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GeoStudio Example File
Slip Surface Optimization

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Introduction

Traditionally, trial slip surfaces are described by a defined geometric shape; for example, the arc of a circle. However, recent studies have explored the possibility of incrementally altering portions of the slip surface to improve limit equilibrium results (Greco, 1996; Malkawi et al., 2001). A variation of the published techniques is available in SLOPE/W, referred to as slip surface optimization. This example outlines the SLOPE/W optimization procedure, compares optimized and non-optimized trial slip surfaces, and provides guidelines on using optimization.

Background

Before the optimization process begins, one of the traditional methods (e.g., Entry and Exit) is used to determine the initial shape of the critical slip surface. Thus, both the slip surface definition and optimization options must be selected (Figure 1). The optimization process then starts by dividing this critical slip surface into a number of straight line segments, similar to a Fully Specified slip surface. Next, the end points of the line segments are individually modified to evaluate the potential for a lower factor of safety. The point where the slip surface enters the ground surface is moved backward and forward randomly along the ground surface until the lowest factor of safety is found. Adjustments are then made to the next point along the slip surface until, again, the lowest factor of safety is found. This process is repeated for all the points along the slip surface.

Once all the points are adjusted to produce the lowest factor of safety, the longest slip surface line segment is subdivided into two parts with a new point inserted in the middle. All the points are individually adjusted again, as described above, and another new point is inserted in the middle of the longest line segment. This process is repeated until the change in the factor of safety is within a specified tolerance or when the process reaches the specified limits (maximum number of optimization trials and the number of line segments), as defined in the Optimization Settings (Figure 2). Thus, slip surface optimization is an iterative procedure.

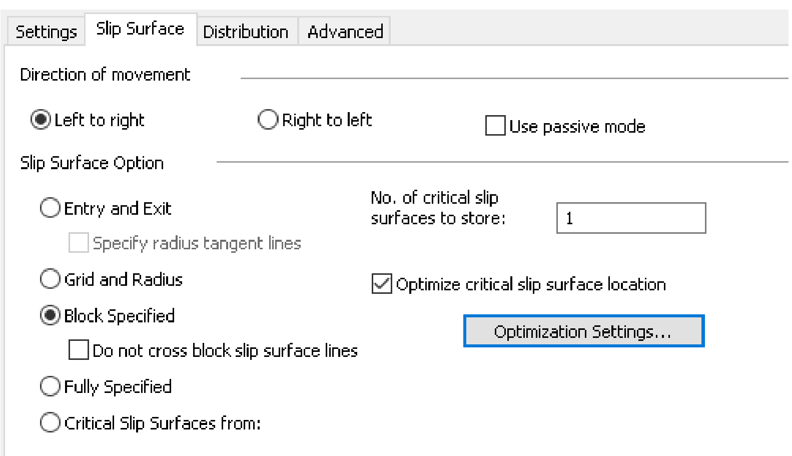

Figure 1. Option to optimize the critical slip surface location.

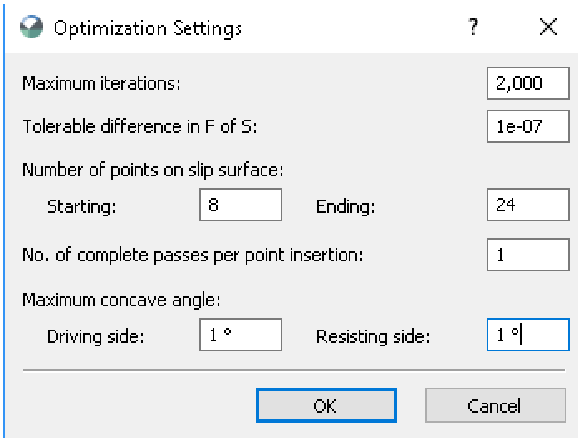

Figure 2. Optimization settings.

A key element of the optimization procedure is the technique for adjusting the end points of the line segments. SLOPE/W moves the points within an elliptical search area using a random procedure based on the Monte Carlo method (Figure 3). In general, the points move outwards from their original location in an elliptical fashion.

