GeoStudio Example File
Reinforcement with Piles

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Introduction

Piles are a common stabilization method for geotechnical systems as they can withstand considerable shear. SLOPE/W stability analyses simulate pile reinforcement by including a resisting force in the limit equilibrium formulation representing the shear capacity of a pile row. This example compares the stability of a riverbank under natural conditions and when the riverbank is reinforced with piles.

Background

In SLOPE/W, pile reinforcement only provides shear resistance. The shear resisting force, S, per unit length along the pile row (in the out-of-page direction) is:

$$SR = \frac{SF}{s \cdot RF_S}$$ **Equation 1**

where SF is the shear force of the piles, s is the pile spacing, and RF_S is the shear reduction factor. The shear resistance is applied at the base of the slice that includes the pile, and may act parallel to the slip surface or perpendicular to the reinforcement.

Numerical Simulation

The simulated geometry was developed to represent a failed riverbank that may continue to move under elevated pore water pressure conditions – for example, due to spring snowmelt (Figure 1). Lacustrine sediments, underlain by a competent till, form the riverbank. Between the lacustrine sediments and till is a weak layer, which is the ultimate source for stability issues in this system. The Mohr-Coulomb material model defines the properties of the lacustrine sediments and weak layer, and the till was set as impenetrable bedrock (Figure 1).

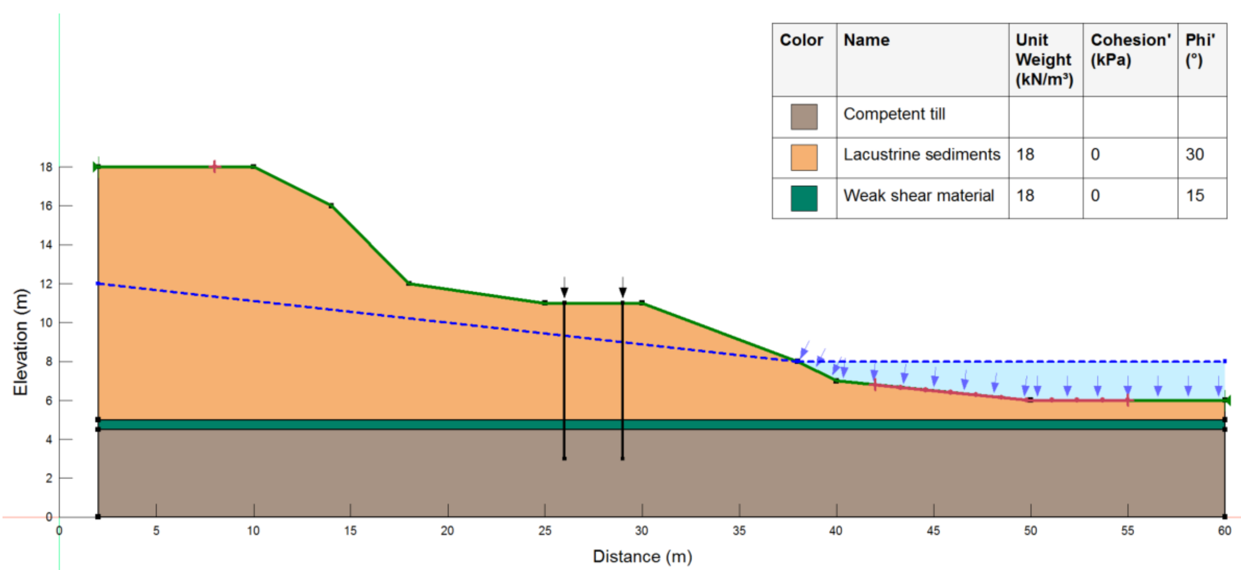

Figure 1. Riverbank configuration including the pile reinforcement, pore water pressure, and trial slip surface definition.

