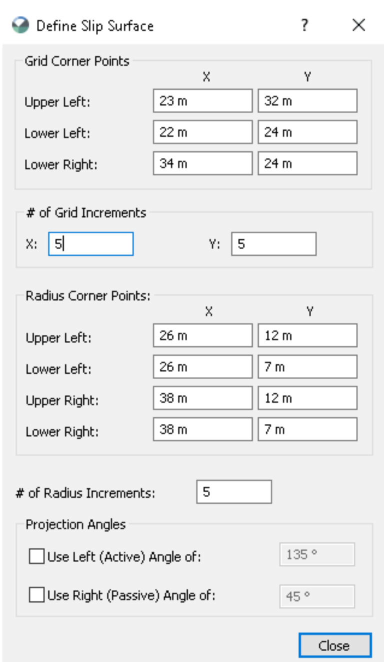

Figure 2. Define Slip Surface (Grid and Radius) dialog box.

GeoStudio Example - Grid and Radius

The radius box does not need to a perfect rectangle. It can have any quadrilateral shape, as illustrated in Figure 3. The radius box may also be collapsed into a series of vertical points when the upper corners have the same x-y coordinate and the bottom corners have the same coordinate (Figure 4). In the Draw Slip Surface Radius mode, this can be defined by clicking at the top point once, then twice at the bottom point, and then once again at the top point. Finally, the radius box can be collapsed to a single point by making the x-y coordinates of all four corners the same. In the Draw Slip Surface Radius mode, this is done by clicking at the same point four times.

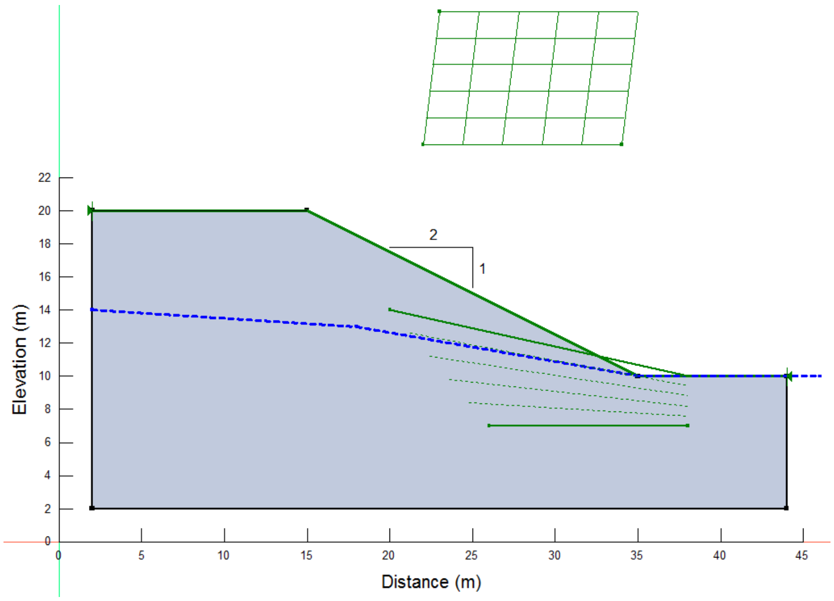

Figure 3. Radius lines as a general quadrilateral.

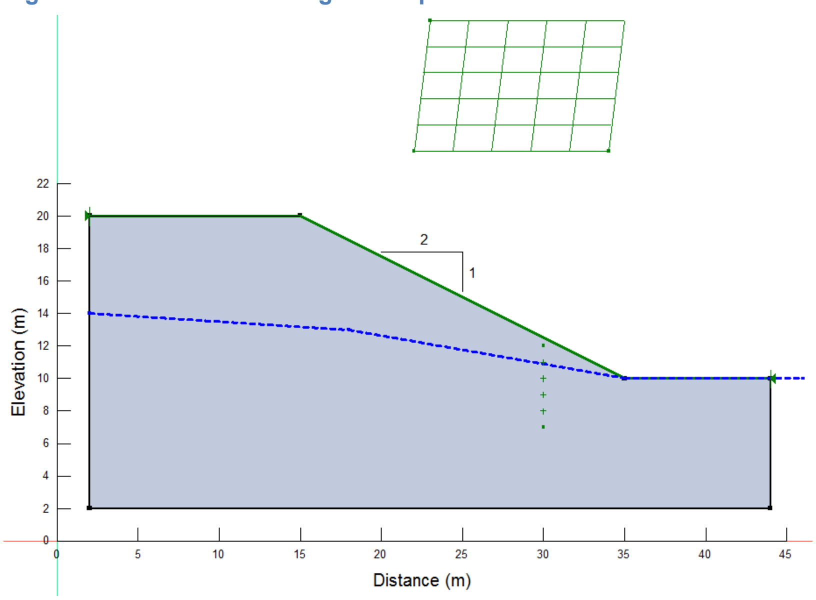

Figure 4. All slip surfaces passing through a series of vertical points.