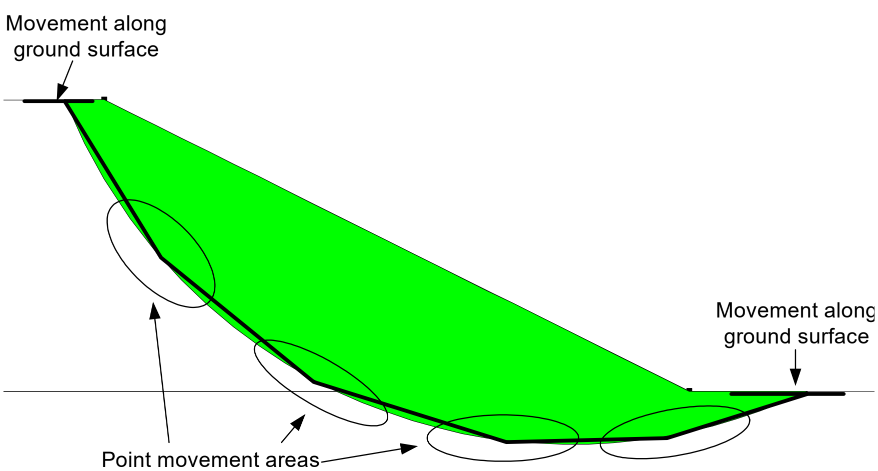

Figure 3. Movement areas of each point in the optimization procedure.

Numerical Simulation

The project file contains four Morgenstern and Price limit equilibrium analyses (Figure 4), with the same pore water pressure definition and materials (as illustrated in Figure 5). The pore water pressures are defined with a piezometric line (Figure 5). The Mohr-Coulomb material model is used for both materials, with a unit weight of 18 kN/m^3. The foundation soil is slightly weaker as it has negligible cohesion and a lower friction angle than the overlying embankment. The first two analyses use the Entry and Exit slip surface option, while the last two have Block Specified slip surfaces. The second Entry and Exit analysis, and second Block Specified analysis, include optimization while the two other analyses do not. Thus, the critical slip surface locations from Analysis 1a and 2a are optimized in Analysis 1b and 2b, respectively. The optimization settings are provided in Figure 2.

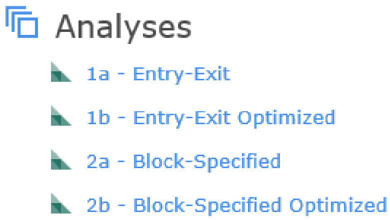

Figure 4: Analysis tree.

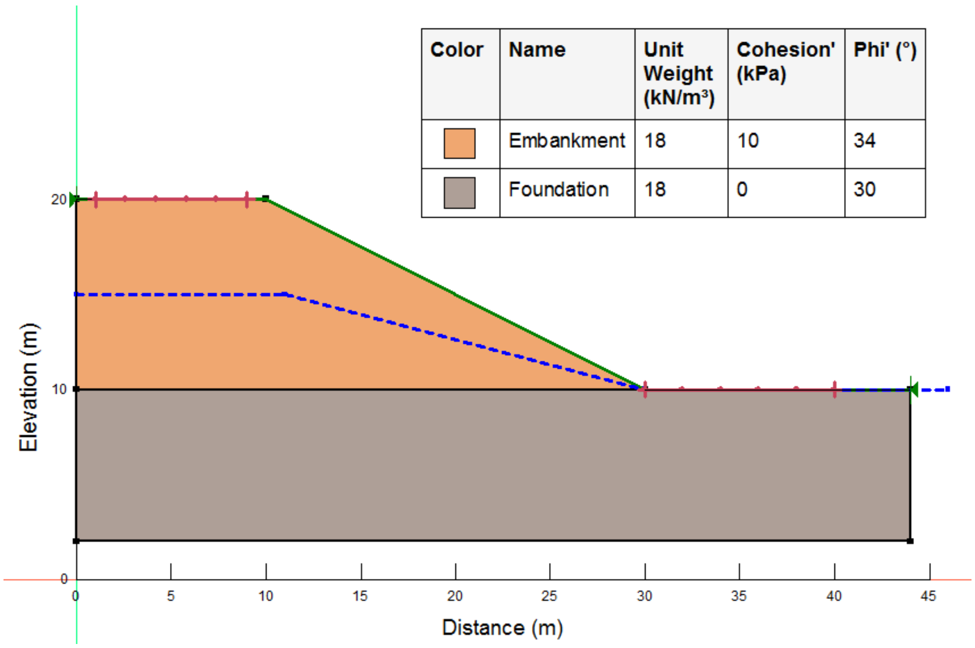

Figure 5. Problem configuration for Analyses 1a and 1b with slip surfaces generated by the Entry and Exit method.