The first analysis in the project file considers the riverbank stability without reinforcement, while the second includes two rows of piles that are founded in the competent till (Figure 1). The piles are 8 m long, 1 m apart (in the out-of-page direction), and are vertically oriented. A shear force of 100 kN and a shear reduction factor of 2 are assigned to each pile row, such that the shear resisting force per unit length along the river is:

$$SR = \frac{100}{(1)(2)} = 50\ kN \quad \text{Equation 2}$$

This resisting force acts parallel to the slip surface, as defined in the pile reinforcements settings.

The trial slip surfaces are defined using the Entry and Exit method in both analyses. All slip surfaces originate from the same point on the top of the bank and exit at the bottom, under the river. The Morgenstern-Price limit equilibrium method is used to determine the factor of safety of the trial slip surfaces. A piezometric line establishes the pore water pressure conditions throughout the domain (Figure 1).

Results and Discussion

Analysis 1 produced a large band of slip surfaces with a factor of safety between 1.0 and 1.1, with the critical factor of safety just above 1 (Figure 2). Thus, under natural conditions, the riverbank is unstable. With pile reinforcement, the two 50 kN shear resisting forces (one for each pile) are included in the limit equilibrium calculations, causing the factor of safety to increase by approximately 15% (Figure 3). Application of the pile resisting forces is evident in the free body diagrams for the slices containing the piles, Slices 13 and 15 (Figure 4). Thus, the piles provided enough resisting force to prevent movement of the riverbank under the given pore water pressure conditions.

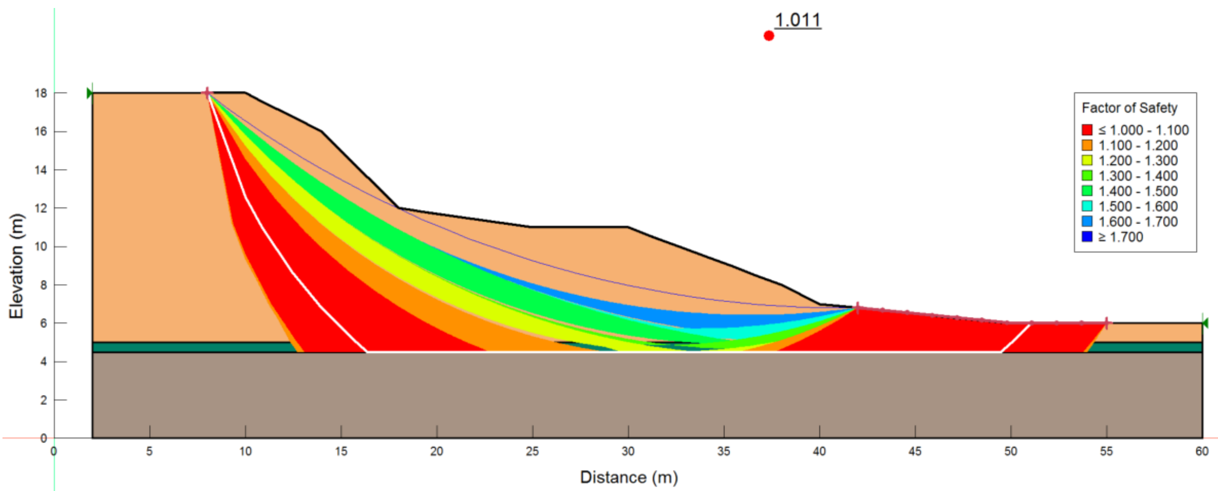

Figure 2. Stability results for the natural state (Analysis 1).