The grid box can also be altered for specific purposes. When the lower two corners of the box have the same x-y coordinate, the circle centers are along a line. When the three grid corners all have the same x-y coordinate, a single circle center is considered. A single circle center and single radius point allows for one single slip surface to be analyzed, which can be very useful for verification and testing purposes. For example, comparison of analysis results to assess the influence of a particular parameter on factor of safety is easier when considering only one slip surface.

At the outset of an analysis, it may be difficult to know how large to make and where to place the grid, as it is difficult to visualize where all trial slips surfaces will be located with this method. Consequently, the tendency is to make the grid much too large, such that the grid dominates the analysis. Also, in the case of long, relatively flat slopes, the radius required to create realistic slip surfaces tends to be very large. Consequently, the grid is far away from the actual slope geometry so attempting to show both the geometry and the grid on the same drawing may limit the ability to show the stability analysis details.

Numerical Simulation

The 2:1 slope illustrated in Figure 1 is used as the basis for the numerical simulation. There are four analyses in the Project file (Figure 5). The first uses the Grid and Radius options shown in Figures 1 and 2. Analyses 2 and 3 both have the same grid positioning but the radius definition varies. In the second analysis, the radius box is shifted horizontally to the left (Figure 6). The radius box is collapsed to a single point at the toe of the slope in the third analysis (Figure 7). The grid and radius definition in Analysis 4 is the same as Analysis 1; however, the materials are altered to consider purely frictional stability conditions.

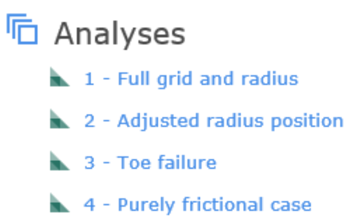

Figure 5. Analysis Tree for the project.

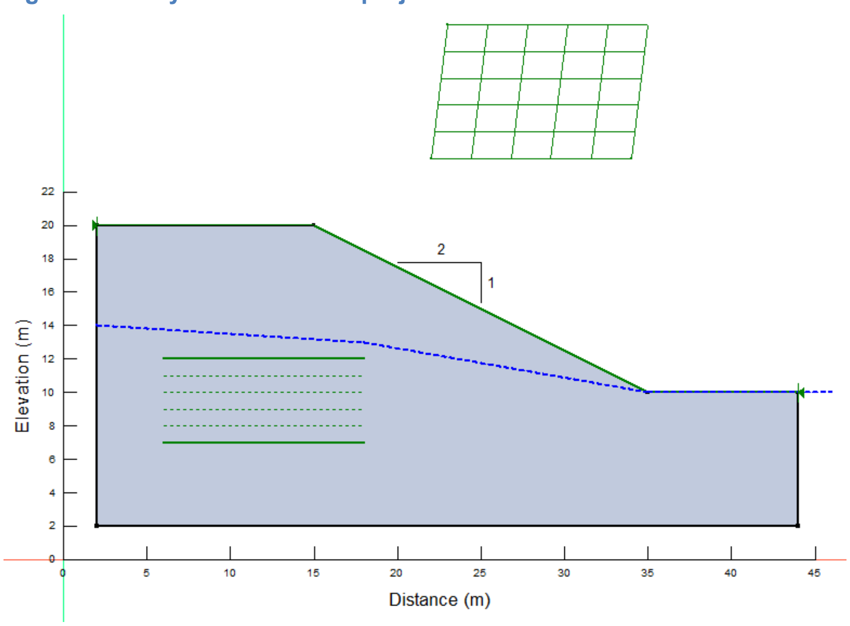

Figure 6: Shifted radius lines in Analysis 2.