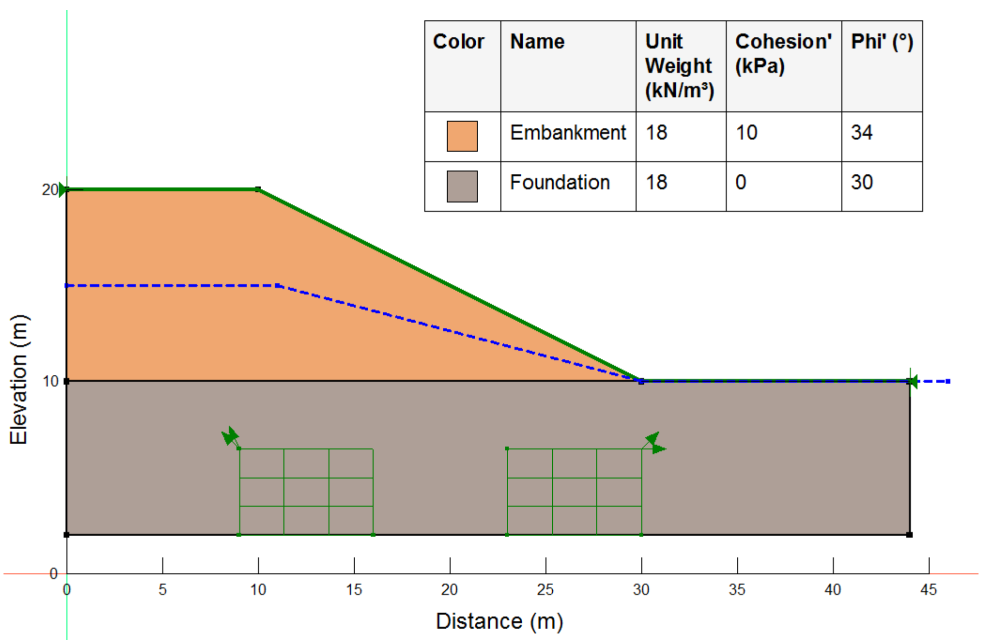

Figure 6: Problem configuration for Analyses 2a and 2b with Block Specified slip surfaces.

Results and Discussion

The critical slip surface from Analysis 1a has a factor of safety of 1.346 (Figure 5). Optimization of this slip surface in Analysis 1b results in a slightly different shape and a slightly lower factor of safety (1.328; Figure 6). The optimized slip surface is more linear within the embankment, while in the foundation the slip surface is more curved. For this simple scenario, the difference is not of practical significance. It does, however, illustrate that it is possible to find a non-geometric slip surface that has a lower factor of safety than what can be achieved with a circular slip surface.

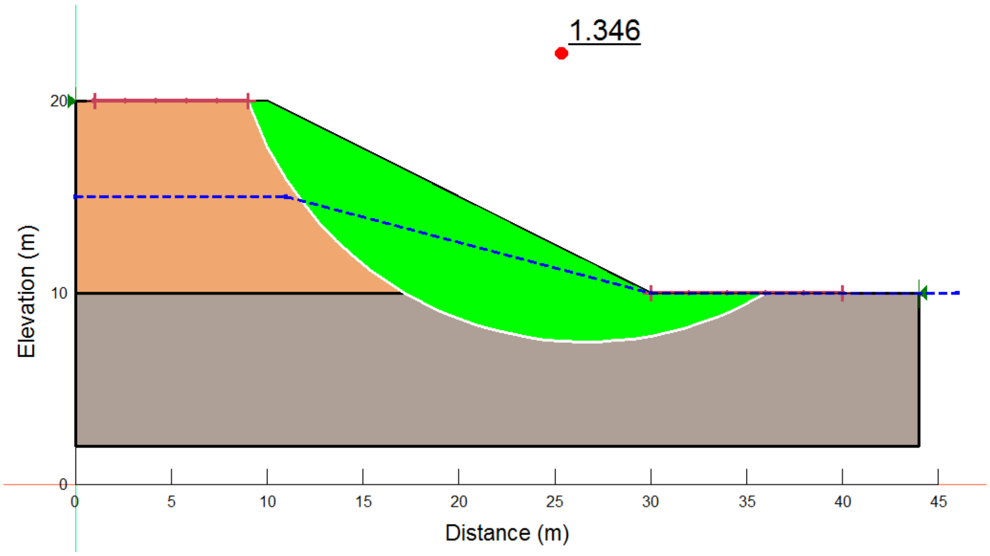

Figure 7. The traditional circular slip surface generated in Analysis 1a.