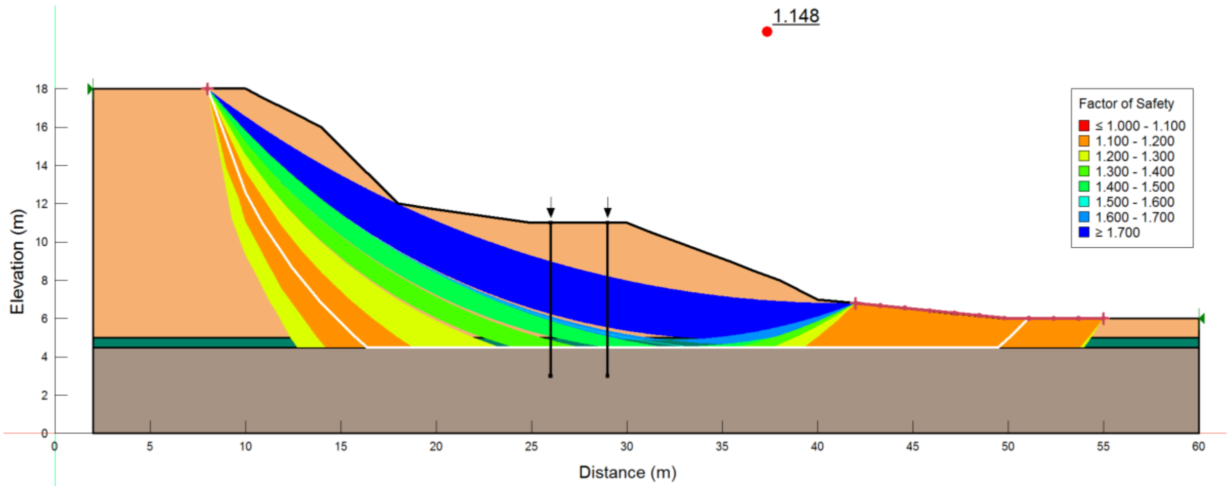

Figure 3. Stability results with pile reinforcement (Analysis 2).

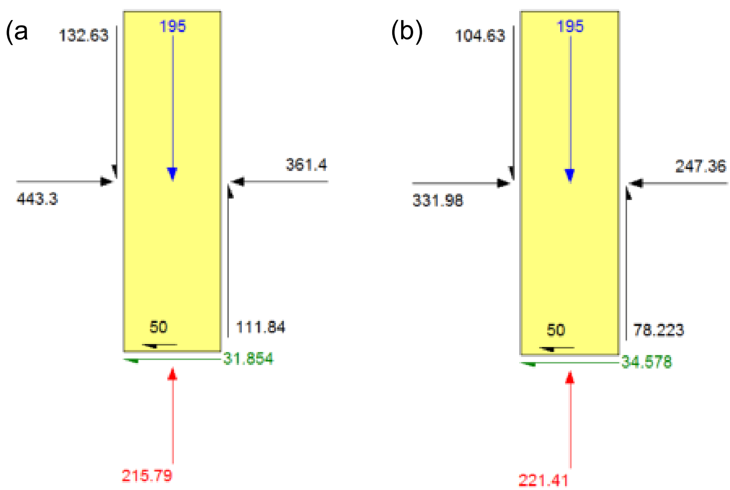

Figure 4. Free body diagrams for (a) Slice 13 and (b) Slice 15 in Analysis 2, with the pile resisting forces (50 kN) acting parallel to the slip surface.

One of the challenges with simulating reinforcement in a limit equilibrium analysis is determining the shear force available from the structural element – which is a true soil-structure interaction problem. For example, the stresses developed in the pile are dependent on the relative stiffness between the pile and the surrounding soil. Thus, SIGMA/W is ideal for assessing stability of systems with reinforcement, as it simulates the shear and moment distributions within the pile.

However, piles can be considered in a SLOPE/W analysis, like this one, with an understanding of the general design philosophy for piles and the implications of using a limitation equilibrium analysis. Pile design ultimately is aimed at halting movement of an unstable slope, as opposed to increasing the factor of safety. Even if the factor of safety of the sliding mass remains around unity, movement ceases as long as the piles remain intact. In this sense, the structural design of piles is more important than the margin of safety against movement.

Summary and Conclusions

Slope stabilization with pile reinforcement can be simulated in SLOPE/W as demonstrated above. In this case, the piles provided enough shear resistance to increase the factor of safety and prevent movement of the riverbank under the applied pore water pressures. SLOPE/W analyses can be used to determine the shear force, provided by the piles, required to achieve the desired factor of safety.