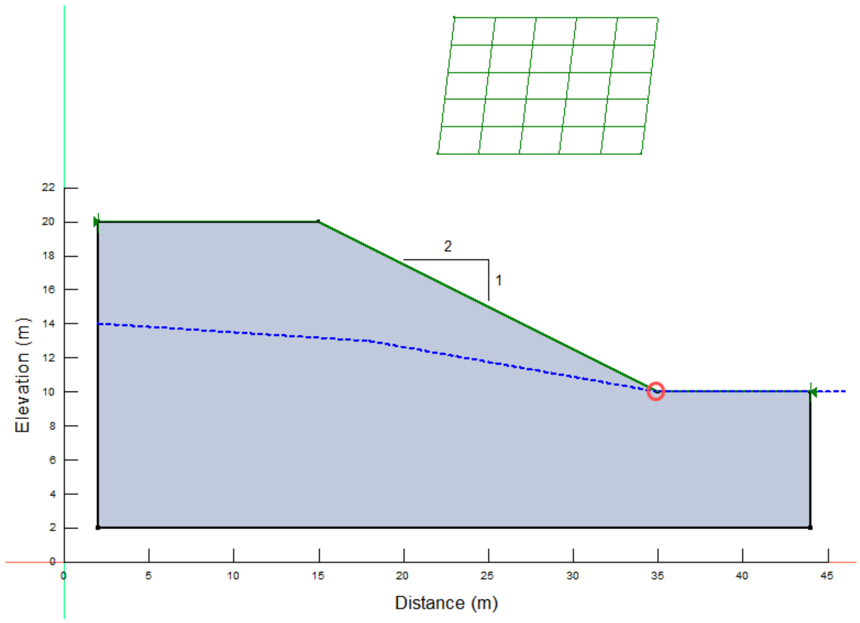

Figure 7: Single radius point at the toe of slope in Analysis 3.

The pore-water pressures are the same for all analyses, and are defined by a piezometric line. All analyses use the Mohr-Coulomb material model. The same material is applied to the slope in the first three analyses. This material has a unit weight of 20 kN/m^3, cohesion of 10 kPa, and the friction angle is 26°. The material is Analysis 4 has all the same properties, except the cohesion is set to 0 kPa such that the strength of the material is purely frictional.

Results and Discussion

In a Grid and Radius stability analysis, the factor of safety of the trial slip surfaces (corresponding to the grid intersection points) are used to create contours over the grid. In Analysis 1, the minimum factor of safety is 1.541 and is within the central part of the grid (Figure 8). This is the ideal position for the critical slip surface as one would generally assume that the trial slip surfaces captured the lowest factor of safety in this case.

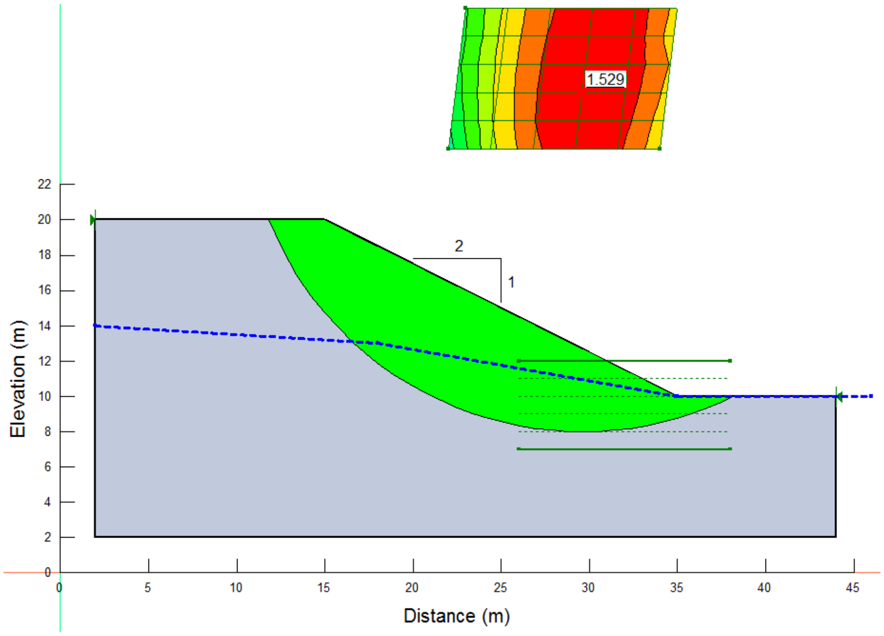

Figure 8: Factor of safety contours for Analysis 1.