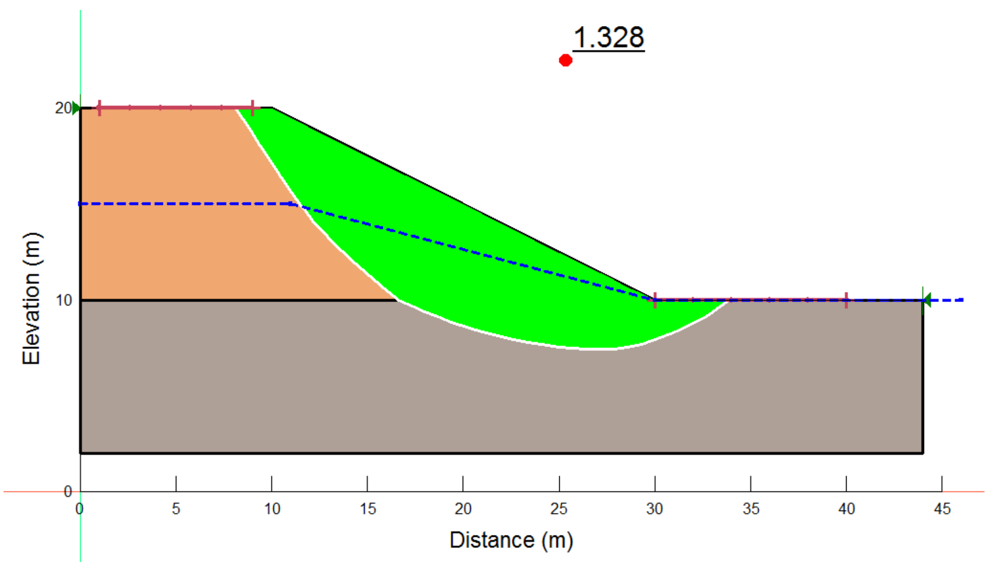

Figure 8. Optimized slip surface from Analysis 1b.

The critical Block Specified slip surface from Analysis 2a has a factor of safety of 1.524 (Figure 9). When this slip surface is optimized in Analysis 2b, its shape and factor of safety change noticeably (Figure 10). The factor of safety decreases by approximately 10% to 1.384, and the optimized critical slip surface is much rounder. The optimization process results in a more realistic slip surface shape.

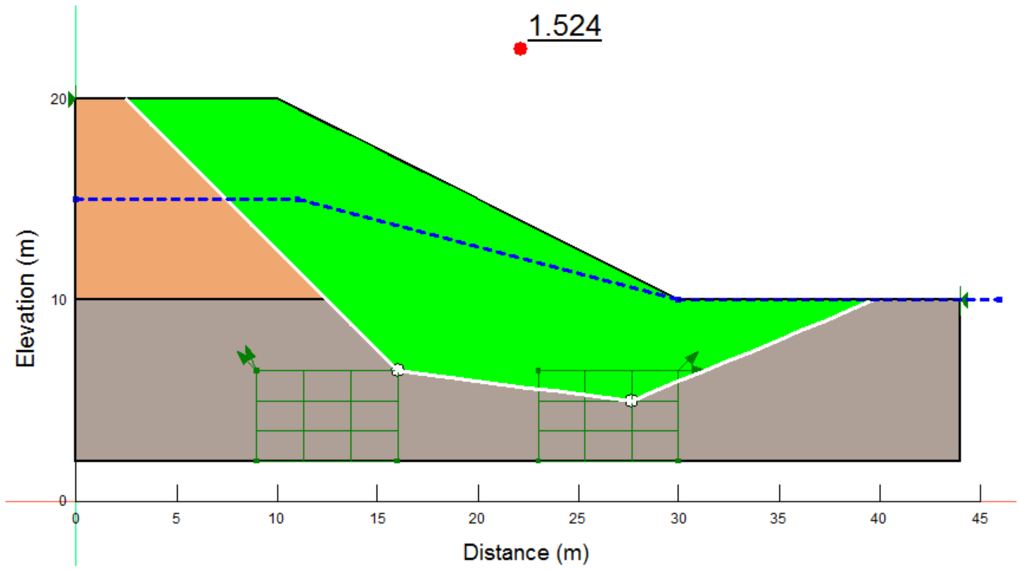

Figure 9. The critical Block Specified slip surface from Analysis 2a.