The results from Analysis 2 are identical to those from Analysis 1 (Figure 9). Even though the radius lines were shifted horizontally, the end points generated the same equations for the tangent lines. These equations do not terminate at the specified end points but are continuous in space. Thus, the trial slip surfaces were exactly the same in Analysis 2.

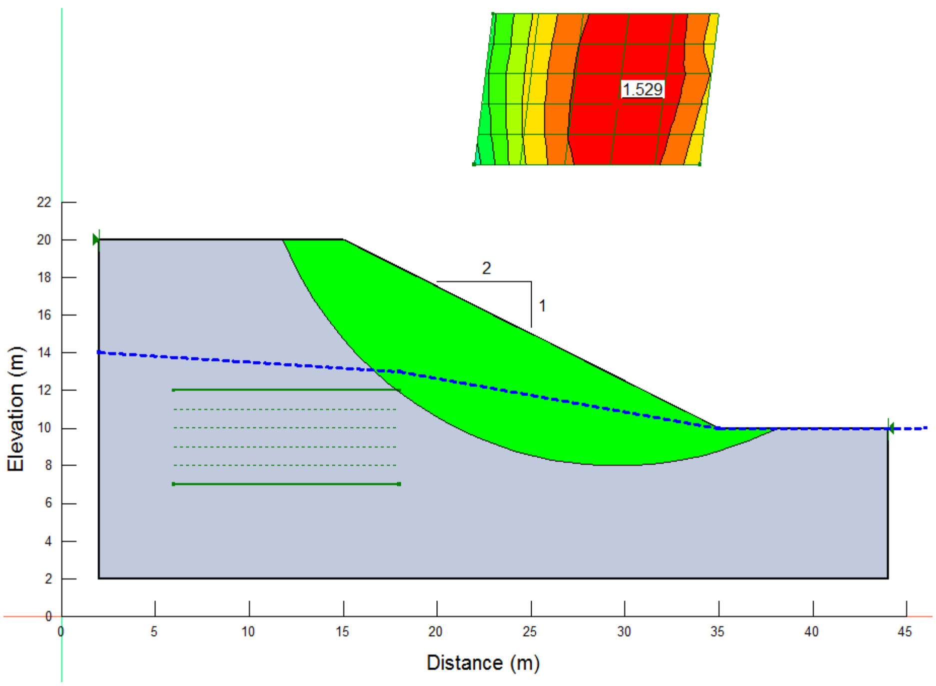

Figure 9. Analysis 2 results with the radius lines shifted to the left.

When the radius box was collapsed to a single point at the slope toe in Analysis 3, all of the trial slip surfaces went through this point (Figure 10). Similar to Analyses 1 and 2, the central positioning of the minimum factor of safety within the grid was ideal.

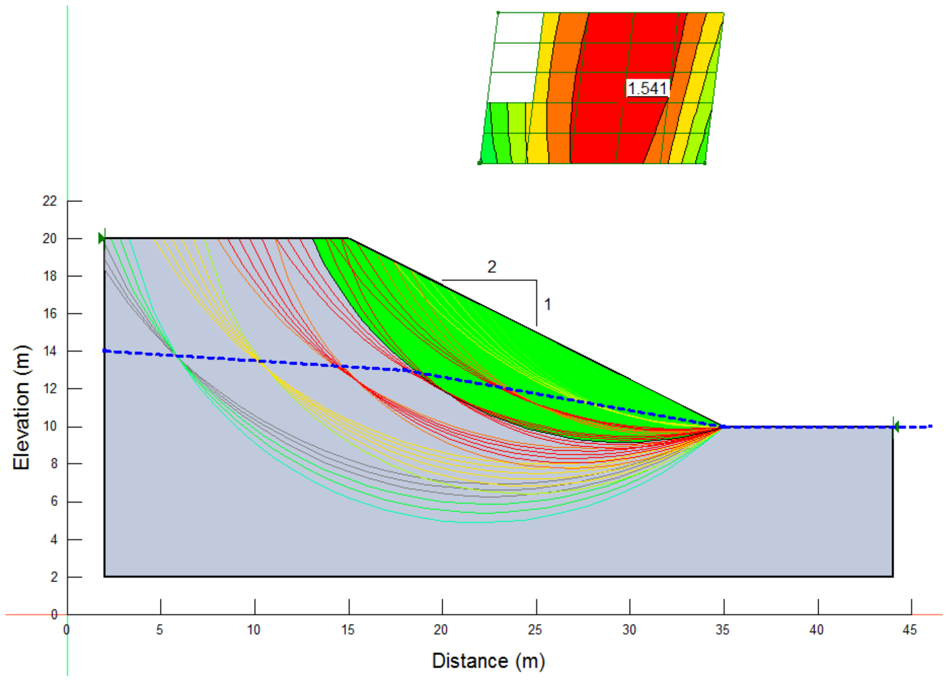

Figure 10. Analysis 3 results with all slip surfaces slips passing through a point.