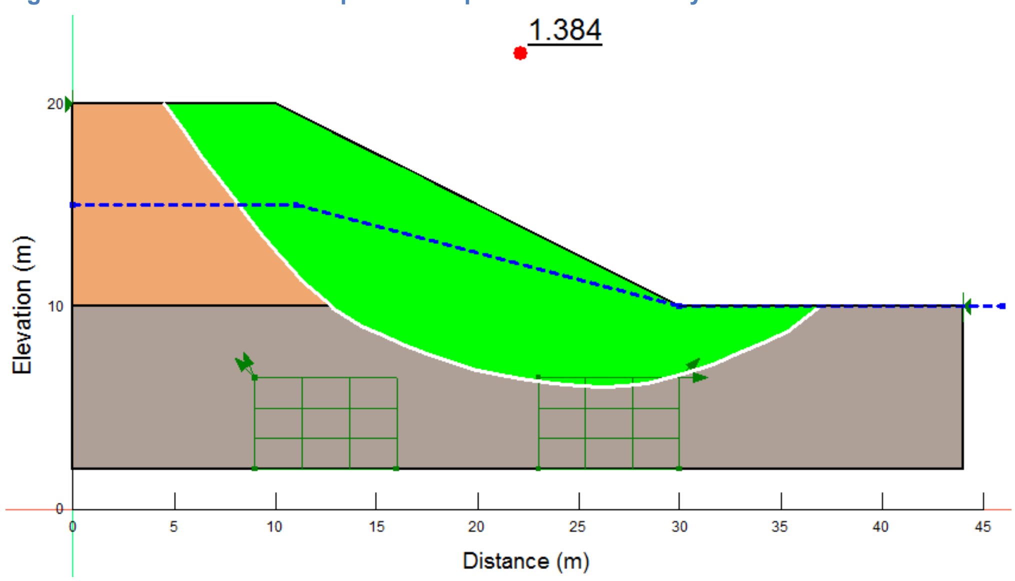

Figure 10. The optimized slip surface from Analysis 2b.

Unfortunately, the optimization technique may break down in complicated SLOPE/W analyses. In some cases, movement of the line segment end points can go astray causing an unrealistic slip surface shape and factor of safety. Thus, the analyst must judge the validity of an optimized solution. Firstly, the optimized and un-optimized factors of safety should be relatively similar. Generally, acceptable optimized factors of safety tend to be within 15% of the un-optimized value. If the difference becomes much larger than this, optimization likely did not generate a realistic solution.

The optimized slip surface must also be a more realistic shape than the un-optimized case. This is easy to judge for situations similar to the Block Specified example described above and depicted in Figures 9 and 10. The gradual curvature of the optimized shape is much more realistic as sharp corners do not often exist in natural systems. Consequently, slip surfaces generally form a convex, bowl-shaped failure. However, SLOPE/W allows the slip surface to become concave during optimization (see the entry fields at the bottom of Figure 2). This feature must be used with great caution, since this shape is not common in real field problems.

Optimization is best used after a highly probable and realistic solution has been obtained for a traditional slip surface shape. Uncertainties associated with material properties and pore water pressure conditions, for example, should be resolved before attempting the optimization. Thus, optimization should be used near the end of a slope stability project to refine an already acceptable solution.

Summary

Optimization of the critical slip surface is a powerful feature in SLOPE/W. Optimization can produce slip surfaces with a lower factor of safety and more realistic shape by ignoring the original geometric parameters used to define the trial slip surfaces. However, this feature must be used carefully and methodically as it may generate unrealistic results. Dramatic changes in the optimized factor of safety (i.e., greater than 15%) or the generation of a highly concave slip surface indicate an unrealistic optimized slip surface. Thus, optimization should be used to enhance an already acceptable solution.

References

Greco, V.R. 1996. Efficient Monte Carlo Technique for locating critical slip surface. Journal of Geotechnical Engineering. Vol 122, No. 7. ASCE. pp. 517-525

Malkawi, A.I.H, Hassan, W.F. and Sarma, S.K. 2001. Global Serach Method for locating general slip surface using Monte Carlo Technique. Journal of Geotechnical and Geoenvironmental Engineering. Vol 127, No. 8. pp. 688-698