Unfortunately, there are scenarios where it is difficult to obtain a minimum factor of safety positioned in the center of the grid. In the case of a soil with negligible cohesion (strength is purely frictional) as in Analysis 4, it is not possible have the minimum factor of safety in the middle of the grid (Figure 11). The minimum factor of safety will likely be along the outer edge, even if the grid is moved further to the right. When cohesion is zero, the solution tends towards the infinite slope case; that is, the critical slip is shallow and wants to be parallel to the slope surface. In mathematical terms, the radius tends towards infinity. Thus, material properties influence the position of the minimum factor of safety within the grid.

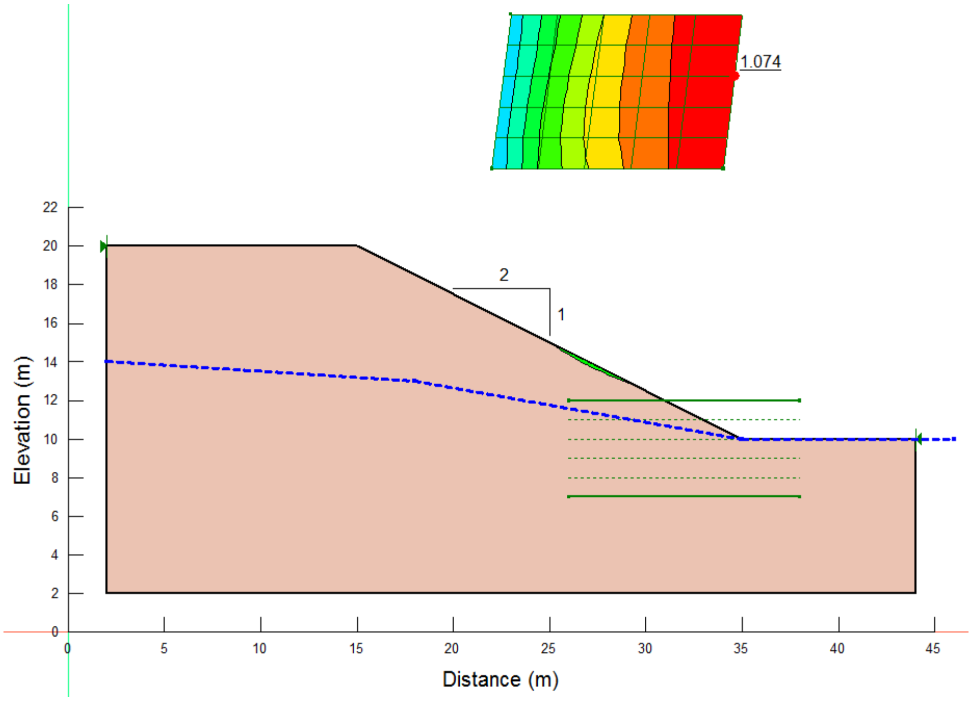

Figure 11. Analysis 4 results for purely frictional soil (φ > zero, c = zero).

A similar situation can occur for the purely undrained case, when the friction angle is zero and the undrained strength is constant with depth. In this case, the critical slip surface tends to go as deep as possible and the minimum factor of safety will be on the lower edge of the grid. This situation can be avoided by increasing the undrained strength with depth.

Summary

The historical Grid and Radius method of specifying trial slip surfaces in a stability analysis remains an option in SLOPE/W. While it is useful for special situations, generally there are better options for establishing the trial slip surfaces in SLOPE/W (e.g., the Entry-Exit method). For example, it may be difficult to determine the appropriate grid placement and size when setting up an analysis. In addition, there are cases where it is not possible to have the minimum factor of safety centrally positioned in the grid. The position of the critical slip surface is a function of the shear strength parameters applied to the slope. This concept is discussed in more detail in another SLOPE/W example file (*Critical Slip Surface Position*).